Submitted in Support of the U.S. Navy's 2024 Annual Marine Species Monitoring Report for the Pacific

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# FY24 Annual Report on Pacific Missile Range Facility Marine Mammal Monitoring

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**14. ABSTRACT**
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) 2024 for Commander, Pacific Fleet (COMPACFLT) at the Pacific Missile Range Facility (PMRF), Kaua‘i, Hawai‘i. The following list highlights tasks completed in FY24 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 describes the collection, processing, and analysis of 7001.1 hours of new data collected and analyzed from August 2023 to September 2024 for FY24.
• Updates and improvements to the NARWHAL analysis algorithms and workflow processes are described; highlights include progress on the transition to Baseline 5 of the code, which includes: improvements to the tracking code for all baleen whale species; improvements to the beaked whale classification algorithms, with the full inclusion of tropical bottlenose whales for the first time; and the inclusion of all three primary mid-frequency active sonar (MFAS) sources (surface ship hull-mounted, helicopter-dipping, and active sonobuoy) for behavioral response analyses.
• Abundance results for baleen whales for FY24 are presented using the mean number of whale tracks present in 2.5-minute snapshots per hour and for each month. The highest monthly mean number of baleen whales were: 1.6 for minke (January 2024); 0.3 for humpback (January 2024); 0.2 for sei (November 2023); 0.5 for fin (December 2023); 0.09 for Bryde's (July 2024); 0.07 for the 20-Hz downsweep category (January 2024); and 0.08 for the 40-Hz downsweep category (January 2024). Additional information is included regarding some observations of sei whale call behavior and a

pulsed call newly described at PMRF attributed to a Bryde's whale. Automatically detected and localized blue whale calls were manually verified in December 2023, February 2024, and March 2024; these included both northwestern Pacific and northeastern Pacific B blue whale vocalizations, as well as an additional 54-Hz tonal potentially attributable to a Watkin's whale.

- Following recommendations by the scientific community, in this report and moving forward, the eponymously named beaked whale species will be referred to by their common names instead: Blainville's beaked whales will be referred to as dense-beaked whales, Cuvier's beaked whales will be goose-beaked whales, and Longman's beaked whales will be tropical bottlenose whales.
- Abundance results of odontocetes from August 2023 to September 2024 included dense-beaked whales, goose-beaked whales, Cross Seamount beaked whales, tropical bottlenose whales, killer whales, and sperm whales. The highest group vocal period (GVP) rates for a full month of data for each beaked whale species was: 3.1 GVPs/hour in March 2024 for dense-beaked whales; 0.3 GVPs/hour in March 2024 for goose-beaked whales; 0.2 GVPs/hour in July 2024 for Cross Seamount beaked whales; and 0.1 GVPs/hour in December 2023 for tropical bottlenose whales. Killer whales were detected throughout the available FY24 data and 7 manually validated groups occurred. The highest mean number of sperm whale tracks in all 2.5-minute snapshots in a month was 0.2 in December 2023.
- During the February 2024 Submarine Command Course (SCC) a total of 11 tracked whales were exposed to MFAS. One fin whale was exposed to all three primary sources of MFAS; two humpback whales were exposed to surface ship hull-mounted MFAS; two humpback whales were exposed to active sonobuoy and helicopter-dipping MFAS; and two fin, one sperm, and three humpback whales were exposed to active sonobuoys only. The median received levels by source were estimated with propagation modeling; the highest median estimated received levels for each source occurred for the same fin whale that had very close points of approach to all three sources: 138.7 dB re 1μPa (active sonobuoy), 124.5 dB re 1μPa (helicopter dipping sonar), and 166.7 dB re 1μPa (surface ship hull-mounted sonar). Two humpback whales also had their highest median estimated received levels at 147.0 dB re 1μPa from surface ship hull-mounted MFAS.
- Group foraging dive rates for all beaked whale species were analyzed before, during, and after the February and August 2024 SCCs. Both SCCs had shorter Phase B periods than in previous years. In February, all beaked whales exhibited a decrease in GVPs/hour from the Before period to Phase A of the SCC. Tropical bottlenose whales were not detected at all in Phase A and remained absent for the remainder of the February SCC, including the After period. All other beaked whale species showed a slight increase in the non-exposure period after Phase A and before Phase B (i.e., Interphase), a further reduction in Phase B of the SCC, and an increase in the After period. The results for the August SCC followed the same general pattern for all except Cross Seamount beaked whales, which did not decrease at all during the SCC, and even had higher GVP rates during Phase A and Phase B than in any non-exposure period (though this observation is accompanied by some caveats regarding false positives).

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# 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) 2024 for Commander, Pacific Fleet (COMPACFLT) at the Pacific Missile Range Facility (PMRF), Kauaʻi, Hawaiʻi. The following list highlights tasks completed in FY24 in support of COMPACFLT monitoring goals:

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# ACRONYMS

| | |
|---|---|
| BOEM | Bureau of Ocean Energy Management |
| BWC | Cross Seamount beaked whale signal |
| COMPACFLT | Commander, Pacific Fleet |
| CPA | Closest point of approach |
| CRC | Cascadia Research Collective |
| DCL | Detection classification localization |
| 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 |
| M3 | Marine Mammal Monitoring |
| MFAS | Mid-frequency active sonar |
| NIWC Pacific | Naval Information Warfare Center Pacific |
| NUWC Newport | Naval Undersea Warfare Center Newport |
| PAM | Passive acoustic monitoring |
| PMRF | Pacific Missile Range Facility |
| SCC | Submarine Command Course |
| SMART | Science, Mathematics, and Research for Transformation |
| SUBEX | Submarine Exercise |
| UH | University of Hawai‘i |
| US | United States |
| UTC | Universal Coordinated Time |
| WARP | Whale Acoustic Reconnaissance Project |

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# 1. Introduction

In fiscal year (FY) 2024, 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.

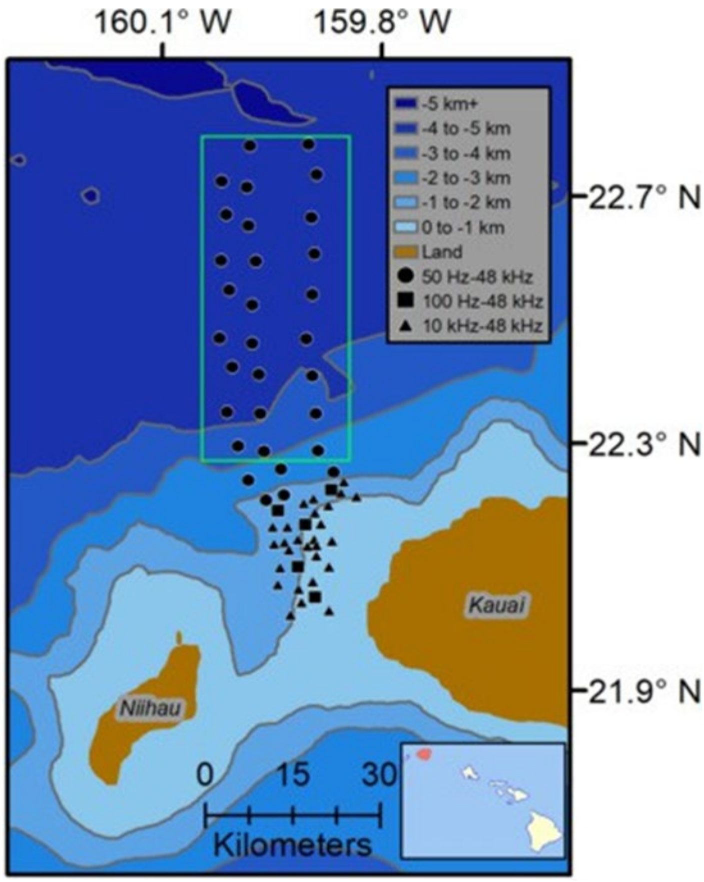
The FY24 goals of this ongoing effort were to:

- Collect raw acoustic data for cetacean species detection, classification, localization (DCL), and 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.

# 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 2023 through September 2024.




- 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 2023 to September 2024. Black symbols indicate approximate hydrophone locations.

Figure 1. Hydrophone array configuration at PMRF's instrumented range for data collected August 2023 to September 2024.

## 2.2 NAVY ACOUSTIC RANGE WHALE ANALYSIS ALGORITHM SUITE

### 2.2.1 Automated Detection, Classification, Localization, and Tracking Algorithms

The Navy Acoustic Range Whale Analysis (NARWHAL) suite of algorithms was used to process recorded data. These algorithms have been previously described in Helble et al. (2012, 2015, 2016, 2020a); Henderson et al. (2016, 2018); Manzano-Roth et al. (2016), and Martin et al. (2015). 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 several baleen whale species), six odontocete vocalizations (dense-beaked, goose-beaked, tropical bottlenose, and Cross Seamount beaked whale clicks, sperm whale clicks, 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.

A separate Matlab Generalized Power Law (GPL) algorithm detects and localizes humpback whale song and certain types of blue whale calls. 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 human analyst manually reviews spectrograms of the data and call intervals along the tracks produced from low-frequency downsweep calls to examine call characteristics and patterns to classify the tracks as fin whales, sei whales, Bryde's whales, and non-specific categories of 20-Hz and 40-Hz downsweeps. Tracks were assigned as fin whales if they contained both "A" and "B" notes (after Helble et al., 2020a) or contained either note in regular patterns. Sei whale tracks must have had at least one paired call (or triple or more) during the manual validation process, as this seems to be a feature ascribed exclusively to sei whales (Baumgartner et al., 2008; Español-Jiménez et al., 2019). Bryde's whale calls are distinctive and not easily confused with any other vocalization. Calls in the 20-Hz and 40-Hz downsweep categories are reserved for low-frequency downsweeps with an end frequency near 20 Hz (usually sweeping from about 40 Hz) or 40 Hz (usually sweeping from about 100 Hz), respectively. As described in more detail in the FY23 annual report (Martin et al., 2024), calls in the 20-Hz category tend to appear very similar to fin whale B notes but vary more in frequency within a track and are believed to belong to either fin or sei whales (Martin et al, 2024, Rankin & Barlow, 2007) while 40-Hz downsweeps have been described for several baleen whale species (Martin et al., 2024). In past years, the GPL algorithm also produced tracks of various low-frequency calls, but because there is substantial overlap with the results produced by the C++ algorithm, only the latter are presented in this report. 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) are presented as the mean number of whale tracks during an instantaneous snapshot every 2.5 minutes. A track counts as part of an instantaneous snapshot if its start and end times occur on either side of the time used for that snapshot. Systematic snapshots of whale tracks enable a census-type abundance estimate for calling whales that are able to 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, fin, sei, Bryde's, and sperm whales, as well as tracks composed of 20-Hz and 40-Hz downsweeps (Figure 1). Because of differences in the localization algorithm, tracks generated by the separate Matlab GPL algorithm for humpback whales 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 frequency-modulated pulses and killer whale HFM signals are not currently localized at PMRF, 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 pulses at depth while they are diving with other group members; therefore, groups of their pulses are referred to as group vocal periods (GVPs), which are used here to quantify abundance. A subset of dense-beaked and Cross Seamount beaked whale GVPs were randomly selected and manually validated using the raw acoustic data. Due to their relative scarcity, all goose-beaked and tropical bottlenose whale GVPs were manually validated. Killer whale HFM signals were also grouped by this algorithm when they occurred close enough in space and time. As they are also comparatively rare, all such groups were manually validated. 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 abundance 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.

#### *2.2.1.1 Transition to Baseline 5*

##### 2.2.1.1.1 Baleen Whale Tracks

For the past few years, the WARP lab has been working on consolidating two different code bases with the NARWHAL suite (Baseline 4 and Baseline 5). Newer developments (Baseline 5) have been used for a few years on odontocetes to accommodate the addition of new species (e.g., goose-beaked and tropical bottlenose whales, killer whales) and to improve the localization and tracking of sperm whale clicks. To conform the baleen whales to the same code base, the code developments have needed to be finalized and exhaustively tested on call types from all species and any weaknesses identified and addressed before final implementation.

For this report, Baseline 4 was ran to generate baleen whale results in Sections 3.2 and 4.1, and Baseline 5 was ran on a representative selection of datasets from throughout the WARP lab's archive of PMRF data. The resulting number and quality of detections, localizations, and tracks are currently being assessed for each dataset. Example quality assessment data products for one test dataset are illustrated here for tracks produced from minke whale boings (Figure 2 and Figure 3) and low-frequency downsweeps produced by several possible baleen whale species (Figure 4 and Figure 5). The final metric (number of tracks per snapshot) appears stable for low-frequency downsweeps (Figure 4), while there is some variability for minke whales (Figure 2). Plotting the track latitudes and longitudes demonstrates that the tracks themselves are largely identical, with some exceptions highlighted for minke whale tracks, which are also more likely to be segmented in Baseline 5 (Figure 3 and Figure 5).

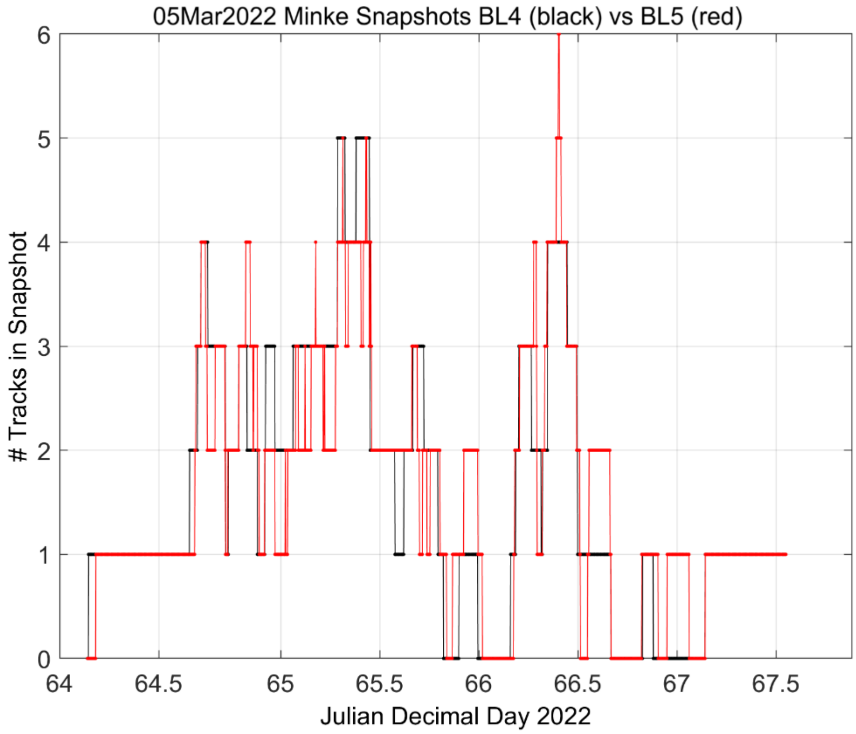
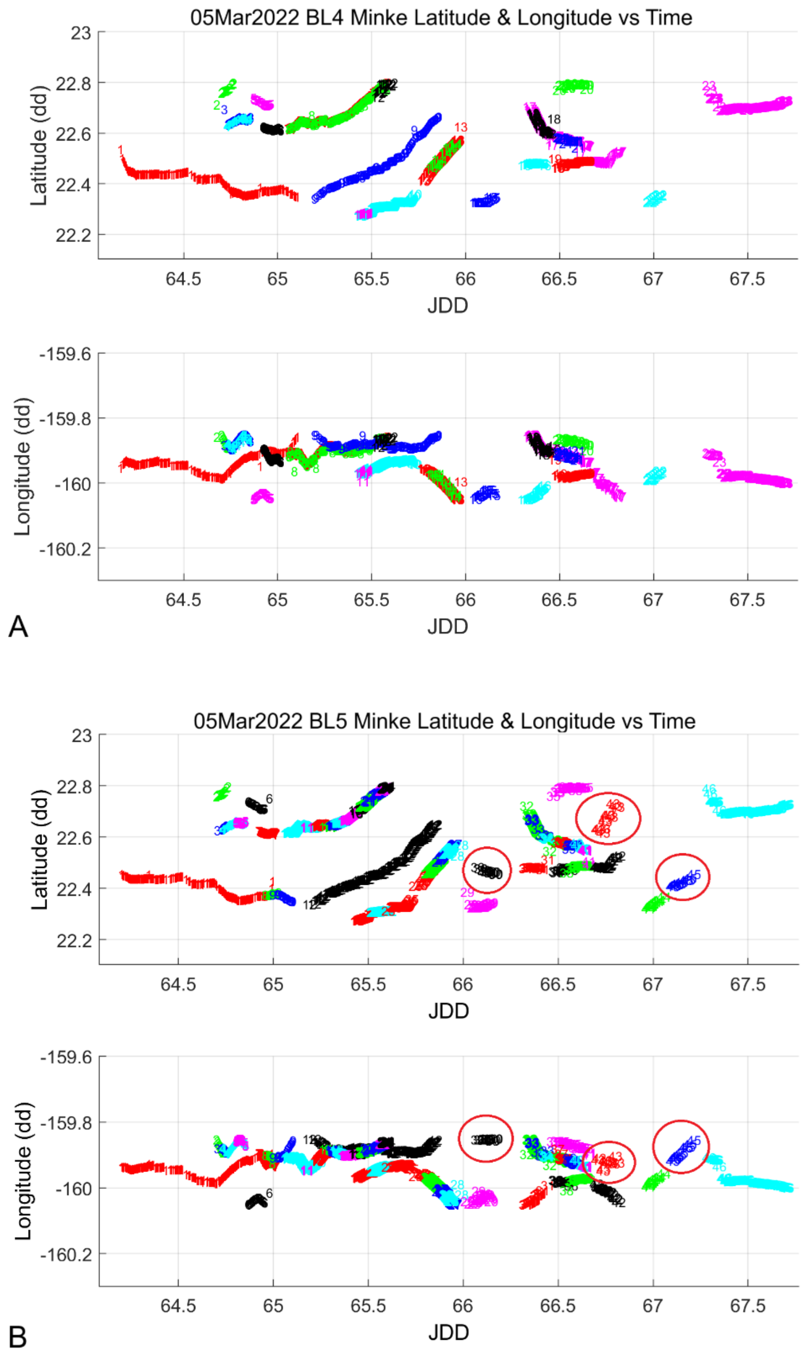



Figure 2. Comparison between the number of minke whale tracks automatically produced from minke whale boing detections by the Baseline 4 (black) and 5 (red) versions of the NARWHAL algorithm suite in sequential instantaneous snapshots during an example test dataset starting on March 5th, 2022 UTC.




- Latitude (top of each) and longitude (bottom of each) are plotted separately against Julian Decimal Day (JDD) for improved visibility and easier track comparison. Each track is assigned a color, though because color palettes are limited relative to the number of tracks, tracks are also plotted using their index number as a marker. The Baseline 4 process produced 23 tracks while the Baseline 5 process produced 46 tracks. Examples of instances of tracks that appear in Baseline 5 but not Baseline 4 are circled, although these may be comprised of spurious localizations of e.g., multi-path arrivals.

Figure 3. Minke whale tracks automatically produced from minke whale boing detections by the Baseline 4 (A) and 5 (B) versions of the NARWHAL algorithm suite during an example test dataset starting on March 5th, 2022 UTC to help assess the impact of changes made in the Baseline 5 code base.

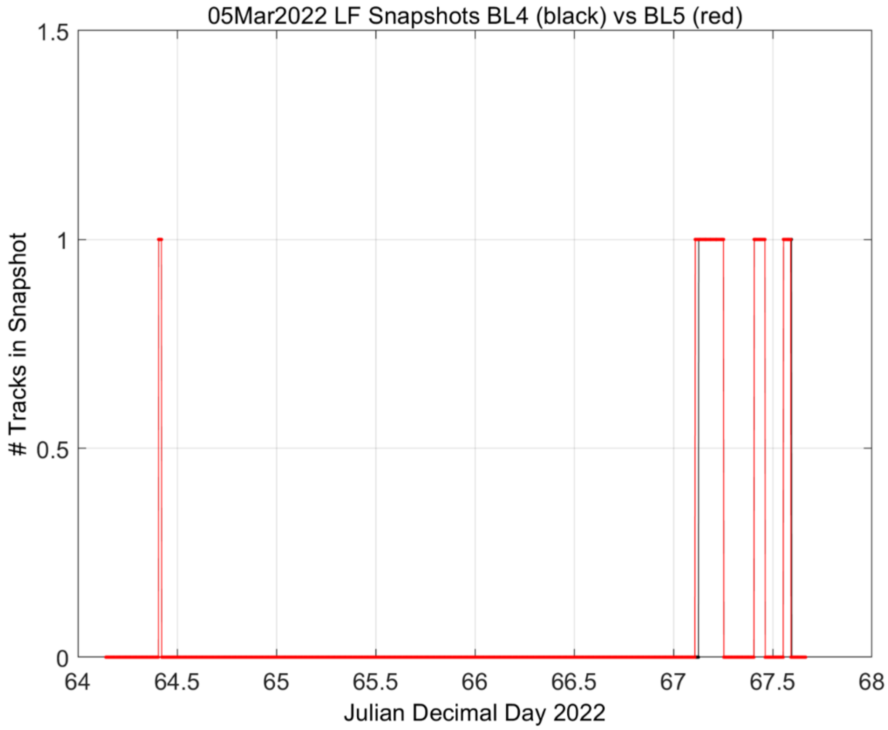
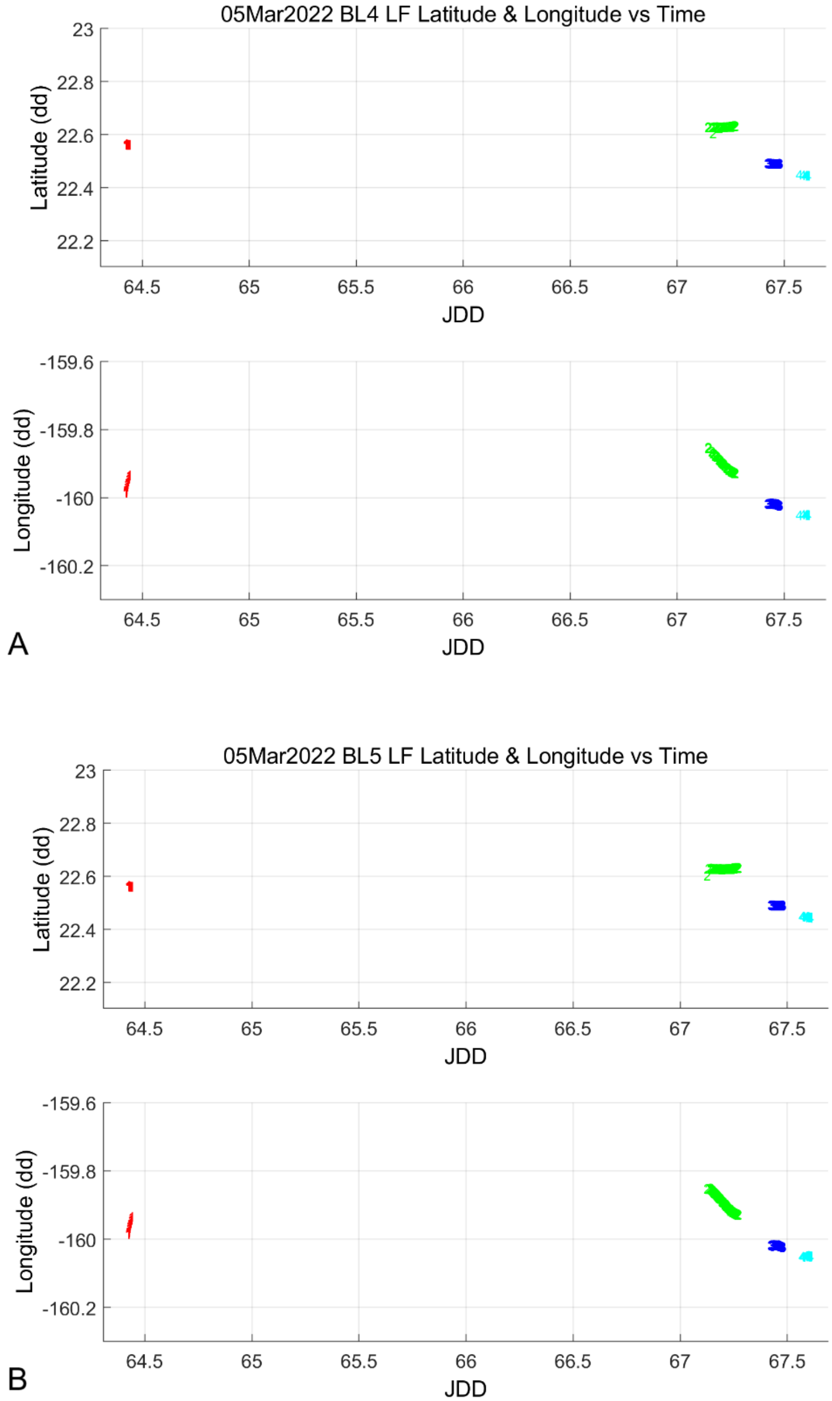



Figure 4. Comparison between the number of baleen whale tracks automatically produced from low-frequency downsweep detections by the Baseline 4 (black) and 5 (red) versions of the NARWHAL algorithm suite in sequential instantaneous snapshots during an example test dataset starting on March 5th, 2022 UTC.




- Latitude (top of each) and longitude (bottom of each) are plotted separately against Julian Decimal Day (JDD) for improved visibility and easier track comparison. Each track is assigned a color and is also plotted using its index number as a marker. Both Baseline 4 and 5 processes produced four total tracks.

Figure 5. Baleen whale tracks automatically produced from low-frequency downsweep detections by the Baseline 4 (A) and 5 (B) versions of the NARWHAL algorithm suite during an example test dataset starting on March 5th, 2022 UTC to help assess the impact of changes made in the Baseline 5 code base.

The variation seen in the tracks produced from minke whale boings (Figure 2 and Figure 3) is believed to be largely attributable to adjustments to the minke boing detection algorithm which increased the number of raw detections, including a corresponding increase in non-direct-path signals. Ultimately, the increase in the final number of tracks (46 in Baseline 5 vs. 23 in Baseline 4) reflect some known sensitivities in the localization and tracking algorithms to large amounts of detections, which will be addressed in the future by attempting to better quantify errors during the localization process and thereby exclude likely multi-paths and spurious localizations from the tracking algorithm.

##### 2.2.1.1.2 Improvements to the Beaked Whale Classifier

Another change the WARP lab is implementing in the Baseline 5 code base is a shift from beaked whale click classification based on logic gates applied to descriptive characteristics (e.g., slope, bandwidth, etc.) to classification based on kernel matching. To generate kernels for this method, a representative selection of archived data was used to automatically generate click kernels from spectrograms of signals from click trains that passed initial high-frequency criteria from the original classifier. An analyst then identified which kernels produced by this automated process belonged to the beaked whale species of interest, as well as a representative selection of kernels for non-beaked whale clicks. This selection of kernels was combined into a final kernel file which could be run with the detection/classification algorithm in its normal operating mode, during which a detected click train was assigned to a beaked whale species if a kernel from that species was the best match (based on the sum of squared differences) to the representative spectrogram for that click train.

Nine datasets throughout the 2023-2024 period analyzed in this report were used to assess and compare the quality of the new kernel matching classification process to the traditional method based on descriptive characteristics (Table 1). Dense-beaked whales are excluded from this analysis because there are far more GVPs for that species than for any other and thus take longer to validate; this analysis is in progress. The new process seemed to reduce the false positives that have tended to occur during the WARP lab's classification of goose-beaked and tropical bottlenose whales (Table 1; Martin et al., 2024), though classification confusion between dense- and Cross Seamount beaked whales remains high. To attempt to mitigate this ongoing confusion, in addition to imposing automatic ICI limits on the mode of goose-beaked whale GVPs during the auto-grouping process, which has been typical in past years, ICI limits were applied to all species of beaked whales using histograms and quantiles of validated GVP ICI modes to estimate effective limits for each species (dense-beaked: 0.18-0.38 seconds; goose-beaked: 0.33-0.60; tropical bottlenose: 0.36-0.56; Cross Seamount beaked: 0.05-0.24). Though this has the potential to exclude the occasional group that does not achieve a typical ICI for that species (e.g., if two individuals are clicking on the same hydrophone), without further development to the classifier the benefit of automatically excluding a significant number of false positives seems to outweigh this risk (Table 1).

Table 1. Comparison of methods for beaked whale classification on a selection of nine datasets evenly distributed across FY24 covering about 745 hours total.

- "Traditional Process" corresponds to the method traditionally used by the WARP lab for beaked whale click classification based on descriptive characteristics of spectrograms. This method was applied to tropical bottlenose dolphins in FY23 as a stopgap during development and was not used in this report, so is excluded here for that species. Results are included for the new kernel matching method both with and without ICI limits applied to each species. TP = True Positive, FP = False Positive, FN = False Negative. In this case, a False Negative is relative and only means that groups present in the output of the Traditional Process were not present in the respective Kernel Matching process. Note that for goose-beaked whales, the traditional process included ICI limits.

| Species | Traditional Process | | Kernel Matching (No ICI Limits) | | | Kernel Matching (w/ ICI Limits) | | |
|---|---|---|---|---|---|---|---|---|
| | # TPs | # FPs | # TPs | # FPs | # FNs | # TPs | # FPs | # FNs |
| Goose-beaked | 58 | 33 | 89 | 119 | 0 | 89 | 4 | 0 |
| Tropical bottlenose | NA | NA | 36 | 20 | NA | 36 | 3 | NA |
| Cross Seamount | 149 | 208 | 166 | 256 | 2 | 162 | 79 | 4 |

The new kernel matching process successfully detected more GVPs for goose- and Cross Seamount beaked whales. When ICI limits are in place the false positive rate was dramatically lowered for all three beaked whale species analyzed. This method was used to generate the presence analysis below solely for tropical bottlenose whales (which were only recently introduced in the NARWHAL process), as the other species have a longstanding record of presence in previous reports and years of data based on the traditional detection and classification method, which will be replaced using the new kernel matching method pending final assessment and fine-tuning.

### 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 active sonobuoys are estimated. The result is an opportunistic passive acoustic behavioral response study to US Navy MFAS sources during training activities. This is accomplished using MFAS localizations, which have been a longstanding output from the NARWHAL 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), source orientations relative to the whale, and distances relative to all active sources. When sources are transmitting sonar, propagation modeling is conducted to calculate received sound levels while individual acoustically-tracked whales were calling.

# 3. Results and Discussion

## 3.1 PMRF RANGE DATA COLLECTION RESULTS

The FY24 data processed for this report spanned August 24, 2023 to September 9, 2024. A total of 7,001.1 hours of data were recorded which includes 217.1, 406.8, and 218.1 hours of classified data collected during the February SCC, Rim of the Pacific (RIMPAC), and August SCC training events, respectively (Table 2). The total number of hours recorded and analyzed during this performance period is more than any other annual performance period to date and is an increase of 851 hours from the FY23 dataset (Martin et al., 2024). Note that the RIMPAC data will be analyzed in detail in FY25.

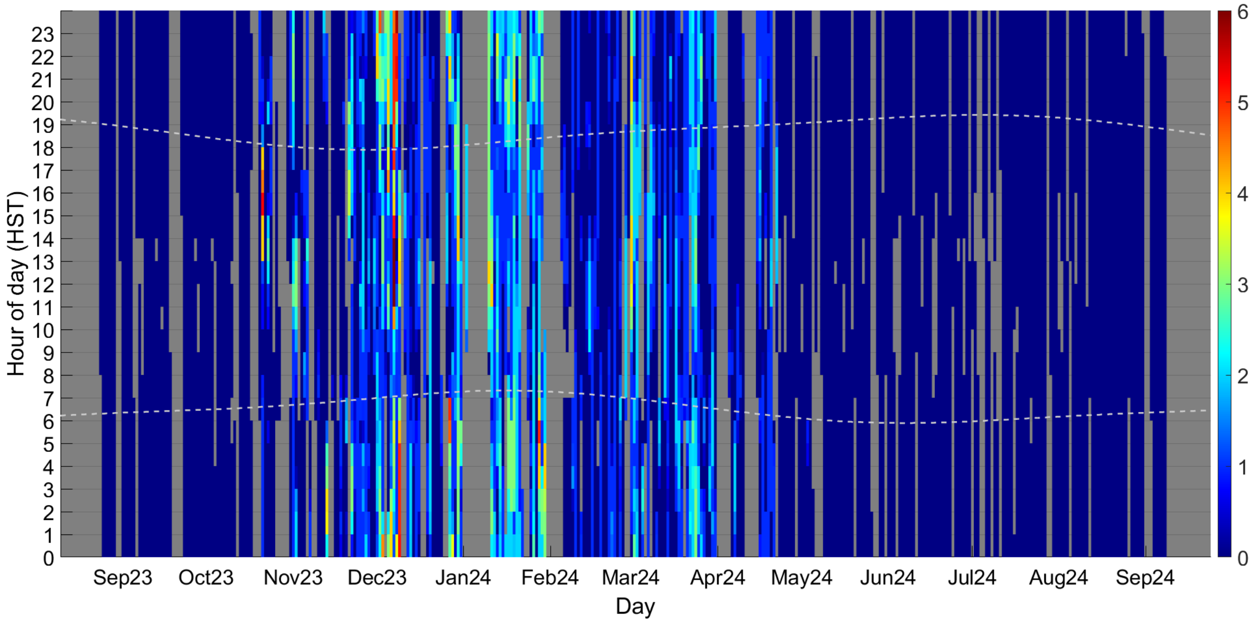
Table 2. Total monthly hours of recording effort for FY24 data (August 2023 to September 2024).

| Month | Hours | % of Time Recorded |
|---|---|---|
| August-23 | 136.5 | 18% |
| September-23 | 568.5 | 79% |
| October-23 | 511.8 | 69% |
| November-23 | 576.1 | 80% |
| December-23 | 613.7 | 82% |
| January-24 | 424.2 | 59% |
| February-24 | 502.9 | 72% |
| March-24 | 667.2 | 90% |
| April-24 | 446.5 | 62% |
| May-24 | 571.5 | 77% |
| June-24 | 618.4 | 86% |
| July-24 | 549.7 | 74% |
| August-24 | 669.7 | 90% |
| September-24 | 144.4 | 20% |
| Total | 7,001.1 | 68% |

## 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 2023 and September 2024 is presented per hour in Figure 6 and per month in Table 3. Seasonal presence typically lasts from fall to spring, and during the current reporting period, minke whales were present starting from late October 2023 to early May 2024. Monthly mean presence was highest in January 2024 (1.6 whales/snapshot) and was elevated from December 2023 to March 2024, except for February 2024 (possibly in response to the SCC, although this has not been observed previously). A peak hourly mean of 6 whales/snapshot occurred three times in December. For comparison, in the FY23 annual report (Martin et al., 2024) minke whale acoustic presence occurred from October 2022 to April 2023. Monthly mean presence was highest in March 2023 (1.3 whales/snapshot), and a peak hourly mean of 5.8 whales/snapshot occurred in November 2022. Relative to the 2022-2023 season in last year's report, the 2023-2024 season was slightly longer, the peak monthly mean presence occurred earlier in January 2024 and was higher, and the peak hourly mean presence occurred later in December 2023 and was higher.




- 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, July, and August 2024. 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 minke whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 6 (dark red).

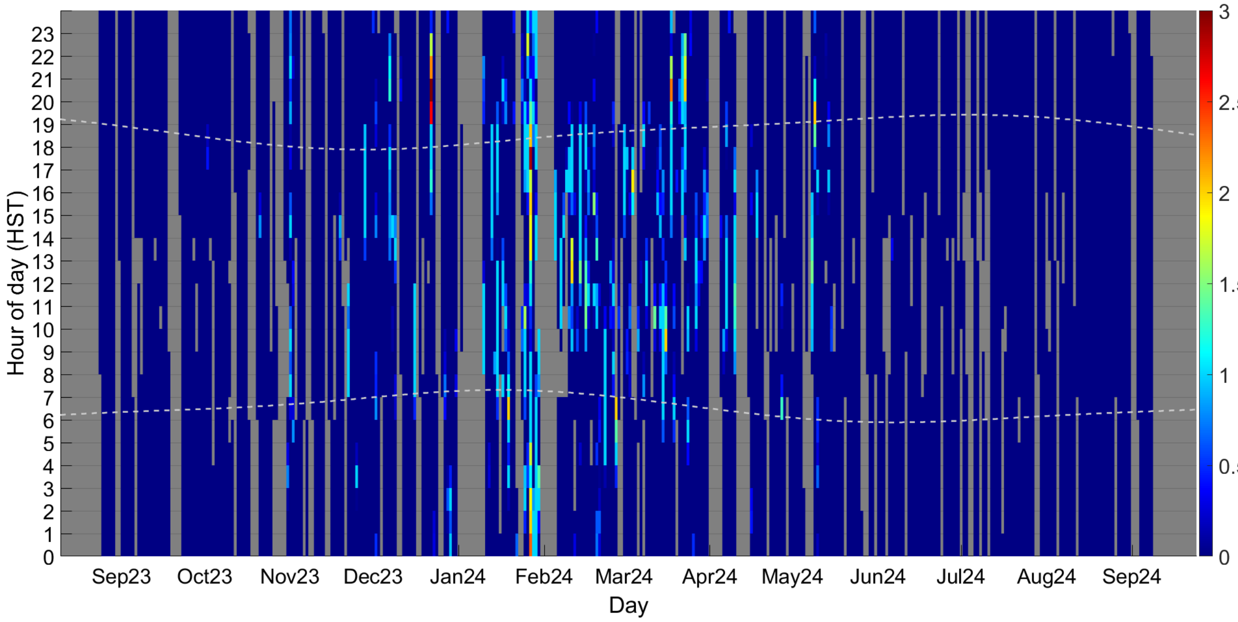
Table 3. Monthly numbers of minke whales detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | 2,964 | 0.48 | 1.00 |
| November-23 | 13,823 | 0.52 | 0.81 |
| December-23 | 14,717 | 1.28 | 1.31 |
| January-24 | 9,920 | 1.63 | 0.97 |
| February-24 | 11,981 | 0.36 | 0.54 |
| March-24 | 16,009 | 0.91 | 0.90 |
| April-24 | 7,296 | 0.48 | 0.63 |
| May-24 | 2,067 | 0.02 | 0.13 |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 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 2023 and September 2024 is presented per hour in Figure 7 and per month in Table 4. Humpback whales were present from October 2023 to June 2024. Monthly mean presence was highest in January 2024 (0.3 whales/snapshot) and elevated in February 2024 (0.2 whales/snapshot). There was a peak mean of 3 whales/snapshot detected in a one-hour bin, once in December 2023. For comparison, in the FY23 annual report (Martin et al., 2024) humpback whale seasonal presence occurred from October 2022 to May 2023. Monthly mean presence was highest in January 2023 (0.2 whales/snapshot), and a peak hourly mean of 2 whales occurred between January and March 2023. Relative to the 2022-2023 season in last year's report, the 2023-2024 season was one month longer and lasted until June 2024, the peak monthly mean presence occurred in the same month (January 2024) and was higher, and the peak hourly mean occurred one month earlier in December 2023 and was higher.




- 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, July, and August 2024. 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 humpback whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 3 (dark red).

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

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | 3,216 | 0.02 | 0.14 |
| November-23 | 7,160 | 0.08 | 0.27 |
| December-23 | 12,826 | 0.08 | 0.33 |
| January-24 | 9,548 | 0.30 | 0.54 |
| February-24 | 11,091 | 0.16 | 0.40 |
| March-24 | 15,664 | 0.13 | 0.37 |
| April-24 | 6,992 | 0.08 | 0.29 |
| May-24 | 4,261 | 0.11 | 0.36 |
| June-24 | 1,140 | 0.01 | 0.08 |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 3.2.3 Sei Whales

Due to processing and validation algorithm improvements, some tracks consisting of low-frequency downsweeps have been identified as sei whales based on comparisons to published call characteristics and their documented tendency to occur in pairs and sometimes triplets (Baumgartner et al., 2008; Español-Jiménez et al., 2019; Martin et al., 2024; Rankin & Barlow, 2007). Because many baleen whales produce downsweeps in the same frequency range, tracks were conservatively classified as sei whales only if at least one of the contributing calls to the track occurred with a paired call during the manual validation process, as this seems to be a feature ascribed exclusively to sei whales (Baumgartner et al., 2008; Español-Jiménez et al., 2019). Rather than being limited to pairs or triplets however, this year it was noted that along at least two tracks (one in October and one in November), much longer series of calls frequently occurred, usually in groups of three to eight but occasionally as many as eleven in a row, usually with about the same inter-call interval as between the more typical pairs and triplets (Figure 8). These sequences were usually separated by a few minutes. As doublets and triplets (in addition to singlets) also occurred between these sequences, and because longer sequences have been documented elsewhere (Nieukirk et al., 2020), these tracks are still presumed to be sei whales for the purposes of this analysis.

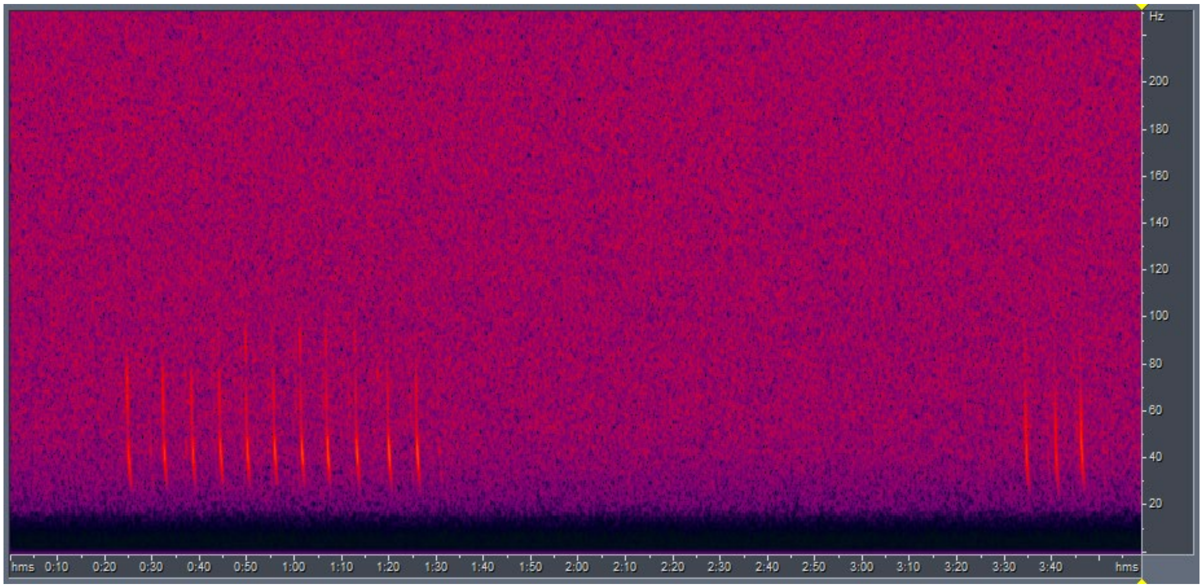
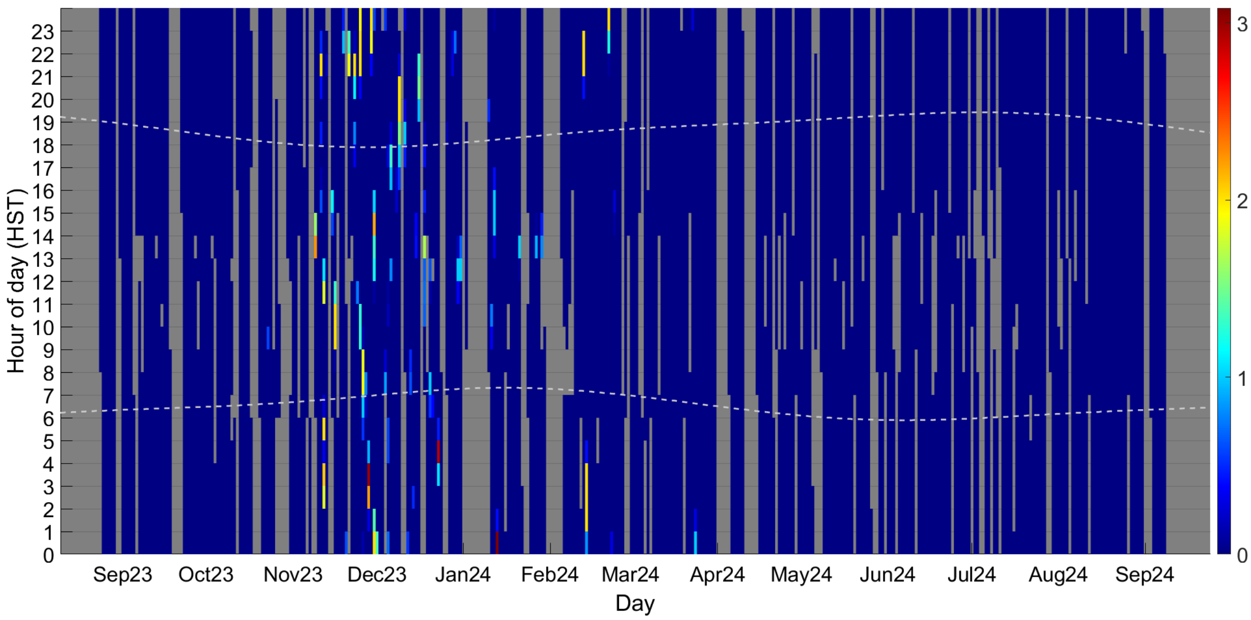



Figure 8. Example spectrogram of low-frequency downsweeps (about 80-30 Hz) detected along a track on PMRF on November 9, 2023 (UTC), occurring in a series of eleven followed by a triplet more typical of documented sei whale calls.

The mean number of automatically tracked sei whales detected in a 2.5-minute snapshot period from August 2023 to September 2024 is reported for each hour of the day in Figure 9 and by month in Table 5. Sei whales were detected on the PMRF range from October 2023 through March 2024. Monthly mean presence was highest in November 2023 (0.2 whales/snapshot). A peak mean of 3.08 whales/snapshot detected in a one-hour bin occurred once in January 2024, while a mean of 2.9 whales/snapshot and 3 whales/snapshot occurred in a one-hour bin in November 2023 and January 2024 respectively (Figure 9). For comparison, in the FY23 annual report (Martin et al., 2024) sei whale presence occurred from October 2022 to March 2023. Monthly mean presence was highest in January 2023 (0.2 whales/snapshot), and a peak hourly mean of 4 whales occurred in January 2023. Relative to the 2022-2023 season in last year's report, the 2023-2024 season occurred during the same months, the peak monthly mean presence occurred two months earlier in November 2023 and was lower, and the peak hourly mean occurred in the same month (January 2024) and was lower.




- 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, July, and August 2024. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 9. The mean number of sei whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 3.1 (dark red).

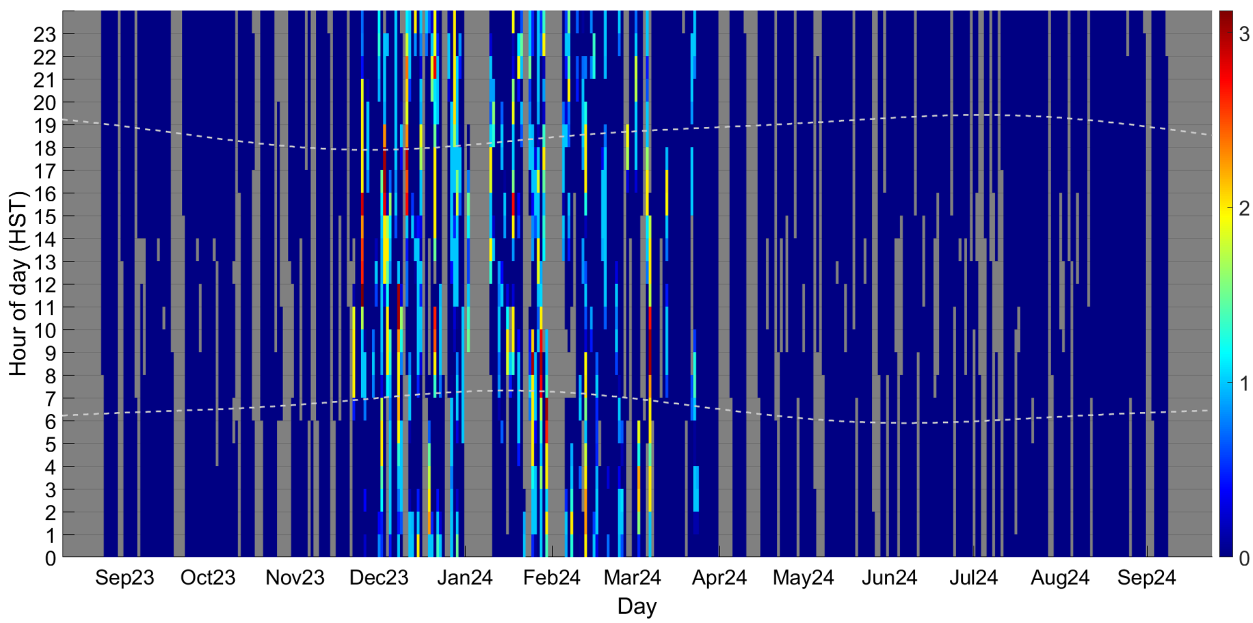
Table 5. Monthly numbers of sei whales detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | 2,935 | 0.004 | 0.07 |
| November-23 | 10,519 | 0.15 | 0.53 |
| December-23 | 14,717 | 0.07 | 0.34 |
| January-24 | 8,550 | 0.03 | 0.23 |
| February-24 | 3,788 | 0.1 | 0.42 |
| March-24 | 2,075 | 0.01 | 0.13 |
| April-24 | – | – | – |
| May-24 | – | – | – |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 3.2.4 Fin Whales

The mean number of automatically tracked fin whales detected in a 2.5-minute snapshot period from August 2023 to September 2024 is given for each hour of the day in Figure 10 and by month in Table 6. These detections are largely made up of fin whale A and B notes in regular inter-note-intervals classified as song; occasionally fin whale tracks include A and B notes as well as non-stereotypical notes in inconsistent patterns and so are not classified as song. Fin whales were detected from November 2023 to March 2024. Peak monthly mean presence occurred in December 2023 with a mean of 0.5 whales/snapshot. A peak hourly mean of 3.1 whales/snapshot occurred once in November 2023. 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 as May (Martin et al., 2024). Since January 2011, presence has typically been highest in December and January with up to four whales in a snapshot (Martin et al., 2023). For comparison, in the FY23 annual report (Martin et al., 2024) fin whale presence occurred from November 2022 to May 2023, monthly mean presence was highest in December 2022 (0.6 whales/snapshot), and a peak hourly mean of 4 whales occurred in December 2022. Relative to the 2022-2023 season in last year's report, the 2023-2024 season ended earlier in March 2024, the peak monthly mean presence occurred in the same month (December 2023) and was lower, and the peak hourly mean occurred one month earlier in November 2023 and was lower.




- 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, July, and August 2024. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 10. The mean number of fin whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 3.13 (dark red).

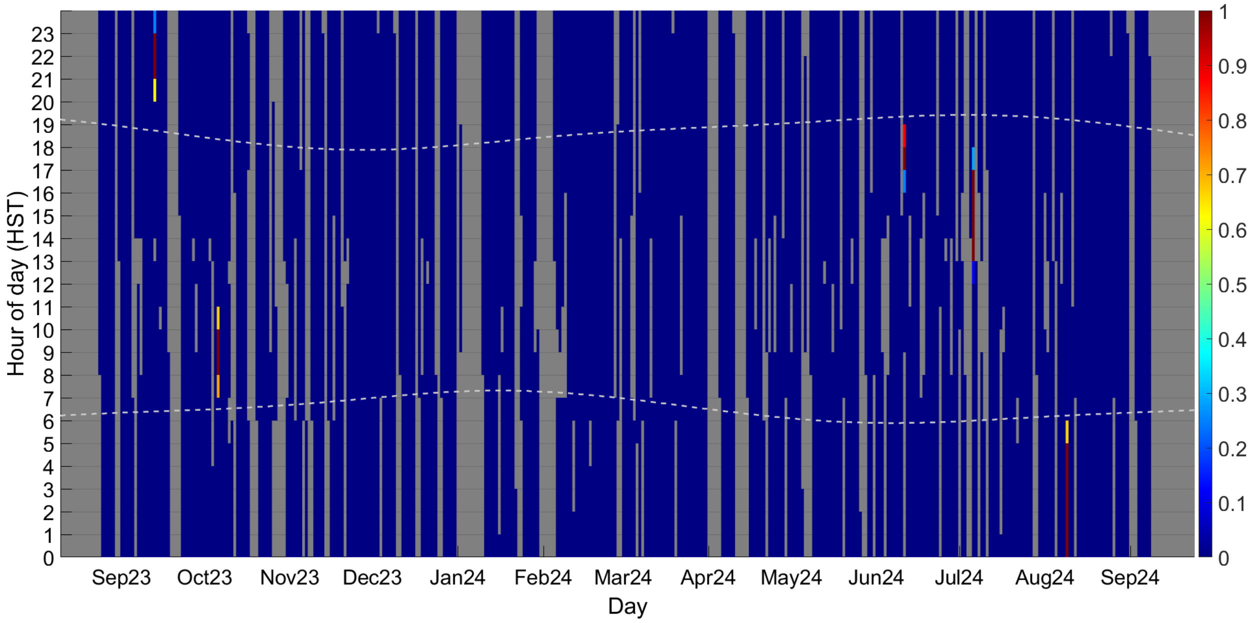
Table 6. Monthly numbers of fin whales detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | – | – | – |
| November-23 | 5,096 | 0.24 | 0.62 |
| December-23 | 14,717 | 0.49 | 0.73 |
| January-24 | 9,959 | 0.45 | 0.72 |
| February-24 | 11,396 | 0.24 | 0.51 |
| March-24 | 7,057 | 0.31 | 0.64 |
| April-24 | – | – | – |
| May-24 | – | – | – |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 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 2023 to September 2024 is reported for each hour of the day in Figure 11 and by month in Table 7. Bryde's whales are the only baleen whale known to potentially be present in the summer months and were detected from September to October 2023, and June to August 2024. Peak monthly presence occurred in July 2024 with a mean of 0.09 whales/snapshot. A peak hourly mean of 1 whale/snapshot occurred in every month they were detected in. This concurs with general peak presence of one to two whales in a snapshot (Martin et al., 2024, 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 times (Martin et al., 2022a). For comparison, in the FY23 annual report (Martin et al., 2024), Bryde's whale presence occurred from October to December 2022. Monthly mean presence was highest in October 2022 (0.2 whales/snapshot), and a peak hourly mean of 2 whales occurred in October 2022. Relative to the 2022-2023 period in last year's report, the 2023-2024 period had Bryde's whale detections spread across more months and had both a lower monthly and hourly mean presence.




- 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, July, and August 2024. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

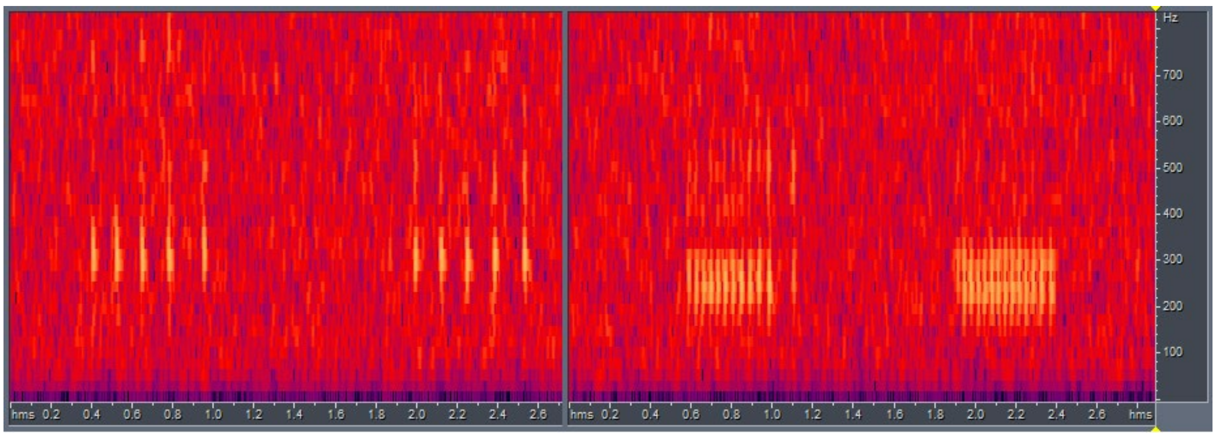
Figure 11. The mean number of Bryde's whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.13 (blue) to 1 (dark red).

Table 7. Monthly numbers of Bryde's whales detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | 1,031 | 0.07 | 0.25 |
| October-23 | 3,253 | 0.02 | 0.16 |
| November-23 | – | – | – |
| December-23 | – | – | – |
| January-24 | – | – | – |
| February-24 | – | – | – |
| March-24 | – | – | – |
| April-24 | – | – | – |
| May-24 | – | – | – |
| June-24 | 1,169 | 0.04 | 0.20 |
| July-24 | 1,125 | 0.09 | 0.29 |
| August-24 | 2,167 | 0.06 | 0.24 |
| September-24 | – | – | – |

This year, the humpback whale detector picked up a whale track on August 10, 2024. Because humpback whales are extremely unlikely to be present in August, this track was manually validated and found to contain pulse trains with a bandwidth between 200 and 400 Hz (Figure 12). Based on documented baleen whale pulse trains (Figueiredo & Simão, 2014, Risch et al., 2014, Rivers 1997, Edds et al., 1993) and the fact that there was a confirmed Bryde's whale track the day before on August 9 (and those are the only baleen whales expected to be present in the summer), this pulse train probably belonged to a Bryde's whale. Like the signals reported by Figueiredo & Simão (2014) off the coast of Brazil, along the PMRF track there seemed to be two general types of pulse trains. The first consisted of typically five pulses with most energy between 250 and 400 Hz with an inter-pulse interval of about 0.1 seconds (Figure 12, left). The second consisted of anywhere from seven to over 22 pulses with a bandwidth slightly lower in frequency (about 175-350 Hz) and a much lower inter-pulse interval of about 0.035 seconds (Figure 12, right).



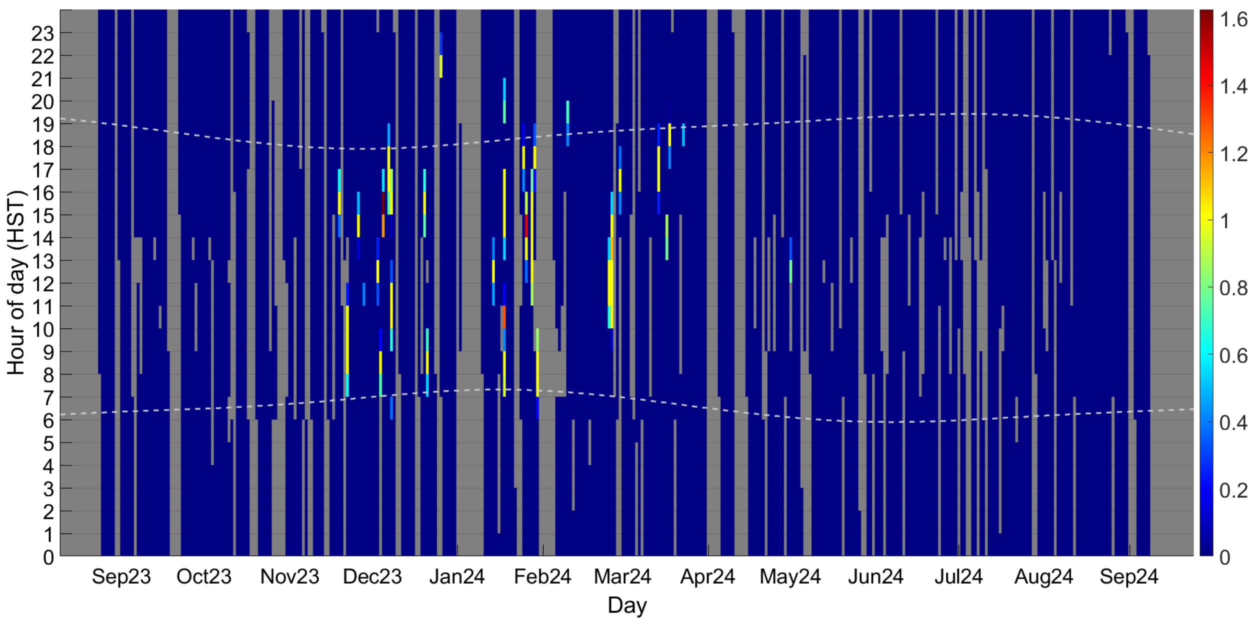

- Two types of pulse trains with slightly different characteristics were detected. The first (left) is comprised of fewer pulses with most of their acoustic energy at higher frequencies (about 250-400 Hz) while the second (right) contains more pulses at a much lower inter-pulse interval and with most energy at somewhat lower frequencies (about 175-350 Hz).

Figure 12. Example spectrograms, each about 2.8 seconds, of pulse trains that were detected along a track on August 10, 2024 (UTC) and presumed to belong to a Bryde's whale.

Other documented instances of Bryde's whale pulse trains suggest that this call may be limited to Bryde's whale calves, or at least when calves are present (Figueiredo & Simão, 2014, Edds et al., 1993). However, such documentation is limited, and pulse trains may serve other purposes in other baleen species. The behavioral function of minke whale pulse trains is unknown (Risch et al., 2013), but in humpback whales in Hawai'i, pulse trains were detected coincident with humpback whale breeding behavior along with song and other social sounds, though it is unclear what specific purpose they serve or whether males or females (or both) might be producing them (Darling, 2005). Pulse trains (or series of A calls) may serve a function in male blue whale song, but the research is limited and inconclusive (Lewis et al., 2018). Though there are currently no detectors explicitly built for this type of signal for any of the baleen whale species on PMRF, it is clearly an area worth exploring. One traditional limitation of using PAM to assess baleen whale ecological questions is that males are typically presumed to be the only individuals producing most vocalizations. If this signal truly belongs to calves (or mothers with calves), that could be a potential inroad to better quantifying population dynamics in at least one species of baleen whale (though that of course presupposes that the signal occurs often in the detection area).

### 3.2.6 20-Hz Downsweeps

The mean number of automatically tracked 20-Hz downsweeps (likely produced by fin or sei whales) detected in a 2.5-minute snapshot period from August 2023 to September 2024 is shown for each hour of the day in Figure 13 and by month in Table 8. Downswept 20-Hz calls were also detected during periods when fin (Figure 10 and Table 6) and sei (Figure 9 and Table 5) whales were detected, and as noted previously are not classified to either species as these calls don't meet the pre-defined criteria. Monthly mean presence was highest in January 2024 with a mean of 0.07 whales/snapshot. A peak hourly mean of 1.6 whales/snapshot occurred once in December 2023. For comparison, in the FY23 annual report (Martin et al., 2024) 20-Hz calls occurred between November 2022 and March 2023. Monthly mean presence was highest in January 2023 (0.10 whales/snapshot), and a peak hourly mean of 1.8 whales also occurred in January 2023. Relative to the 2022-2023 period in last year's report, the 2023-2024 period had 20-Hz downsweep detections later until May 2024, peak monthly mean presence occurred in the same month (January 2024) and was lower, and the peak hourly mean occurred one month earlier in December 2023 and was lower. These data also suggest there may be a potential diurnal pattern associated with the detection of 20-Hz downsweeps (Figure 13) that was not apparent in the FY23 results (Martin et al., 2024).




- 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, July, and August 2024. 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 2023 to September 2024 ranged from 0.04 (blue) to 1.63 (dark red).

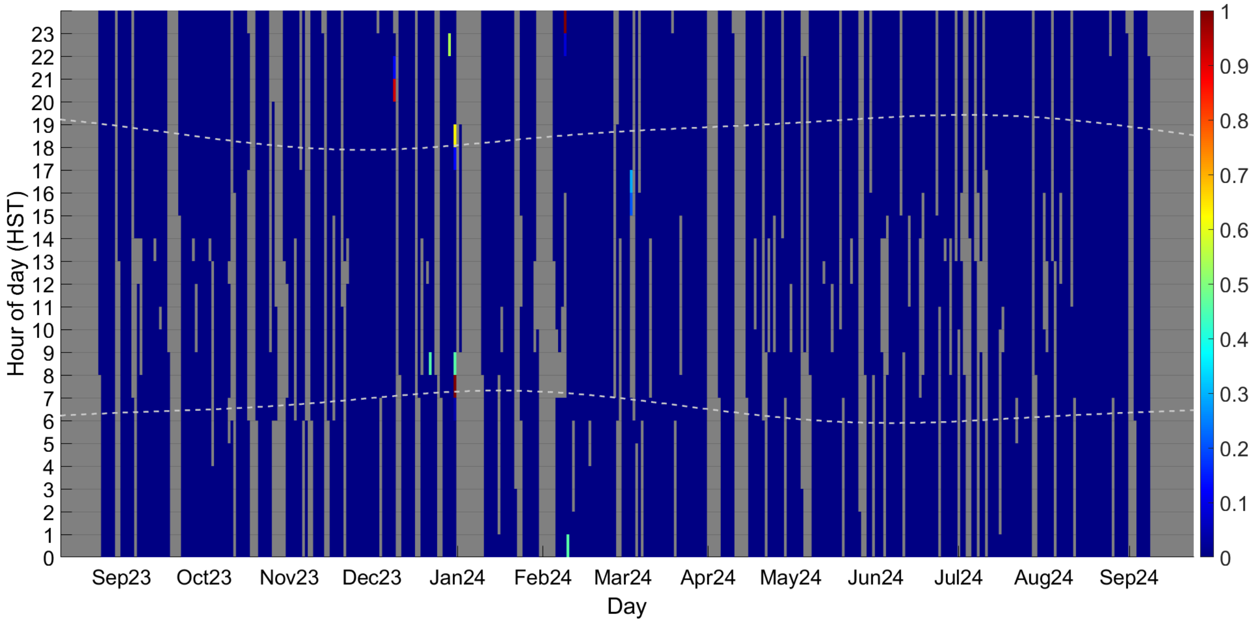
Table 8. Monthly numbers of tracks comprised of 20-Hz downsweeps (suspected to be either fin or sei whales) detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | – | – | – |
| November-23 | 6,691 | 0.03 | 0.17 |
| December-23 | 9,294 | 0.06 | 0.24 |
| January-24 | 8,560 | 0.07 | 0.27 |
| February-24 | 4,242 | 0.06 | 0.24 |
| March-24 | 7,433 | 0.03 | 0.16 |
| April-24 | – | – | – |
| May-24 | 2,067 | 0.01 | 0.10 |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 3.2.7 40-Hz Downsweeps

The mean number of automatically tracked 40-Hz downsweeps, attributable to several possible species of baleen whale, detected in a 2.5-minute snapshot period from August 2023 to September 2024 is shown for each hour of the day in Figure 14 and by month in Table 9. As mentioned in Sections 2.2.1 and 3.2.6, these aren't classified to any specific species as they don't meet pre-defined criteria. Downswept 40-Hz calls occurred between December 2023 and March 2024. This concurs with previously reported presence from November (Martin et al., 2022b) to April (Martin et al., 2024). Peak monthly presence occurred in January 2024 with a mean of 0.08 whales/snapshot. A peak hourly mean of 1.00 whales/snapshot occurred once in December 2023 and in February 2024. Since January 2011, typically at most 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). For comparison, in the FY23 annual report (Martin et al., 2024) 40-Hz calls occurred between November 2022 and April 2023. Monthly mean presence was highest in January 2023 (0.12 whales/snapshot), and a peak hourly mean of 1.00 whales occurred several times between November 2022 and April 2023. Relative to the 2022-2023 period in last year's report, the 2023-2024 period had 40-Hz downsweep detections over a shorter period by starting one month later in December 2023, and ending one month earlier in March 2024. Peak monthly mean presence occurred in the same month (January 2024) and was lower, and the peak hourly mean was the same but occurred less often and across fewer months.




- 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, July, and August 2024. 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 (possibly attributable to several baleen whale species) detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 1 (dark red).

Table 9. Monthly numbers of tracks comprised of 40-Hz downsweeps (possibly attributable to several baleen whale species) detected in 2.5-minute snapshots.

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | – | – | – |
| November-23 | – | – | – |
| December-23 | 7,885 | 0.01 | 0.10 |
| January-24 | 219 | 0.08 | 0.28 |
| February-24 | 1,379 | 0.03 | 0.16 |
| March-24 | 347 | 0.03 | 0.18 |
| April-24 | – | – | – |
| May-24 | – | – | – |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

### 3.2.8 Blue Whales

Detections of long tonal signals in the frequency range expected for certain blue whale calls were localized and tracked in a similar fashion to humpback whales (see Section 2.2.1). The spectral characteristics of these calls (i.e., long duration and little frequency modulation) and the fact that the calls are loud and low enough to be detected from well outside the PMRF area often preclude precise localization, so the localizations produced are assessed for presence/absence rather than track counts. Because the detection process will occasionally pick up series of low-frequency downsweeps (such as those produced by fin whales) and because not many localizations are produced overall, in datasets where there are at least 20 localizations with a maximum least squared error of 0.1, all calls contributing to those localizations were manually validated, and any confirmed blue whale presence reported here.

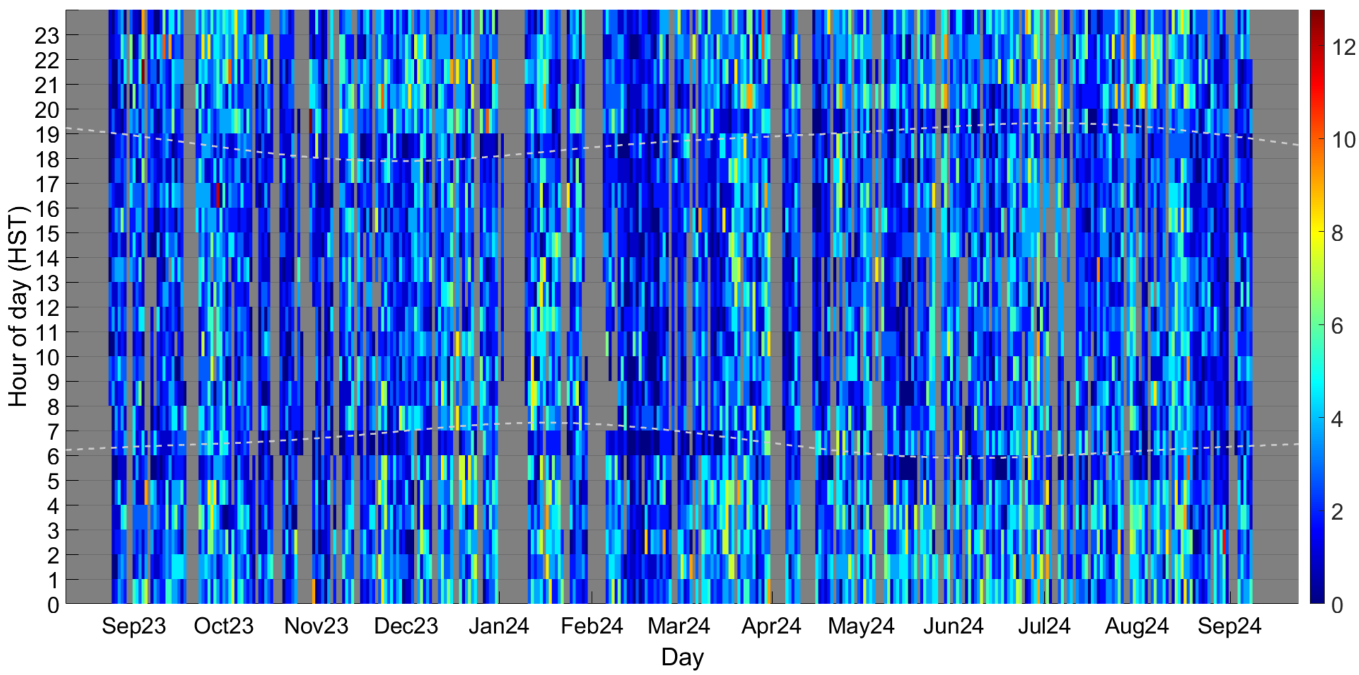
There are three different call types that have been detected in previous years of analysis and all three were present at some point in the FY24 dataset. Northwestern Pacific and northeastern Pacific B blue whale calls (after Stafford et al. 2001) are both usually detected at some point during the winter. In FY23, an additional tonal call with a spectral peak at about 54-Hz was identified and is very similar in character to the other two identifiable call types. This could be an unusual harmonic or a Watkins' whale (Watkins et al. 2004), but it cannot be conclusively attributed to a blue whale (Martin et al., 2024). A mix of northwestern Pacific and northeastern Pacific B blue whale calls were detected on or near PMRF on December 22-24, 2023, February 10-11, and March 20-21, 2024. In addition, northwestern Pacific calls were detected January 12-13 and March 1, 2024, while northeastern Pacific B calls were detected January 18-22, 25, and 27 and March 25, 2024. The 54-Hz unknown whale call was faintly detected January 18-19, 2024.

Despite difficulties with localization and tracking these call types, three confirmed blue whale tracks were found transiting across the northern portion of PMRF. On December 22, 2023, two overlapped somewhat in space and time heading southeast and both northwestern Pacific and northeastern Pacific B blue whale calls were present. There has been some uncertainty in past years regarding whether an individual blue whale could produce both call types in a sequence (Martin et al., 2021), but based on the timing of the calls in the raw data and despite some uncertainty in the localizations, in this particular case it seems that one track contained northwestern Pacific calls while the other contained northeastern Pacific B calls (i.e., it appears to have been two animals, each sticking to one call type). The third track occurred on February 11, 2024 moving northwest and contained only northwestern Pacific calls, although other poorly localized northeastern Pacific B blue whale calls were also present in that dataset (likely off-range).

### 3.2.9 Dense-Beaked Whales

Dense-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, subsets of six 24-hour baseline periods, two 24-hour periods from SCC data, and one 24-hour period from RIMPAC data were randomly selected to determine false positive and missed dive rates and ensure the groups were sorted correctly. The results from these nine 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 FY24 baseline data was 91.2% and for the training data was 85.3%, while the corresponding false positive rates were 8.8% for baseline data and 14.7% for training data, reflecting a marked improvement in the processing algorithms from FY23. These values were applied to the remaining autogrouped datasets and the results are visualized by hour in Figure 15 and shown by month in Table 10. The training data are also discussed separately in Section 4.2.1. Note that the detection data used for this analysis were from the older version of the beaked whale detection and classification code; it is anticipated that the classification results will continue to improve when the next iteration of the code is finalized and applied, as was demonstrated for the other species of beaked whales in Section 2.2.1.1.2.

The highest GVP/hour rates occurred in March 2024 at 3.11 GVPs/hour, while the lowest GVP/hour rates occurred in February 2024 at 1.9 GVPs/hour. The mean GVP/hour rate for the year was 2.8 (with a median rate by month of 2.9). These high rates are comparable to what was recorded in FY23 and continue to 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, July, and August 2024. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 15. The total number of dense-beaked whale GVPs/hour corrected using manually validated dives from six unclassified datasets and three classified datasets from August 2023 to September 2024 ranged from 0.85 (blue) to 12.77 (dark red).

Table 10. Dense-beaked whale monthly GVP summary.

| Date | Hours | GVPs | GVPs/hour |
|---|---|---|---|
| August-23 | 136.5 | 291 | 2.13 |
| September-23 | 568.5 | 1614 | 2.84 |
| October-23 | 511.8 | 1182 | 2.31 |
| November-23 | 576.1 | 1,454 | 2.52 |
| December-23 | 613.7 | 1,895 | 3.09 |
| January-24 | 424.2 | 1249 | 2.94 |
| February-24 | 502.9 | 978 | 1.94 |
| March-24 | 667.2 | 2,072 | 3.11 |
| April-24 | 446.5 | 1,106 | 2.48 |
| May-24 | 571.5 | 1,681 | 2.94 |
| June-24 | 618.4 | 1,880 | 3.04 |
| July-24 | 549.7 | 1,641 | 2.99 |
| August-24 | 669.7 | 1,870 | 2.79 |
| September-24 | 144.4 | 316 | 2.19 |

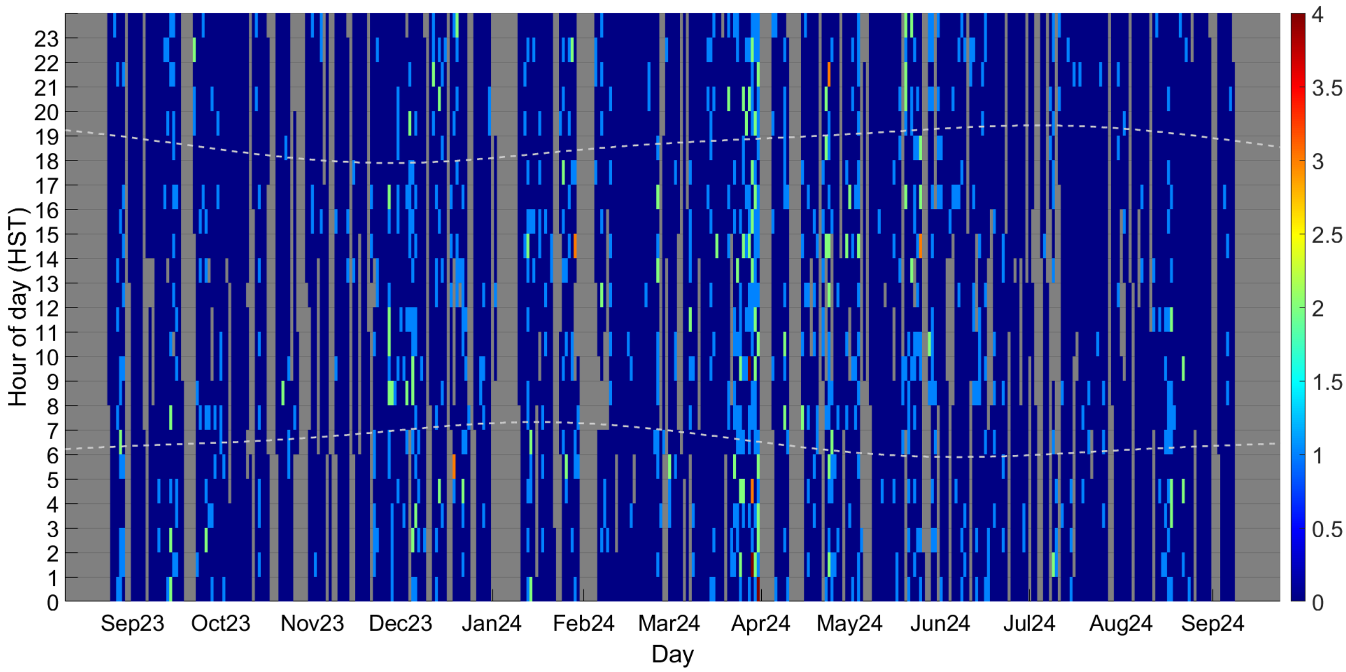
### 3.2.10 Goose-Beaked Whales

For goose-beaked whales, only GVPs with an ICI mode between 0.3 and 0.6 seconds were included in the results to exclude false positives that tend to occur due to the presence of other odontocetes. Goose-beaked whale presence in all FY24 data was fully validated by manually reviewing the spectrograms of clicks contributing to automatically generated GVPs for accuracy. Estimates of relative abundances are reported in Figure 16 and Table 11. Overall trends during baseline periods are discussed below while those during SCCs are discussed separately in Section 4.2.2.

There were a total confirmed 867 goose-beaked whale GVPs during baseline periods with a false positive rate of 28%, and an additional 44 confirmed GVPs during training activities with a false positive rate of 45%. With over 800 more recording hours, this is reasonably higher than the estimated 634 GVPs previously reported (Martin et al., 2024), but still lower than the historic confirmed high of 911 GVPs the year prior (Martin et al., 2023) despite about 1,000 more recording hours.

On average (including training activities) there were 0.13 GVPs/hour (median by month = 0.10 GVPs/hour) which falls between the rates estimated for FY23 and FY22 which had means of 0.10 GVPs/hour and 0.16 GVPs/hour, respectively (Martin et al., 2023, 2024). The peak monthly GVP rate occurred in March with 0.28 GVPs/hour (Table 11), which is a little higher but consistent with most other monthly peaks in recent years (0.24 GVPs/hour in February 2023, 0.2 GVPs/hour in July 2021, and 0.2 in May 2020 [Martin et al., 2022a, 2022b, 2024]). The lowest monthly GVP rate occurred in September 2024 at 0.03 GVPs/hour, followed by October 2023 at 0.04 GVPs/hour (Table 11). These are consistent with the lowest monthly GVP rates in previous reports (0.04 GVPs/hour in August 2022, 0.05 GVPs/hour in October 2022, and 0.03 GVPs/hour in February 2022 [Martin et al., 2023, 2024]). When present, hourly GVP presence ranged from 1 to 4 GVPs (Figure 16) which is very similar to the past three years which all had a maximum of three GVPs/hour (Martin et al., 2022b, 2023, 2024).

As in previous reports, there do not seem to be any strong seasonal patterns exhibited by goose-beaked whales based on hourly GVP rates and no evidence of a diel pattern (Figure 16). This year, presence was generally highest in spring, peaking in March (0.3 GVPs/hour) through April and May (0.2 GVPs/hour for both months), with some smaller peaks in August and December 2023, and January 2024 (0.2 GVPs/hour for all three months; Table 11) while in previous years peaks have occurred in all seasons (Martin et al., 2023, 2024).




- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February, July, and August 2024. 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 fully validated goose-beaked whale GVPs/hour from August 2023 to September 2024 ranged from 1 (blue) to 4 (dark red).

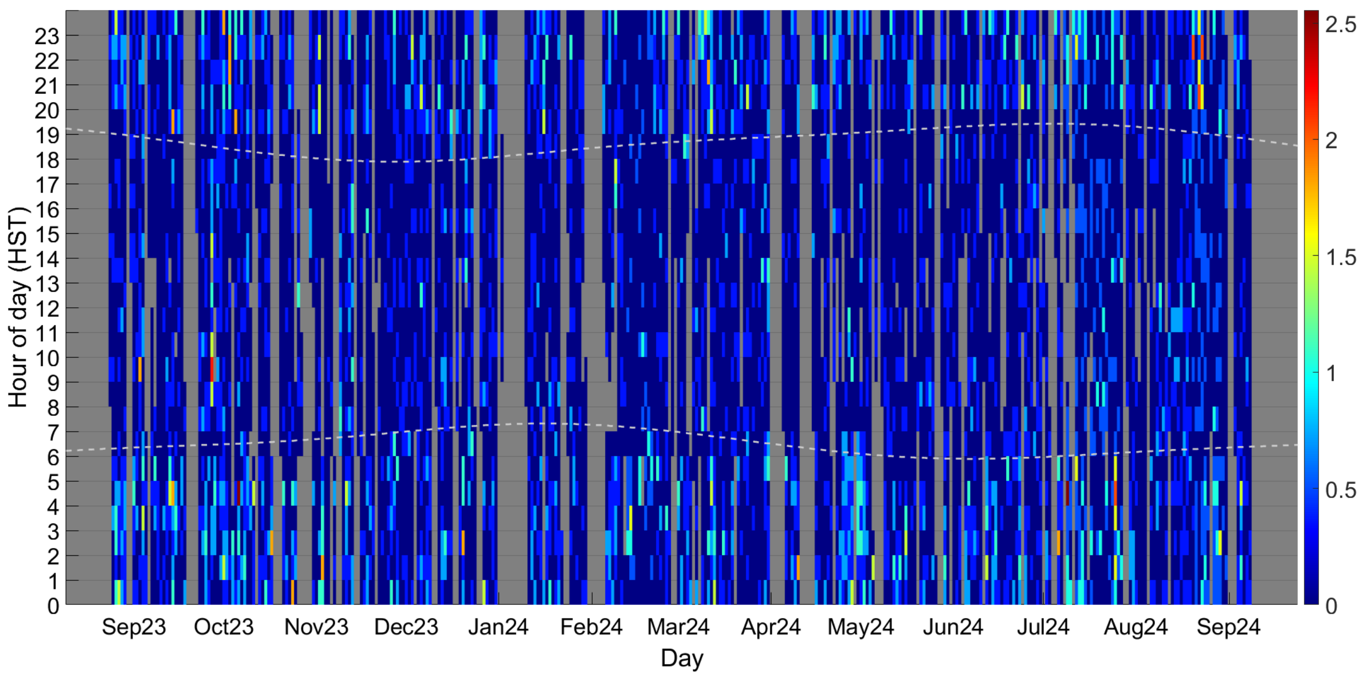
Table 11. Goose-beaked whale monthly GVP summary.

| Date | Hours | GVPs | GVPs/hour |
|---|---|---|---|
| August-23 | 136.5 | 23 | 0.17 |
| September-23 | 568.5 | 57 | 0.10 |
| October-23 | 511.8 | 22 | 0.04 |
| November-23 | 576.1 | 52 | 0.09 |
| December-23 | 613.7 | 107 | 0.17 |
| January-24 | 424.2 | 71 | 0.17 |
| February-24 | 502.9 | 41 | 0.08 |
| March-24 | 667.2 | 186 | 0.28 |
| April-24 | 446.5 | 94 | 0.21 |
| May-24 | 571.5 | 114 | 0.20 |
| June-24 | 618.4 | 56 | 0.09 |
| July-24 | 549.7 | 37 | 0.07 |
| August-24 | 669.7 | 46 | 0.07 |
| September-24 | 144.4 | 5 | 0.03 |

### 3.2.11 Cross Seamount Beaked Whales

Cross Seamount beaked whale echolocation pulses (BWC) were similarly automatically detected and grouped, with randomly selected 24-hour subsets of datasets manually validated, including six baseline datasets, two SCC datasets, and one RIMPAC dataset. These true positive (36.2% baseline and 51.1% during training) and false positive (63.8% baseline and 48.9% during training) rates were then applied to the rest of the automatically grouped GVPs. The resulting GVPs/hour are given in Figure 17 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 17 that are false positives. The low true positive rates for this echolocation pulse are due to the confusion in the classification code between these pulses and dense-beaked whale pulses due to the higher frequency portion of these pulses getting cut off by the sampling bandwidth and the similarity in slope and duration in the remaining portion of the pulse between the two species. It is anticipated that the classification results will continue to improve when the next iteration of the code is finalized and applied, as was demonstrated for BWC pulses in Section 2.2.1.1.2.

The highest monthly rate of Cross Seamount beaked whales occurred in August 2023 with 0.3 GVPs/hour, while the lowest rate occurred in September 2024 with 0.1 GVPs/hour. The mean and median rates for FY24 were 0.2 and 0.2 GVPs/hour, respectively. These rates are comparable, if slightly lower, to what was reported for FY23 (Martin et al. 2024).




- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February, July, and August 2024. 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 Cross Seamount beaked whale GVPs/hour corrected using manually validated dives from 14 unclassified datasets and two classified datasets from August 2023 to September 2024 ranged from 0.36 (blue) to 2.56 (dark red).

Table 12. Cross Seamount beaked whale monthly GVP summary.

| Date | Hours | GVPs | GVPs/hour |
|---|---|---|---|
| August-23 | 136.5 | 34 | 0.25 |
| September-23 | 568.5 | 118 | 0.21 |
| October-23 | 511.8 | 110 | 0.21 |
| November-23 | 576.1 | 84 | 0.15 |
| December-23 | 613.7 | 106 | 0.17 |
| January-24 | 424.2 | 58 | 0.14 |
| February-24 | 502.9 | 72 | 0.14 |
| March-24 | 667.2 | 115 | 0.17 |
| April-24 | 446.5 | 73 | 0.16 |
| May-24 | 571.5 | 80 | 0.14 |
| June-24 | 618.4 | 97 | 0.16 |
| July-24 | 549.7 | 125 | 0.23 |
| August-24 | 669.7 | 117 | 0.17 |
| September-24 | 144.4 | 19 | 0.13 |

### 3.2.12 Tropical Bottlenose Whales

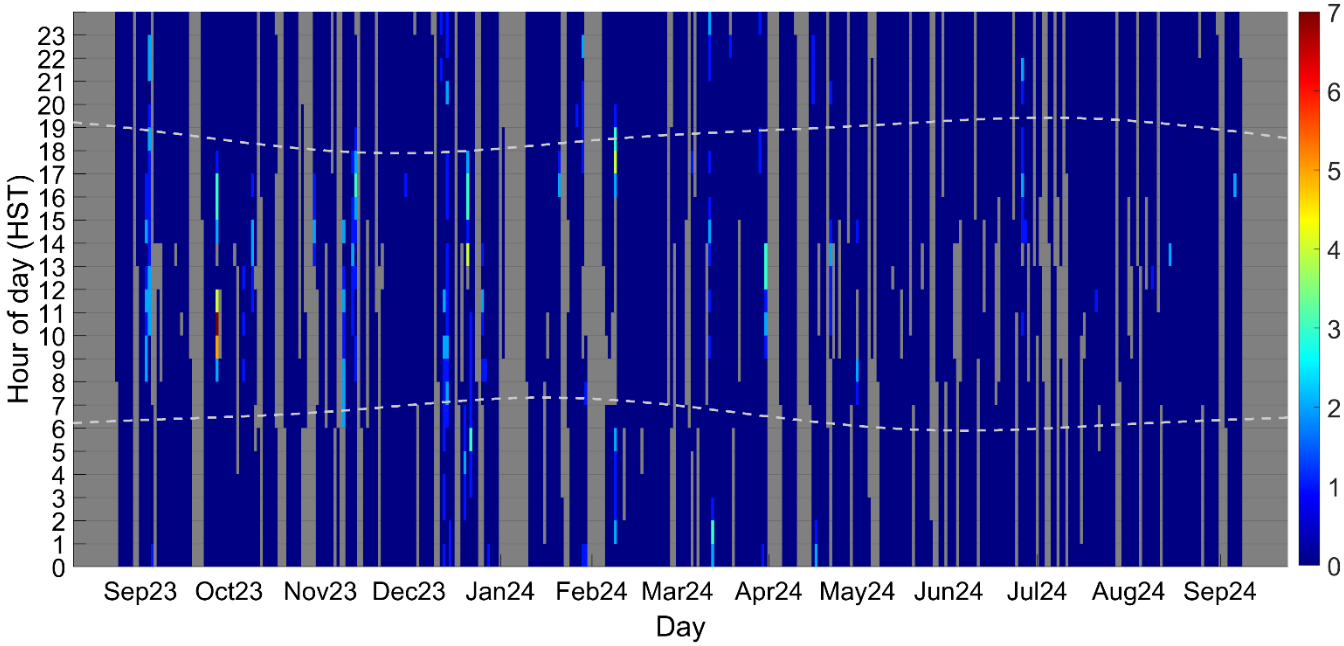
Because they are a new addition to NARWHAL, tropical bottlenose whales were processed using the new kernel-matching method for beaked whale classification with automatically generated GVPs required to have an ICI mode between 0.36 and 0.56 seconds (see Section 2.2.1.1.2). Due to their relatively sparse occurrence in the area compared to the other beaked whale species, tropical bottlenose whale presence was able to be fully validated for all FY24 data. Consequently, a true positive correction factor was not necessary, and the results presented in Figure 18 and Table 13 reflect confirmed tropical bottlenose whale GVPs. Compared to the preliminary classifier that was ran for the FY23 report and used descriptive characteristics of spectrograms, the false positive rate was much lower (3.2% vs. 64.5%; Martin et al., 2024). Based on manual review, the character of the false positives is also different, now due most commonly to an unidentified delphinid rather than confusion with Cross Seamount beaked whale clicks as was the case last year (Martin et al., 2024).

There were a total 272 confirmed tropical bottlenose whale GVPs (all but one of which occurred during baseline data). This is higher but on the order of the total in the FY23 report (227 GVPs during baseline data; Martin et al., 2024). The surplus may be due to the increased coverage (800 more recording hours; Martin et al., 2024) or the new classification algorithm may be more permissive (see Section 2.2.1.1.2), or both. On average (including training activities), there were 0.04 tropical bottlenose whale GVPs/hour (median by month also 0.03 GVPs/hour), which is the same as the FY23 report (Martin et al, 2024).

Presence varied from month to month and reflects a likely autocorrelation where the same group of animals probably produces multiple detected GVPs while present on PMRF (Figure 18, Table 13). Some months had extremely low or no hourly presence, such as August 2023 and September 2024 with zero and two GVPs, respectively (Figure 18), but both months bookend the current dataset and therefore reflect fractional effort) and May, July, and August 2024 (four, one, and four GVPs, respectively; Figure 18). In contrast, September and December 2023 had averages of 0.1 and 0.1 GVPs/hour, respectively, which is even comparable to some of the monthly means for goose beaked whales (Table 11, Table 13), though falls short of the FY23 maximum GVP rate in June 2023 (Martin et al., 2024). In the FY23 report, June and November had the highest GVP presence (Martin et al., 2024), which, combined with the results from the current dataset, suggests no obvious seasonal pattern. Neither this year nor last year suggest any strong diel trends

(Figure 18, Martin et al., 2024), although this year GVP presence was perhaps elevated during the day, particularly when presence was generally higher at the end of 2023 (Figure 18). As was largely the case in the FY23 report, almost all GVPs were detected on hydrophones deeper than 4 km in the middle of the range, with occasional exceptions on the shelf area on the east side of PMRF (Figure 1; Martin et al., 2024).

The previously mentioned possible autocorrelation could impact the comparison of specific averages, particularly over different time spans (e.g., a monthly mean vs. the overall mean for the year). This species, though present at some point every month, is relatively rare compared to the other beaked whale species and many datasets contain no GVPs at all. Averages could thus be biased depending on the duration of time sampled and whether or not tropical bottlenose whales were present during that time. More detailed spatial and temporal trends of tropical bottlenose whales as seen at PMRF will likely become more concrete as more years of archived data are processed with the new classifier.




- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February, July, and August 2024. 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 fully validated tropical bottlenose whale GVPs/hour from August 2023 to September 2024 ranged from 1 (blue) to 7 (dark red).

Table 13. Tropical bottlenose whale monthly GVP summary.

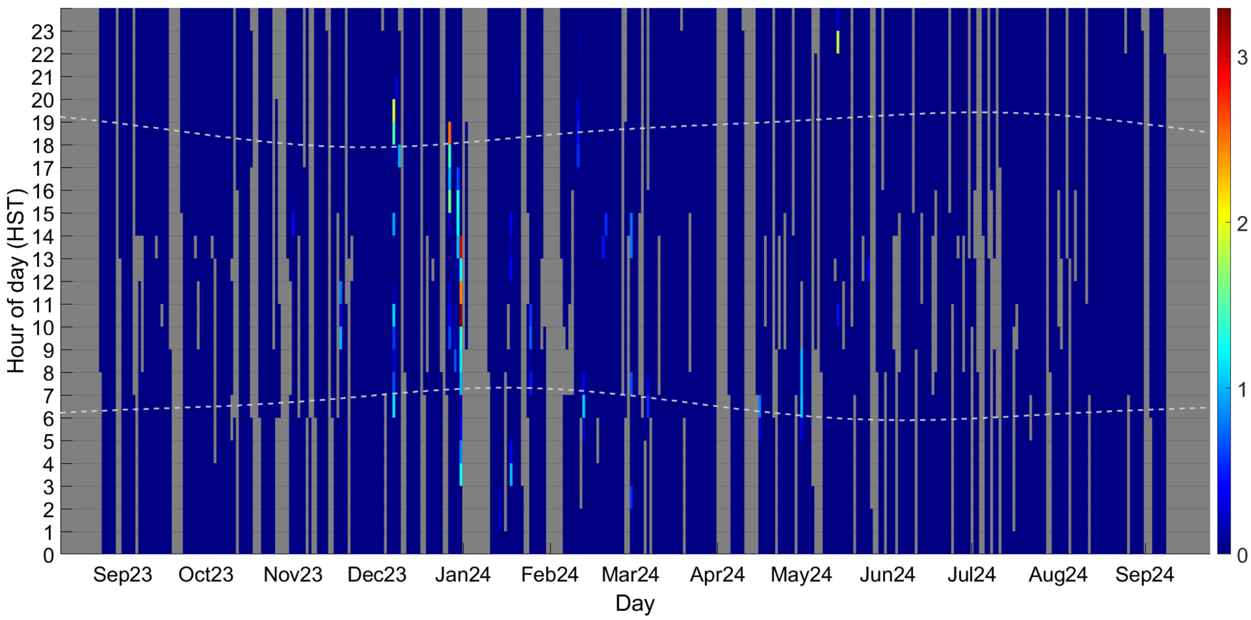
| Date | Hours | GVPs | GVPs/hour |
|---|---|---|---|
| August-23 | 136.5 | 0 | 0.00 |
| September-23 | 568.5 | 58 | 0.10 |
| October-23 | 511.8 | 15 | 0.03 |
| November-23 | 576.1 | 34 | 0.06 |
| December-23 | 613.7 | 68 | 0.11 |
| January-24 | 424.2 | 13 | 0.03 |
| February-24 | 502.9 | 17 | 0.03 |
| March-24 | 667.2 | 33 | 0.05 |
| April-24 | 446.5 | 13 | 0.03 |
| May-24 | 571.5 | 4 | 0.01 |
| June-24 | 618.4 | 11 | 0.02 |
| July-24 | 549.7 | 1 | 0.00 |
| August-24 | 669.7 | 3 | 0.00 |
| September-24 | 144.4 | 2 | 0.01 |

### 3.2.13 Killer Whales

As noted in Section 2.2.1, killer whale HFM signal detections (described in Simonis et al., 2012, Samarra et al., 2010, and as seen on PMRF in Henderson et al., 2018 and Jarvis et al. 2019) were grouped in a similar fashion to beaked whale GVPs. Since the automated process ultimately yields few groups and the high-frequency whistles of other odontocetes are occasionally detected with the algorithm, all groups were manually validated. This process yielded only seven confirmed groups of killer whale HFMs, two of which occurred within the same dataset in the same area of PMRF and were separated by only about 27 hours. They were otherwise spread throughout almost all seasons, occurring on August 24, October 31, and December 20, 2023, and then January 24 and March 16-17, 2024. As in past years of monitoring, groups of HFM signals only occurred during daylight hours (five groups out of seven) or when the moon was risen and mostly illuminated (the remaining two).

### 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 2023 and September 2024 is presented by hour in Figure 19 and by month in Table 14. Sperm whale detections occurred from November 2023 to May 2024, which happens to align with the season typically exhibited by baleen whales though sperm whales are not expected to adhere to any particular seasonality in this area. Peak monthly presence occurred in December 2023 with a mean of 0.2 whales/snapshot. A peak hourly mean of 3.3 whales/snapshot occurred once in December 2023. For comparison, in the FY23 annual report (Martin et al., 2024) sperm whales were detected between September 2022 and July 2023. Monthly mean presence was highest in November 2022 (0.3 whales/snapshot), and a peak hourly mean of 2.08 whales/snapshot occurred in January 2023. Relative to the 2022-2023 period in last year's report, the 2023-2024 period had fewer sperm whale detections throughout the year. Peak monthly mean presence occurred one month later in December 2023 and was lower, and the peak hourly mean occurred one month earlier in December 2023 and was higher.




- 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, July, and August 2024. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 19. The mean number of sperm whales detected in 2.5-minute snapshot periods for each hour of the day from August 2023 to September 2024 ranged from 0.04 (blue) to 3.30 (dark red).

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

- The number of 2.5-minutes snapshots includes periods that contained any number of whales. The mean and standard deviation of tracks per snapshot are based on the number of whales that were present in 2.5-minute snapshots.

| Date | Number of Snapshots | Mean Number of Tracks Per Snapshot | Standard Deviation of Tracks Per Snapshot |
|---|---|---|---|
| August-23 | – | – | – |
| September-23 | – | – | – |
| October-23 | – | – | – |
| November-23 | 3,124 | 0.02 | 0.14 |
| December-23 | 6,286 | 0.15 | 0.54 |
| January-24 | 6,435 | 0.02 | 0.13 |
| February-24 | 4,958 | 0.02 | 0.15 |
| March-24 | 2,906 | 0.03 | 0.18 |
| April-24 | 1,370 | 0.02 | 0.13 |
| May-24 | 3,488 | 0.04 | 0.25 |
| June-24 | – | – | – |
| July-24 | – | – | – |
| August-24 | – | – | – |
| September-24 | – | – | – |

# 4. Behavioral Response Analyses

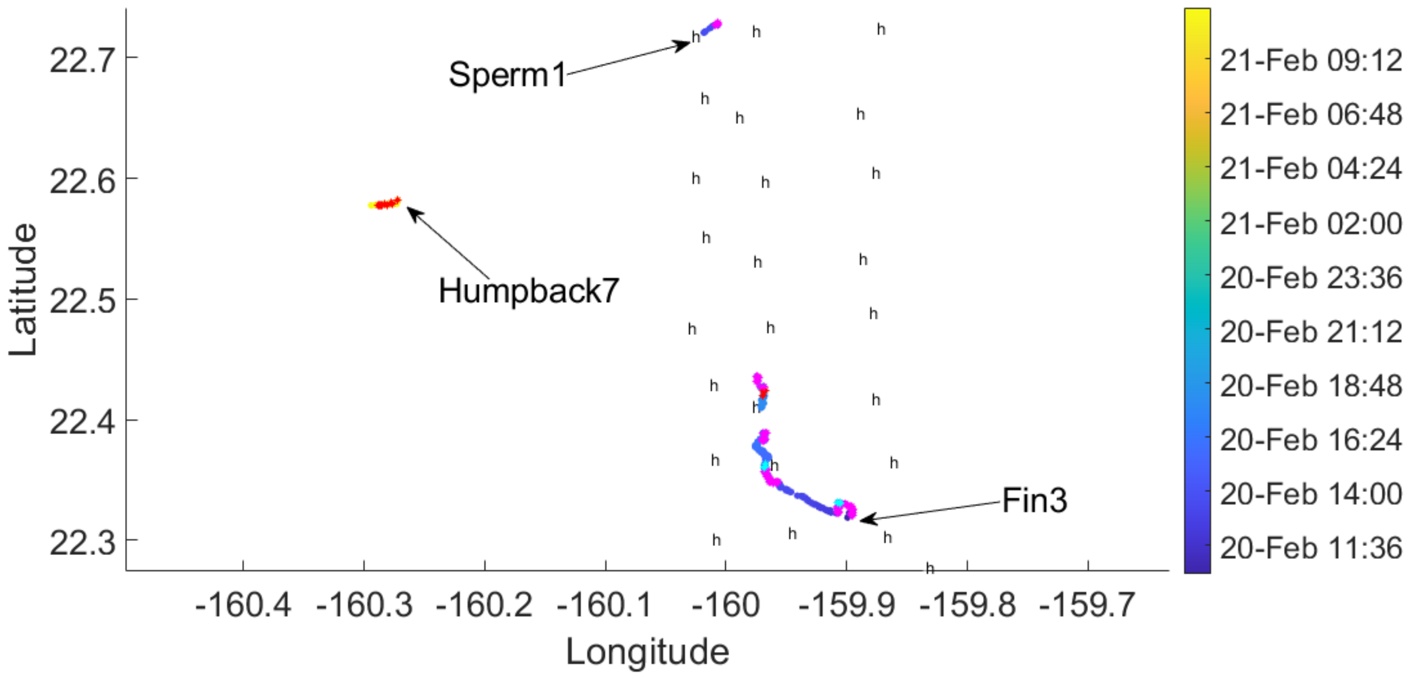
## 4.1 TRACKED WHALES

A total of 11 acoustically-tracked whales were exposed to MFAS during the February 2024 SCC. One fin whale was exposed to surface ship, sonobuoy, and helicopter-dipping sonar transmissions, two humpback whales were exposed to surface ship transmissions only, two humpback whales were exposed to sonobuoy and helicopter-dipping sonar transmissions, and two fin, one sperm, and three humpback whales were exposed to sonobuoy transmissions only (Table 15). Bold entries in Table 15 were selected for further investigation since they have the highest received level for each exposed and tracked species. Estimated exposures use methods and standardized metrics developed by Henderson et al. (2024a), Henderson et al. (2024b), and Henderson et al. (2025). Table 15 shows the highest median received level during a whale track, and two times the standard deviation (2*SD) in parentheses to provide a range of possible exposure values, with levels in units dB re 1 µPa. Each level was based on a single ping and estimated using propagation modeling and nominal source levels and depths, and an omnidirectional source. Animals are assumed to be located near the surface where they are likely to receive the highest received levels. The median received level accounts for animal location uncertainty by summarizing received levels within approximately +/-100 m of an animal's localized position, and from 1 to 54 m of depth. The distances in Table 15 are the closest points of approach (CPA) for each source type that overlaps with a whale track and do not necessarily correspond to the distance for the given estimated levels.

Table 15. Tracked whale exposures during the February 2024 SCC.

- Bold entries have the highest received level for each exposed species. Exposure levels and standard deviations in parentheses are in units dB re 1 µPa.

| Track | Start | End | Ship | Sonobuoy | Dipping Sonar |
|---|---|---|---|---|---|
| Fin1 | 2/12 17:06 | 2/12 21:42 | – | 97.2 (0.6) 14.4 km | – |
| Fin2 | 2/19 13:05 | 2/19 17:19 | – | 108.3 (1.0) 9.3 km | – |
| **Fin3** | **2/20 10:20** | **2/20 18:45** | **166.7 (2.5) 4.0 km** | **138.7 (0.4) 1.5 km** | **124.5 (3.2) 12.5 km** |
| **Sperm1** | **2/20 13:31** | **2/20 13:59** | **–** | **100.6 (2.1) 20.4 km** | **–** |
| Humpback1 | 2/19 10:55 | 2/19 11:59 | – | 97.1 (1.5) 14.1 km | – |
| Humpback2 | 2/19 16:51 | 2/19 17:29 | – | 91.1 (1.8) 37.8 km | – |
| Humpback3 | 2/19 22:09 | 2/19 22:12 | 147.0 (1.5) 41.1 km | – | – |
| Humpback4 | 2/20 10:03 | 2/20 11:49 | – | 101.5 (2.0) 23.6 km | 124.6 (0.2) 38.2 km |
| Humpback5 | 2/20 13:01 | 2/20 13:57 | – | 103.3 (1.7) 24.8 km | – |
| Humpback6 | 2/20 13:36 | 2/20 14:34 | – | 99.3 (0.4) 26.6 km | 122.8 (0.2) 34.9 km |
| **Humpback7** | **2/21 11:11** | **2/21 11:26** | **147.0 (1.0) 33.8 km** | – | – |




- Times in HST. Approximate hydrophone locations are depicted with "h" symbols. Arrows point to the start of a whale track. Asterisks indicate exposure to different MFAS sources: sonobuoys (magenta), helicopter dipping sonar (cyan), and hull-mounted (red).

Figure 20. Fin, sperm, and humpback whale MFAS exposures in February 2024.

Figure 21 to Figure 23 depict the exposure history for fin whale track 3, sperm whale track 1, and humpback whale track 7 and include the highest median received level (dB re 1 µPa) in a 5-minute bin by source type. Error bars are ± two times the standard deviation for the ping that produced the highest median received level in each 5-minute bin. The exposure history figures also include two 5-minute bins before the start and after the end of a whale track. Since the number of pings cannot be publicly stated, the symbols in Figure 21 to Figure 23 are color coded to indicate the level of sonar activity in a 5-minute bin by green (low), yellow (medium), and red (high). Symbols and line colors indicate source types with circles with blue lines for surface ship hull-mounted MFAS, squares with gray lines for dipping sonar, and diamonds with black lines for sonobuoy sonar.

Fin whale track 3 started on February 20$^{th}$ at 10:20 and was centrally located within the instrumented range at 22.32° latitude and -159.90° longitude (Figure 20). Based on the timeline of exposures in Figure 21, fin whale track 3 was exposed to four temporally discrete bouts of MFAS. In the first bout, the whale had a north/northwest heading (Figure 20) when sonobuoy exposures began at 10:53. From 11:43 to 11:46, dipping sonar exposures occurred in two bins with a highest median received level of 124.5 dB re 1 µPa (SD = 3.2) and a CPA of 12.5 km. Concurrent with dipping sonar exposures, the whale received the highest sonobuoy sonar exposures during bout 1 of 104.1 dB re 1 µPa (SD = 2.2). After the dipping and sonobuoy sonar exposures ended, the whale changed to a southerly heading (Figure 20). It continued south and was exposed to only sonobuoy sonar until the end of bout 1 at 12:17, at which point the whale changed to a northwest heading (Figure 20). From 12:18 to 13:47 there were no exposures and the whale remained on a northwest heading (Figure 20). Bout 2 began with sonobuoy exposures at 13:48 and lasted until 14:34, ending with dipping sonar exposures from 14:42 to 14:57. Overall, the whale remained on a northwest/northerly heading (Figure 20). During bout 2, sonobuoy sonar exposures had a highest median received level of 104.9 dB re 1 µPa (SD = 0.9) with a CPA of 14.9 km, and dipping sonar exposures had a highest median received level of 123.7 dB re 1 µPa (SD = 0.6) with a CPA of 28.4 km. From 14:58 to 16:32, no exposures occurred and the whale had multiple heading changes from northerly/northeasterly, to northwesterly, then northeasterly

(Figure 20). Bout 3 included sonobuoy exposures from 16:33 to 17:17, during which the whale milled and had minimal movement to the north. During bout 3, sonobuoy sonar exposures had a highest median received level of 122.8 dB re 1 µPa (SD = 0.3) with a CPA of 4.5 km. From 17:18 to 18:05 there were no exposures and the whale had a northerly heading (Figure 20). Bout 4 began at 18:06 with surface ship hull-mounted MFAS exposures that lasted until 05:30 and had a highest median received level of 166.7 dB re 1 µPa (SD = 2.5) with a CPA of 4.0 km. Sonobuoy sonar exposures occurred from 18:19 to 18:41 and had a highest median received level of 138.7 dB re 1 µPa (SD = 0.3) with a CPA of 1.5 km. During bout 4, fin whale track 3 continued to travel north/northwesterly (Figure 20) and ceased calling at 18:45. Overall, fin whale track 3 was exposed to multiple sources of MFAS and may have responded with changes in heading; however, the whale also exhibited changes in heading between sonar bouts when no exposures occurred.

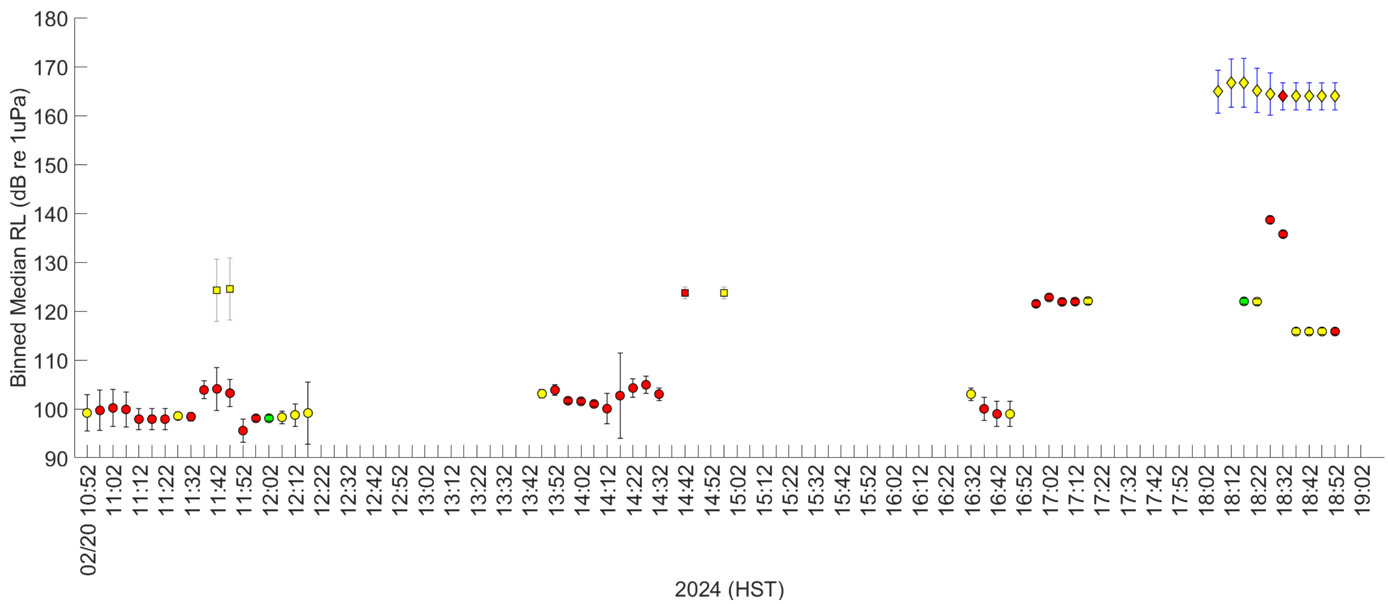



Figure 21. Fin whale track 3 exposure history to surface ship hull-mounted, sonobuoy, and helicopter dipping sonar.

Sperm whale track 1 started on February 20th at 13:31 on the northwest portion of the instrumented range at 22.72° latitude and -160.02° longitude (Figure 20). It traveled northeast for 17 minutes before sonobuoy exposures began at 13:48. The whale received sonobuoy exposures across four 5-minute bins and had a highest median received level of 100.6 dB re 1 µPa (SD = 2.1) (Figure 22) and a CPA of 20.4 km. Sperm whale track 1 ceased calling at 13:59 and at 22.73° latitude and -160.01° longitude (Figure 20). While the whale was acoustically tracked, there was not an apparent change in movement behavior in response to MFAS exposures.

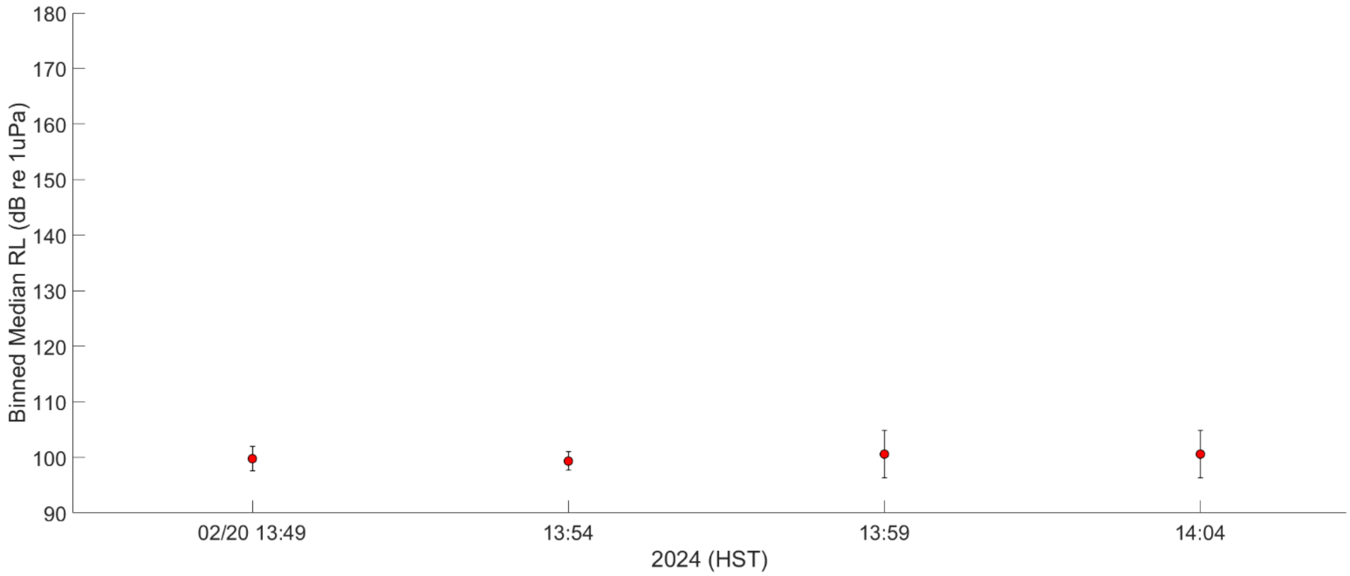



Figure 22. Sperm whale track 1 exposure history to sonobuoy sonar.

Humpback whale track 7 started on February 20st at 11:11 and was west of the instrumented range at 22.58° latitude and -160.27° longitude (Figure 20). The whale was exposed to surface ship hull-mounted MFAS the entire time it was acoustically tracked and had a highest median received level of 147.0 dB re 1 µPa (SD = 1.0) (Figure 23) and a CPA of 33.8 km. Humpback whale track 7 traveled west for 15 minutes and ceased calling at 11:26 and at 22.58° latitude and -160.28° longitude (Figure 20). While the whale was acoustically tracked, there was not an apparent change in movement behavior in response to MFAS exposures. As a note, given the whale's location outside of the instrumented range, the track likely contained indirect path localizations which can affect the accuracy of its estimated positions.

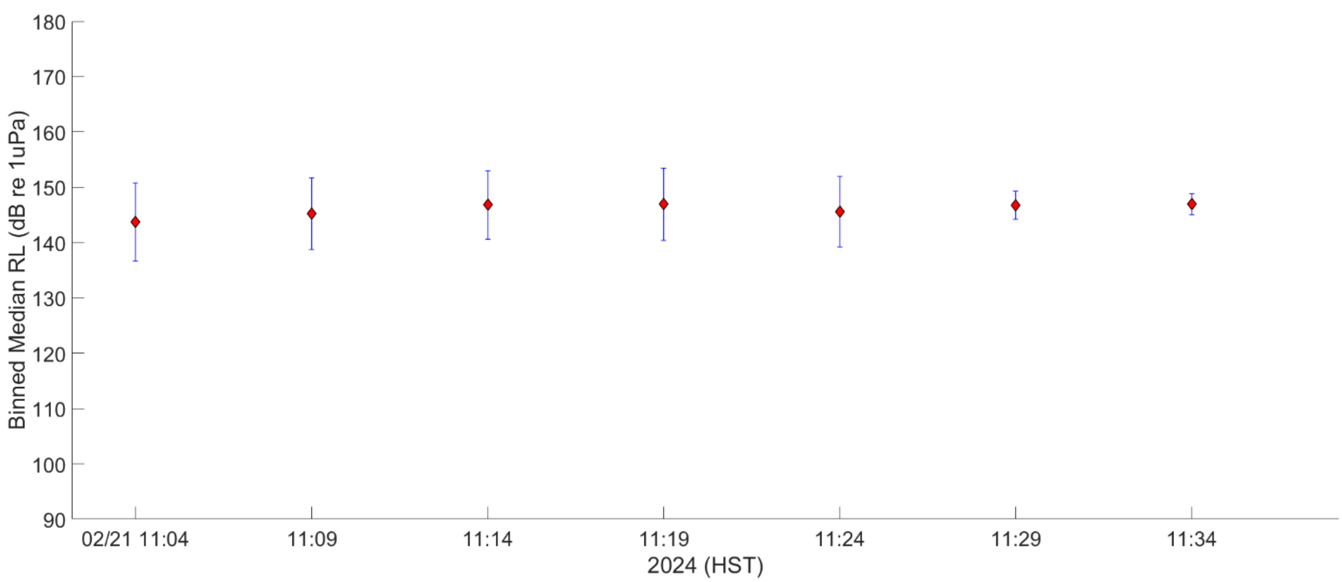



Figure 23. Humpback whale track 7 exposure history to surface ship hull-mounted sonar.

## 4.2 BEAKED WHALES

In FY24, data were recorded before, during, and after the February and August SCCs, as well as during a one-day submarine exercise (SUBEX) that included surface ship hull-mounted MFAS transmissions. In the February 2024 SCC, the SUBEX was conducted the day prior to the start of Phase A; however, for data presentation purposes we have combined them such the SUBEX is the start of Phase A. Data were manually validated for one dataset from each SCC for dense-beaked and Cross Seamount beaked whales and then the true positive rate for each species was applied to the remaining During data as described in Section 3.2.9 to Section 3.2.11 of this report. For goose-beaked whales and tropical bottlenose whales, all data in the time periods reported below were fully validated due to both species' relatively sparse occurrence. Tropical bottlenose whale presence was described before, during, and after the SCCs for the first time in this report.

### 4.2.1 Dense-Beaked Whales SCC

Dense-beaked whale GVP patterns were very typical during the FY24 SCCs, with the exception of Phase B. The Phase B period in both SCCs was shorter than it has been in the past, with only 57-59 hours for each SCC. This may be why the reduction in GVPs during Phase B was not as extreme as it has been in the past, resulting in similar GVP rates as observed in the respective Phase A.

In the week prior to the February SCC, dense-beaked whales had an overall corrected GVP/hour rate of 2.6. This decreased by over half to 1.2 GVPs/hour during Phase A, increased slightly to 1.7 GVPs/hour in the Interphase, and dropped again slightly to 1.3 GVPs/hour during Phase B. The rate increased to 2 GVPs/hour after the SCC (Table 16) and rose back to 3.1 GVPs/hour in March (Table 10).

Dense-beaked whale GVP rates were high in the week before the August SCC at 3.9 GVPs/hour. As is typical, they dropped to 1.9 GVPs/hour during Phase A, increased to 2.5 GVPs/hour in the Interphase, dropped back to 1.8 GVPs/hour in Phase B, and rose again to 2.2 GVPs/hour After the SCC. This SCC occurred slightly later in the month of August than it has in years past, such that the After data was recorded in September rather than the end of August, and no additional FY24 data are available to assess for further GVP recovery rates.

Table 16. Dense-beaked whale GVPs before, during, and after the February and August SCCs. Times are in UTC.

| Period | Start Date | End Date | Duration (hours) | GVP count | GVPs/ Hour |
|---|---|---|---|---|---|
| February 2024 SCC | | | | | |
| Before | 2/5/2024 23:38 | 2/12/2024 22:00 | 140.7 | 371 | 2.64 |
| Phase A | 2/12/2024 22:00 | 2/17/2024 2:37 | 100.6 | 117 | 1.16 |
| Interphase | 2/17/2024 2:37 | 2/19/2024 17:15 | 59.4 | 101 | 1.69 |
| Phase B | 2/19/2024 17:15 | 2/22/2024 2:21 | 57.1 | 77 | 1.34 |
| After | 2/22/2024 2:21 | 2/29/2024 4:30 | 145.9 | 291 | 1.99 |
| August 2024 SCC | | | | | |
| Before | 8/12/2024 16:57 | 8/20/2024 16:20 | 190.3 | 735 | 3.86 |
| Phase A | 8/20/2024 16:20 | 8/24/2024 23:59 | 103.6 | 201 | 1.94 |
| Interphase | 8/24/2024 23:59 | 8/27/2024 17:00 | 55.4 | 136 | 2.45 |
| Phase B | 8/27/2024 17:00 | 8/30/2024 4:06 | 59.1 | 105 | 1.77 |
| After | 8/30/2024 4:06 | 9/9/2024 7:51 | 188.3 | 414 | 2.20 |

### 4.2.2 Goose-Beaked Whales SCC

Goose-beaked whale presence with respect to the SCCs was similar to that seen last FY and to beaked whale behavior in general as seen on PMRF (Martin et al., 2024; see also Section 4.2.1 above). GVP rates tend to be typical of baseline data or higher preceding each SCC, decrease throughout the SCC, and then increase somewhat or climb fully to baseline levels afterwards. Details for this FY are broken up by SCC phase as shown for goose-beaked whales in Table 17.

Compared to the baseline average of 0.1 GVPs/hour (Section 3.2.10), the mean GVP rate for goose-beaked whales in the week before the February SCC was the same (0.1 GVPs/hour), and was higher in the week before the August SCC (0.2 GVPs/hour). During Phase A, GVP presence dropped quite a bit during both SCCs (0.01 GVPs/hour in February and 0.08 GVPs/hour for Phase A in August). During the February SCC, GVP rates marginally increased again during Interphase (0.03 GVPs/hour), before dropping to 0 GVPs for Phase B. In August, the drop to 0 GVPs occurred during Interphase and persisted through Phase B. After each SCC, GVP presence began to increase again to 0.03 GVPs/hour in August and near baseline levels in February at 0.1 GVPs/hour.

The overall patterns were very similar in both SCCs, though GVP presence after the SCCs was higher in February and closer to baseline levels despite higher initial GVP presence in August. The marginal bump in GVP presence in the February Interphase was also not evident in August.

Table 17. Goose-beaked whale GVPs before, during, and after the February and August SCCs. Times are in UTC.

| Period | Start Date | End Date | Duration (hours) | GVP count | GVPs/ Hour |
|---|---|---|---|---|---|
| February 2024 SCC | | | | | |
| Before | 2/5/2024 23:38 | 2/12/2024 22:00 | 140.7 | 19 | 0.14 |
| Phase A | 2/12/2024 22:00 | 2/17/2024 2:37 | 100.6 | 1 | 0.01 |
| Interphase | 2/17/2024 2:37 | 2/19/2024 17:15 | 59.4 | 2 | 0.03 |
| Phase B | 2/19/2024 17:15 | 2/22/2024 2:21 | 57.1 | 0 | 0.00 |
| After | 2/22/2024 2:21 | 2/29/2024 4:30 | 145.9 | 18 | 0.12 |
| August 2024 SCC | | | | | |
| Before | 8/12/2024 16:57 | 8/20/2024 16:20 | 190.3 | 34 | 0.18 |
| Phase A | 8/20/2024 16:20 | 8/24/2024 23:59 | 103.6 | 8 | 0.08 |
| Interphase | 8/24/2024 23:59 | 8/27/2024 17:00 | 55.4 | 0 | 0.00 |
| Phase B | 8/27/2024 17:00 | 8/30/2024 4:06 | 59.1 | 0 | 0.00 |
| After | 8/30/2024 4:06 | 9/9/2024 7:51 | 188.3 | 5 | 0.03 |

### 4.2.3 Cross Seamount Beaked Whales SCC

The pattern of corrected Cross Seamount beaked whale GVPs was typical during the February SCC. There were 0.2 GVPs/hour in the week before the SCC, which was reduced to 0.09 GVP/hour during Phase A. This increased to 0.2 GVPs/hour in the Interphase, dropped back slightly to 0.1 GVPs/hour in Phase B, and rose slightly to 0.2 GVPs/hour After (Table 18). The rate increased in March to a similar level as Before, at 0.2 GVPs/hour (Table 12).

The pattern of corrected Cross Seamount beaked whale GVPs during the August SCC reflected an inversion to the typical GVPs/hour pattern with higher GVPs/hour in Phase A and Phase B than the Before and Interphase periods (Table 18). There were fewer dives Before the SCC (0.2 GVPs/hour), then the GVP rate rose to its highest level of 0.4 GVPs/hour in Phase A. The Interphase GVP rate was the same as Before at 0.1 GVPs/hour, rose again during Phase B to 0.2 GVPs/hour, and then dropped again After the SCC to 0.1 GVPs/hour. It should be noted that these are the corrected, unvalidated results, and it may be that there were more false positive BWC pulses detected during the August SCC for some reason. This will be checked when these data are processed with the updated detection and classification code to verify whether this pattern is real, and what might have driven it, or if this is a spurious result.

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

| Period | Start Date | End Date | Duration (hours) | GVP count | GVPs/ Hour |
|---|---|---|---|---|---|
| February 2024 SCC | | | | | |
| Before | 2/5/2024 23:38 | 2/12/2024 22:00 | 140.7 | 26 | 0.19 |
| Phase A | 2/12/2024 22:00 | 2/17/2024 2:37 | 100.6 | 9 | 0.09 |
| Interphase | 2/17/2024 2:37 | 2/19/2024 17:15 | 59.4 | 9 | 0.15 |
| Phase B | 2/19/2024 17:15 | 2/22/2024 2:21 | 57.1 | 7 | 0.12 |
| After | 2/22/2024 2:21 | 2/29/2024 4:30 | 145.9 | 20 | 0.14 |
| August 2024 SCC | | | | | |
| Before | 8/12/2024 16:57 | 8/20/2024 16:20 | 190.3 | 31 | 0.17 |
| Phase A | 8/20/2024 16:20 | 8/24/2024 23:59 | 103.6 | 37 | 0.36 |
| Interphase | 8/24/2024 23:59 | 8/27/2024 17:00 | 55.4 | 9 | 0.17 |
| Phase B | 8/27/2024 17:00 | 8/30/2024 4:06 | 59.1 | 14 | 0.23 |
| After | 8/30/2024 4:06 | 9/9/2024 7:51 | 188.3 | 24 | 0.13 |

### 4.2.4 Tropical Bottlenose Whales SCC

Tropical bottlenose whale presence before, during, and after the SCCs is presented this FY for the first time. All information presented for tropical bottlenose whales comes from fully validated GVPs. The overall pattern seen was typical of other beaked whale species at PMRF, where GVP rates occur at about baseline levels before, decrease during, and somewhat increase following the end of the SCCs (see Sections 4.2.1 and 4.2.2 above), although in this case no tropical bottlenose whale GVPs were detected in any phase during either SCC. Details are shown by phase in Table 19.

There were 0.12 GVPs/hour in the week preceding the February SCC, which was well over the overall mean of 0.04 GVPs/hour for this species (see Section 3.2.12). Once the February SCC began, there were no tropical bottlenose whale GVP detections for the remainder of the SCC or during the week following (the next confirmed tropical bottlenose whale GVP occurred on March 6$^{th}$).

In August there were far fewer GVPs detected before the SCC than in February, but the same rate occurred in the week following the SCC (0.01 GVPs/hour). Again, once the SCC began, there were no tropical bottlenose whale GVP detections during the entirety of the SCC.

As noted in Section 3.2.12, there may be an element of autocorrelation (i.e., only one group is present and is detected repeatedly, but each dive is treated as unique GVPs) when reviewing these trends and comparing GVP rates over a matter of days or weeks, particularly given the relative scarcity of tropical bottlenose whales on PMRF. For example, in February, the fact that there were tropical bottlenose whales present at all in the week preceding the SCC (likely producing multiple GVPs in that window) likely biases that week's average GVP rate. However, the strength of this potential biases is unclear, as it does not seem to have as great an impact before or after the August SCC.

Table 19. Tropical bottlenose whale GVPs before, during, and after the February and August SCCs. Times are in UTC.

| Period | Start Date | End Date | Duration (hours) | GVP count | GVPs/ Hour |
|---|---|---|---|---|---|
| February 2024 SCC | | | | | |
| Before | 2/5/2024 23:38 | 2/12/2024 22:00 | 140.7 | 17 | 0.12 |
| Phase A | 2/12/2024 22:00 | 2/17/2024 2:37 | 100.6 | 0 | 0.00 |
| Interphase | 2/17/2024 2:37 | 2/19/2024 17:15 | 59.4 | 0 | 0.00 |
| Phase B | 2/19/2024 17:15 | 2/22/2024 2:21 | 57.1 | 0 | 0.00 |
| After | 2/22/2024 2:21 | 2/29/2024 4:30 | 145.9 | 0 | 0.00 |
| August 2024 SCC | | | | | |
| Before | 8/12/2024 16:57 | 8/20/2024 16:20 | 190.3 | 2 | 0.01 |
| Phase A | 8/20/2024 16:20 | 8/24/2024 23:59 | 103.6 | 0 | 0.00 |
| Interphase | 8/24/2024 23:59 | 8/27/2024 17:00 | 55.4 | 0 | 0.00 |
| Phase B | 8/27/2024 17:00 | 8/30/2024 4:06 | 59.1 | 0 | 0.00 |
| After | 8/30/2024 4:06 | 9/9/2024 7:51 | 188.3 | 2 | 0.01 |

# 5. Concurrent and Related Efforts

## 5.1 LMR - BREVE TRANSITION

The transition of the LMR-funded BREVE code to the NARWHAL suite of algorithms was completed in FY24. The routine analysis of MFAS sources now includes both helicopter-dipping and active sonobuoy MFAS. A new method to determine MFAS activity was developed and MFAS tracks are routinely 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 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 TAGGING AT PMRF

Cascadia Research Collective (CRC) conducted satellite tagging of odontocetes on PMRF February 11-19, 2024. Twelve total tags were deployed on short-finned pilot whales (8), bottlenose dolphins (1), and humpback whales (3). In addition to supporting the tagging effort at PMRF, in FY24 NIWC Pacific also worked with CRC to analyze the satellite tag data from the 2023 and 2024 field seasons. A separate report will be submitted on the resulting received levels and possible behavioral responses of the tagged animals from those two field seasons, with a total of 22 tags and 5 species.

In addition to the standard received level analysis for the FY23 and FY24 tagging data, all historic rough-toothed dolphin tags were processed and included exposures from all three sources at PMRF. Some of this work was completed for the 2021 report (Henderson et al., 2021), but a few tags were still outstanding, and none had been analyzed for helicopter-dipping or sonobuoy MFAS. These data will be shared with COMPACFLT in a separate report, either as a standalone document or included with a possible future analysis of rough-toothed dolphin acoustic data recorded at PMRF by NIWC Pacific and Naval Undersea Warfare Center (NUWC) Newport.

Finally, analysis results for the horizonal and vertical movement patterns of four dense-beaked whales tagged by CRC in 2014, 2021, and 2022 were presented at the 8th International Bio-logging Science Symposium and were submitted for publication in the *Movement Ecology* journal.

## 5.3 SMART/LMR - LARGE WHALE BEHAVIOR IN THE NORTH ATLANTIC

R. Guazzo has been studying large whale behavior in the North Atlantic using US Navy Marine Mammal Monitoring (M3) arrays with support from a Science, Mathematics, and Research for Transformation (SMART) SEED Grant and LMR (FY22-FY24). This effort is in collaboration with Dorene Stevenson and Michael Edell from Marine Acoustics, Inc. who are funded by COMPACFLT to collect the data. This project was divided into two main tasks:

1) Understanding the behavioral response of large whales to a commercial seismic survey
2) Analyzing the song patterns and along-song cue rates of North Atlantic fin whales

For task 1, the hypothesis that baleen whale behavior changes during seismic surveys was tested by analyzing vocalizing whale kinematic behavior during periods of seismic survey activity and comparing that behavior to baseline behavior. Tracks of blue whales, fin whales, and sei whales were collected during a seismic survey that was tracked on the Navy's M3 system for approximately a month. We used hidden Markov models to determine how swimming speed was related to the independent variables of hour, ship distance and heading, and survey phase. Blue whales were more likely to be in a fast state when they were closer to the seismic survey vessel during both the active and inactive phases. Fin and sei whale behavior did not show any behavioral change with respect to the seismic survey variables tested. To compare this behavior to baseline behavior, vocalizing blue whale tracks from the same month, but three years surrounding the survey were analyzed in the same way. The blue whale tracks were closer to the area of the survey and overall swim speeds were faster during baseline years. But, using the hidden Markov models, we also saw a higher probability of a whale being in a fast state as a function of distance to the "phantom" ship, similar to the pattern that was observed during the survey. Therefore, we could not conclude that the change in blue whale behavioral state with distance was a result of the seismic survey. Perhaps the feature that the ship was mapping is also a feature that blue whales follow and why they swim faster through that area. We conclude that adequate and appropriate baseline information is needed to understand normal, undisturbed behavior, otherwise incorrect conclusions could be drawn about the impact of disturbance. These results are currently in review in *Marine Pollution Bulletin* (Guazzo et al., *In Review*).

For task 2, fin whale song patterns from 119 tracks were analyzed over 10 years (2013-2023) 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 would 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. We observed four distinct song patterns with inter-note intervals for one pattern increasing over inter-annual timescales and inter-note intervals for another pattern increasing over 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. Many of these nuances in fin whale singing behavior have not been described in previous research and can be applied to assessing responses to disturbance and estimating the abundance and distribution of a poorly understood species. This work was published in *Frontiers in Marine Science* in FY24 (Guazzo et al., 2024).

## 5.4 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 (some of these data were based on tracks of satellite tagged animals from CRC). The UH researchers continue to develop and test the algorithms to detect odontocete groups on large arrays. The algorithm was successfully tested on groups of sperm whales at PMRF in FY24, and these data were presented at the ONR program review meeting in Washington D.C. in April 2024, as well as at the 27th International Conference on Information Fusion with an associated conference paper (Gruden et al., 2024). Once the algorithm is finalized, it can be integrated into the NARWHAL algorithm suite so that WARP can begin tracking odontocete groups in a similar manner.

## 5.5 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 COMPACFLT-supported effort to tag humpback whales off Kauaʻi. This project was supposed to end in 2024 but was extended into 2025 to allow time for the preparation of an additional manuscript.

## 5.6 LMR - RAVEN-X

RAVEN-X is a joint project with Naval Undersea Warfare Center (NUWC) aimed at enhancing the efficiency of processing and analytics for large-scale passive acoustic data. Many of the tools from the NIWC NARWHAL software suite used in this report are being integrated into the common processing software package of RAVEN-X, allowing them to be used at NUWC and by other Navy stakeholders. RAVEN-X also allows for processing of multiple data formats, which includes binary archive data in addition to raw acoustic data from Navy ranges. These data may prove useful for additional processing opportunities of historical data at PMRF, SOAR, and other Navy ranges.

## 5.7 ONR - FIN WHALE SONG EVOLUTION

The goal for this ongoing project is to quantify fin whale song patterns and cue rates over time in the central and eastern North Pacific. Enhancements to the GPL detection and localization system were completed with the help of RAVEN-X to automatically detect, localize, track, and classify fin whale notes with a miss rate of 6.2% (Helble et al., *In Review*). Between August 2017 and March 2023, 331 singing fin whales were tracked on PMRF, and their song patterns were compared with those described in a previous study from January 2011 to July 2017 (Helble et al., 2020a; Helble et al., *In Review*). Separately, we will conduct a first-look analysis from opportunistic SOAR data with the goal of investigating population connectedness between Hawaiian waters and the Southern California Bight.

# 6. FY24 Publications

Gruden, P., Nosal, E-M., & Henderson, E. E. (2024). Automated Acoustic Tracking of a Sperm Whale (*Physeter macrocephalus*) using a Wide Baseline Array of Sensors. 27th International Conference on Information Fusion (FUSION), Venice, Italy, 2024, *IEEE Explore*, pp. 1-7, doi: 10.23919/FUSION59988.2024.10706418.

Gruden, P., Nosal, E. M., & Henderson, E. E. (2025). The MAMBAT framework for acoustic tracking of multiple animals. Scientific reports, 15(1), 16505. https://doi.org/10.1038/s41598-025-00535-z

Guazzo, R.A., Stevenson, D.L., Edell, M.K., Gagnon, G.J., & Helble, T.A. (2024). A decade of change and stability for fin whale song in the North Atlantic. *Frontiers in Marine Science*, *11*, 1278068.

Helble, T.A., Alongi, G.C., Guazzo, R.A., Allhusen, D.R., Martin, C.R., Martin, S.W., Durbach, I.N., & Henderson, E.E. (2024). Swimming and acoustic calling behavior attributed to Bryde's whales in the Central North Pacific. *Frontiers in Marine Science*, *11*, 1305505.

Henderson, E. E., Martin, C. R., Kratofil, M. A., Baird, R. W., Harnish, A.E., Martin, S. W., & Southall, B. L. (2024a). Assessing Exposure and Responses of Satellite-Tagged Blainville's Beaked Whales on the Pacific Missile Range Facility, Kaua‘i, Hawai‘i. Report, Naval Information Warfare Center Pacific.

Henderson, E. E., Martin, C. R., Harnish, A.E., Kratofil, M. A., Baird, R. W., Martin, S. W. (2024b). Received Level Estimation, Behavioral Response, and Diel Behavior Analyses for Delphinids Tagged at the Pacific Missile Range Facility in 2021-2022. Report, Naval Information Warfare Center Pacific.

Henderson, E. E., Kratofil, M. A., Baird, R. W., Martin, C. R., Harnish, A. E., Alongi, G. C., Martin, S. W., & Southall, B. L. (2025). Exposure and response of satellite-tagged Blainville's beaked whales to mid-frequency active sonar off Kaua'i, Hawai'i. *Movement Ecology*, *13*(1), 29. https://doi.org/10.1186/s40462-025-00550-9

# 7. FY24 Presentations

Alongi, G.C., T.A. Helble, R.A. Guazzo, S.W. Martin, C.R. Martin, and E.E. Henderson. 2024. Strengths and weaknesses of using DCLDE algorithms to track baleen whales and examine their behavior using long-term acoustic recordings with a large-scale hydrophone array. Detection, Classification, Localization, and Density Estimation (DCLDE) of Marine Mammals Workshop. June 3-7, 2024. Rotterdam, The Netherlands.

Gruden, P., E. -M. Nosal and E. E. Henderson. 2024. Automated Acoustic Tracking of a Sperm Whale (*Physeter macrocephalus*) using a Wide Baseline Array of Sensors. 27th International Conference on Information Fusion (FUSION). July 7-11, 2024. Venice, Italy.

Henderson, E.E., C.R. Martin, M.A. Kratofil, S.W. Martin, R.W. Baird, and B.L. Southall. 2024. Estimating Received Levels and Behavioral Responses of Tagged Odontocetes at PMRF. US Navy Monitoring Meeting, 20 March 2024, San Diego, CA.

Henderson, E.E. R.W. Baird, C.R. Martin, M.A. Kratofil, A.E. Harnish, S.W. Martin, and B.L. Southall. 2024. Behavioral Response of Blainville's Beaked Whales (*Mesoplodon densirostris*) to U.S. Navy Training Activity. 8th International Bio-Logging Science Symposium. 4-8 March, 2024. Tokyo, Japan.

Martin, C.R., Henderson, E.E., Alongi, G.A., Martin, S.W., Helble, T.A. and Guazzo, R.A. 2024. PMRF Marine Mammal Monitoring Abundance and Distribution FY22-FY23. U.S. Navy Marine Species Monitoring Meeting, San Diego, CA.

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