Submitted in Support of the U.S. Navy's 2022 Annual Marine Species Monitoring Report for the Pacific

Naval Information Warfare Center

PACIFIC

APRIL 2023

FY22 Annual Report on Pacific Missile Range Facility Marine Mammal Monitoring

Cameron R. Martin
E. Elizabeth Henderson
Stephen W. Martin
Gabriela C. Alongi
Regina A. Guazzo
Tyler A. Helble
Roanne A. Manzano-Roth

NIWC Pacific

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San Diego, CA 92152-5001

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Naval Information Warfare Center

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NIWC Pacific
San Diego, CA 92152-5001

NIWC Pacific
San Diego, California 92152-5001

A. D. Gainer, CAPT, USN
Commanding Officer

C. A. Jackson
Acting Executive Director

ADMINISTRATIVE INFORMATION

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Released by
Mark Xitco, Division Head
Reconnaissance and Interdiction Division

Under authority of
Michael McMillan, Department Head
Intelligence, Surveillance, and
Reconnaissance Department

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Cameron R. Martin
E. Elizabeth Henderson
Stephen W. Martin
NIWC Pacific

Gabriela C. Alongi
Regina A. Guazzo
Tyler A. Helble
NIWC Pacific

Roanne A. Manzano-Roth
NIWC Pacific

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NIWC Pacific
53560 Hull Street
San Diego, CA 92152–5001

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14. ABSTRACT
This report documents Naval Information Warfare Center Pacific (NIWC Pacific) marine mammal monitoring efforts in fiscal year (FY) 2022 for Commander, Pacific Fleet (COMPACFLT) at the Pacific Missile Range Facility (PMRF), Kauaʻi, Hawaiʻi.
This report includes our team's research of four areas:
1) Collect raw acoustic data for marine mammal species detection, classification, localization, tracking, and kinematic analyses;
2) Understand short-term and long-term baseline occurrence patterns and quantify abundance for multiple marine mammal species;
3) Continue to update our processing algorithms in order to add new species as possible, improve existing tools, and integrate other tools as available;
4) Estimate sound levels to which marine mammals are exposed during U.S. Navy training with hull-mounted mid-frequency active sonar (MFAS), as well as other sources of noise (e.g. torpedoes, surface ships), and investigate behavioral responses;
5) Collaborate with researchers conducting other monitoring efforts (e.g. MFAS exposure and response by tagged animals), including other U.S. Navy laboratories, academic institutions, and research organizations, to fill data gaps and provide a more complete monitoring data product.

15. SUBJECT TERMS
Minke whale; humpback whale, low-frequency baleen whale, beaked whale; killer whale; sperm whale; passive acoustic monitoring; instrumented range; marine mammal monitoring; behavioral response analysis; noise analysis

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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) 2022 for Commander, Pacific Fleet (COMPACFLT) at the Pacific Missile Range Facility (PMRF), Kauaʻi, Hawaiʻi. The following list highlights tasks completed in FY22 in support of COMPACFLT monitoring goals:

1. Raw acoustic data from 63 bottom-mounted hydrophones at PMRF were recorded at a sampling rate of 96 kHz. This report updates last year's report with inclusion of 5395.6 hours of new data collected and analyzed from September 2021 to August 2022 for FY22.
2. Abundance results for baleen whales for FY22 are presented using both the same metric previously used (maximum number of whales present in any 10-minute snapshot of whale tracks) as well as a new metric of the mean number of whales present in 10-minute snapshots per hour and for each month. The mean numbers for a month better represent the peak of the whale season when the most whales are typically present while the maximum numbers may represent outliers in whale presence. Processed results for the highest mean number of baleen whales during the peak whale season (January to March 2022) were: minke (0.94 in February); humpback (0.16 in February); fin (0.5 in January); fin/sei 40 Hz downsweep category (0.05 in February); and Bryde's (0.04 in March).
3. Minke whale boing calls were found to have a strong bimodal call rate with a more common "nominal" rate that averages one call every 7 min and a more "rapid" rate averaging 0.6 min. A total of 502 manually validated individual tracks composed of 36,033 calls occurred between August 2012 and July 2017. Hidden Markov Models (HMMs) were used to quantify the relationship between call rate and the distance to the nearest calling conspecific. Overall, the probability that the rapid call rate would occur increased as the distance to the nearest conspecific decreased, and the probability of the nominal call rate occurring increased as the distance to the nearest conspecific increased. Case studies have shown that minke whales exhibit multiple responses (i.e., increased speed, changes in heading, and cessation of calling) when nearby conspecifics are calling at the rapid rate. These findings help to better understand the challenges associated with cue rate-based density estimation of baleen whales, as well as providing new information about minke whale calling behavior on what are likely their breeding grounds.
4. HMMs were developed based on the travel speeds and turning angles of the same set of smoothed minke whale acoustic tracks for 5 seasons of all recorded acoustic baseline data; these tracks could be split into two behavioral state categories. It was determined that the overall mean speed was 1.3 m/s while minke whales were observed on the PMRF range. The Slow State had less directional movement, a mean speed of 0.5 m/s, and occurred in 67% of tracks. The Faster State had more directional movement, a mean speed of 1.9 m/s, and occurred in the other 33% of tracks. Furthermore, the Faster state was more likely to occur when the whale was calling rapidly, and when other minke whales were nearby. However, the Faster State was still slower and less directional than the Fast State found by Durbach et al. (2021) that occurred during active Navy sonar, with a mean speed of 2.4 m/s.
5. Abundance results for odontocetes from September 2021 to August 2022 included Blainville's, Cross Seamount (BWC), and Cuvier's beaked whales, sperm whales, and killer whales. An apparent increase in beaked whale group vocal period (GVP) detections may be a result of the increased sensitivity of the new analog-to-digital board installed at PMRF in July 2021 and is planned to be tested soon. The number of Blainville's beaked whale GVPs was corrected based on sample validation of six FY22 baseline recordings (96% true positive rate

and 4% false positive rate); the highest GVP rate of 3.72 GVPs/hr occurred in September 2021. The number of fully validated Cuvier's and BWC beaked whale GVPs occurred far less frequently than Blainville's beaked whale GVPs, resulting in a maximum of 0.42 GVPs/hr in December 2021 for Cuvier's beaked whales and 0.18 GVPs/hr for BWC beaked whales in September 2021. Ten groups of killer whales were detected throughout the available FY22 data. The highest mean number of sperm whales in all 10-minute snapshots in a month was 0.18 in February 2022.

6. Five minke whales, one fin whale, and six humpback whales were tracked during the February 2022 Submarine Command Course (SCC), and minimum ship distances, minimum mid-frequency active sonar (MFAS) source distances, and cumulative sound exposure levels (cSEL) were estimated for each track. Minimum ship distances varied from 700 m to 41.5 km, while minimum MFAS distances ranged from 7.4 to 41.6 km, and associated cSEL values varied from 135.3 to 173.2 dB re 1μPa^{2}s. Although some heading changes were detected in a few of the humpback and minke whales after the onset of MFAS, an apparent behavioral response was only evident in one minke whale. This whale made a distinct heading change and began calling rapidly (increased calling rate) at the onset of MFAS when the source vessel was 9.1 km away and the cSEL was 170.3 dB re 1μPa^{2}s. The whale resumed its nominal calling rate after the sonar ended and while ships continued maneuvering on the range. The whale changed its heading during subsequent bouts of MFAS and exhibited decreased calling when a ship transmitting MFAS was 7.4 km away and the whale received a cSEL of 173.2 dB re 1μPa^{2}s.
7. As observed in previous years, Blainville's beaked whale GVPs decreased during the February and August SCC training events, with the lowest GVP rates occurring during Phase B activities, and then increased again after the training was complete. A similar trend was observed for Cuvier's beaked whales in February, while in August no dives were detected at all during or after the SCC. BWC beaked whales decreased their GVP rates during the first part of the February training but then had a high number of GVPs during Phase B, and then GVP rates decreased again after the SCC. There was a relatively high number of GVPs during the first active phase of the August SCC which contained most of the training event, followed by a decrease in GVP rates in subsequent phases, and then an increase after the SCC.

ACRONYMS

AIC	Akaike Information Criterion
BREVE	Behavioral Response Evaluations
BRS	Behavioral Response Study
BWC	Cross Seamount beaked whale signal
COMPACFLT	Commander, Pacific Fleet
CEE	Controlled Exposure Experiment
crawl	Continuous-time correlated random walk model R package *crawl* (Johnson et al., 2008)
DCL	Detection Classification Localization
DICASS	Directional Command-Activated Sonobuoy System
E-BREVE	Environmentally-influenced Behavioral Response Evaluations
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
LFA	Low-Frequency Active
LOW SWARM	Low-frequency Sources with Whale Acoustic Reconnaissance for Mitigation
LMR	Living Marne Resources Program
M3	Marine Mammal Monitoring Program at NOPF Dam Neck
M3R	Marine Mammal Monitoring on Navy Ranges
MAI	Marine Acoustics, Inc.
MFAS	Mid-Frequency Active Sonar
NARWHAL	Navy Acoustic Range Whale Analysis
NIWC Pacific	Naval Information Warfare Center Pacific
NMMF	National Marine Mammal Foundation
NOPF Dam Neck	Naval Ocean Processing Facility Dam Neck
NUWC Newport	Naval Undersea Warfare Center Newport
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
PAM	Passive Acoustic Monitoring
PMRF	Pacific Missile Range Facility
SCC	Submarine Command Course
SEED	SMART Scholar Seed Grant
SMART	Science, Mathematics, and Research for Transformation
SOAR	Southern California Anti-Submarine Warfare Range

SUBEX	Submarine Exercise
ULT	Unit Level Training
U.S.	United States
WARP	Whale Acoustic Reconnaissance Project

CONTENTS

FIGURES

TABLES

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1. INTRODUCTION

In fiscal year (FY) 2022 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), Kauaʻi, Hawaiʻi to monitor vocalizing marine mammals both during baseline periods and during United States (U.S.) Navy training activities.

The FY22 goals of this ongoing effort were to:

1) Collect raw acoustic data for cetacean species detection, classification, localization, tracking (DCL), and perform kinematic analyses;

2) Understand short-term and long-term baseline occurrence patterns and quantify abundance for multiple cetacean species;

3) Continue to update our processing algorithms in order to add new species, improve existing tools, and integrate additional tools as available;

4) Estimate sound levels received by cetaceans during U.S. Navy training with hull-mounted mid-frequency active sonar (MFAS). 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;

5) Collaborate with researchers conducting other monitoring efforts (e.g., MFAS exposure and response by tagged animals), including other U.S. Navy laboratories, academic institutions, and research organizations, to fill data gaps and provide a more complete monitoring data product.

This report also highlights specific analyses that were conducted to support publication of peer review papers in FY22 in pursuit of the above goals, including minke whale cue rates and swim kinematics in relation to environmental variables, proximity of conspecifics, and call repetition rates; a comparison of long-term dive patterns in Blainville's, Cuvier's, and Cross Seamount beaked whales; and a detailed disturbance analysis of tracked baleen whales.

2. METHODS

2.1 PMRF RANGE DATA

- Passive acoustic monitoring (PAM) data were recorded for 63 of the PMRF bottom-mounted hydrophones (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 September 2021 to August 2022. For reference, the white box outlines the approximate boundary for the "focal study area" used by Martin et al. (2022b) and Helble et al. (in press) for tracking minke whales from August 2012 to July 2017 (discussed in Sections 3.2.1.2 to 3.2.1.3). Minke whale tracks used by Martin et al. (2022b) and Helble et al. (in press) used recordings from broadband hydrophones only (i.e., frequency response from 50 Hz to 48 kHz and 100 Hz to 48 kHz).

Figure 1) to support analyses of marine mammal vocalizations and MFAS transmissions. Full-bandwidth (96 kHz sampling rate) recordings were conducted from September 2021 through August 2022. Since the new recorder became operational in July 2021, only full bandwidth recordings have been conducted. Since the new recorder accepts larger hard drives, longer datasets can be recorded continuously over multiple days and eliminates the need to conduct recordings at the decimated 6 kHz sample rate.

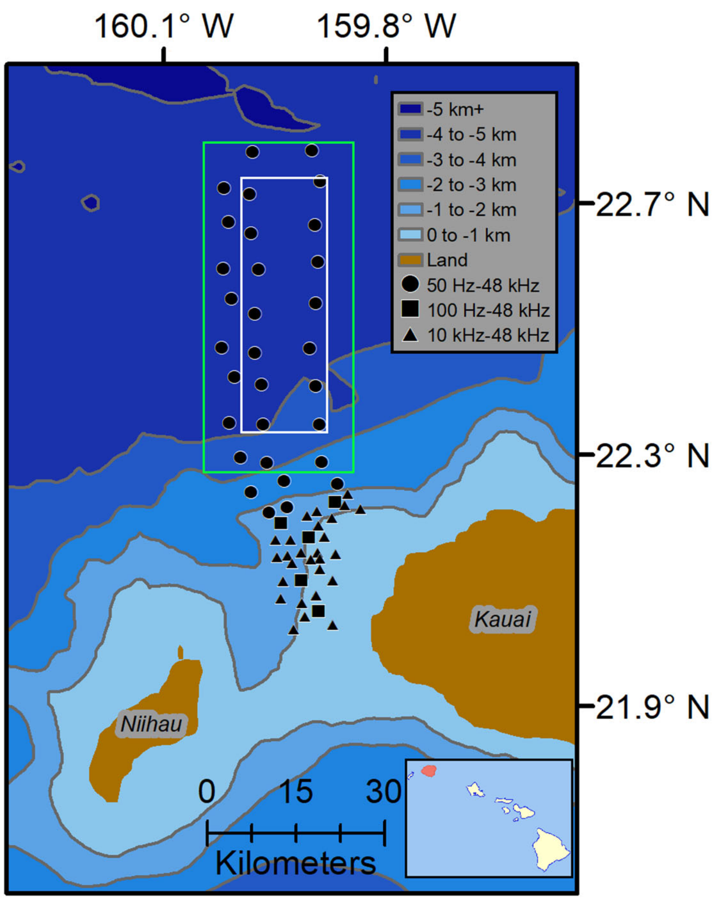

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Figure 1. Hydrophone array configuration at PMRF's instrumented range for data collected September 2021 to August 2022.

2.2 NAVY ACOUSTIC RANGE WHALE ANALYSIS ALGORITHM SUITE

2.2.1 Automated Detection, Classification, and Localization Algorithms

A suite of several algorithms was used to process recorded data for marine mammal vocalizations and was previously described in Helble et al., 2012, Helble et al., 2015, Helble et al., 2016, Helble et al., 2020, Henderson et al., 2016, Henderson et al., 2018, Manzano-Roth et al., 2016, and Martin et al., 2015. As a brief review, one custom C++ algorithm automatically detects and classifies two types of baleen whale vocalizations (minke whale boing calls and low-frequency calls that could be attributable to Bryde's, sei, fin, or blue whales), five odontocete vocalizations (Blainville's, Cuvier's, and Cross Seamount [BWC] 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, certain types of blue whale calls, and low-frequency calls. Based on the results of the GPL algorithm, a human analyst manually reviewed spectrograms of the data to examine call characteristics and patterns and classify low-frequency localizations as fin whale song or non-song, fin and/or sei, Bryde's whale calls, and 40-Hz downsweeps (attributable to fin and/or sei whales). Fin whale tracks presented in this report are comprised of tracks from the fin whale song and non-song categories, and the fin and/or sei category.

After localization, an automated localization association tracker (LAT) algorithm in Matlab (originally described in Klay et al., 2015) uses spatial and temporal parameters based on general calling rate expectations for different species to connect localizations into tracks. Systematic snapshots of existing tracks every 10-minutes enables a census-type abundance estimate for calling whales that can be localized and tracked. For individual whale track results presented in 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 (Figure 1).

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

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

2.2.2 Improvements to Processing Algorithms

In FY22, two different code baselines (Baseline 4 and the newer Baseline 5) for the custom C++ algorithms have been used to classify, localize, and track marine mammal vocalizations. The WARP lab is in the process of updating all code to Baseline 5, and there are currently capabilities that have been developed in Baseline 5 and tested on individual species (e.g., detecting and classifying killer whale HFM whistles, improvements to sperm whale localization and tracking, and the ongoing improvement and addition of different beaked whale species) but have not yet been exhaustively tested on other species. Efforts to thoroughly document and archive these changes and quantify their impact on all species at every processing stage (detection, classification, localization or grouping, and tracking) were initiated in FY21 and were continued in FY22. WARP will continue to characterize the performance between Baseline 4 and 5 to understand how changes to the C++ algorithms affect results, and conduct manual validations and comparisons of groups and tracks identified in Baseline 5 to those from Baseline 4. These findings will be used to guide a full transition to Baseline 5.

2.2.3 Behavioral Response Analyses

The Behavioral Response Analysis process investigates whether whale presence overlaps with and is affected by anthropogenic activities such as MFAS transmissions and proximity of ships (even when not transmitting MFAS), thereby conducting an opportunistic, passive acoustic behavioral response study (BRS). When overlap occurs with whale tracks, a variety of metrics are calculated/estimated such as whale orientations (i.e., moving towards or away from the source), ship orientations relative to the whale, and distances relative to all ships. When ships are transmitting sonar, propagation modeling is conducted to calculate received sound levels at each individual from multiple ships over the duration it was acoustically active. Cumulative sound exposure levels are calculated using nominal SL of 235 dB re 1 μPa at 1 m and by estimating transmission loss (TL) from the source to the whale using a parabolic equation propagation model. The magnitude of the RLs were then summed to estimate cSEL (in dB re1 μPa^2).

The ability to accurately detect and localize MFAS localizations is a longstanding capability in the C++ algorithm suite that has been used for our behavioral response analysis. In FY22, the WARP Laboratory added the capability to track MFAS transmissions to expand the behavioral response analysis processing to include exposures from other sources such as helicopter dipping sonar (e.g., AN/AQS-22 and AN/AQS-13) and sonobuoys (e.g., Directional Command-Activated Sonobuoy System [DICASS]). Signals in the acoustic data and PMRF range products (e.g., Tsunami, which includes time and positional data of sources and event situational information) were examined to evaluate the performance of the automated MFAS tracking algorithm.

A test case of 3 hours and 40 minutes of data from the February 2017 SCC was identified that contained both active sonobuoys and helicopter sonar dips (a dip is one deployment/retrieval of the helicopter's MFAS soundhead). Analysts reviewed raw waveforms and spectrograms from multiple hydrophones to provide ground truth information in terms of the number of MFAS transmissions in the raw data. Baseline 4 MFAS detection and localization results were reviewed and a new capability for tracking MFAS localizations via modifying the LAT was developed and evaluated on the test case data. MFAS tracking included the use of the frequencies of the different MFAS sources to separate tracks. A single MFAS tracking parameter file was utilized to track all sonar localizations (primarily surface ship, sonobuoy, and helicopter dipping sonars). Given that many sonobuoy and helicopter dipping sonar events contain a limited number of MFAS transmissions, the tracking parameter file required at least 3 localizations with no more than 300 sec separation to declare a track (security limits the sharing of other parameters related to MFAS tracking). Performance metrics for the probabilities of detecting, localizing, and tracking both true tracks (P_{dlt}) and false positive tracks (P_{fpt}) of MFAS transmissions were determined for the test case.

Given that the amount of test case data was limited, the selected MFAS tracking parameter file was utilized with the modified LAT tracking algorithm to process additional data from the February 2017 SCC in addition to data from two other SCCs in February 2014 and 2015. While the results from this additional data do not include ground truth information, as for the test case data, it provides MFAS track results for additional data and the MFAS tracks can be separated into sonobuoy and helicopter sonar sources to gain additional insight into the MFAS sources.

An additional sonar detector was developed in a concurrent Living Marine Resources Program (LMR) project in FY21 and is planned to be implemented in the Navy Acoustic Range Whale Analysis (NARWHAL) suite of algorithms in FY23. This detector is currently a presence/absence only detector, but further developments under a new start LMR project are planned to add bandwidth-based signal classification, and potentially signal start times. This detector will supplement the current C++ detection algorithm and may provide a way to detect additional broadband or higher frequency sonar signals.

The Office of Naval Research (ONR) project Behavioral Response Evaluations (BREVE) employing robust baselines and actual Navy training was officially completed in FY21. Most of the work was completed early in FY21, followed by publication of results (Durbach et al., 2021). Transitioning of the BREVE code to the PACFLT behavioral response analyses applications is in progress under a current LMR project. Code to transition includes the spatial analysis code utilized by Harris et al. (2019) and Hidden Markov model (HMM) code used by Durbach et al. (2021). Transition efforts include using full resolution ship positional information, and not limiting the data to one sonar transmission per five-minute bin as was done in BREVE for security reasons. In addition, only cardinal directions for ship headings and relative position of the whales from the ships in 90° quadrants were used in Durbach et al. (2021) due to security limitations. The changes from these limited types of data to full resolution data may cause the Akaike information criterion (AIC)-selected model from Durbach et al. (2021) to change; additional changes in the final models may also include results from the use of additional estimated received levels and numbers of MFAS emissions, which were not included in the AIC-selected model in BREVE. Additionally, the use of a third HMM state is under consideration to represent whale repulsion from MFAS ships, similar to effort reported by Mul et al. (2020), which used a third HMM state to represent killer whale attraction to fisheries.

The BREVE HMM modeling code has also been successfully transitioned by WARP for use in the Environmentally-influenced Behavioral Response Evaluations (E-BREVE) project sponsored by ONR (Guazzo et al., 2021 and Helble et al., 2023), and the cue rates project sponsored by PACFLT (Martin et al., 2022b). These projects examined the effect that environmental variables (e.g., wind speed and wave height) and conspecifics have on minke and fin whale calling and kinematic behavior, which helps contextualize the effects of Navy sonar.

2.2.4 Noise Analysis

In FY21 a collaborative effort was conducted between WARP and the M3R team at NUWC Newport to investigate and quantify ambient noise levels at PMRF and the Southern California Anti-Submarine Offshore Range (SOAR) across our respective recording systems. A continuation of this effort was planned for FY22; however, this was intended to co-occur with an LMR-funded project to integrate the archived data products recorded by M3R into the RavenX framework alongside WARP's raw acoustic data to more easily combine and compare the two data streams. This effort was unfortunately repeatedly delayed throughout FY22 and ultimately was pushed to FY23 (but is funded in FY23), which resulted in the concurrent push of the noise analysis to FY23. Therefore, no noise analyses were conducted by WARP at PMRF in FY22.

3. RESULTS AND DISCUSSION

3.1 PMRF RANGE DATA COLLECTION RESULTS

The FY22 data processed for this report spanned September 9, 2021 to August 28, 2022. A total of 5,395.6 hours of data were recorded and they include 586.6 hours of classified data collected during the SCC training events in February and August, a unit level training (ULT) event in February (includes surface ship(s) with hull-mounted MFAS), and a SUBEX (does not include surface ship hull-mounted MFAS) in August (Table 1). This report contains the most data recorded and analyzed during an annual performance period to date for this project due to the increased recording capabilities of our new system.

Table 1. Total monthly hours of recording effort for FY22 data (September 2021 to August 2022).

Date	Hours
September-21	224.7
October-21	634.0
November-21	600.4
December-21	563.1
January-22	313.3
February-22	496.3
March-22	479.2
April-22	229.7
May-22	369.3
June-22	405.6
July-22	450.4
August-22	629.6
Total	**5395.6**

3.2 ABUNDANCE AND DISTRIBUTION

In prior reports, whale track abundance results were presented as the maximum number of whales detected in a 10-minute snapshot. While that metric has utility to determine peak presence and identify periods with erroneous tracks (e.g., duplicate or segmented tracks), it is not appropriate for calculating density estimation, which is the metric we are working towards. Therefore, whale track abundance results (Section 3.2.1 to Section 3.2.3) are now presented as the mean number of tracks detected in 10-minute snapshots for each hour of the day, and the mean number of tracks detected in all 10-minute snapshot per month with an accompanying standard deviation. For compatibility with results in prior reports and to compare metrics, the maximum number of tracks detected in a 10-minute snapshot per month are presented alongside the mean results in this report. The monthly mean values may be lower than the hourly mean values due to the occurrence of snapshots with zero tracks, which are factored into the reported monthly mean. In the FY22 abundance figures in Section 3.2.1 to Section 3.2.3, it is possible for the mean number of tracks detected in a 10-minute snapshot for each hour of the day to approximate the maximum number of tracks if peak whale presence occurred in a 10-minute snapshot. The ability to conduct instantaneous snapshots on all recorded data are planned for integration in the NARWAHL algorithm suite in FY23.

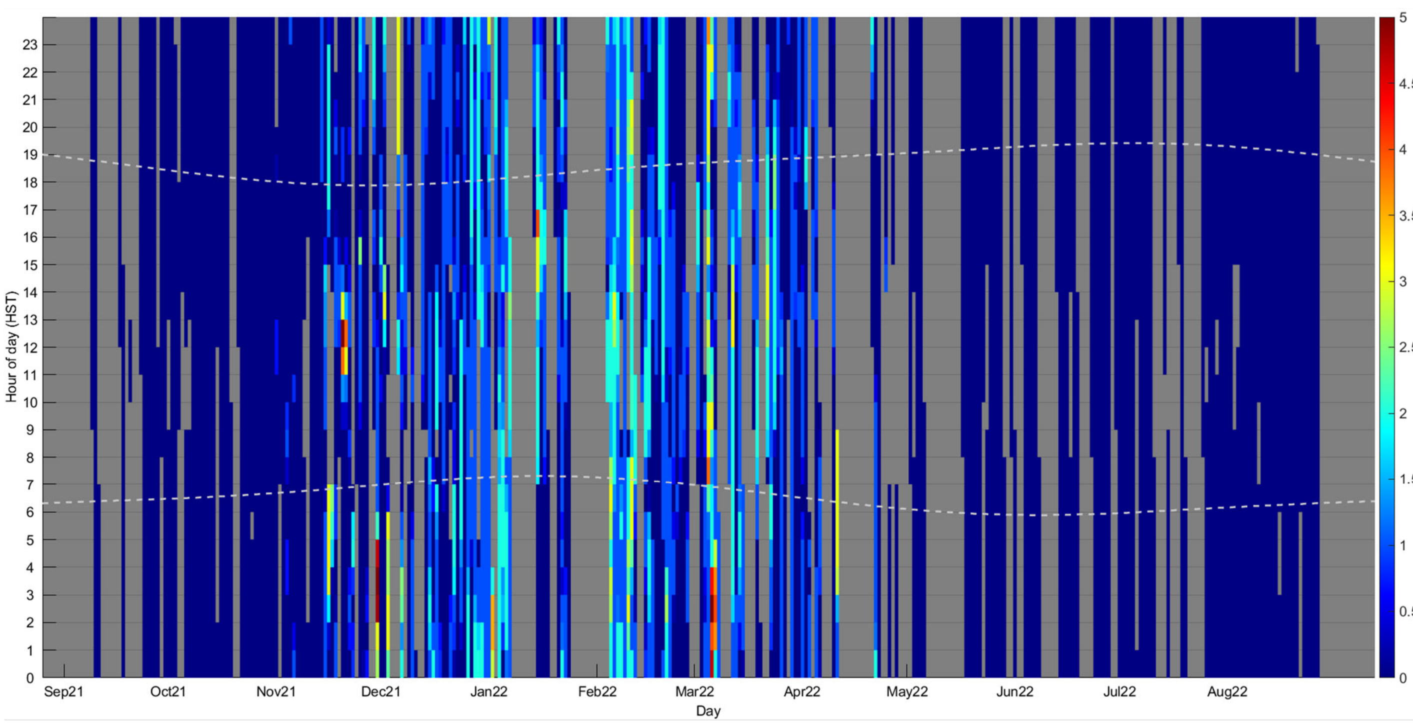
3.2.1 Minke Whales

3.2.1.1 Snapshot Tracks September 2021 to August 2022

The mean number of automatically tracked, individual calling minke whales in 10-minute snapshot periods from both unclassified and classified recordings made between September 2021 and August 2022 are presented per month in Table 2 and per hour in Figure 2. Minke whale seasonal presence started in November 2021 with a mean of 0.3 whales detected in 10-minute snapshots for that month, and a mean between 0.17 and 4.83 whales detected in 10-minute snapshots per hour. Seasonal presence typically occurs from fall to spring, the end of which is captured here with a mean of 0.47 whales detected in 10-minute snapshots in April 2022, and a mean between 0.17 and 2.83 whales detected in 10-minute snapshots per hour. There was a peak mean of five minke whales detected in a one-hour bin, twice in November 2021, and once in March 2022. For comparison, in recent reports which analyzed data from 2018 to 2020 (Martin et al., 2020, 2021, 2022a), the maximum number of whales in a one-hour bin ranged from 4 to 5. In the last comprehensive analysis of all data from 2002 to 2018 (Martin et al., 2020), the monthly maximum number of whales detected in a 10-minute snapshot ranged from 1 to 9; the maximum monthly snapshots from the FY22 data (Table 2) are within this range. This variation could be attributed to the hours of data recorded and measurement artifacts (such as when tracks are segmented incorrectly by the algorithm), as well as natural trends and fluctuations in occurrence. Peak minke whale presence typically occurs during the winter months and is observed in these data with a mean snapshot of 0.94 in February and elevated mean snapshots of 0.91 and 0.86 in January and March, respectively. This is also depicted in Figure 2 with persistent presence across snapshots in winter months.

Table 2. Monthly numbers of minke whales detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	906	0	0	0
November-21	3,510	5	0.30	0.73
December-21	3,270	3	0.68	0.77
January-22	1,842	4	0.91	0.83
February-22	2,946	3	0.94	0.85
March-22	2,857	5	0.86	0.95
April-22	1,277	3	0.47	0.67
May-22	--	0	0	0
June-22	--	0	0	0
July-22	--	0	0	0
August-22	--	0	0	0

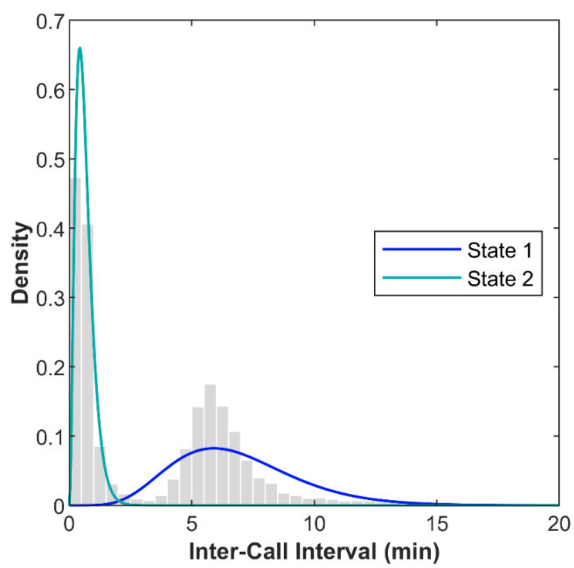


- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 2. The mean number of minke whales detected in 10-minute snapshot periods for each hour of the day from September 2021 to August 2022 ranged from 0.17 (blue) to 5 (dark red).

3.2.1.2 Minke Whale Calling Rates

Minke whales have a strong bimodal call rate with a more common "nominal" rate and a more "rapid" rate. Thompson and Friedl (1982) were the first to hypothesize that the call rate increased when two whales were in close proximity to each other using limited encounters recorded off O'ahu. The WARP Laboratory began to explore this topic in Martin et al. (2019) and Martin et al. (2020), and thoroughly investigated how minke whale calling rate is related to proximity of calling conspecifics in FY21-22 (Martin et al., 2022b). Between August 2012 and July 2017, 2,245 individual minke whale tracks were observed containing 223,732 minke whale boings, from 599 days of acoustic recording effort on each hydrophone. Of the 2,245 total tracks, 509 were located within a smaller focal area to maximize probability of detection and ensure detection of a calling conspecific out to a 15 km threshold (Figure 1). The subset of focal tracks contained 36,033 localized calls. Martin et al. (2022b) found two minke whale calling rates, a nominal calling rate (State 1) of approximately 1 call every 7 min and a rapid rate (State 2) of approximately 1 call every 40 sec (Figure 3).



- The gray histogram shows the observed inter-call intervals normalized by the area of each bar, the blue curve shows the probability density function of State 1 (nominal calling rate), and the teal curve shows the probability density function of State 2 (rapid calling rate).

Figure 3. Distribution of inter-call-intervals from 509 minke whale tracks at PMRF (from Martin et al., 2022b).

The probability of a minke whale being in State 1 and therefore calling at a nominal rate increased as its distance to the nearest calling conspecific increased and the probability of a minke whale being in State 2 and therefore calling at a rapid rate increased as its distance to the nearest calling conspecific decreased (Figure 4). Since each observation is a localized call, the plotted probabilities are the probability of a call being in a given state and not the length of time that a whale is in a state (Figure 4 upper). When a whale is calling rapidly, more localizations are available for a given time than when a whale is calling nominally. Of the 36,033 localized calls that were part of focal tracks, 49% were categorized as being in State 1 and 51% were categorized as being in State 2. Cumulatively, these tracked whales include a total of 84.7 days calling nominally (State 1) and 8.0 days calling rapidly (State 2), which is equal to 91% of the time in State 1 and 9% of the time in State 2. Therefore, regardless of the distance to the closest calling conspecific, at any given time, minke whales are most likely in State 1 (Figure 4 lower). Calling rapidly has a higher probability when whales are closer together, but it is never more likely than calling nominally. This work documenting minke whale call rate as a function of distance to the nearest calling minke whale was presented at the Detection, Classification, Localization, and Density Estimation (DCLDE) conference in O'ahu, Hawai'i in March 2022 and was published in *Frontiers in Marine Science* in August 2022 (Martin et al., 2022b). Based on observations of minke whale interactions during this analysis, Martin et al. (2022b) hypothesized that call rate and the distance to the nearest conspecific might also influence swimming behavior, which is further investigated in Helble et al. (2023; Section 3.2.1.3).

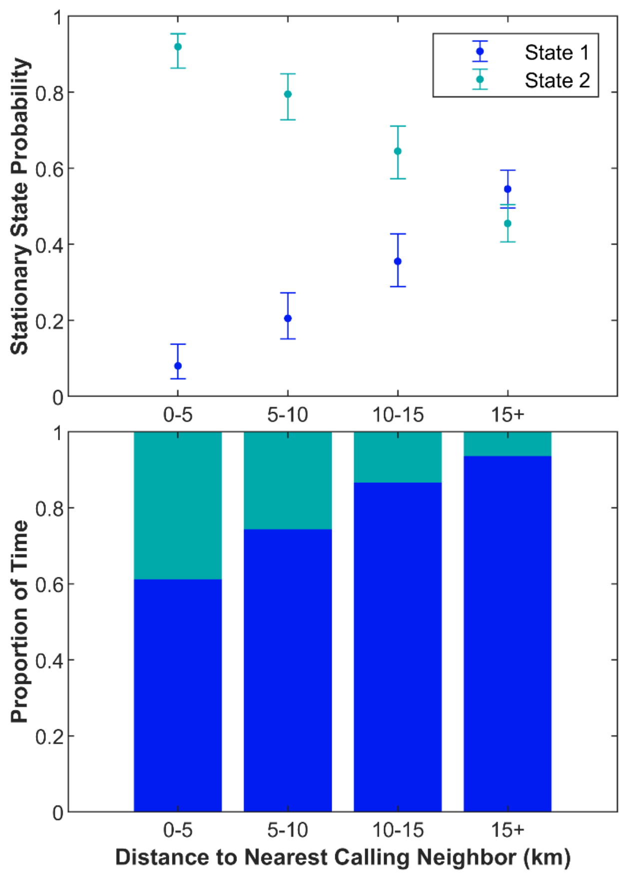
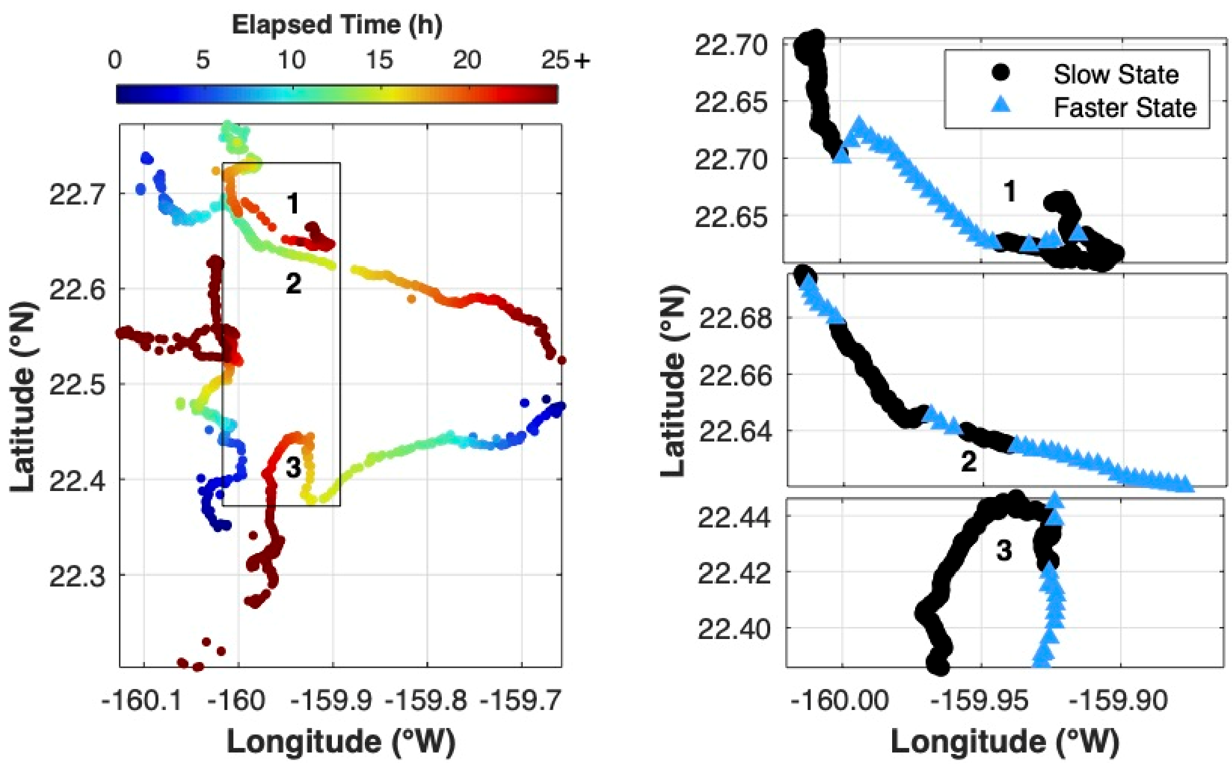


Figure 4. The probability of a minke whale call being a part of State 1 (nominal calling rate) or State 2 (rapid calling rate) as a function of its distance to the nearest calling minke whale (upper plot) and the proportion of time in each of the states (lower plot) (from Martin et al., 2022b).

3.2.1.3 Minke Whale Kinematics

For the third year of effort of the ONR funded E-BREVE project and as a follow-on to the effort in Martin et al. (2022b), minke whale swimming behavior was contextualized by comparing natural variation in minke whale swimming kinematics to the changes found during MFAS exposure (studied extensively in the BREVE project). The BREVE project used acoustic minke whale boing detections to localize and track individual whales on PMRF before, during, and after Navy training and testing activity. These analyses found significant changes in minke whale distribution and swimming behavior during Navy sonar events (Durbach et al., 2021). In order to contextualize changes in animal movement relative to Navy sonar, this research was expanded to examine the natural variation in minke whale movement as a function of various temporal and behavioral variables, as well as wind speed, over the full season of minke whale presence at PMRF when Navy sonar was not present. A manuscript is in publication and results were also presented at the "Effects of Noise on Aquatic Life" Conference in Berlin, Germany (July 2022).

Helble et al. (2023) used the same 509 focal area minke whale tracks analyzed by Martin et al. (2022b) from August 2012 through June 2017. Track kinematics were noted for the portions of the 509 focal tracks that occurred within the focal study area. As in Guazzo et al. (2021) and Durbach et al. (2021), the continuous-time correlated random walk (*crawl*) model and momentuHMM package (Johnson et al., 2008; McClintock and Michelot, 2018) were used to generate smoothed tracks that were evenly sampled in 5-min steps. Using the Viterbi algorithm, each 5-min bin was categorized into one of two kinematic states (Langrock et al., 2012; McClintock and Michelot, 2018). The state that occurred more often had slower speeds with less directional travel, and henceforth will be referred to as the "Slow State." The second state occurred less often and was faster with more directional travel; this will be referred to as the "Faster State." The distribution of the two states can be seen in Figure 5. The example tracks shown in Figure 5 (right) are marked in black for the Slow State and blue for the Faster State.



- The sections of the tracks that are within the focal area are shown to the right for three of the tracks, with numbers 1–3 marking the three tracks in both plots. The west-most track is not shown in the right panel because the whale was moving in and out of the focal area. These positions are estimates of the original positions in evenly spaced 5-min intervals derived from the *crawl* model with colors indicating kinematic state derived from the HMM model ("Slow State" in black and "Faster State" in blue).

Figure 5. Four example minke whale tracks are shown using the original positions (before *crawl* processing) for a 36-hour period as the whales traversed the range (left plot), with the boxed area indicating the focal study area (Helble et al., 2023).

Overall, vocalizing minke whales on PMRF traveled along a mostly direct path with little turning (Figure 6). The whales favored traveling toward the west (circular mean of the average track headings = 275.1°; average heading calculated by averaging the unit vectors for each 5 min interval and then calculating the heading of the result). The mean of the mean track speeds was 1.3 m/s with a standard deviation of 1.0 m/s. The median directivity index was 0.75 and the mode was between 0.9 and 1 (Figure 6). The directivity index was measured as straight-line distance traveled in a track divided by the total distance traveled. Speed, heading, and directivity index showed no apparent trends over days since October 1 (set as the start of minke whale seasonal presence on PMRF). Of all the 5-min intervals categorized into kinematic behavioral state, 67% were categorized as the Slow State and 33% as the Faster State. The average speed for whales in the Slow State was 0.5 m/s and the average speed for whales in the Faster State was 1.9 m/s (Figure 7).

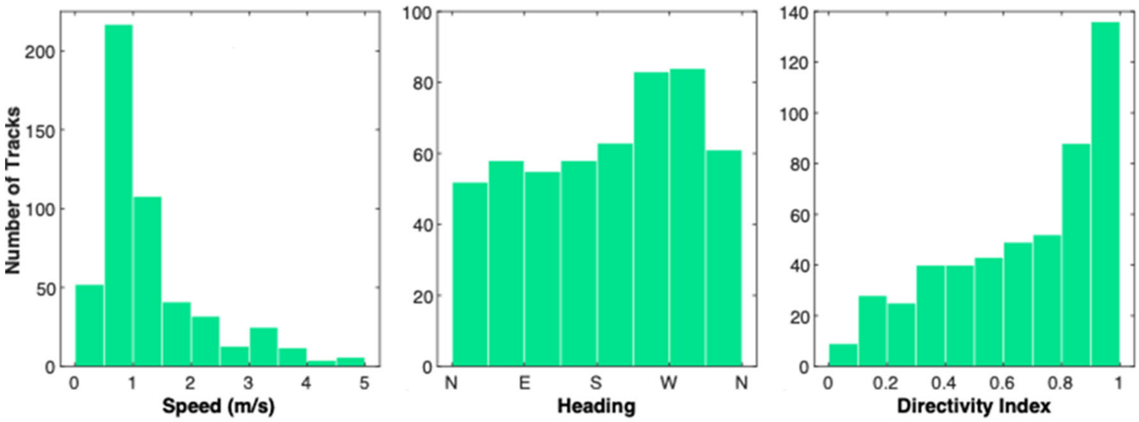
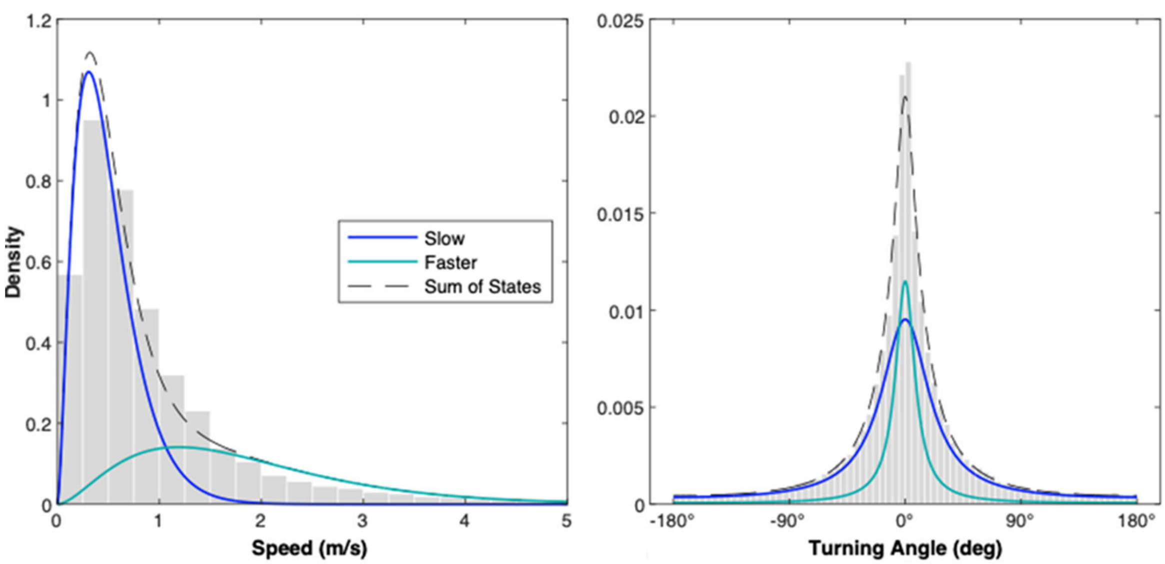


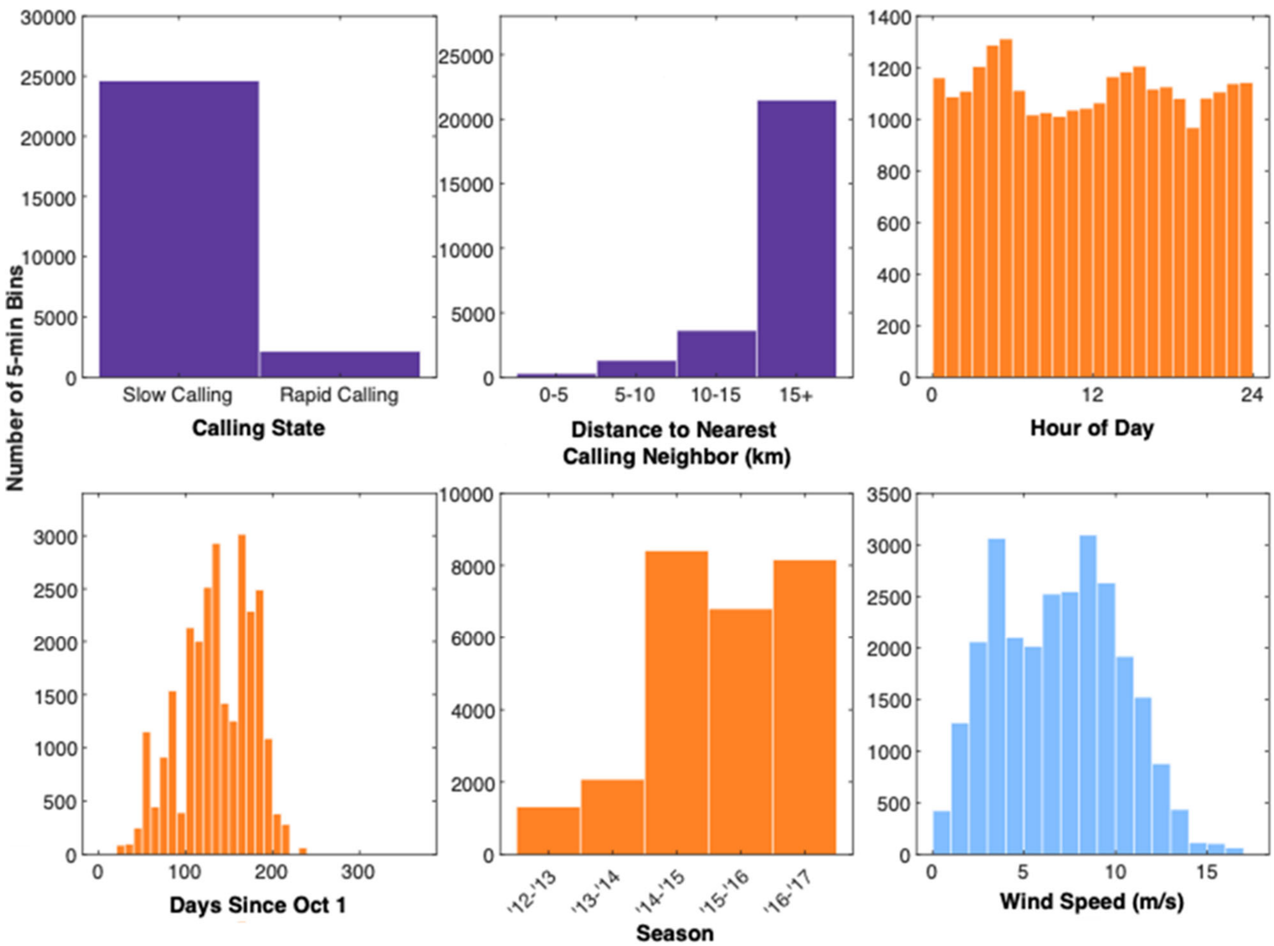
Figure 6. Histograms of the average speed (m/s), average heading, and directivity index (straight-line distance traveled divided by the total distance traveled) for each minke whale track. (Helble et al., 2023).



- The gray histograms show the observed values normalized by the area of each bar, the blue curves show the probability density function of the Slow State, the teal curves show the probability density function of the Faster State, and the black dashed line shows the sum of two states. The kinematic states were estimated using a hidden Markov model. (Helble et al., 2023).

Figure 7. Distributions of the observed variables for the minke whale acoustic tracks normalized by the probability density function.

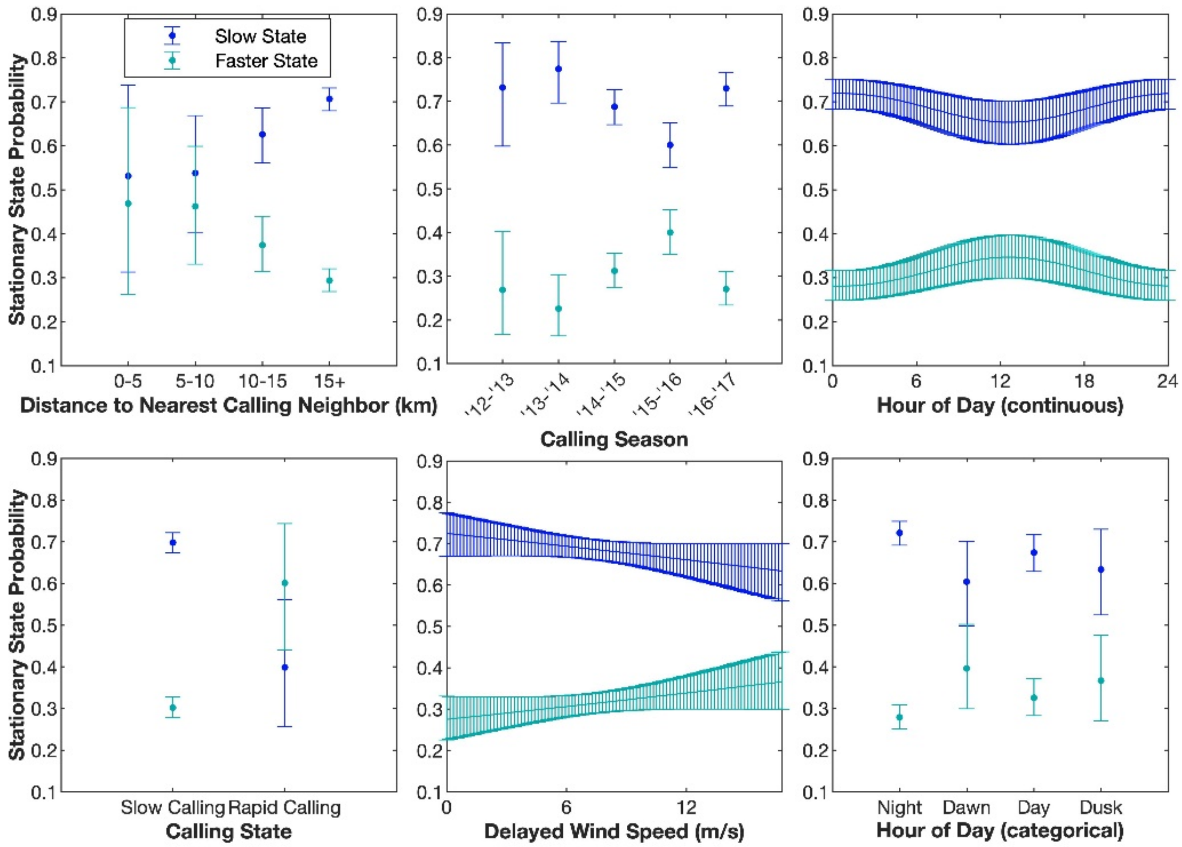
Six different independent variables were tested with HMMs that were hypothesized to influence minke whale swimming behavior while vocalizing (Figure 8) and the models were ranked according to the Akaike Information Criterion (AIC) (Akaike, 1974; Burnham and Anderson, 2002). The covariates tested in order of the AIC of each model were delayed wind speed, hour of day (categorical and continuous), calling state, calling season (defined as the time from October–May across two calendar years when calling minke whales are recorded on PMRF), distance to the nearest conspecific, and days since October 1. Calling season is used rather than year as seasonal presence crosses over two calendar years. The number of days since October 1 had a ΔAIC of 1 compared to the null model and was therefore not explored further. The stationary state probability models for the six best models tested are depicted in Figure 9. Whales were slightly more likely to be in the Faster State during sunrise than any other time of the day, but the change in behavior throughout the day was overall unremarkable. Little changes were observed in kinematic behavior over 24-hour cycles using both simple day/night model or a categorical model (night, dawn, day, dusk). The larger error bars for dawn and dusk are most likely due to the fewer hours compared to day and night (Figure 9). Delayed wind speed with a 6-hour lag resulted in the lowest AIC score, but still had minimal impact on the minke whale kinematics, with higher wind speeds resulting in a slightly higher chance of the whales being in the Faster State.



- The y-axis counts are the number of 5-minute bins. Minke behavioral variables are shown in purple, time variables are shown in orange, and the environmental variable is shown in blue. Hour of Day is in local Hawai'i Standard Time. (Helble et al., 2023).

Figure 8. Histograms of the independent variables observed during minke whale tracks.

Findings indicated that minke whales were more likely to travel in a faster, more directional state when they were calling rapidly and when other minke whales were nearby (Figure 9), but the changes in movement were less intense than the changes observed during exposure to Navy sonar, when swim speeds were the fastest at 2.4 m/s (Durbach et al., 2021). Temporal and environmental variables had relatively small influences on the minke track kinematics. These results start to provide context of natural changes in baseline behavior and responses to regular cues in their environment to understand the severity of behavioral responses to MFAS.



- The blue and teal curves show the stationary state probabilities of the Slow State and the Faster State, respectively. The error bounds show the 95% confidence intervals. (Helble et al., 2023).

Figure 9. The probability of a 5-min observation being in the Slow State or the Faster State based on the independent variable tested.

3.2.1.4 Minke Whale Snapshots August 2012 to July 2017

Using the data analyzed by Martin et al. (2022b) and Helble et al. (2023), the mean number of minke whales tracked in 10-minute snapshots per month from August 2012 to July 2017 are depicted in Figure 10. As described in Martin et al. (2022b), these tracks are within the focal study area which is smaller than and within the study area used for the 2021-2022 whale tracks in this report (Figure 1). These data are provided to examine mean calling whale abundance over five calling seasons, rather than the maximum number of tracks in a 10-minute snapshot as was previously reported. Overall, minke whale calls were detected at PMRF as early as October and typically lasted as late as May. Elevated presence typically occurred during the winter months (January 2012 mean=1, December 2013 mean=0.78, February 2015 mean=0.83, January 2016 mean=0.6, and February 2017 mean=0.64). However, in some years peak presence for the whale season occurred in early spring

(April 2013 mean=0.85, March 2016 mean=0.67, and March 2017 mean=0.96). Of these whale seasons, highest peak presence occurred in the 2012-2013 calling season, with lowest peak presence in the 2015-2016 calling season.

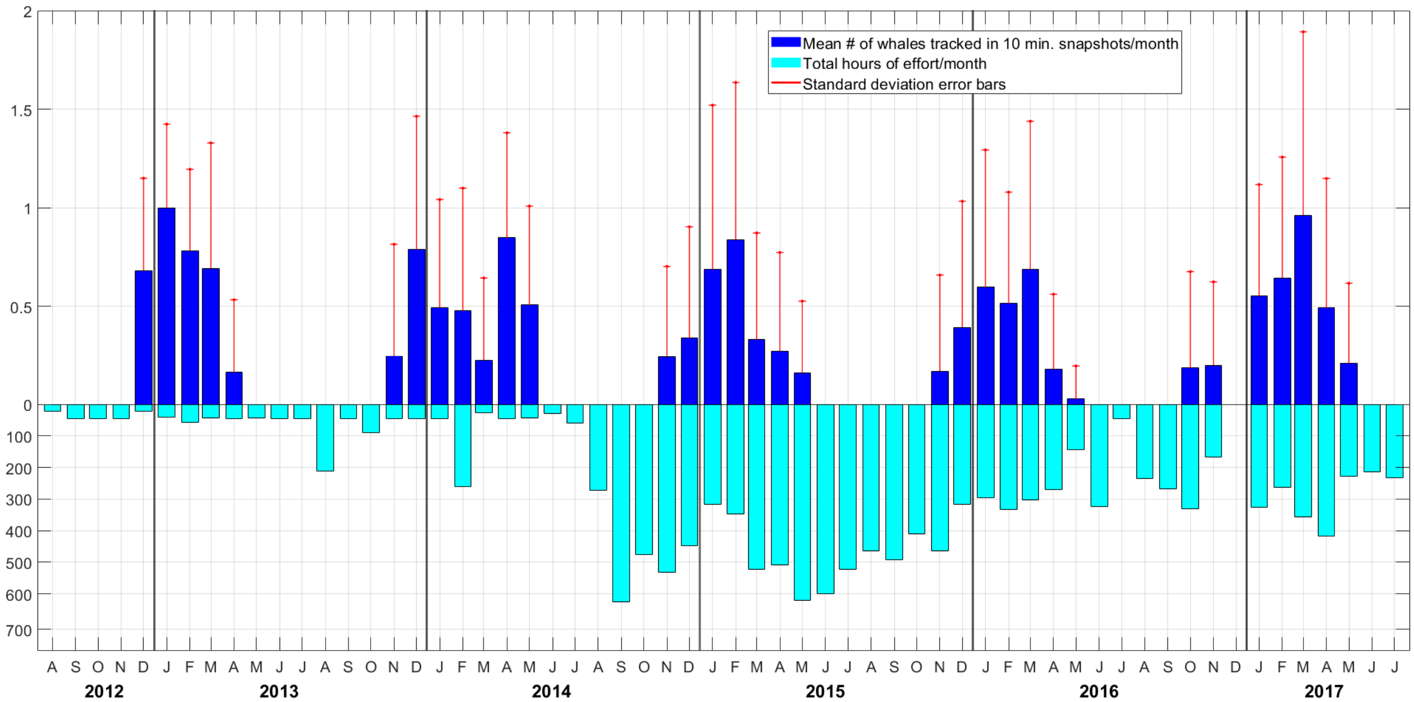


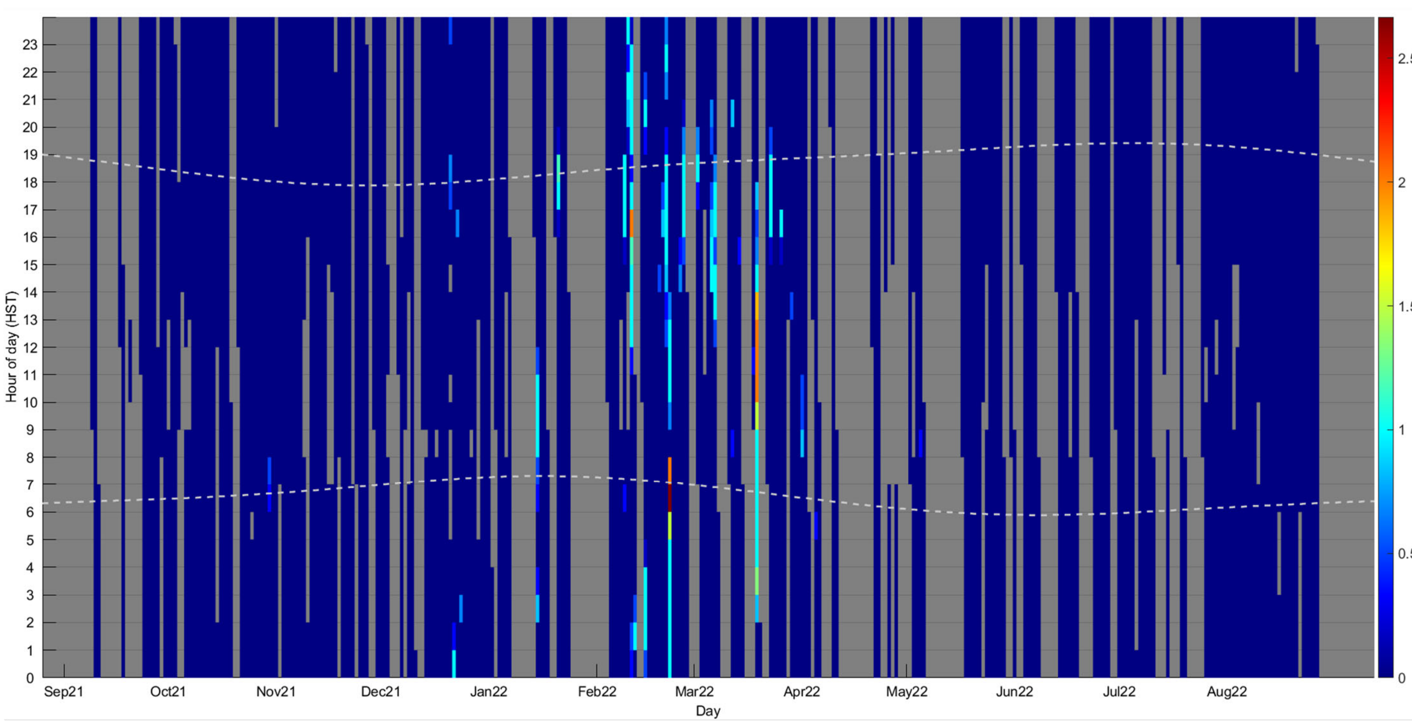
Figure 10. The mean number of minke whales tracked in 10-minute snapshots from August 2012 to July 2017.

3.2.2 Humpback Whales

The mean number of automatically tracked, individual calling humpback whales in a 10-minute snapshot period from both unclassified and classified recordings made between September 2021 and August 2022 are presented per month in Table 3 and per hour in Figure 11. The start of humpback whale seasonal presence occurred in late October 2021 with a mean of 0.01 whales detected in 10-minute snapshots for that month, and a mean between 0.33 and 0.5 whales detected in 10-minute snapshots per hour. Seasonal presence lasted until May 2022, with a mean of 0.01 whales detected in 10-minute snapshots for that month and a mean of 0.33 whales detected in 10-minute snapshots per hour. The maximum number of whales in a 10-minute snapshot was three in February 2022. For comparison, in recent reports which analyzed data from 2018 to 2021 (Martin et al., 2020, 2021, 2022a) the maximum number of whales in a 10-min snapshot ranged from 1 to 4. In the last comprehensive analysis of all data from 2002 to 2018 (Martin et al., 2020), the monthly maximum number of whales detected in a 10-minute snapshot ranged from one to two. These previously reported values are in line with the monthly maximum number of whales in Table 3 which was typically one or two, with a maximum of three whales in February 2022.

Table 3. Monthly numbers of humpback whales detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	906	1	0.01	0.07
November-21	174	0	0	0
December-21	816	1	0.03	0.18
January-22	1080	2	0.04	0.21
February-22	2076	3	0.16	0.41
March-22	2857	2	0.08	0.31
April-22	641	1	0.02	0.14
May-22	402	1	0.01	0.07
June-22	--	0	0	0
July-22	--	0	0	0
August-22	--	0	0	0



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

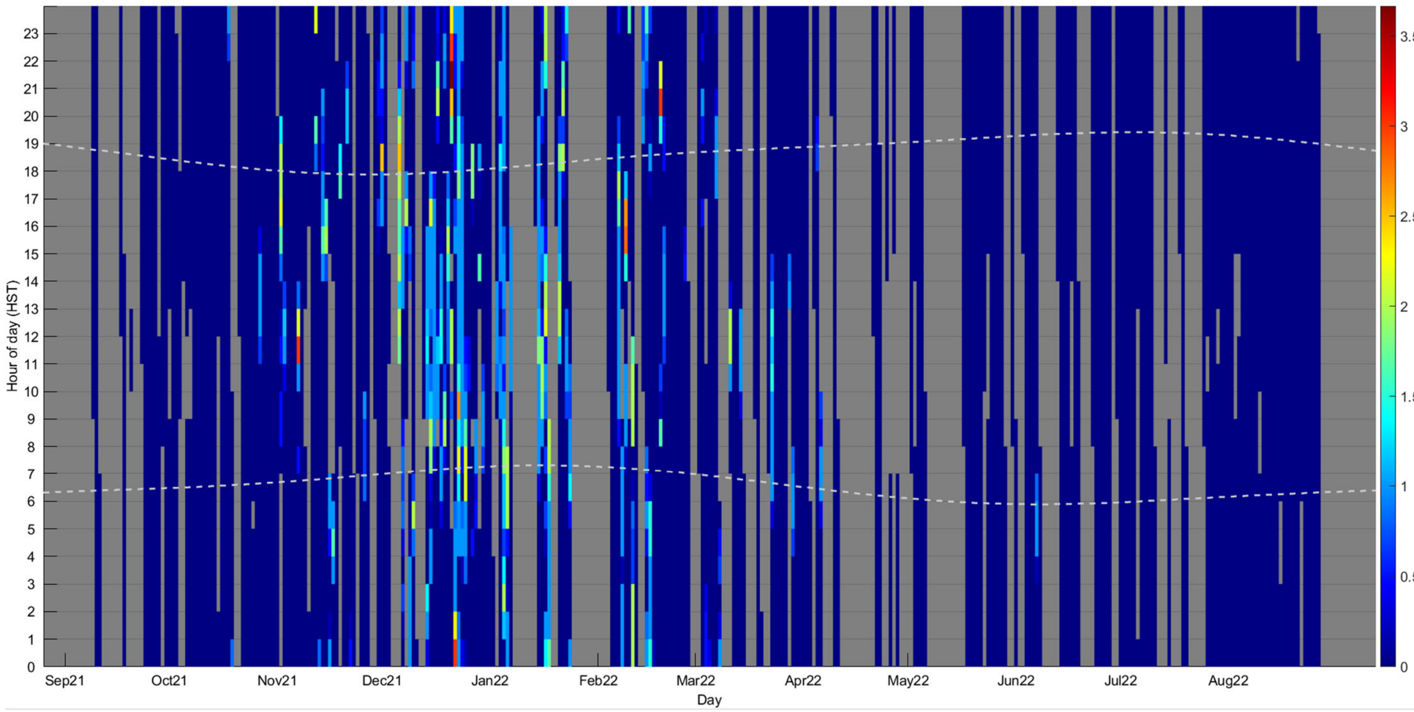
Figure 11. The mean number of humpback whales detected in 10-minute snapshot periods for each hour of the day from September 2020 to August 2021 ranged from 0.17 (blue) to 2.67 (dark red).

3.2.3 Low-Frequency Baleen Whales

The mean number of automatically tracked, individual calling low-frequency baleen whales (e.g. fin, sei, Bryde's, and blue whales) in 10-minute snapshot periods from both unclassified and classified recordings made between September 2021 and August 2022 are presented per month in Table 4 and per hour in Figure 12. These results are from the C++ detection and localization algorithms described in Section 2.2.1 and the individual fin and Bryde's whales, and 40 Hz downsweep results from the Matlab GPL algorithm are presented below in Section 3.2.3.1. The mean number of low-frequency whales detected in 10-minute snapshots per hour ranged between 0.17 and 3.67, with the peak occurring in late December 2021 (Figure 12). The monthly mean number of whales ranged from 0.03 to 0.5 with a peak in January 2022, and the monthly maximum number of whales detected in a 10-minute snapshot ranged from 1 to 5 with a peak in December 2021. For comparison, in recent reports which analyzed data from 2018 to 2021 (Martin et al., 2020, 2021, 2022a), the maximum number of whales in a 10-min snapshot ranged from 3 to 4. In the last comprehensive analysis of all data from 2002 to 2018 (Martin et al., 2020), the maximum number of whales detected in a 10-minute snapshot ranged from 1 to 5. The track in June (Table 4 and Figure 12) was confirmed to be a Bryde's whale track.

Table 4. Monthly numbers of low-frequency baleen whales detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	1,464	1	0.03	0.16
November-21	3,324	3	0.10	0.41
December-21	3,210	5	0.40	0.68
January-22	1,644	3	0.50	0.67
February-22	2,628	3	0.20	0.52
March-22	2,617	2	0.08	0.30
April-22	641	1	0.04	0.19
May-22	--	0	0	0
June-22	666	1	0.03	0.16
July-22	--	0	0	0
August-22	--	0	0	0



- Dark blue regions indicate periods of effort when acoustic recordings were collected and no whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 12. The mean number of low-frequency baleen whales detected in 10-minute snapshot periods for each hour of the day from September 2021 to August 2022 ranged from 0.17 (blue) to 3.67 (dark red).

3.2.3.1 Bryde's, Fin, and Sei Whales

As in last year's report (Martin et al., 2022a), custom Matlab algorithms were used separately from the C++ algorithms above to detect low-frequency whales using specific localization arrays and group localizations into tracks using a large study area spanning about one degree of latitude and longitude centered on the PMRF array, while an analyst manually classified tracks to species. Possible classifications included: 1) fin whales, 2) Bryde's whales, or 3) 40-Hz downsweeps unattributed to a single species (but are likely produced by fin or sei whales). 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. The maximum numbers of automatically tracked individuals detected in a 10-minute snapshot period for each hour of the day for each species category present in the recorded data from September 2021 to August 2022 are shown in Table 5 to Table 7 and Figure 13 to Figure 15. Seasonal presence this year agrees with general knowledge and the long-term seasonal patterns found in recent reports (Martin et al., 2021 and 2022a).

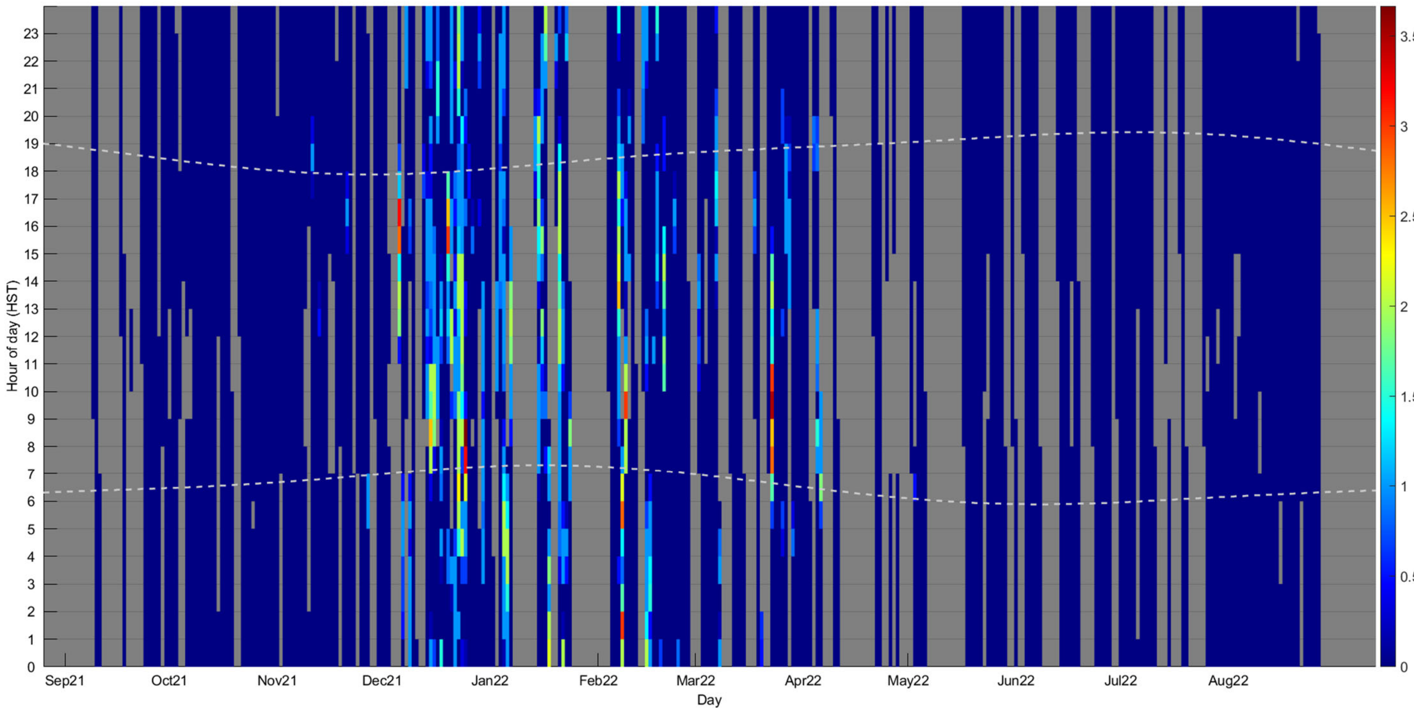
Fin whales were detected from November through May (Table 5 and Figure 13). Peak presence occurred in January 2022 with a mean snapshot of 0.5 in January 2022 and an elevated mean snapshot of 0.45 in December 2021 (Table 5). This concurs with previously reported fin whale acoustic seasonality. Fin whale presence was detected as early as October in data from 2011 to 2020 (Martin et al., 2021) and in November 2020 (Martin et al., 2022a), and ended as late as April (Martin et al., 2021). Peak presence occurred in December and January with a maximum of three to four whales per 10 min snapshot in those months.

The only baleen whale known to potentially call in the summer months is the Bryde's whale, which was only present in October and March in the results from the Matlab GPL algorithm (Table 6 and Figure 14), but was present in June in the results from the C++ algorithm (Table 4 and Figure 12). A maximum of one Bryde's whale was detected in a snapshot in these months (Table 6 and Figure 14). This concurs with typical presence of one to two whales in a snapshot. Although presence has been reported as high as three to four whales in a snapshot, it is a rare occurrence and has only occurred in October 2015 and February 2017 (Martin et al., 2021).

Downswept 40-Hz calls, potentially attributable to fin or sei whales, were less frequent and occurred between January and March 2022 with elevated monthly mean snapshots of 0.04 and 0.05 in January and February 2022 respectively (Table 7). This agrees with previously reported presence from November to April and peak presence during winter months (Martin et al., 2021 and 2022a). No more than one individual track consisting of 40 Hz calls was ever detected in a 10-min snapshot (Figure 15).

Table 5. Monthly numbers of manually confirmed fin whales detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	--	0	0	0
November-21	1,884	1	0.02	0.14
December-21	2,676	4	0.45	0.70
January-22	1,644	3	0.50	0.68
February-22	2,502	3	0.24	0.57
March-22	2,287	4	0.13	0.45
April-22	641	2	0.12	0.39
May-22	144	1	0.02	0.14
June-22	--	0	0	0
July-22	--	0	0	0
August-22	--	0	0	0

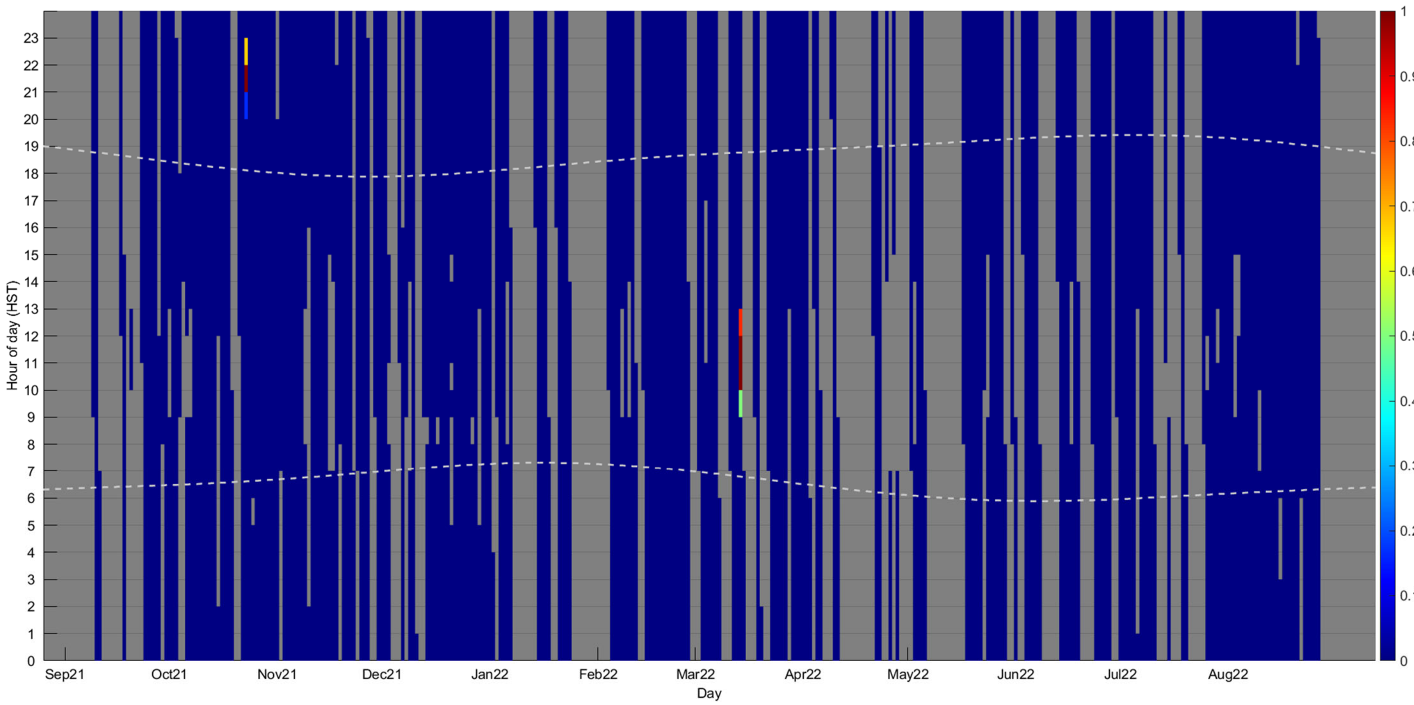


- Dark blue regions indicate periods of effort when acoustic recordings were collected and no whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 13. The mean number of manually confirmed fin whales detected in 10-minute snapshot periods for each hour of the day from September 2020 to August 2021 ranged from 0.17 (blue) to 3.67 (dark red).

Table 6. Monthly numbers of manually confirmed Bryde's whales detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	522	1	0.02	0.14
November-21	--	0	0	0
December-21	--	0	0	0
January-22	--	0	0	0
February-22	--	0	0	0
March-22	570	1	0.04	0.18
April-22	--	0	0	0
May-22	--	0	0	0
June-22	--	0	0	0
July-22		0	0	0
August-22	--	0	0	0



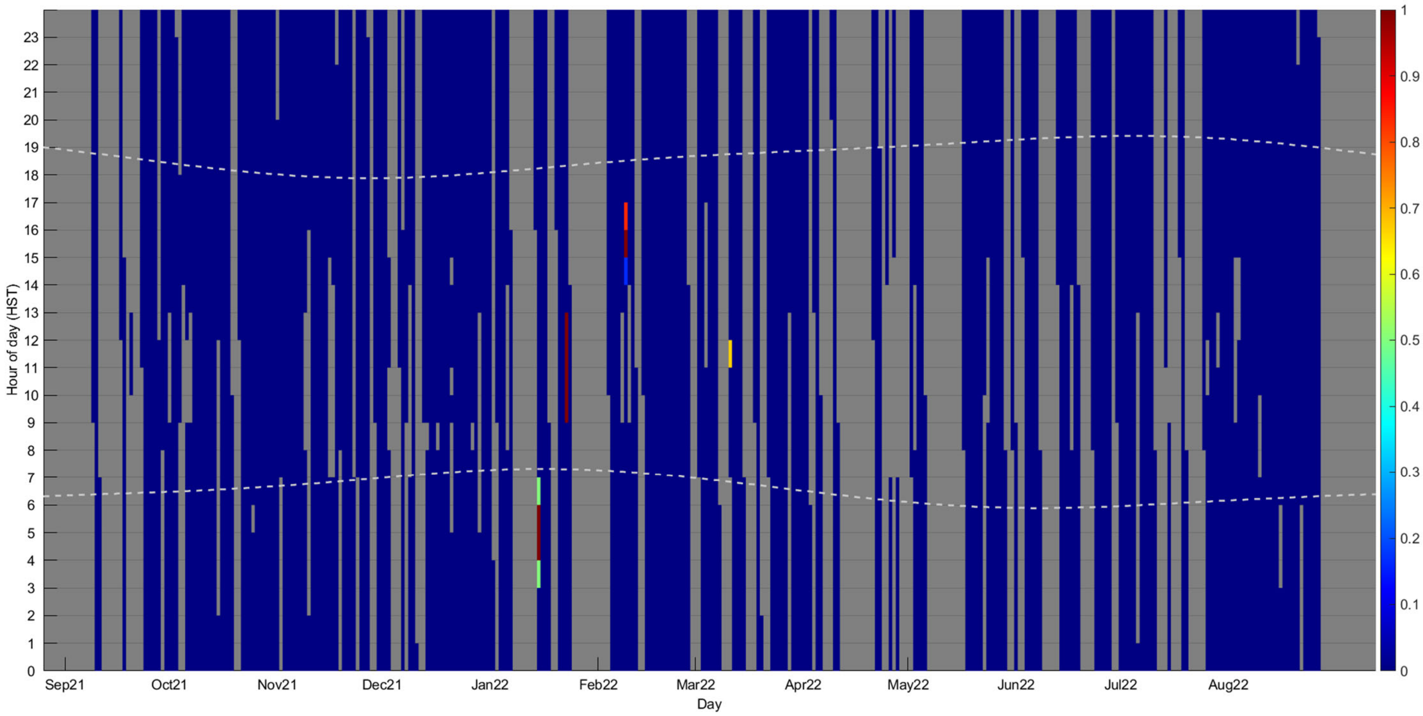
- Dark blue regions indicate periods of effort when acoustic recordings were collected and no whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 14. The mean number of manually confirmed Bryde's whales detected in 10-minute snapshot periods for each hour of the day from September 2021 to August 2022 ranged from 0.17 (blue) to one (dark red).

Table 7. Monthly numbers of manually confirmed tracks comprised of 40-Hz downsweeps (suspected to be either fin or sei whales) detected in 10-minute snapshots.

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0	0
October-21	--	0	0	0
November-21	--	0	0	0
December-21	--	0	0	0
January-22	1,080	1	0.04	0.19
February-22	252	1	0.05	0.21
March-22	570	1	0.01	0.08
April-22	--	0	0	0
May-22	--	0	0	0
June-22	--	0	0	0
July-22	--	0	0	0

Date	Number of Snapshots	Max Snapshot	Mean Snapshot	Standard Deviation
August-22	--	0	0	0



- Dark blue regions indicate periods of effort when acoustic recordings were collected and no whale tracks were present. Results are from decimated and full bandwidth data collections, including classified full bandwidth data collected in August 2021. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 15. The mean number of manually confirmed tracks comprised of 40-Hz downsweeps (suspected to be either fin or sei whales) detected in 10-minute snapshot periods for each hour of the day from September 2021 to August 2022 ranged from 0.17 (blue) to one (dark red).

3.2.4 Blue Whales

As in last year's report (Martin et al., 2022a), two different blue whale call types known to occur on PMRF were automatically detected and localized using a custom Matlab GPL algorithm. These include the northwestern and northeastern Pacific calls (as described by Stafford et al., [2001]; see also Martin et al. [2020] which includes spectrograms of each type as detected on PMRF). Blue whale calls are low frequency and thus have the potential to propagate long distances, but these two call types are long duration, have a near constant frequency, and tend to occur north and west of the range, making localization difficult and prone to uncertainty. An analyst manually classified the calls in datasets that contained at least 20 localizations, of which there were only four in FY22. Of these, only the December 13, 2021 dataset contained actual blue whale calls. Upon examination of the raw acoustic data, both northwestern and northeastern Pacific calls were present in the same detection set, occasionally switching between patterns, as was displayed in the example spectrogram in FY19 (Martin et al., 2020). Because of the lack of localization accuracy, these calls cannot be confidently ascribed to the same individual, but the consistent spacing and lack of overlap between the two call types suggests that either the same whale is switching between the call types (with repercussions for assigning call types to distinct Pacific populations) or at least two individuals produced the calls in an extremely coordinated effort.

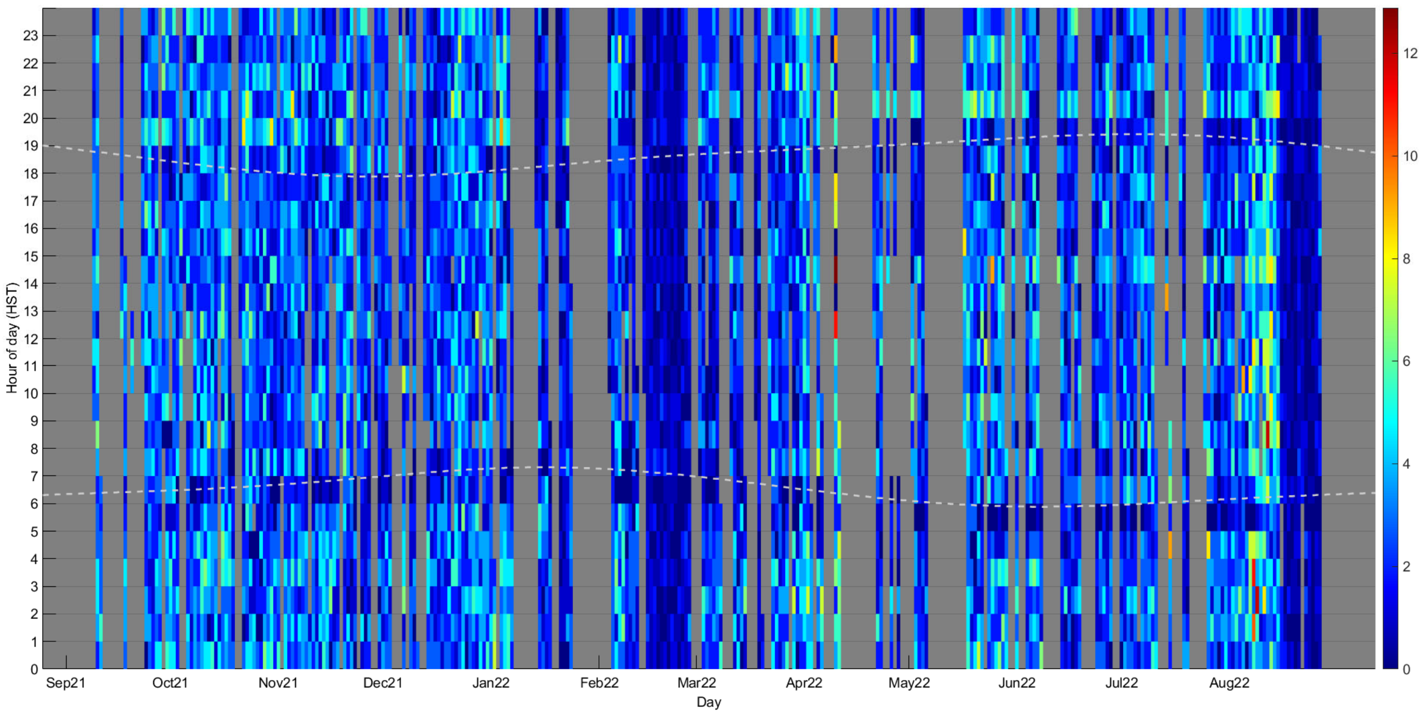
3.2.5 Blainville's Beaked Whales

As in previous years, Blainville's beaked whales were the most commonly detected beaked whale at PMRF and were detected year-round and in every recording. The detections in all recordings were automatically grouped into GVPs, then the grouped data were manually checked to ensure the GVPs were sorted correctly (e.g., no detections on incorrect phones included, dive start and end times were correct, etc.). Based on GVP ICIs, false positive GVPs were removed if the ICIs were less than 0.2 or greater than 0.4 s. Echolocation pulses from eight (six unclassified and two classified) 24-hour periods were manually validated by systematically matching click spectrograms, spectra, and ICIs to known Blainville's beaked whale echolocation click characteristics to ensure that the detector was correctly selecting Blainville's beaked whale pulses. The results of these eight validated time periods were used to estimate average false positive rates during baseline data and during training in February and August (Section 3.3.2), which were then applied to all automatically grouped dive counts accordingly. The resulting numbers of corrected GVPs from baseline data (corrected by the true positive rate [96%] and false positive rate [4%] from validating a subset of baseline data) and data during training in February and August (corrected by the true positive rate [81%] and false positive rate [19%] from validating a subset of the exposure data) are presented in Table 8 as monthly dive rates. The behavioral response analysis for GVPs that occurred in February and August are discussed separately in Section 3.3.2. Monthly GVP rates are the total number of GVPs with start times in a month over the total hours of effort for a month.

Table 8. FY22 Blainville's beaked whale baseline GVP summary.

Date	Sum of GVPs	Hours of Effort	GVPs/Hr
September-21	835	224.7	3.72
October-21	2199	634.0	3.47
November-21	1984	600.4	3.30
December-21	1812	563.1	3.22
January-22	895	313.3	2.86
February-22	914	496.3	1.84
March-22	1219	479.2	2.54
April-22	793	229.7	3.45
May-22	1121	369.3	3.04
June-22	1145	405.6	2.82
July-22	1195	450.4	2.65
August-22	1762	629.6	2.80
Total	15874	5395.6	2.98

The highest number of GVPs/hr of recording effort occurred in September 2021 with 3.72 GVPs/hr, while the lowest number occurred in February 2022 with 1.84 GVPs/hr (which includes the reduced dives during the SCC, see Section 3.3.2). Overall, there appeared to be a higher number of GVPs occurring on PMRF in FY22, with a mean rate of 2.98 and a median rate of 2.95 GVPs/hr. This does not seem to be a result of the increased recording rate with the new recorder and higher drive size capacity, as the GVP counts are normalized relative to the recording effort; however, it may be an artifact of the new analog-to-digital board with increased sensitivity used in the new recorder. The increase in GVPs may also be due in part to the recording of more hydrophones in the preferred beaked whale slope habitat. However, that change occurred in 2018, and this increase in GVP rates did not occur until this year. In the last three years the mean GVP per hour rate ranged between 2.01 and 2.20, with median values from 1.84 to 2.36 GVPs/hr (Martin et al., 2020, 2021, 2022a). Similarly, in 2012 and 2013 the mean rates were 2.5 and 2.0 GVPs/hr respectively (Henderson et al., 2016), even though during this period there were fewer phones recorded in the slope region. While there have been higher mean GVP rates occasionally in earlier years (e.g., 3.3 in 2013 [Henderson et al. 2016], 4.4 in 2020 [Martin et al. 2021]), there seemed to be consistently more GVPs throughout FY22, and frequently multiple GVPs occurring almost simultaneously across the range. This has been referred to as "chorusing" and has been observed to occur in beaked whales at other Navy ranges (pers. comm., Dave Moretti) and will be investigated further for Blainville's beaked whales at PMRF. This can be observed in Figure 16, where there are periodic pulses of high rates of GVPs (up to 12.88 per hour).



- The total number of GVP starts in a one-hour bin ranged from 0.6 (blue) to 12.88 (dark red). Results include classified data collected in February and August 2022. Gray areas indicate periods when data were not available. The gray dashed line indicates sunrise and sunset times.

Figure 16. The total number of Blainville's beaked whale GVPs/hr corrected using manually validated dives from six unclassified datasets and two classified datasets between September 2021 and August 2022.

3.2.6 Cuvier's Beaked Whales

As with the other beaked whales, automatically classified Cuvier's beaked whale clicks were algorithmically associated into GVPs. However, because of the relatively high false positive rate for the Cuvier's click classifier, GVPs were automatically excluded from further consideration if the mode of the ICIs in that GVP was less than 0.3 seconds or more than 0.6 seconds as this is well outside the known Cuvier's beaked whale ICI of 0.4 s (Zimmer et al. 2005). The high false positive rate is due to misclassified group dives that were composed of clicks mostly from dolphins. Due to the relative infrequency of Cuvier's beaked whale GVPs on PMRF, the clicks comprising all remaining GVPs were able to be manually validated by systemically reviewing click spectrograms, spectra, and ICIs to meet known Cuvier's beaked whale echolocation click characteristics.

This FY there were 911 total confirmed Cuvier's beaked whale GVPs (including GVPs during training in February and August). The true positive rate for the baseline dives (897 total) was 81.0%. This true positive rate is consistent with that of FY21 (76%), but both years are higher than FY19 and FY20 (54.1% and 49.2%, respectively; Martin et al., 2020, 2021). Approximately 75% of the FY21 data were recorded with the new recording system and the number of true positive dives in FY21 (221 dives) was 40% and 48% higher than the number of true positive dives in FY19 and FY20 respectively. As seen with the Blainville's beaked whale results, the increase in the number of dives might be attributed to changes in the recording system, natural fluctuation in abundance, or a combination thereof. False positives in this case tend to be due to misclassification of other odontocete species and the algorithm erroneously splitting GVPs, which can occur depending on the spatial and temporal density of click detections. Improvements to the grouping algorithm as well as the underlying detector (in concert with attempts to detect Longman's beaked whale, see Section 3.2.8) are underway. The true positive and false positive rates for dives validated during training are discussed separately in Section 3.3.2

Table 9 gives the total number of fully validated Cuvier's beaked whale GVPs during baseline periods, and periods with training in February and August, with the hours of recording effort for each month and the resulting metric of GVPs/hr of recording. The number of overall groups was much higher this year (911, compared to 132, 116, and 221 from FY19, FY20, and FY21, respectively), likely due to the significant increase in recording effort. The monthly GVP rate per hour of effort ranged from 0.03 GVPs/hr in February 2022 to a peak of 0.42 GVPs/hr in December 2021. The average monthly GVP rate for FY22 recordings was 0.16 GVPs/hr, which was the same as FY21 (0.16), but about twice that in FY19 and FY20 (0.09 and 0.08, respectively). The monthly peak of 0.42 GVPs/hr in December 2021 is also unmatched by previous years (0.23 in July 2021, 0.19 in May 2020, and 0.24 in February 2019). Although GVPs are normalized by recording effort, it is possible that while the duration and cycle of individual GVPs (on the order of minutes) is well within traditional recording times (usually a day or two), it is possible that chorusing (see Section 3.2.5) or some other longer-term cyclical behavior is present which operates on the order of days, which would have been impossible to capture previously but can now be investigated.

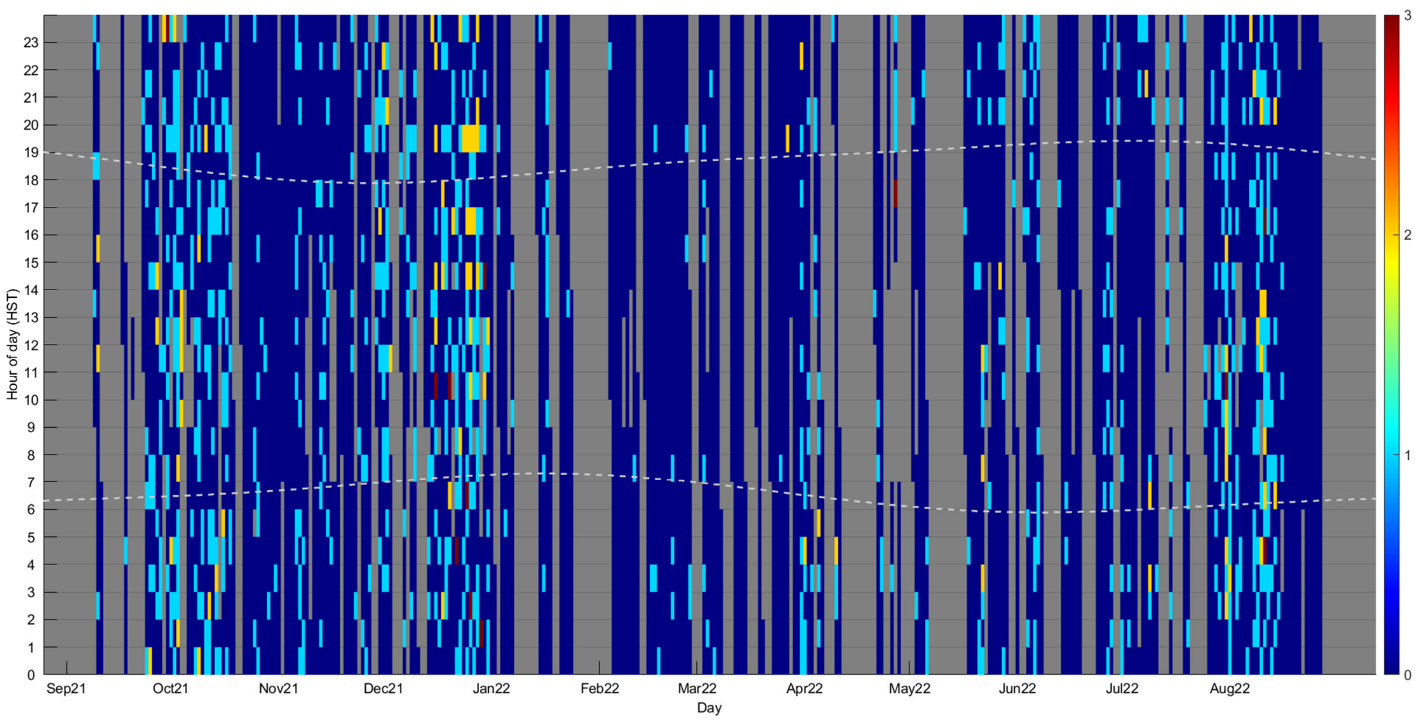
Table 9. FY22 Cuvier's beaked whale manually validated GVP summary.

Date	Sum of GVPs	Hours of Effort	GVPs/Hr
September-21	54	224.7	0.24
October-21	160	634.0	0.25
November-21	63	600.4	0.10
December-21	236	563.1	0.42
January-22	23	313.3	0.07
February-22	13	496.3	0.03
March-22	18	479.2	0.04
April-22	43	229.7	0.19
May-22	39	369.3	0.11
June-22	48	405.6	0.12

Date	Sum of GVPs	Hours of Effort	GVPs/Hr
July-22	78	450.4	0.17
August-22	136	629.6	0.22
Total	911	5395.6	0.16

Cuvier's beaked whale presence seemed to pulse through PMRF periodically in FY22, with GVP rates increasing an order of magnitude in September, October, December, April, July, and August over the other months, with those summer months remaining consistently high (

Table 9, Figure 17). The maximum number of GVPs in a one-hour bin was 3, which is consistent with that in previous years (3, 2, and 2 in FY21, FY20, and FY19, respectively). In FY21, December, July and August had similarly high rates of GVPs/hr (0.16, 0.23 and 0.16, respectively). This may indicate that Cuvier's beaked whales have a seasonal or even biannual peak in presence at PMRF, with a peak in foraging behavior occurring in the summer and again in December. In FY21 it was posited that hours in which multiple GVPs occurred may be more frequent at night, but that does not seem to be supported by the results this year, and no diel pattern is immediately apparent (also see Section 3.2.9). With increased recording effort going forward, it should become increasingly possible to statistically assess any temporal trends.



- Results include classified data collected in February and August 2022. The total number of GVP starts in a one-hour bin ranged from one (blue) to three (dark red). Gray areas indicate periods when data were not available. The gray dashed line indicates sunrise and sunset times.

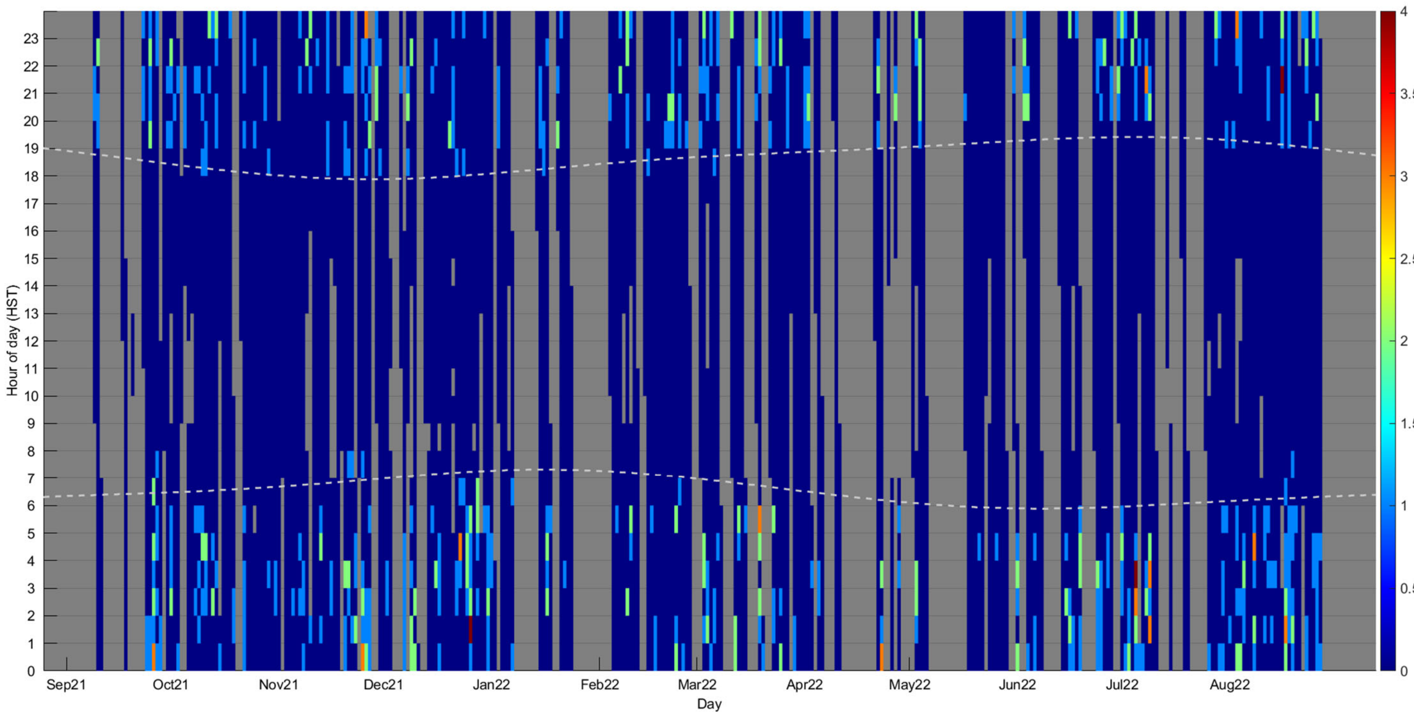
Figure 17. The total number of manually validated Cuvier's beaked whale GVPs/hr from September 2021 to August 2022.

3.2.7 Cross Seamount Beaked Whales

Cross Seamount beaked whale (BWC) pulses were automatically detected and grouped, then fully manually validated by systemically reviewing click spectrograms, spectra, and ICIs to meet known BWC beaked whale echolocation click characteristics. This FY there were 696 total confirmed BWC GVPs (including GVPs during training in February and August). The BWC results in the baseline data (i.e., not including data during training in February and August) contained 610 validated true positive GVPs relative to the automatically detected and grouped GVPs (20.1% true positive rate) and 2366 validated false positive GVPs (78% false positive rate). The behavioral response analysis and true positive and false positive rates for GVPs validated during training are discussed separately in Section 3.3.2. Work on the BWC click classifier continues (see Section 3.2.8) in order to improve performance and reduce misclassification of BWC beaked whale clicks. The normalized monthly GVP rate per hour of effort ranged from 0.05 GVPs/hr (May 2022) to 0.18 GVPs/hr (September 2021), and the average monthly GVP rate for FY22 recordings was 0.13 GVPs/hr (Table 10). These GVP rates are similar to what was detected in FY21, with minimum GVP rates of 0.09 in July and November and a maximum GVP rate of 0.23 in December. These rates are also similar to what was found in the long-term analysis conducted by Manzano-Roth et al. (2022) and reported by Martin et al. (2022a), where the long-term average GVP rate was 0.05 GVPs/hour, while the nighttime only GVP rate was 0.11 GVPs/hour.

Table 10. FY22 Cross Seamount beaked whale manually validated GVP summary.

Date	Sum of GVPs	Hours of Effort	GVPs/Hr
September-21	40	224.7	0.18
October-21	70	634.0	0.11
November-21	81	600.4	0.13
December-21	87	563.1	0.15
January-22	25	313.3	0.08
February-22	43	496.3	0.09
March-22	75	479.2	0.16
April-22	27	229.7	0.12
May-22	18	369.3	0.05
June-22	59	405.6	0.15
July-22	69	450.4	0.15
August-22	102	629.6	0.16
Total	696	5395.6	0.13



- The total number of GVPs in a one-hour bin ranged from one (blue) to four (dark red). Results include classified data collected in February and August 2022. Gray areas indicate periods when data were not available. The gray dashed line indicates sunrise and sunset times.

Figure 18. The total number of BWC beaked whale GVPs per hour corrected using manually validated dives between September 2021 to August 2022

3.2.8 Longman's Beaked Whales

As mentioned in last year's report (Martin et al., 2022a), a preliminary Longman's beaked whale classifier (with simultaneous improvements to the classification accuracy of the Cuvier's and BWC beaked whale classifiers) was developed using a dataset known to include GVPs from all four beaked whales click types (September 7, 2019). Because of the significant overlap in acoustic character, efforts are ongoing to refine each classifier without negatively impacting the efficacy of the other three. Further testing is required on more datasets and in various conditions (different times of year, during other marine mammal activity, during anthropogenic activity, etc.). Because of the relative sparsity of Longman's beaked whale GVPs on PMRF, the dramatic increase in recording effort this FY should make a substantial contribution of data from which to continue building on and refining these efforts.

3.2.9 Long-Term Beaked Whale GVP Comparison

With full bandwidth hydrophone recordings beginning at PMRF in 2006, WARP now has seventeen years of beaked whale data. With the upcoming reprocessing of all our data with the Baseline 5 code, WARP will finally have all our data processed with the same baseline version and can conduct some detailed analyses of these long-term data, including obtaining density estimations, comparing habitat use, and examining changes in GVP rates on longer time scales and relative to SCC activities.

As a preliminary step in preparation of this upcoming analysis effort, the existing beaked whale GVP data has been collated so that a comparison can be made across processing methods to ensure consistency. These collected data, although not the data that will be used for the long-term analysis, can still be examined to start to look for trends and differences across species. For example, using the code available in the online repository for acoustic metadata Tethys (Roch et al., 2016), the GVP starts can be plotted against the diel cycle for each full long-term dataset. Although these plots don't normalize by effort, they can still demonstrate some of the clear trends observed for each species. For example, the increase in numbers of GVPs in FY22 is obvious for all species, but particularly Blainville's beaked whales (Figure 19), as is the strong diel pattern in BWC GVPs (Figure 21). Pulses in GVP rates can also be observed for both Blainville's and Cuvier's beaked whales (Figure 20). These types of patterns can be examined systematically and statistically once all the data have been processed using the same baseline code, and comparisons can begin to be drawn across species. The cause of the increase in GVPs for all species in FY22 is likely an increased sensitivity in the analog-to-digital board in the new recorder deployed in FY21, similar to the apparent increase in beaked whale dives in 2011 when the recorded hydrophones changed with inclusion of an additional 41 hydrophones capable of detecting beaked whale clicks (e.g., Figure 19). This will be investigated further to tease out any increased dive rates that are artifacts of this change from potential real increases in beaked whale presence.

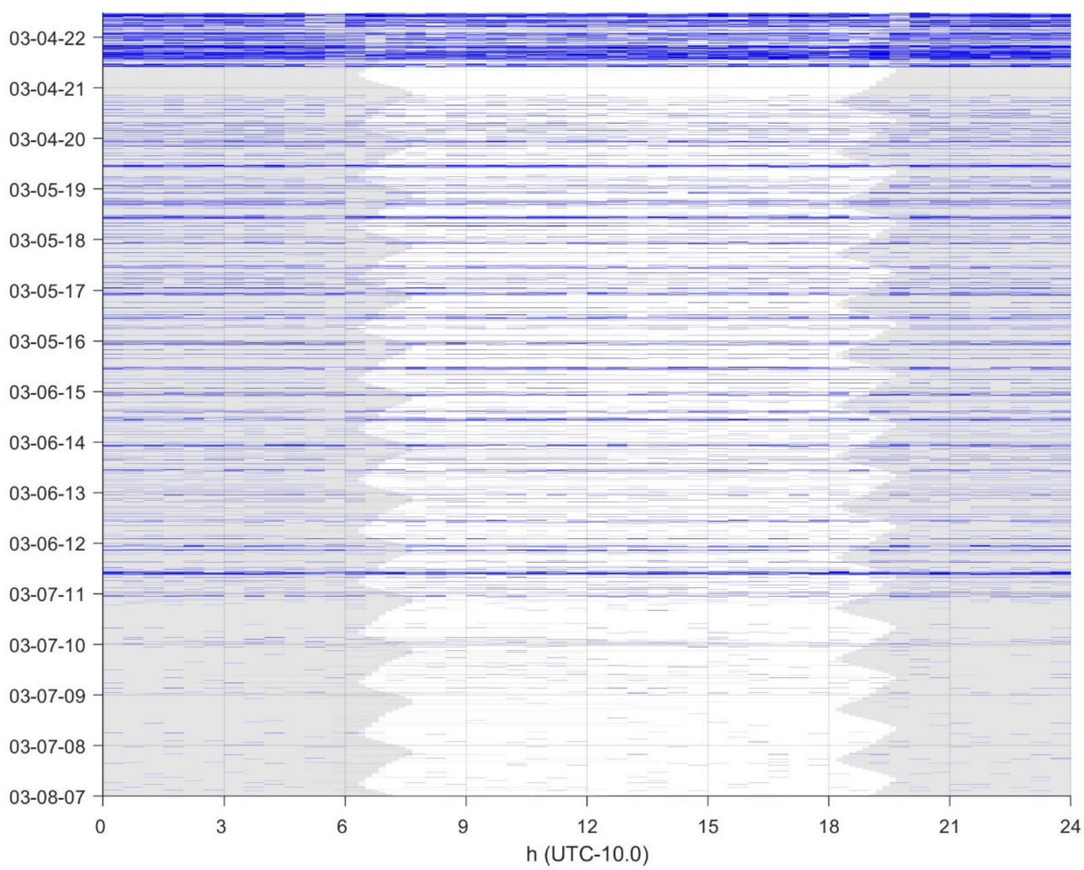


Figure 19. Blainville's beaked whale GVP starts per half hour bin from 8 March 2007 through 23 August 2022. If more than one dive start occurred in a half hour period, the color will be darker. Night throughout this period is indicated by the gray shading. Periodic increases in GVP rates throughout the years can be observed, particularly in 2022.

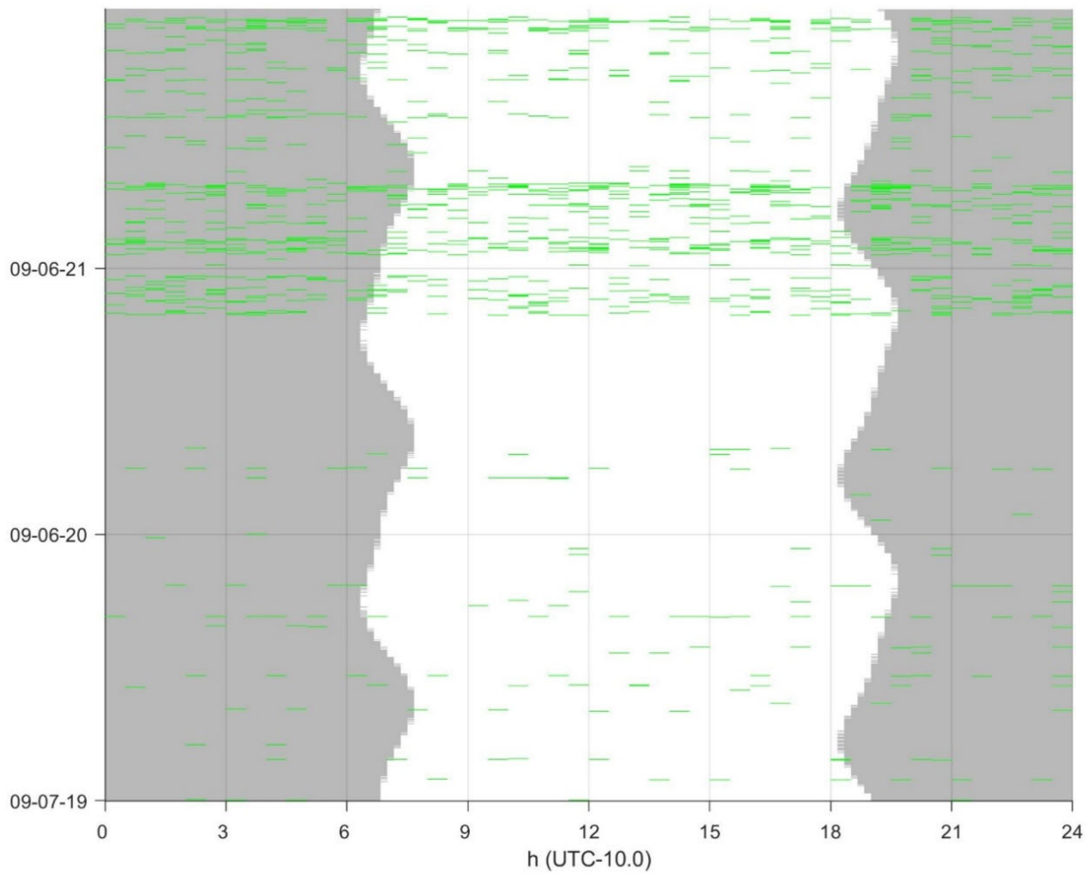


Figure 20. Cuvier's beaked whale GVP starts per half hour bin from 7 September 2019 through 23 August 2022. If more than one dive start occurred in a half hour period, the color will be darker. Night throughout this period is indicated by the gray shading.

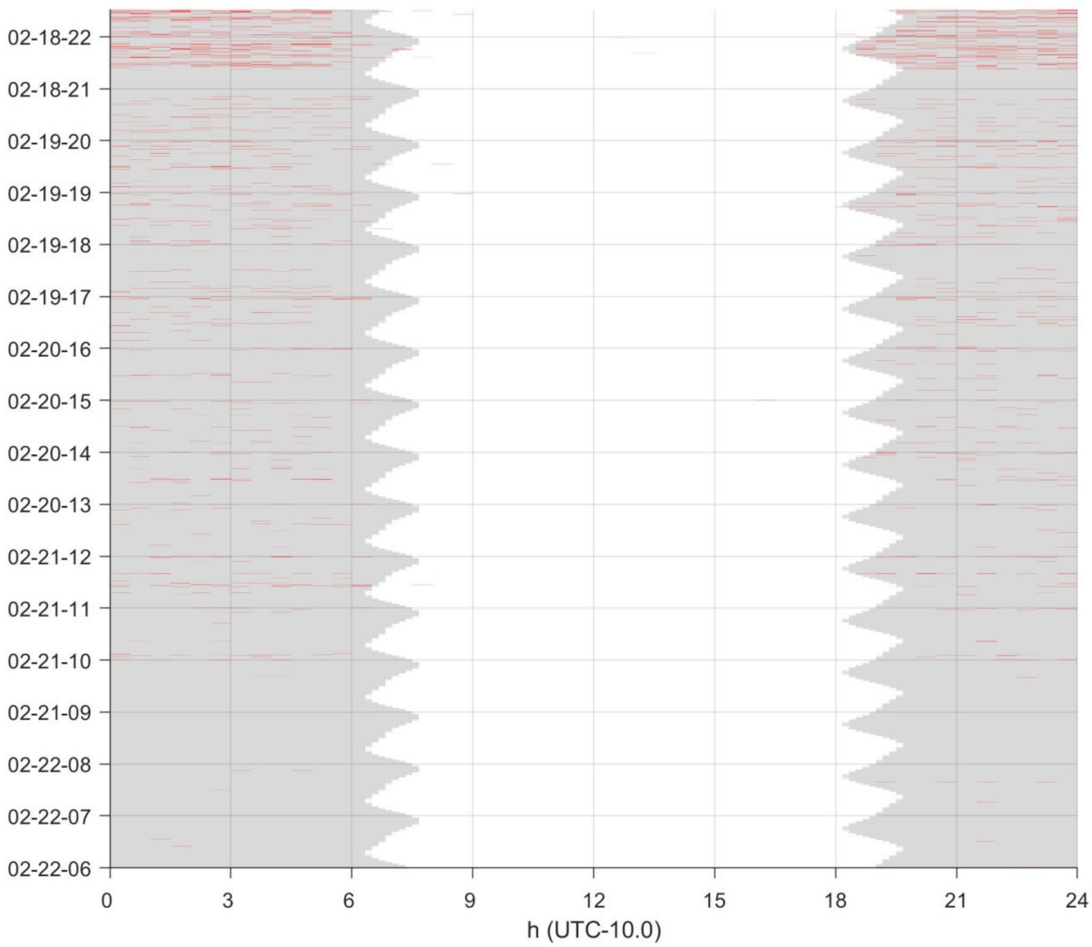


Figure 21. BWC beaked whale GVP starts per half hour bin from 22 February 2006 through 23 August 2022. If more than one dive start occurred in a half hour period, the color will be darker. Night throughout this period is indicated by the gray shading. The strong diel periodicity in BWC dives is easily observed.

3.2.10 Killer Whales

Killer whale HFM call detections (see Simonis et al., 2012, Samarra et al., 2010) were automatically associated into groups based on temporal and spatial proximity (see Section 2.2.1), but due to their rare occurrence and a high false positive rate due to other high-frequency whistling delphinids, all groups are fully manually validated. In the current FY22 data there were ten groups of confirmed HFM calls, the second-highest number in an annual reporting period to date, again likely due to the increase in recording effort (the highest number of groups confirmed previously was 12 in FY10). As noted in previous reports, groups of HFM calls have so far exclusively occurred during daylight hours or – if at night – during or near full moon. In the current FY22 data eight groups of HFM calls took place during the day (the earliest starting 06:23 HST in October and the latest starting at 16:02 HST in December) and the other two took place at night but when the moon was at least three-quarters full (on December 16th and January 18th). More recording coverage with, in turn, more instances of killer whale acoustic presence will hopefully allow the WARP Lab to build a sample size large enough to assess any behavioral responses of other whales to the only potential marine mammal predator in the area, and thus continue to contextualize behavioral responses to anthropogenic activity.

3.2.11 Sperm Whales

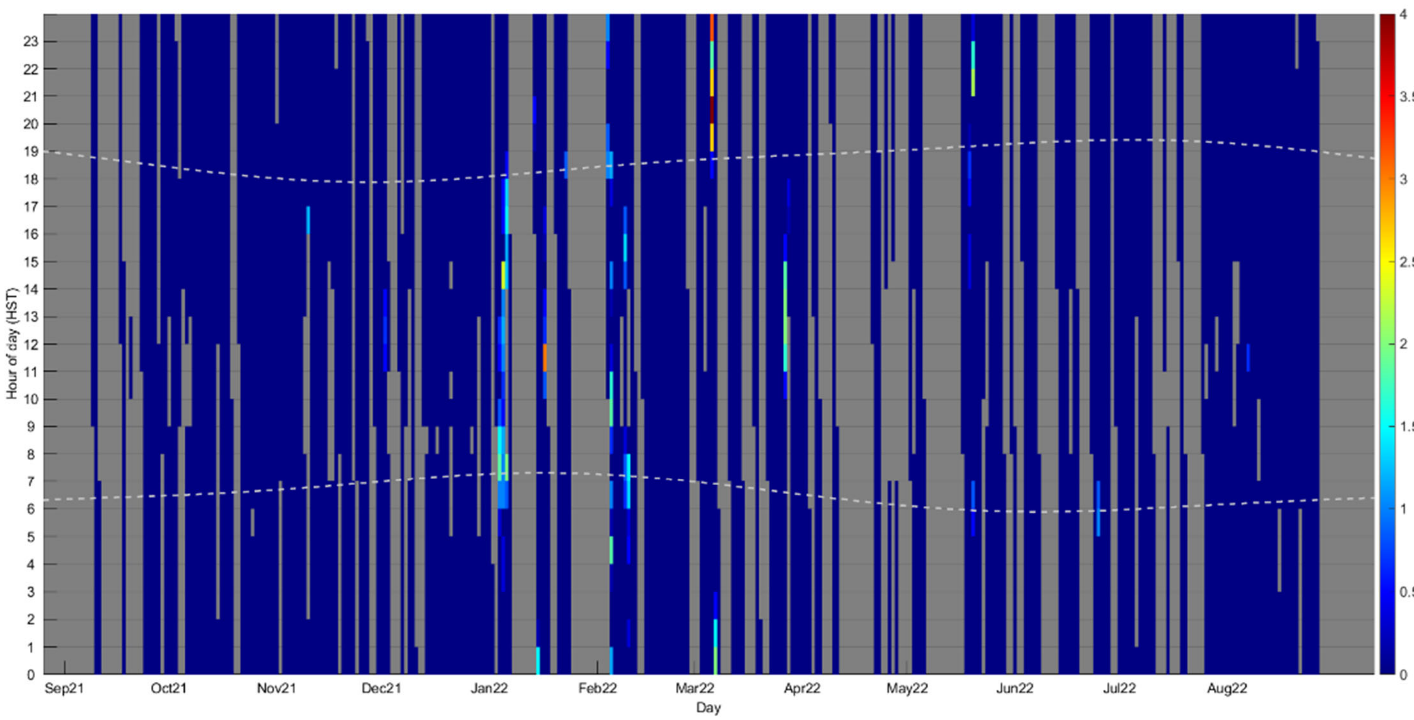
The maximum and mean number of automatically tracked individual calling sperm whales detected in 10-minute snapshots every month from both unclassified and classified recordings made between September 2021 and August 2022 are displayed in Table 11. The maximum number of tracked sperm whales detected in a 10-minute snapshot period for each hour of the day during those recordings is also shown in Figure 22. Although the sperm whale detector has not yet been validated to assess potential false positives in the classified data, only two automatic tracks were generated and they were manually determined to be false positives and are therefore not included in this analysis.

The maximum number of sperm whale tracks detected in a 10-min snapshot was six in March 2022 (Table 11, dark red in Figure 22). As noted in previous reports, the ability for the LAT algorithm to successfully isolate tracks (and thus produce an accurate snapshot) can depend on the density of groups of animals and calling characteristics (Martin et al., 2020, 2021). This is particularly true for sperm whales, which occasionally form relatively tight-knit foraging groups whose acoustics are comprised of overlapping click trains resulting in small ICIs. It is possible that relatively elevated max snapshots (such as that in March) are due to erroneous splitting and recombining of neighboring tracks in a group. Though advances in the detection, localization, and LAT algorithms have helped to mitigate this problem (Martin et al., 2019, 2020), it is still a known issue.

Mean numbers of sperm whale tracks detected in 10-min snapshots varied from 0 in multiple months to a peak of 0.18 in February 2022. The density of sperm whale tracks was generally higher from November to March, which is also when baleen whale seasonal presence peaks, although unlike baleen whales, sperm whales were sometimes detected in summer months (May, June, and August). In FY21 (which had relatively few recordings), the only month in which sperm whales occurred was December (Martin et al., 2021). In previous reports, sperm whales have been detected year-round, but their presence in some years does seem higher during the winter months (Martin et al., 2021, 2022a). Due to their relatively low occurrence on PMRF compared to some other species, the increase in recording effort should provide the opportunity going forward to better assess and formalize any seasonal fluctuations in sperm whale presence and/or behavior.

Table 11. Monthly numbers of sperm whales detected in 10-minute snapshots.

Date	Max Snapshot	Mean Snapshot	Standard Deviation
September-21	--	0	0
October-21	--	0	0
November-21	2	0.01	0.09
December-21	1	0.03	0.16
January-22	4	0.13	0.44
February-22	3	0.18	0.46
March-22	6	0.10	0.52
April-22	--	0	0
May-22	3	0.06	0.31
June-22	1	0.01	0.12
July-22	--	0	0
August-22	1	0	0.07



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2022. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 22. The mean number of sperm whales detected in 10-minute snapshot periods for each hour of the day from September 2021 to August 2022 ranged from 0.17 (blue) to 4 (dark red).

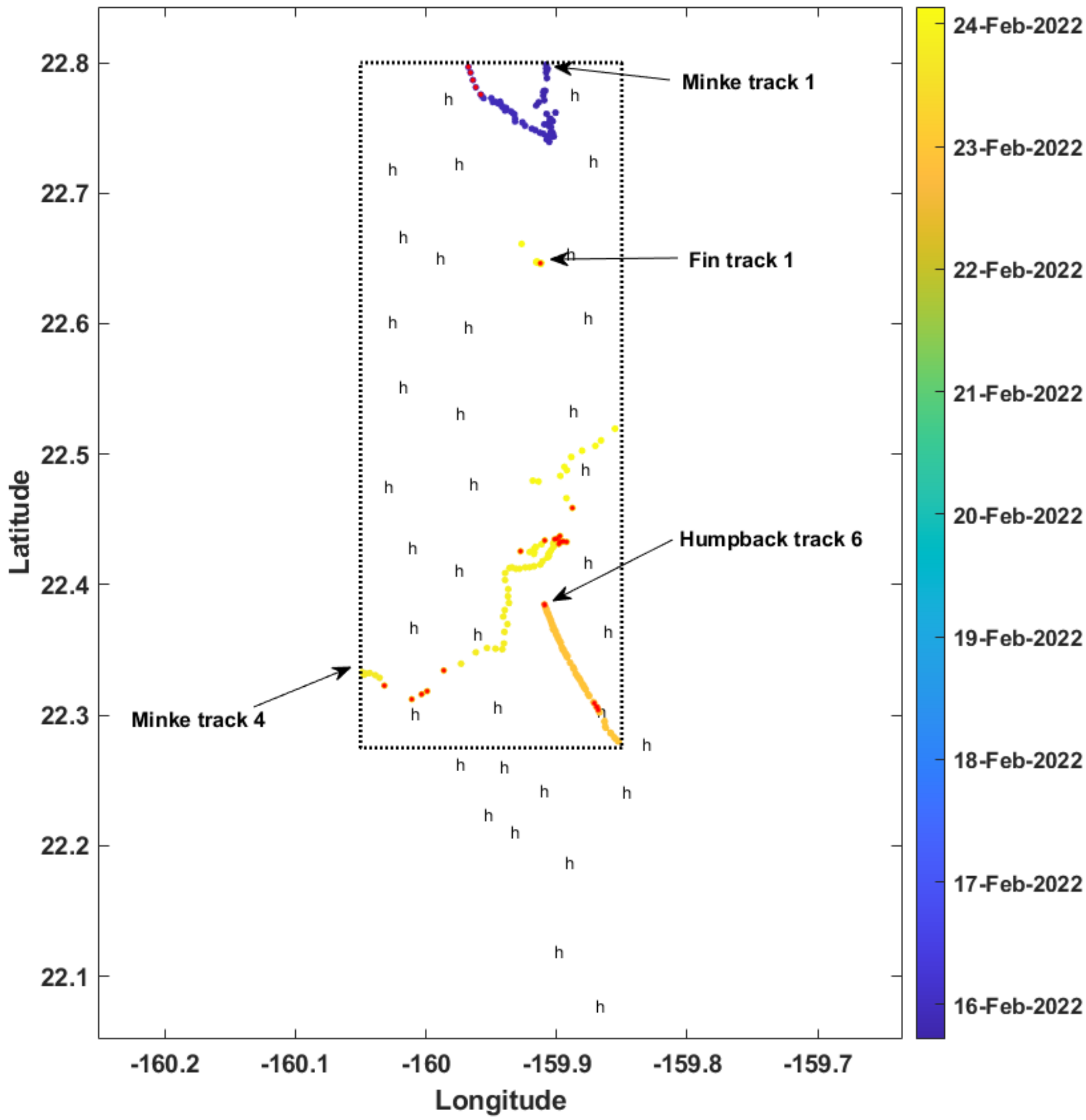
3.3 BEHAVIORAL RESPONSE ANALYSES

3.3.1 Baleen Whales February 2022

The Behavioral Response Analysis (previously referred to as the Disturbance Analysis, e.g., Martin et al. 2022a) is currently conducted for baleen whales that can be localized and tracked, and that are exposed to surface ships with hull-mounted MFAS. Baleen whale tracks overlapped with the February 2022 ULT and SCC, but no tracks (i.e., Bryde's whales) overlapped with the August 2022 SUBEX or SCC. In February 2022 there were relatively more exposures than previously reported (Table 12) due to the occurrence of a ULT and a relatively high level of MFAS activity during the SCC. For this report the following tracks exposed to MFAS will be analyzed in detail (in **bold** from Table 12): minke 1 (sole confirmed track during the ULT); fin 1 (sole fin whale track during the ULT and SCC); humpback 6 and minke 4 (the tracks from each respective species with the most exposures and highest cSEL during the SCC).

Table 12. February 2022 baleen whale exposure summary

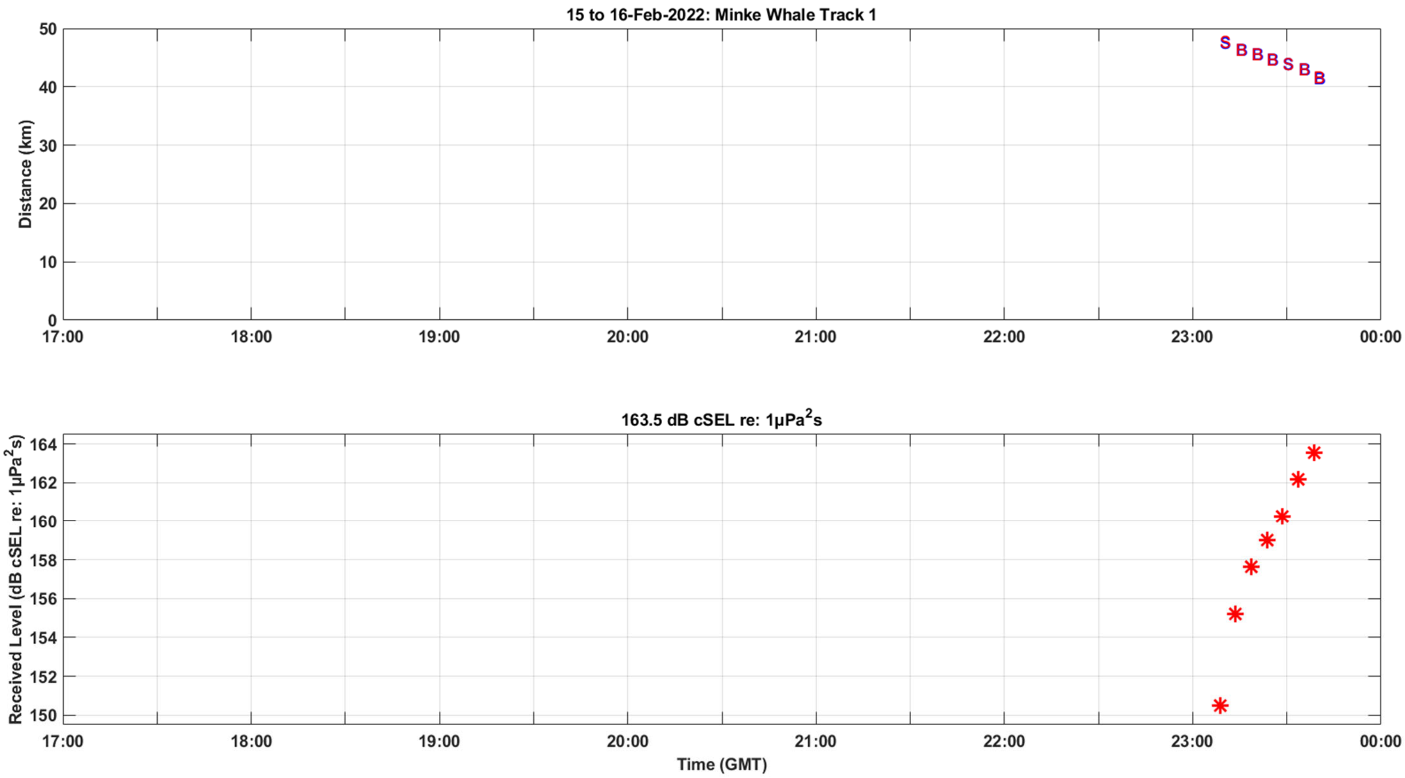
Event	Whale	Track Start (GMT)	Track End (GMT)	Min CPA Ship (km)	Min CPA MFAS (km)	Bins with MFAS Exposures	cSEL (dB re: $1 \mu Pa^2 s$)
ULT	**Minke 1**	15Feb 17:13	15Feb 23:36	41.5	41.6	7	163.5
SCC	**Fin 1**	24Feb 01:20	24Feb 03:03	0.7	18	1	135.3
SCC	Humpback 1	22Feb 15:44	22Feb 17:46	23.6	N/A	0	N/A
SCC	Humpback 2	22Feb 16:23	22Feb 17:00	36.8	N/A	0	N/A
SCC	Humpback 3	22Feb 16:32	22 Feb 17:08	9.2	N/A	0	N/A
SCC	Humpback 4	22Feb 17:19	22Feb 17:37	5.3	N/A	0	N/A
SCC	Humpback 5	22Feb 19:20	22Feb 20:52	21.9	30.7	11	162.8
SCC	**Humpback 6**	22Feb 21:02	22Feb 23:31	6.8	10.2	6	163.7
SCC	Minke 2	22Feb 15:13	22Feb 17:45	30.4	N/A	0	N/A
SCC	Minke 3	22Feb 21:15	23Feb 02:27	14.1	15.8	13	164
SCC	**Minke 4**	23Feb 17:15	24Feb 03:22	0.9	7.4	33	173.2
SCC	Minke 5	24Feb 15:33	24Feb 16:44	8.7	N/A	0	N/A



- Arrows point to the starting location of each respective track. Red dots indicate when whale tracks were exposed to sonar. The dashed box outlines the area used for tracking localized whale calls (same as the green box in Figure 1) and "h" symbols indicate the approximate locations of the 36 broadband hydrophones with the frequency response necessary to detect baleen whale calls.

Figure 23. Four whale tracks analyzed for exposures in February 2022.

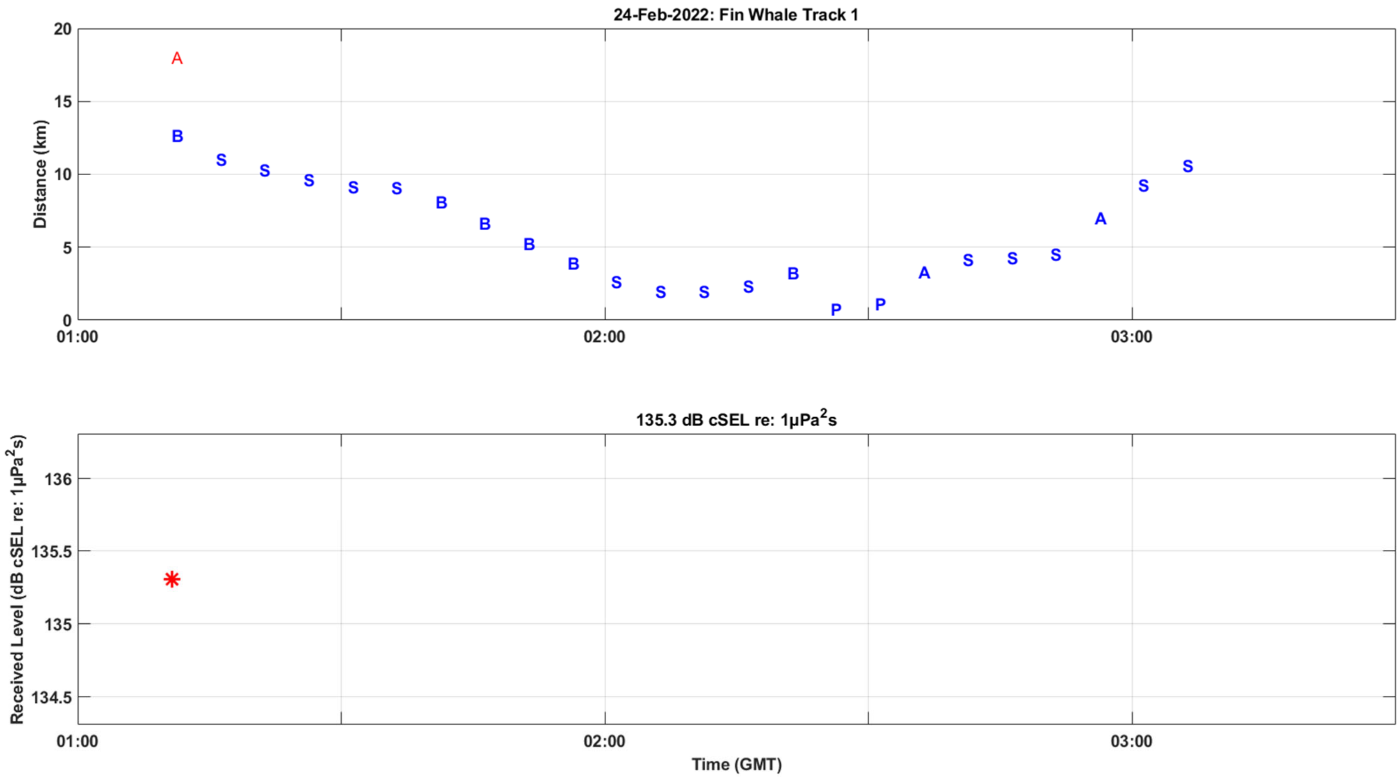
Minke whale track 1 was present for approximately 6 hours before it was exposed to MFAS transmissions during the February 2022 ULT starting at 15 Feb 23:15. Exposures for this track were captured for 16 minutes before it left the study area and was no longer tracked (Figure 23). During this time minke track 1 was primarily off the bow sector of the closest ship transmitting MFAS which closed from 47.7 to 41.6 km and received a cumulative sound exposure level of 163.5 dB cSEL re: 1μPa^{2}s (Figure 24). It is difficult to discern an apparent behavioral response during the time of exposure since there was no distinct change in ICI. Although the whale was already traveling NW prior to the exposure, its heading appears to be slightly more directed north during the exposure (Figure 23).



- Text symbols in the upper plot indicates the angle off the bow of the whale in 5-minute bins and 90-degree sectors for the closest ship not transmitting MFAS (blue letters) and the closest ship transmitting MFAS (red letters). 0°=Bow (B), +90°=Starboard (S), -90°=Port (P), +/-180°=Aft (A).

Figure 24. Exposure details for minke whale track 1 during the February 2022 ULT

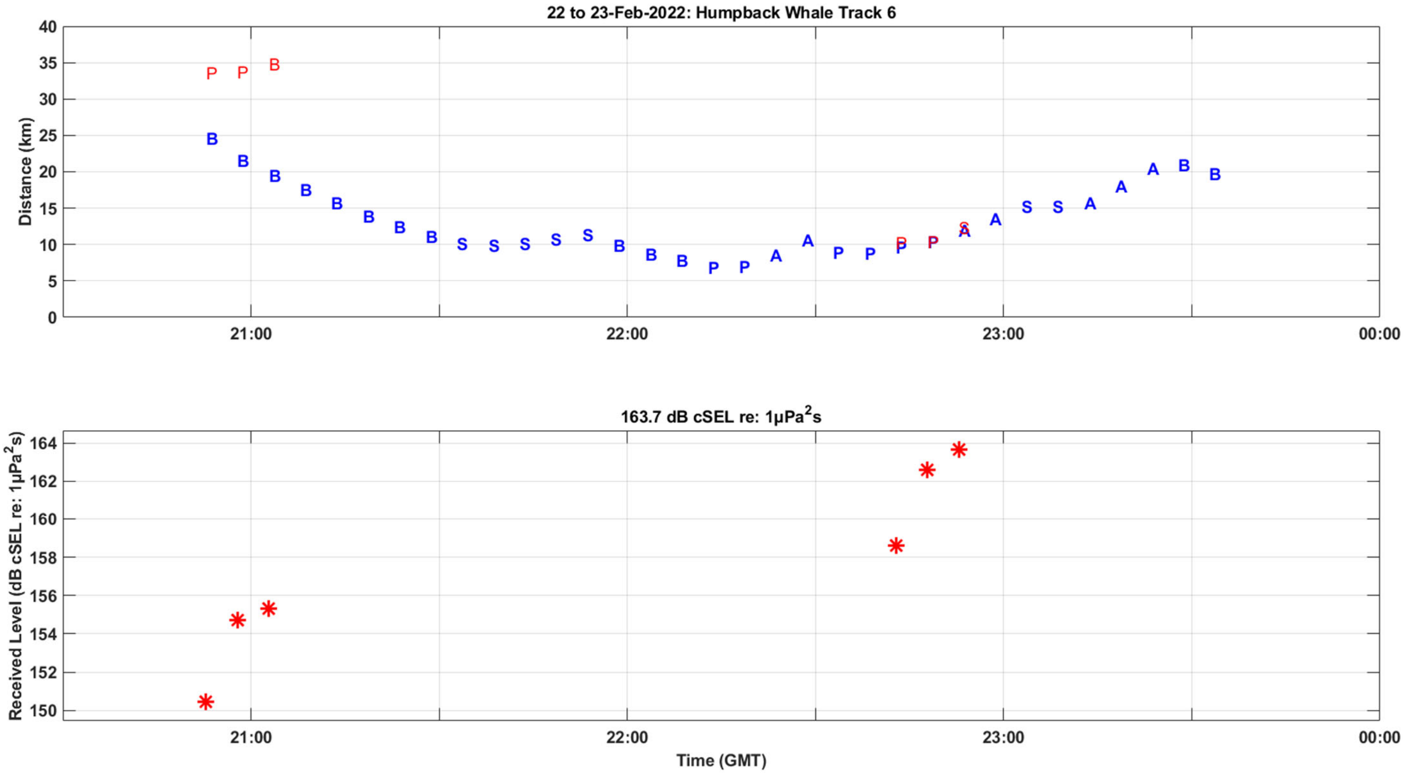
At the start of fin whale track 1, ships both transmitting MFAS and not transmitting MFAS were present (Figure 25). Exposure to MFAS only occurred in the first 5-minute bin in which the whale was 18 km off the aft sector of the closest ship transmitting MFAS and received a sound exposure level of 135.3 dB SEL re: 1µPa²s (Figure 25). Initially, the whale was 12.6 km away from the closest ship not transmitting MFAS and off the bow sector, which closed to a CPA of 726 m off the port sector, then opened to 10.7 km off the starboard sector. Despite a relatively close approach of a ship not transmitting MFAS, there appears to be no discernable behavioral response. Overall, this track only moved a cumulative distance of 3.3 km and emitted 17 calls. The heading was primarily to the NW (Figure 23) and the track had a highly variable call interval with no relation to the close approach (range: 15.4 to 1,869.5 s, mean: 383.3 s, standard deviation: 553.5 s).



- Text symbols in the upper plot indicates the angle off the bow of the whale in 5-minute bins and 90-degree sectors for the closest ship not transmitting MFAS (blue letters) and the closest ship transmitting MFAS (red letters). 0°=Bow (B), +90°=Starboard (S), -90°=Port (P), +/-180°=Aft (A).

Figure 25. Exposure details for fin whale track 1 during the February 2022 SCC.

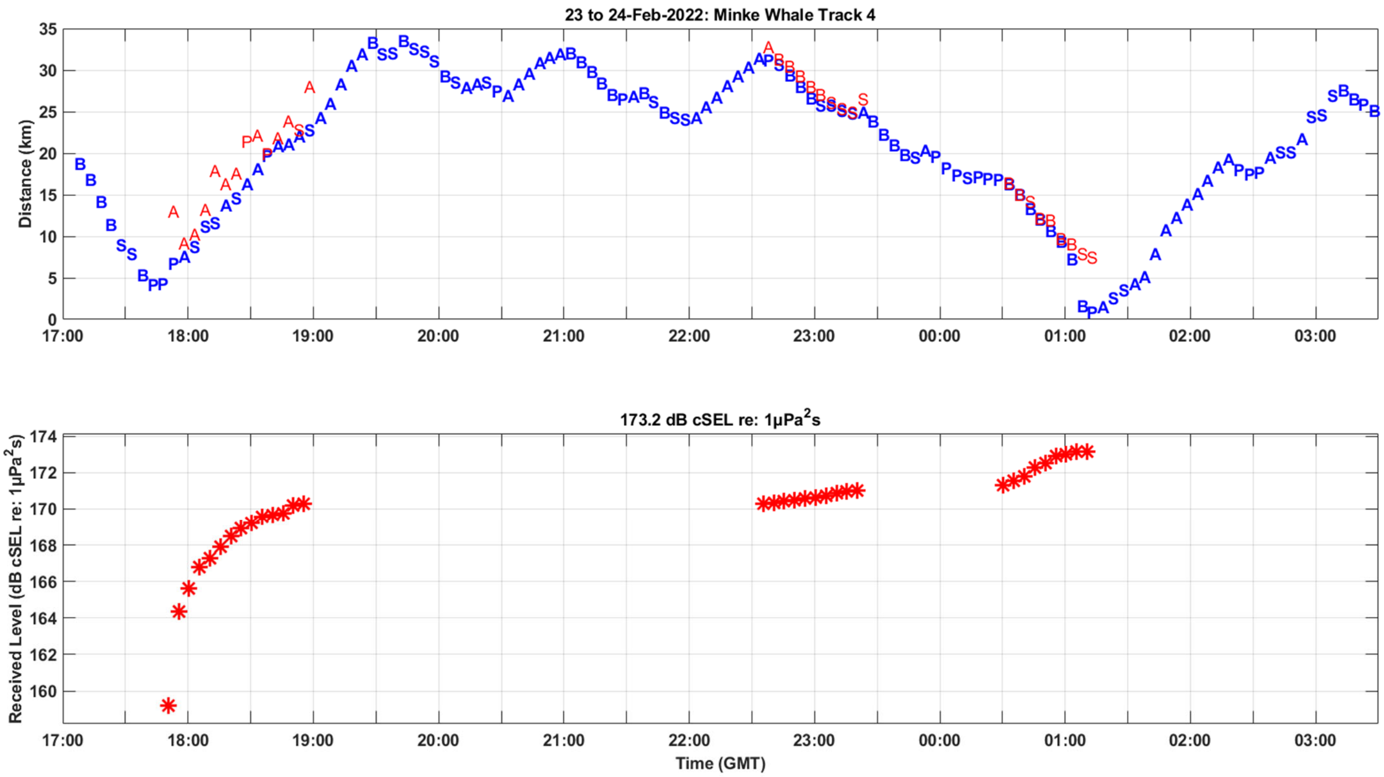
Humpback whale track 6 began when ships both transmitting MFAS and not transmitting MFAS were present (Figure 26). The whale was initially off the bow sector and 24.6 km away from the closest ship not transmitting MFAS, and off the port sector and 33.5 km away from the closest ship transmitting MFS. The first three 5-minute bins had MFAS exposures, with a cumulative sound exposure level of 155.3 dB cSEL re: 1µPa²s. This was followed by a pause in MFAS exposures for approximately 2.5 hours while the ships participating in the SCC repositioned between events. During this time the track had a CPA of 6.8 km off the port sector of the closest ship not transmitting MFAS. At the onset of the second bout of sonar in the bin starting at 22:42, the whale was off the port sector and 10.2 km away from the closest ship transmitting MFAS, and off the port sector and 9.7 km away from the closest ship not transmitting MFAS. After the last bout of MFAS exposure, the whale had a cumulative sound exposure level of 163.7 dB cSEL re: 1µPa²s and no apparent change in ICI. Shortly after the exposure there was a heading change to the south for approximately 5 min before the whale resumed heading SE (Figure 23). Although this heading change is apparent in Figure 23, the potential significance is uncertain since it is very slight and short duration. Overall, while this whale was tracked within the study area, its movement was highly directed to the SE (Figure 23) with a consistent ICI (median 2.7 s).



- Text symbols in the upper plot indicates the angle off the bow of the whale in 5-minute bins and 90-degree sectors for the closest ship not transmitting MFAS (blue letters) and the closest ship transmitting MFAS (red letters). 0°=Bow (B), +90°=Starboard (S), -90°=Port (P), +/-180°=Aft (A).

Figure 26. Exposure details for humpback whale track 6 during the February 2022 SCC.

Minke whale track 4 began with the presence of ships not transmitting MFAS closing from 18.7 km off the bow sector to 4.1 km off the port sector (mean ICI=373.13 s, n=6 calls) (Figure 27). Shortly after, the closest ship not transmitting MFAS began to open in range and the first bout of MFAS exposure occurred. At the CPA, the whale was 9.1 km off the aft sector of the closest ship transmitting MFAS and received a cumulative sound exposure level of 170.3 dB cSEL re: 1μPa^{2}s. There was a heading change from SE to NE during the initial exposures and an increase in ICI (mean=930.4 s, n=5 calls). At 20:00, the whale made an abrupt heading change to the N. For 5 h and 31 min, minke whale track 4 overlapped with ship presence only, which repeatedly opened and closed ranging from 24.1 km off the starboard sector to 33.5 km off the bow sector. While calling at the nominal rate (mean=403.58 s, n=31 calls), the whale traveled N, made an abrupt heading change to the E, and then traveled primarily with a NE heading. During the second bout of MFAS exposure the closest ship transmitting MFAS was off the starboard sector and 24.9 km away. The calling rate was still within the nominal rate (mean=498.4 s, n=7 calls), however, the whale appeared to make multiple heading changes from N to E then W. This was followed by approximately 53 min of the whale traveling SE to N then NE at the nominal call rate (mean=453.7 s, n=10 calls) while ships not transmitting sonar closed to a CPA of 16.8 km off the port sector. At the onset of MFAS exposure, the closest ship transmitting sonar closed to the minimum CPA of 7.4 km off the starboard sector and the whale received a cumulative sound exposure level of 173.2 dB cSEL re: 1μPa^{2}s. This relatively high cSEL was due to cumulating the SEL over the entire track duration; since this track was of a longer duration and had three bouts of MFAS the cumulated SEL ended up being fairly high. In addition, the closest ship not transmitting sonar closed to a CPA of 890 m. The whale only emitted three calls during the third bout of MFAS and had increased ICIs (1,410.34 and 1,744.2 s) and distance between calls with the whale doubling back and traveling to the NE. For the remainder of the whale track there was only overlap with ship presence. As the closest ship opened in range the whale adjusted its heading from NE to NW, then back to NE. Over the duration of minke whale track 4, there were multiple apparent behavioral responses to MFAS and ship presence including changes in heading and call rate.



- Text symbols in the upper plot indicates the angle off the bow of the whale in 5-minute bins and 90-degree sectors for the closest ship not transmitting MFAS (blue letters) and the closest ship transmitting MFAS (red letters). 0°=Bow (B), +90°=Starboard (S), -90°=Port (P), +/-180°=Aft (A).

Figure 27. Exposure details for minke whale track 4 during the February 2022 SCC.

3.3.2 Beaked Whales February and August 2022

In FY22, exposure data were collected during a ULT in February prior to the SCC and during a SUBEX prior to the August SCC, as well as during the regular February and August SCCs. The number of Blainville's, Cuvier's, and BWC beaked whale GVPs/hr of effort during training events (i.e. ULT [includes surface ship(s) with hull-mounted MFAS], SUBEX [does not include surface ship hull-mounted MFAS], Phase A [does not include surface ship hull-mounted MFAS] and Phase B [includes surface ship(s) with hull-mounted MFAS]), as well as during the non-training phases of Before, Between the phases, and Post-SCC, are shown in Table 13 through Table 15. A simple timeline has been included to help clarify the different periods (Figure 28).

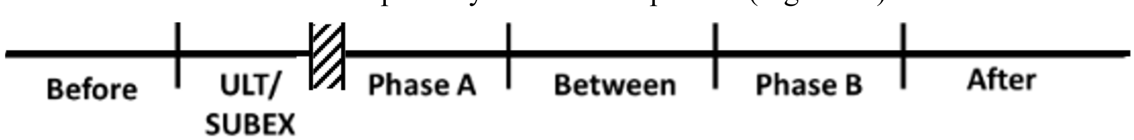


Figure 28. Simplified timeline of February 2022 (includes ULT) and August 2022 (includes SUBEX) training events (not scaled to actual durations). Note there is a gap in time between the ULT/SUBEX and Phase A.

As in previous years, two of the SCC datasets were manually validated for Blainville's beaked whales to provide a metric against which to calibrate the rest of the automatically classified GVPs. During training the true positive for Blainville's beaked whales was 81% and the false positive rate was 19%, which was a decrease in performance compared to rates during baseline periods (Section 3.2.5). The mean GVP per hour rate for Blainville's beaked whales in February before the SCC was 2.74, while the rates during the SCC dropped to 1.29 during Phase A and 0.94 during Phase B. In fact, the GVP rate had already dropped to 1.97 during the preceding ULT and did not change in the Between phase when no MFAS use occurs and GVPs typically start to increase. This SCC had a high number of active sources, which may have contributed to the fact that the GVPs remained low throughout the ten-day period. However, GVP rates returned to normal levels relatively quickly; while the immediate post-SCC GVP per hour rate was 2.00, the rate in the week after increased to 2.18, and for the duration of March was 2.54.

The mean GVP rate in the Before phase in August was 4.32, which decreased to 1.30 GVPs/hr during the SUBEX prior to the SCC. The August 2022 SCC was organized in a different manner than typical SCCs at PMRF; the activities of Phase A and Phase B were intermingled rather than occurring one at a time. The GVP per hour decreased to 0.95 during the first part of the August SCC which contained most of the training event, increased in the Between phase, decreased to its lowest level of 0.60 during the second part of the SCC, then increased to 1.42 in the immediate Post-SCC phase. The week after in this case runs into September, for which data is not yet available for this analysis.

Table 13. Blainville's beaked whale dives and hours of effort around periods of training in February and August (times in GMT).

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Feb Before	2/4 20:34	2/12 20:22	180.8	495	2.74
Feb ULT	2/14 20:16	2/16 ~1:00	28.7	57	1.97
Feb Phase A	2/17 5:10	2/19 6:19	49.1	63	1.29
Feb Between	2/19 6:30	2/22 16:55	82.3	107	1.29
Feb Phase B	2/22 16:55	2/25 5:36	60.6	57	0.94
Feb Post-SCC	2/25 5:37	2/27 23:58	66.4	132	2.00
Aug Before	8/4 1:17	8/16 12:29	291.6	1260	4.32
Aug SUBEX	8/16 16:01	8/17 2:00	10.0	13	1.30
Aug SCC A/B	8/17 16:30	8/21 9:31	89.0	84	0.95

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Aug Between	8/21 9:32	8/24 20:29	73.3	98	1.34
Aug SCC B/A	8/24 20:30	8/25 1:53	5.4	3	0.60
Aug Post-SCC	8/25 1:54	8/28 8:54	79.0	112	1.42

As with the baseline data, Cuvier's beaked whale dives during the SCC were fully validated. The false positive rate for Cuvier's beaked whales was much higher during the SCC (73.5%) than during the baseline periods (19.0%). During the February SCC, the false positive rate was 70.3% while the rate of confirmed Cuvier's beaked whale GVPs seemed to increase from 0.01 GVPs/hr during baseline data in February before the SCC to an average of 0.04 GVPs/hr during the SCC (Table 14). In contrast, during the August SCC the false positive rate was 81.2% and the GVP rate was 0, compared to a relatively high rate of 0.35 GVPs/hr during baseline data before the SCC (

Table 9). This higher false positive rate is likely due to the presence of other sources of sounds during the SCCs.

Within each SCC, Cuvier's beaked whale GVP patterns were inconsistent with respect to anthropogenic activity. During the February SCC, there were no Cuvier's beaked whales detected during the ULT, but at least one group detected throughout every phase of the SCC (Table 14), and overall Cuvier's beaked whale presence was higher than baseline periods in early February and comparable to GVP rates in March (0.04 GVPs/hr,

Table 9). In contrast, in August, during the SUBEX, Cuvier's beaked whale presence was relatively high compared to year-round GVP rates including baseline data collected earlier in August (0.22 GVPs/hr,

Table 9). However, after the SUBEX, there were no Cuvier's beaked whale GVPs detected during the entire SCC, the Between Phase, and the Post-SCC Phase.

Table 14. Cuvier's beaked whale dives and hours of effort during baseline and exposure conditions during FY22 SCCs (times in GMT).

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Feb Before	2/4 20:34	2/12 20:22	180.8	2	0.01
Feb ULT	2/14 20:16	2/16 ~1:00	28.7	0	0
Feb Phase A	2/17 5:10	2/19 6:19	49.1	3	0.06
Feb Between	2/19 6:30	2/22 16:55	82.3	2	0.02
Feb Phase B	2/22 16:55	2/25 5:36	60.6	1	0.02

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Feb Post-SCC	2/25 5:37	2/27 23:58	66.4	4	0.06
Aug Before	8/4 1:17	8/16 12:29	291.6	102	0.35
Aug SUBEX	8/16 16:01	8/17 2:00	10.0	3	0.30
Aug SCC A/B	8/17 16:30	8/21 9:31	89.0	0	0
Aug Between	8/21 9:32	8/24 20:29	73.3	0	0
Aug SCC B/A	8/24 20:30	8/25 1:53	5.4	0	0
Aug Post-SCC	8/25 1:54	8/28 8:54	79.0	0	0

BWC beaked whale GVPs in Table 15 were fully validated. The FY22 SCC GVPs had very high false positive rates, ranging from 45% to 89% (mean 70%), with true positive rates ranging from 22% to 44% (mean 27%). Like the baseline data, the overall GVP rate was an order of magnitude less for BWC beaked whales than for Blainville's beaked whales.

The dive behavior of BWC beaked whales differed during the two FY22 SCCs but was unusual relative to what seems to be typical beaked whale behavior in both cases. The GVP per hour rate in February prior to the SCC was 0.09 but dropped to zero during the ULT and remained low during Phase A and into the Between period (0.04 and 0.05 GVP per hour, respectively). Then the GVP rate increased to 0.21 during Phase B, which is in strong contrast to the dive behavior during the previous FY21 August SCC when the lowest GVP rate was during Phase B (Martin et al., 2022a).

The August GVP rates were high during the first part of the SCC at 0.21, which intermingled Phases A and B of the SCC. This is particularly interesting given the GVP rate before the SCC was 0.12 and there were no GVPs during the SUBEX. In the Between phase the GVP rate decreased to 0.10, further decreased in the second active phase of the SCC, then increased to 0.20 in the Post-SCC phase. In comparison, Phase A of the August 2021 SCC also had the highest rate out of all phases during the August 2021 SCC with 0.40 GVPs/hr; and a similar trend with rates decreasing from the Between phase (0.38) to Phase B (0.02), followed by an increase in the Post-SCC phase to 0.10 (Martin et al., 2022a).

Table 15. Cross Seamount beaked whale dives and hours of effort during baseline and exposure conditions during FY22 SCCs (times in GMT).

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Feb Before	2/4 20:34	2/12 20:22	180.8	17	0.09
Feb ULT	2/14 20:16	2/16 ~1:00	28.7	0	0

Phase	Start Date	End Date	Duration (Hrs)	GVPs	GVPs/Hr
Feb Phase A	2/17 5:10	2/19 6:19	49.1	2	0.04
Feb Between	2/19 6:30	2/22 16:55	82.3	4	0.05
Feb Phase B	2/22 16:55	2/25 5:36	60.6	13	0.21
Feb Post-SCC	2/25 5:37	2/27 23:58	66.4	4	0.06
Aug Before	8/4 1:17	8/16 12:29	291.6	34	0.12
Aug SUBEX	8/16 16:01	8/17 2:00	10.0	0	0
Aug SCC A/B	8/17 16:30	8/21 9:31	89.0	19	0.21
Aug Between	8/21 9:32	8/24 20:29	73.3	7	0.10
Aug SCC B/A	8/24 20:30	8/25 1:53	5.4	0	0
Aug Post-SCC	8/25 1:54	8/28 8:54	79.0	16	0.20

3.3.3 Dipping Sonar and Sonobuoy Behavioral Response Analysis

The results of the 3 hour and 40 minute test case of data that was analyzed for MFAS detection, localization and tracking are limited in what can be shared in an unclassified venue. Ground truth efforts identified over 30 helicopter dipping MFAS transmissions and over 3 times as many active sonobuoy MFAS transmissions in the test case data. Table 16 provides results for the probabilities of correct detection, localization, and tracking (P_{dlt}) as well as false positives (P_{fp}) for individual MFAS transmissions from sonobuoy and helicopter dipping sonar for the test case data. The total number of MFAS tracks generated for the test case data was on the order of two dozen tracks, which includes surface ship hull mounted MFAS transmissions. As given in Table 16, the performance of the sonobuoy tracking analysis is quite high with a proportion of 0.94 of the sonobuoy MFAS transmissions being detected, localized and tracked. The performance of the tracking analysis for all helicopter dipping MFAS transmissions was lower than for the sonobuoy analysis, however all four sonar 'dips' were properly identified although some pings in each dip were missed for a variety of reasons. No false positive MFAS tracks occurred in the test case data.

Table 16. Results of the MFAS test case for 3 hours and 40 minutes of data on 17 February 2017.

MFAS source	P_{dlt}	P_{fp}
Sonobuoy	0.94	0.0
Helicopter	0.76	0.0

Application of the MFAS tracking methods was also performed for additional SCC data sets in February 2014 and 2015 and are briefly summarized, given the current lack of ground truth for those datasets and security concerns. The amount of data processed included over 57 hours from February 2014, over 120 hours from February 2015, and over 55 hours of data from February 2017 (including the test case data). The number of MFAS tracks generated were 175 for February 2014, 196 for February 2015, and 132 for February 2017. While the number of MFAS tracks is high, the majority are for surface ship hull mounted MFAS due to segmentation. Some of tracks with segmentation result from ship MFAS activity and some result from the sonar detector picking up different components of the MFAS signals. The sonobuoy and helicopter MFAS tracks appear reasonable based upon the track durations, frequencies, and number of MFAS transmissions. Additional work is planned to extend the analysis to other periods of time given this analysis was limited to only February data.

4. CONCURRENT AND RELATED EFFORTS

4.1 LMR BREVE TRANSITION

The ONR-funded project BREVE was a collaboration between the National Marine Mammal Foundation (NMMF), NIWC Pacific and researchers from University of St Andrews to develop statistical methods to test for changes in behavior relative to U.S. Navy training activity involving MFAS operations at PMRF. The methods to analyze BRS and CEE data were applied to opportunistic PAM BRS data from PMRF. However, detailed data involving MFAS training at PMRF cannot be openly shared and are limited in multiple ways, such as reporting only the presence or absence of the closest ship emitting MFAS for each 5-min bin, providing only relative ship/whale geometry angular data with +/- 45 degrees uncertainty, and providing only the presence or absence of MFAS in each bin along with the cumulative SEL. Using three years of data, a limited number of acoustically tracked minke whales were documented to have horizontal avoidance responses to MFAS exposures as well as increase their travel speed and directionality (Harris et al., 2020; Durbach et al., 2021). The ONR BREVE code developed to conduct the final analysis was transitioned to the WARP laboratory and so far, the results from BREVE have been duplicated (Martin et al., 2022a).

Under LMR funding, WARP is in the process of transitioning the methods employed during the ONR effort into the classified environment, where all pieces of information can be used at their full resolutions (e.g., ship tracks and headings, sonar pings, distances to whales, etc.). This requires modification of the transitioned code to accommodate additional information. Also, as adequate information on other sonar sources (localizations and probability of localizations) becomes available those sources can be integrated into the analysis. Tracks of additional species (e.g., fin whales, humpback whales, Bryde's whales) could also be processed with the improved exposure / response analysis to be developed in this effort. This type of effort supports the LMR goal of improving Fleet-funded analyses of marine mammals' behavioral responses to MFAS.

4.2 LMR BRYDE'S WHALE CUE RATES AND KINEMATICS

This project leverages the methods developed in the last two years used to calculate the along-track cue rates and movement kinematics for fin whales (Helble et al., 2020, Guazzo et al 2021) and minke whales (Martin et al., 2022b; Helble et al., in press.) under the ONR E-BREVE effort (see below). Both fin whales and minke whales were found to have changes in swim kinematics and cue rates based on changes in environmental variables and interactions with conspecifics.

Part of this effort is planned to calculate the along-track cue rates of vocalizing Bryde's whales (*Balaenoptera edeni*) and their track kinematics at PMRF. Datasets that span a decade are intended to be used to investigate the vocalizations and cue rates of Bryde's whales and compare the cue rates over time and kinematic behavioral state. Calls for these species have already been identified in the dataset, although the manual validation effort still needs to be conducted. These results will be assessed to determine if and how cue rates can be applied to density estimation. The results from this effort can also be compared to published cue rates to assess stability over time, location, or population. The track kinematics can be examined against environmental variables such as time of year, season, wind, and wave data, and against other situational data (such as distance to the nearest calling conspecific). Throughout this effort, the data will also be examined for additional Bryde's whale call types, such as the newly discovered "biotwang" recorded in the Mariana Archipelago (unpublished, A. Allen, DCLDE 2022).

Finally, since some cue rates for these species have been calculated for other regions, the cue rates resulting from this study, and any variability associated with the temporal, spatial, environmental (e.g., wind speed, wave height, sea surface temperature and salinity, the presence of fronts, and the diel and lunar cycle), or behavioral variables, can be compared against the rates found elsewhere. This allows a direct assessment of the applicability of cue rates found in one region to animals of the same species or population in a different region. If the rates are similar, that provides confidence that these and other previously estimated cue rates can be broadly applicable. However, if the rates seem to vary across regions, behaviors, or other variables then their general applicability would be limited.

A small amount of funding was received in FY22 to launch this project, with most of the work to be completed in FY23.

4.3 ONR E-BREVE MINKE WHALE KINEMATICS

The goal of E-BREVE was to quantify baseline baleen whale behavior at PMRF relative to naturally occurring sources of noise and other environmental variables. Environmental data from the Tethys database and elsewhere were utilized to model baleen whale behavior as a function of environmental variables and determine which variables might influence baleen whale behavior. Positions of conspecifics were also utilized to determine if nearby whales affect both calling behavior and swimming behavior. In addition, vocalization patterns and cue rates of the focal animal were included (funded through COMPACFLT) to assess the relationship between swimming behavior and vocalization behavior. For FY22, the focus of E-BREVE was on minke whale swimming behavior, and the results are outlined in Section 3.2.1.3 of this report. The project results were compared to those from BREVE to contextualize baleen whale responses to Navy MFAS.

4.4 TAGGING AT PMRF

Cascadia Research Collective is separately funded by COMPACFLT to tag marine mammals prior to the bi-annual SCC training events. Personnel from the NIWC Pacific WARP Laboratory supported the tagging effort in August 2022 by recording additional acoustic data and directing the tagging boat to areas where species of interest were acoustically detected. These data have been used in past analyses to estimate received levels of the tagged animals during periods of sonar use (e.g., Henderson et al., 2021). Received levels for tags deployed at PMRF in FY21 and FY22 are currently being analyzed and a separate collaborative report between WARP and Cascadia Research Collective will be produced in FY23.

4.5 SMART/LMR Large Whale Behavior in the North Atlantic

A NIWC Pacific WARP Lab member (RG) is analyzing tracks collected by M3 technicians with Marine Acoustics, Inc. (MAI) from a Navy system in the North Atlantic. This work was funded by the SMART SEED Grant in FY22 and LMR in FY23-24, leveraging previous funding to track vocalizing whales from Office of the Chief of Naval Operations (OPNAV) N974 and COMPACFLT. This work builds upon methods and code developed for BREVE, E-BREVE, and the Acoustics Cues projects and is investigating potential behavioral responses to seismic air gun surveys (Task 1) as well as North Atlantic fin whale vocalization behavior and cue rates (Task 2). Task 1 of this effort is testing whether kinematic behavior of large whales can be explained by the time of day, relative position of a seismic vessel, and air gun status (on or off). Task 2 of this effort is analyzing fin whale recordings to assess the stability of fin whale song patterns and any sudden or gradual changes in song patterns over time to compare with what was reported by Helble et al. (2020) for fin whales tracked on PMRF.

4.6 ONR ODONTOCETE TRACKING

WARP is participating in a collaborative effort with researchers at the University of Hawai’i who are developing model-based passive acoustic methods to track odontocete groups using multi-sensor arrays. WARP is contributing unclassified data from groups of sperm whales, killer whales, and other odontocetes to test these new methods. If successful, these methods can be integrated into NARWHAL and used by WARP to track odontocete groups on both future and past datasets.

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5. FY22 PUBLICATIONS

E.E. Henderson, M. Deakos and D. Engelhaupt. 2021. Dive and movement behavior of a humpback whale competitive group and a multiday association between a primary escort and female in Hawaiʻi. Marine Mammal Science, p. 1-12.

E. E. Henderson, M. Deakos, J. Aschettino, D. Englehaupt and **G.C. Alongi**. 2022. Behavior and inter-island movements of satellite-tagged humpback whales in Hawaiʻi, USA. Marine Ecology Progress Series, 685, p. 197-213.

E. E. Henderson, **T. A. Helble**, S. Jarvis and S. Watwood. 2022. Standardized Unclassified Nomenclature to Describe Navy Sonar Signals. Naval Information Warfare Center Pacific Technical Report.

E.K. Jacobson, **E.E. Henderson**, D.L. Miller, C.S. Oedekoven, D.J. Moretti and L. Thomas. 2022. Quantifying the response of Blainville's beaked whales to US naval sonar exercises in Hawaiʻi. Marine Mammal Science, 38, p. 1545-1565.

R.A. Manzano-Roth, **E.E. Henderson**, **G.C. Alongi**, **C.R. Martin**, **S.W. Martin** and **B. Matsuyama**. 2022. Dive characteristics of Cross Seamount beaked whales from long-term passive acoustic monitoring at the Pacific Missile Range Facility, Kaua’i. Marine Mammal Science, p. 1-20.

C.R. Martin, **R.A. Guazzo**, **T.A. Helble**, **G.C. Alongi**, I.N. Durbach, **S.W. Martin**, **B.M. Matsuyama**, **E.E. Henderson**. 2022. North Pacific minke whales call rapidly when calling conspecifics are nearby. Frontiers in Marine Science, 9, 897298.

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6. FY22 PRESENTATIONS

Guazzo, R.A., Durbach, I. N., **Helble, T. A., Alongi, G. C., Martin, C. M., Martin, S. W., & Henderson, E. E.** 2022. Singing fin whale swimming behavior in the central North Pacific. 24th Biennial Conference on the Biology of Marine Mammals. Palm Beach, FL. Oral Presentation.

Guazzo, R.A., Gagnon, G. J., Stevenson, D. L., Edell, M. K., Frankel, A. S., & **Helble, T. A.** 2022. Close encounters of the seismic kind: Behavioral response of large whales to a seismic survey ship. Effects of Sound on Marine Mammals. Beaufort, NC. Oral Presentation.

Guazzo, R. A., Helble, T. A., & Henderson, E. E. (2021). Environmentally-influenced behavioral response evaluations (E-BREVE). ONR Marine Mammals and Biology Program Review. Virtual. Oral Presentation

Guazzo, R. A., Stevenson, D. L., Edell, M. K., Gagnon, G. J., Frankel, A. S., **Helble, T. A.** 2022. Low-frequency sources with whale acoustic reconnaissance for mitigation (Low SWARM). SMART SEED Annual Review. Tysons, VA.

Helble, T. A., Guazzo, R. A., Alongi, G. C., Martin, C. M., Martin, S. W., & Henderson, E. E. 2022. Fin whale song patterns shift over time in the central North Pacific. 24th Biennial Conference on the Biology of Marine Mammals. Palm Beach, FL. Oral Presentation.

Helble, T. A., Dugan, P. **Henderson, E. E.,** Jarvis, S. & S. Watwood. 2022. Improving Methods for Automated Detection of Navy Sonar. The 9th International Workshop On Detection, Classification, Localization, And Density Estimation Of Marine Mammals Using Passive Acoustics. Honolulu, HI.

Helble, T. A., Martin, C. M., Guazzo, R. A., Henderson, E. E., C. R., Alongi, G. C., Martin, S. W., & I. Durbach. 2022. Slow, faster, fastest - contextualizing minke whale swimming behavior relative to the environment, conspecifics, and Navy sonar. 6th International Conference on the Effects of Noise on Aquatic Life. Berlin, Germany.

Henderson, E.E., J. Aschettino, M. Deakos, D. Engelhaupt, **G. Alongi.** 2021. Track behavior, dive behavior, and inter-island movements of satellite-tagged humpback whales in Hawai'i. 7th International Bio-logging Science Symposium. Honolulu, HI.

Henderson, E. E., J. Barlow, G. Cárdenas-Hinojosa, D. C. Lopez-Arzate, D. Breese, & E. Hildago, R. Huerta Patino, B. Pitman, and T. Pusser. 2022. Beaked Whale Expedition to Baja, Mexico,

November 2020 and 2021. Navy Marine Species Monitoring Meeting, April 2022. San Diego, CA.

Henderson, E. E. and N. DiMarzio. 2022. Ambient Noise Analyses at PMRF. Navy Marine Species Monitoring Meeting, April 2022. San Diego, CA.

Henderson, E.E., M. Deakos, D. Engelhaupt. 2022. The first record of a continuous multi-day association between a primary escort and female in Hawai'i. 24th Biennial Conference on the Biology of Marine Mammals. Ft. Lauderdale, FL.

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