FY19 Annual Report on

Pacific Missile Range Facility Marine Mammal Monitoring

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14. ABSTRACT
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3) Abundance results for odontocetes from August 21, 2018 to August 24, 2019 included Blainville's, Cross Seamount (CSM), and Cuvier's beaked whales, sperm whales, and killer whales. The number of FY19 Blainville's beaked whale dives were corrected based on FY19 sample validation and had a monthly maximum of 2.59 dives per hour (December 2018) and a maximum count of 10.53 dives that occurred in a one-hour time bin (August 2019). The number of fully validated FY19 CSM beaked whale dives had a strong diel trend at night and occurred far less frequently than Blainville's beaked whale dives, resulting in a monthly maximum of 0.18 dives per hour (October 2018) and a maximum count of two dives that occurred in a one-hour time bin (multiple times during FY19). The number of fully validated FY19 Cuvier's beaked whale dives had a slightly higher number of group foraging dives per hour than CSM beaked whales, with a monthly maximum of 0.24 dives per hour (February 2019), and a maximum count of two dives that occurred in a one-hour time bin (multiple times from November 2018 to April 2019). The number of fully validated FY19 killer whale high-frequency modulated (HFM) calling groups occurred infrequently and had a low abundance with a monthly maximum of 0.022 groups per hour (May and June 2019), and a maximum count of one killer whale HFM calling group detected in a one-hour time bin (multiple times from November 2018 to Jun 2019). Individual/group tracking of the improved sperm whale detection and localization processing was performed for the first-time on all non-decimated data between Feb 6, 2002 and Aug 24, 2019. The maximum number of automatically generated sperm whale tracks in a 10-minute snapshot during a month typically varied from zero to four whales with a maximum of eight in May 2016.

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a) Disturbance analyses were conducted for minke whales utilizing tools developed under an Office of Naval Research project titled Behavioral Response EValuation Employing robust baselines and actual United States (U.S.) Navy training (BREVE). A clear change in the spatial distribution of minke whale acoustic presence and absence related to mid-frequency active sonar (MFAS) was observed in recordings from February 2014 and January and February of 2017. Preliminary analyses also indicate that whale speeds were higher and headings were more directed during periods of MFAS compared to periods without MFAS. Periods of time after sonar retained lower probabilities of presence, suggesting the return to baseline conditions may take more than five days.

b) The spatial distribution and number of validated Blainville's beaked whale dives were analyzed before, during and after 16 SCCs. A Generalized Additive Model (GAM) of the spatial distribution of foraging dives found no change in the spatial distribution of dives during the first, non-MFAS phase of the SCC, but did find a 58% reduction in the number of foraging dives in that phase. Both a spatial change to the distribution of dives and a further reduction in the number of dives was observed during the subsequent MFAS Phase of the SCC.

c) Validated CSM beaked whale dives from February and August 2011 to 2018 exhibited a statistically significant reduction in the number of dives during SCCs compared to baseline periods. The average dive rate was 0.1 dives/hour during SCCs and 0.14 dives/hour during baseline periods. CSM detections during SCCs were on hydrophones located closer to shore and installed at depths < 1000 m, which shows a spatial redistribution compared to baseline periods, when they are found in depths up to 1,526 m.

d) For the first time, preliminary disturbance analyses were performed for three minke whale tracks and one suspected fin whale track in the presence of opportunistically recorded explosive impulse sounds. As a general observation, all three minke whales exhibited slightly increased call rates, all whales seemed to make some heading adjustments, and two whales slightly increased their swim speeds.

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a) Minke whales acoustically tracked from 2012 to 2017 increased the source levels of their boing calls during periods with increased background noise. Animal source levels were estimated by adding transmission loss estimates to

measured received levels of 42,159 individual minke whale boings. Results suggest minke whales increase their RMS source level by an average of 0.24 dB per 1 dB increase in background noise level in the 1,250 -1,600 Hz band for the full range of noise encountered from 65-90 dB, and a maximum source level increase of 0.34 dB per 1 dB increase in background noise level in the 1,250-1,600 Hz band when the noise was 82 dB.

b) A current ONR project titled Environmentally-influenced Behavioral Response EValuations (E-BREVE) has started investigating how minke and other baleen whales respond to wind-wave events by analyzing whale acoustic tracks relative to environmental data. Recent analysis of results from January 2017 supports prior findings from Martin et al., 2019a and Helble et al., 2020 that minke whales decrease calling during periods of high wind-wave events. The behavioral response of whales to naturally occurring events at PMRF is a helpful step towards contextualizing the response to U.S. Navy activity.

15. SUBJECT TERMS

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Executive Summary

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List of Acronyms

ACCM – Alternative or compensatory control measures
ARGOS – Advanced Research and Global Observation Satellite
BARSTUR – Barking Sands Tactical Underwater Range
Bcpa – behavioral change point analysis R package
BREVE – Behavioral Response EValuation Employing robust baselines and actual U.S. Navy training (ONR project)
BRS – Behavioral response study
BSURE – Barking Sands Underwater Range Expansion
COMPACFLT – Commander, Pacific Fleet
CSM – Cross Seamount
DCLTDE – Detection, classification, localization, tracking and density estimation laboratory (NIWC Pacific, San Diego, California)
DCL – Detection, classification, and localization
E-BREVE – Environmentally-influenced Behavioral Response Evaluations (ONR project)
FY – Fiscal year
GPL – Generalized Power Law
GAM – Generalized Additive Model
GEE – Generalized Estimating Equation
HFM – High-frequency modulated vocalizations attributed to killer whales
ICI – Inter-call-interval
IPI – Interpulse-interval
LIMPET – Low Impact Minimally Percutaneous Electronic Transmitter
LMR – Living Marine Resources program
M3R – Marine Mammal Monitoring on Navy Ranges
Matlab – Mathworks copyrighted scientific software environment
MFAS – Mid-frequency active sonar (1-10 kHz) (primarily surface ship sonar)
NARWHAL – The Navy Acoustic Range WHale AnaLysis (algorithm suite)
NIWC Pacific – Naval Information Warfare Center Pacific (Formerly SPAWAR Systems Center Pacific)
NL – Noise level
NUWC Newport – Naval Undersea Warfare Center, Newport, RI
ONR – Office of Naval Research
PAM – Passive acoustic monitoring
PMRF – Pacific Missile Range Facility, Kauai, HI
SCC – Submarine Command Course training event
SL – Source level
SOAR – Southern California Offshore Anti-Submarine Warfare Range
SWTR – Shallow Water Training Range
U.S. – United States

1 Introduction

In fiscal year (FY) 2019 the Naval Information Warfare Center (NIWC) Pacific Detection, Classification, Localization, Tracking, and Density Estimation (DCLTDE) Laboratory (San Diego, California) utilized passive acoustic data recordings from bottom mounted range hydrophones at the Pacific Missile Range Facility (PMRF) to monitor vocalizing marine mammals both during baseline periods and during U.S. Navy training activities. No acoustic data during the regularly monitored Submarine Command Course (SCC) training event were collected in February or August 2019 (Section 2.1), however, recorded data from past SCCs were analyzed for multiple species (Section 3.3).

The overall FY19 goals of this ongoing effort were to:

1) Collect raw acoustic data for detailed verification of automated processing results and to allow future processing with new marine mammal species detection, classification, and localization (DCL) algorithms;

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

3) Estimate sound levels that marine mammals are exposed to during U.S. Navy training with hull-mounted mid-frequency active sonar (MFAS), and investigate behavioral responses;

4) Test and evaluate concurrent data recordings collected on NIWC Pacific's legacy PC recorder, and the Marine Mammal Monitoring on Navy Ranges (M3R) packet recorder with recent improvements by NIWC Pacific and the Naval Undersea Warfare Center (NUWC) Newport. Concurrent data recordings are crucial to ensure consistent recording performance and reveal necessary modifications before NIWC Pacific transitions to recording data solely on the M3R packet recorder.

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

Overall, this report highlights multiple areas where progress was made in FY19. For the first time, tracks attributed to low-frequency baleen whale species were classified by utilizing spectral correlation call templates based on currently available scientific literature regarding Bryde's, fin, and sei whale calling (Helble et al., 2019). All available data with the frequency response necessary to detect low-frequency baleen whale calls (i.e. since January 11, 2011) were processed and results are provided in Section 3.2.3. Minke whale tracks from 2012 to 2017 were utilized to investigate the effect of environmental background noise levels during baseline data collections on minke whale source levels (a phenomenon called the Lombard effect). This effort also produced the first published source levels for minke whale boing calls (Helble et al., 2020). The minke whale bimodal call rate was characterized using minke whale tracks from 15 years of acoustic recordings, and for the first time the minke whale call rate as a function of distance to the nearest calling conspecific was investigated in detail to determine minimum distances at which minke whales call at an increased rate (Martin et al., 2019b). Preliminary disturbance analyses were performed for three minke whale tracks and one suspected fin whale track in the presence of opportunistically recorded explosive impulse sounds that were recorded at PMRF on March 10, 2017

(Alongi et al., 2019a). The Office of Naval Research (ONR) effort titled Behavioral Response EValuation Employing robust baselines and actual U.S. Navy training (BREVE) developed tools to investigate minke whale spatial distribution during SCCs using data from the February 2014 and 2017 SCCs (Harris et al., 2019). Minke whale speeds and headings derived from the behavioral change point analysis (bcpa) R package (Gurarie et al., 2009) were utilized for investigating speed and heading directivity during SCCs (Harris et al., 2019). The BREVE effort also developed tools to estimate error ellipses for each localized call to support continuous time animal movement modeling (Martin et al., 2018). These tools are being transitioned to the Commander, Pacific Fleet (COMPACFLT) supported monitoring effort as they become available.

Results for odontocetes included analyses of data collected since January 2007 that were processed to detect Cross Seamount (CSM) beaked whale clicks that were automatically sorted into group dives in which all contributing detected clicks were manually validated. Dives rates (dives/hour) during baseline periods were also analyzed relative to dive rates during February and August SCCs from 2011 to 2018, which is the first time reporting potential impacts from MFAS on CSM dives (Manzano-Roth et al., 2019).

Blainville's beaked whale dive counts and spatial distribution were investigated for 16 SCCs (February and August 2011 to 2018) to investigate Blainville's beaked whale presence before, during, and after SCCs with the distinction of analyzing presence during the first phase of the SCC that does not utilize surface ship hull mounted MFAS, and the second phase which does (Henderson et al., 2019). Advances made to the sperm whale processing previously reported in FY18 were expanded in FY19 to improve sperm whale tracking (Alongi et al., 2019b), with automatically generated sperm whale tracks since February 2002 presented for the first time in Section 3.2.8.

2 Methods

2.1 PMRF Range Data

Passive acoustic monitoring (PAM) data were recorded for 62 of the PMRF bottom mounted hydrophones (Figure 1) to support analyses of marine mammal vocalizations and MFAS transmission times and locations. An in-depth overview of historical and present hydrophone array configurations, data collection regimes, and hardware specifications (i.e. hydrophone frequency response and data recorder sampling rate) has been provided in prior reports (Martin et al., 2017, Martin et al., 2018).

In FY19, three types of acoustic recordings were obtained:

1) Standard full-bandwidth recordings at the 96 kHz native sample rate (frequency response up to approximately 45 kHz) were recorded during two separate periods of time (for a minimum of 24 hours and up to a maximum of 45 hours) a month for 62 hydrophones.
2) Decimated data recordings at the reduced sample rate of 6 kHz provide 3 kHz of bandwidth for longer duration baseline sampling of both baleen whale vocalizations and lower frequency noise conditions.
3) Select full-bandwidth data were concurrently collected using the NIWC Pacific legacy PC recorder and the M3R packet recorder developed by NIWC Pacific and NUWC Newport to

evaluate the performance of the M3R packet recorder. Full bandwidth data collected on the M3R packet recorder utilized the same 62 hydrophones, and an additional 39 high-pass hydrophones for a total of 101 channels recorded. The capability to record more channels is particularly useful for odontocete analyses, since all available 36 broadband hydrophones are already recorded for baleen, odontocete, and noise analyses.

Due to enforcement of alternative or compensatory control measures (ACCM) by PMRF personnel, classified data were not recorded during the February SCC in FY19. Personnel at the NIWC Pacific DCLTDE Laboratory have since undergone training and have been approved for handling and recording ACCM classified data and intend to collect data during FY20 SCCs. In addition, the August SCC in FY19 was moved to the Southern California Offshore Anti-Submarine Warfare Range (SOAR) range in Southern California, and due to restricted access to classified data at that range, that SCC was also not recorded.

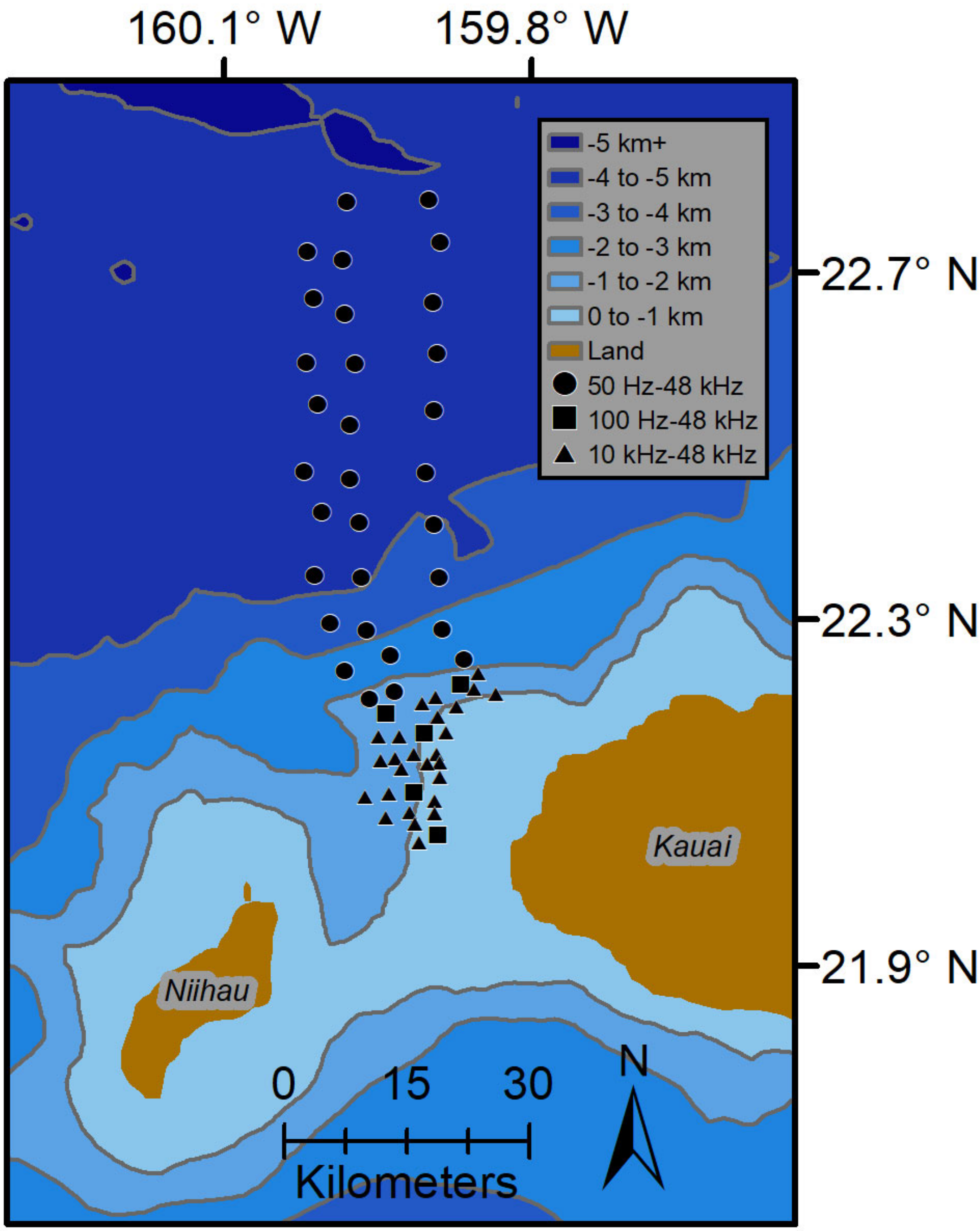

Figure 1: Hydrophone array configuration at PMRF's instrumented range. Symbols indicate the approximate location of the 62 hydrophones recorded in FY19 and their frequency response range.

2.2 Navy Acoustic Range WHale AnaLysis (NARWHAL) Algorithm Suite

2.2.1 Automated Detection, Classification, and Localization Algorithms

Multiple algorithms are utilized to process PMRF recorded data to detect a variety of marine mammal vocalizations and to localize and track when possible. A custom C++ detection algorithm automatically processes detections of beaked whales (Blainville's, CSM, and Cuvier's), killer whales, sperm whales, baleen whales (minke whales, and the low-frequency baleen group of whales [Bryde's, sei, fin, and blue whales] as a single group not identified to species), and MFAS transmissions. When post-processing recorded data, different operating points (i.e. algorithm versions and parameters) can be utilized, and the data are available for future versions of the algorithms with capabilities to process additional species. For full bandwidth data recordings, the custom C++ algorithms process data at rates approximately five times faster than real-time. A custom Matlab algorithm separately processes humpback whale song detections and localizations. Most of these algorithms have been discussed in detail in peer-reviewed journal publications and reports (Helble et al. 2012, Helble et al. 2015, Helble et al. 2016, Henderson et al. 2016, Henderson et al. 2018a, Manzano-Roth et al. 2016, Martin et al. 2015, Martin et al. 2016, Martin et al. 2017, Martin et al. 2018, Martin et al. 2019a). An effort funded by the Living Marine Resources (LMR) program developed tools to classify low-frequency baleen whale calls to species by utilizing call templates. These classification tools have now been developed and are currently being implemented for results generated by the custom Matlab algorithm. Methods exist for classifying calls attributed to Bryde's, fin, sei, and fin and/or sei.

2.2.2 Tracking for Annual and Long-Term Abundance

The existing semi-automated Matlab localization association tracker was previously described in Martin, C.R. et al. (2018), and was utilized to track automated localizations from baleen and sperm whales. Tracks of individual whales were analyzed via systematic snapshots taken every 10 minutes (Buckland et al., 2001). The logic is that at any instantaneous snapshot time, if a whale is being tracked (i.e. calls occur before and after the snapshot time) it is counted as present. This allows a census-type abundance estimate of whale counts in the study area.

The number of tracks represented by the snapshot results is a stable metric; whale tracks that occur over the PMRF hydrophone array are assumed to have: a probability of detecting a calling whale equal or very close to 1.0; a high probability of localizing all calls within a track; and improved localization accuracy as compared to tracks outside the array. As one extends the study area beyond the hydrophone array, both localization accuracy and the probability of detecting whale tracks decreases.

Substantial improvements to the sperm whale detection and localization process were previously described in last year's report (Martin et al., 2019a). This year, several adjustments and a new set of parameters specific to sperm whales were established to automatically track this species, although not all whales in a group may be tracked, and tracks could jump between individuals in a group. Challenges associated with sperm whale tracking include high call rates (which can be as rapid as 1-2 clicks/second) and social behavior not often exhibited by baleen whales (e.g. grouping that makes automatic track separation challenging).

The species that are not able to be localized and individually tracked include Blainville's, CSM, and Cuvier's beaked whales, and killer whales. The calls detected from these species occur when multiple whales are within close proximity and emitting similar calls, such as the case when beaked whales emit echolocation clicks during a group foraging dive, which is the metric used to quantify abundance for that species. Calls concurrently detected on adjacent hydrophones are attributed to the same group, and the hydrophone with the most detections is considered the approximate location of the group (see Manzano-Roth et al, 2016 for additional details).

The number of tracks and group dives can be used to estimate abundances on short-term (over the duration of a training event) to long-term (annual or decadal) scales. These abundance estimates are limited to the number of animals vocalizing, which is often related to behavioral state for baleen whales, and group activity for odontocetes. Overall, these numbers represent a minimum number of calling whales and can be converted to a minimum density of animals on the range. To extend PAM analyses to include all members of a baleen whale species requires additional information relating the proportion of calling whales (e.g. males) to all whales (i.e. females, calves, and juveniles), which is currently unknown. For some odontocete species (e.g. beaked whales) the group foraging dives can be converted to a minimum density of animals by employing an average group size.

2.2.3 Disturbance Analysis

Disturbance analysis is the process of investigating whether whale presence overlaps with and is affected by anthropogenic activities such as MFAS transmissions and close proximity of ships (even when not transmitting MFAS), thereby conducting an opportunistic, passive acoustic behavioral response study (BRS). When overlap occurs, a variety of metrics are calculated/estimated such as whale orientations (i.e. moving towards or away) and distances relative to all ships. When ships are transmitting sonar (i.e. during SCC exercises as determined by PAM analysis of MFAS localizations), complex propagation modeling calculates the cumulative SEL that an animal may have received from multiple ships over the duration it was acoustically present. Additional processes are utilized to look at baleen whale spatial distributions and their estimated speeds and headings (utilizing a behavioral change point analysis method) for documenting behavioral responses to MFAS. In addition to looking at the behavior of individual whales (e.g. minke, fin, sei, Bryde's, humpback, and potentially sperm whales) in response to ships and MFAS, we also look at the overall impact of the training events on the occurrence and abundance of vocal animal groups (e.g. Blainville's, Cuvier's, and CSM beaked whales, and killer whales) before, during, and after the training event. In addition, a preliminary analysis of tracked minke whales and a suspected fin whale to explosive events was also performed. Potential responses were gauged using call rates, headings, and swim speeds estimated using call-to-call moving averages.

2.2.4 Noise Analysis

The primary goals of conducting noise analyses on PMRF acoustic data is to better understand PAM processing results that are affected by noise levels, and to assess vocal behavioral changes relative to environmental noise levels. The noise analyses characterize noise in relevant frequency bands of interest, to look for changes in noise over a wide variety of spatial and temporal scales, and to assess any impact these changes may have on detecting and localizing marine mammal vocalizations. Ocean noise is an important parameter that is often overlooked in marine mammal acoustic analyses. It can affect the probability of detecting a marine mammal signal, and therefore can influence PAM processed results for the number of detections and localizations (and possibly the number of tracks counted). Ocean noise can also influence marine mammal behavior, and characterizing ocean noise is important for both abundance estimation and behavioral response analyses. Current noise analyses processes are conducted for the following purposes:

- Identify data dropouts or suspicious "unnatural" noise readings that could affect recording effort.
- Look for long-term trends in changes in ambient noise over the last decade.
- Understand both the natural variability in background noise and those changes contributed from anthropogenic noise sources.
- Understand our limitations on our ability to detect and localize calls in different noise environments.
- Look for biological relationships between marine mammal activity and noise.

A recently-developed noise analysis tool processes recorded data to provide spectrum-level measurements for selected hydrophones. The spectrum-level energy is also integrated over the frequency bands matching the processing bands for detection of species' calls. These integrated noise band levels include all sources of sound in the ocean (e.g. species calls, environmental noise, and anthropogenic sounds) and when integrated over all frequencies, provides a soundscape noise level.

In FY19, the Matlab noise analysis tool was also used to identify periods of time when noise levels deviated from that expected, even given natural variation. These recordings included instances where hydrophones were non-responsive or recorded self-noise and drop behavior. The Matlab noise analysis tool was then used as a template to develop a specific data integrity assessment tool in C++. This tool used all available data to establish a spectral profile for each hydrophone. This tool used all available data including 6 kHz decimated data, and 96 kHz full bandwidth data resampled to 6 kHz to establish a spectral profile for each hydrophone. This was done by first calculating a background average spectrum using 1,000 consecutive 1,024-point FFTs with 6.25% overlap every ten minutes during a recording. Second, the minimum level for each frequency bin was taken from these spectra, producing a minimum spectral profile for each recording for each hydrophone. Since hydrophone outages typically result in unusually low spectral levels, the goal was to determine minimum ocean noise levels for all frequency bins on each hydrophone. To determine a robust spectral profile for each hydrophone, these minima for every frequency bin were averaged across hundreds of recordings from multiple years to account for any long-term variations. This information was integrated into the detection algorithms described in Section 2.2.1 and could be used to detect significant deviations from the spectral profile for each hydrophone as the data were being processed for whale detections. So far, this tool has been tested and partially validated on all the decimated data.

2.2.5 Nearest Conspecific Analysis

A recently developed nearest conspecific tool determines spatio-temporal overlap between tracked localizations to investigate potential interactions between conspecifics. The nearest conspecific tool recursively examines each tracked localization relative to all localizations from other tracks. Since it is possible for multiple tracked localizations to temporally overlap within a short amount of time, the overlapping tracked localization within a +/- 10-minute time difference with the minimum distance was considered the nearest conspecific. In FY19 this tool was utilized to investigate the minke whale bimodal call rate as a function of distance between conspecifics for the first time (Martin et al., 2019b), and is discussed in Section 3.2.1.1.

3 Results and Discussion

3.1 PMRF Range Data Collection Results

The FY19 data utilized for this report spanned from August 21, 2018 to August 24, 2019. The previous annual report (Martin et al., 2019a) utilized data through August 20, 2018. The total hours of recording effort for full bandwidth and decimated data collections, and the percentage of total time recorded are shown in Table 1. Overall, full bandwidth and decimated data collections recorded 28.3% of the total time between August 21, 2018 and August 24, 2019. Seven recordings in FY19 were concurrently collected on NIWC Pacific's legacy PC recorder and the M3R packet recorder starting on March 15, 2019. As discussed in Section 2.1, the M3R packet recorder is capable of recording an additional 39 high-pass hydrophones utilized for beaked whale analyses. The concurrent data collection on March 15, 2019 was processed using the same 62 hydrophones and same NIWC NARWHAL processing algorithms and settings for comparative results and are shown in Table 2 (for minke, the low-frequency baleen whale group, and sperm whale tracks) and Table 3 (for Blainville's, Cuvier's, and CSM group foraging dives, in addition to killer whale groups).

Table 1: Total hours of recording effort for full bandwidth and decimated data collections between August 2018 and August 2019. The percentage of total time recorded is the ratio of hours of recording effort to hours of total time between the start of recording effort on August 21, 2018 and the end of recording effort on August 24, 2019.

Data type (recorder)	Hydrophones	Hours	Percentage of total time recorded
96 kHz full bandwidth (NIWC Pacific PC)	62	1,420	16%
6 kHz decimated (NIWC Pacific PC)	37	1,089.2	12.3%
96 kHz full bandwidth (M3R packet recorder)	62/101	180.7	2%

Overall, higher order results (e.g. tracks and group foraging dives) compared well between the two recorders for data analyzed to date (i.e. March 15, 2019), while the number of detections and localizations either increased or decreased between the two methods depending on the species processed. The differences in processed results for higher frequency and broadband vocalizations (e.g. beaked whale foraging clicks) may be due to the difference in the full-scale input voltage between the two recorders. The NIWC Pacific legacy PC recorder has a full-scale input Voltage of +/- 1 V_p (2 V_{p-p}) whereas the M3R packet recorder currently has a full-scale input voltage of +/- 10 V_p (20 V_{p-p}). Both recorders utilize 16 bit analog-to-digital converters which have a theoretical dynamic range of 96 dB. However, the NIWC Pacific legacy PC recorder uses sigma-delta analog-to-digital converters whereas the M3R packet recorder uses successive approximation analog-to-digital converters and both achieve different actual dynamic ranges. The end result is the dynamic range for the M3R packet recorder is shifted to higher sound pressure levels and therefore when NIWC detectors are run may miss some lower level signals, which may impact detectability of some species vocalizations and echolocation clicks using existing NIWC detection algorithms. In other words, the NIWC Pacific legacy PC recorder is ocean noise limited while the M3R packet recorder is likely limited by electrical noise based on current settings. This difference is expected to have less of an impact on the detectability of calls from baleen whales currently detected (e.g. minke whales). Personnel from NIWC Pacific and NUWC Newport will travel to PMRF in early CY20 to collect test recordings with lower full-scale input voltages for further evaluation.

In addition, emergent technical challenges have been recently identified, and NIWC Pacific and NUWC Newport are continuing collaborations to address them and to collect more concurrent recordings to fully characterize operating performance before NIWC Pacific transitions to the M3R packet recorder. It is important to resolve such technical challenges and to characterize performance and capabilities to enable the continuation of collecting high-quality recordings, which have been proven to be a valuable resource for acoustic monitoring needs.

Table 2: Comparison of processed whale track results from 16.6 hours of data concurrently recorded on NIWC Pacific's legacy PC recorder and the M3R packet recorder on March 15, 2019

	Total Detections		**Total Localizations**		**Tracked Localizations**		**Total Tracks**		**Average Track Duration (hrs)**	
	Legacy	**M3R**	**Legacy**	**M3R**	**Legacy**	**M3R**	**Legacy**	**M3R**	**Legacy**	**M3R**
Minke whale	19,103	18,826	808	788	275	276	5	5	5.9	5.9
Fin/Sei/Bryde's whale	823	836	0	0	0	0	N/A	N/A	N/A	N/A
Sperm whale	71,570	64,894	658	866	44	58	1	1	0.6	0.5

Table 3: Comparison of processed whale dive results from 16.6 hours of data concurrently recorded on NIWC Pacific's legacy PC recorder and the M3R packet recorder on March 15, 2019

	Detections		Dives/Groups		Average Dive/Group Duration (mins)	
	Legacy	M3R	Legacy	M3R	Legacy	M3R
Blainville's beaked whale	21,554	20,106	51	50	28.2	28.5
Cuvier's beaked whale	1,522	1,213	4	3	35.3	35.9
CSM beaked whale	125	135	5	5	31.7	13.4
Killer whale	4	3	0	0	N/A	N/A

3.2 Abundance and Distribution

3.2.1 Minke Whales

The maximum number of automatically-tracked, individual calling minke whales in snapshots taken every 10 minutes for each hour of the day from recordings made between August 2018 and August 2019 are shown in Figure 2 and utilized a study area focused on the hydrophone array. Minke whale seasonal presence at PMRF is captured in Figure 2, with hourly maximums from one to three individual whales starting in November 2018, and one to two individual whales present per hour in April 2019. The absolute maximum number of minke whales present in a one-hour bin from August 2018 to August 2019 occurred on December 27, 2018, when four whales were present in the 06:00 and 07:00 HST hour bins (dark red). Minke whale tracks occurred with no apparent diel pattern, as indicated in Figure 2. For reference, Martin et al. (2019a) utilized the same tracking parameters and from June 3, 2017 to August 20, 2018 there was a maximum of 5 minke whales present in a one-hour bin that occurred once in December 2017, and once in February 2018.

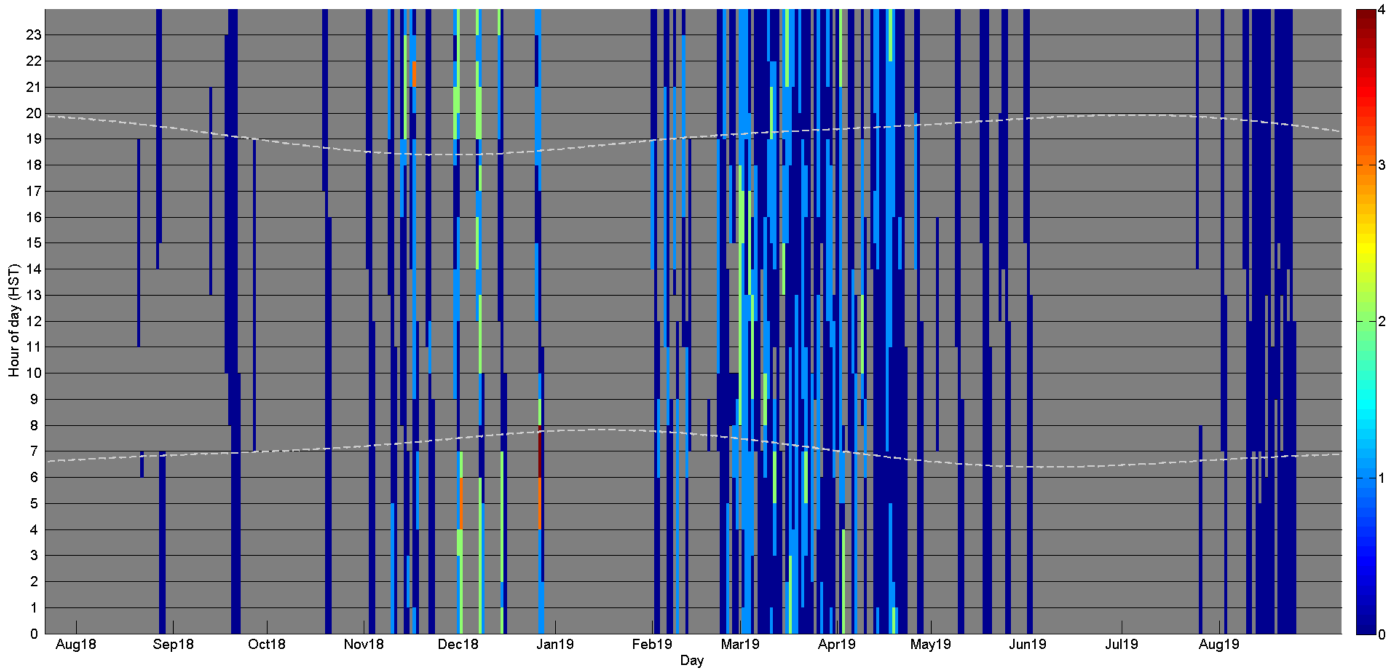

Figure 2: The maximum number of minke whales in snapshots taken every 10 minutes for each hour of the day from August 2018 to August 2019 ranged from one (light blue) to four (dark red). Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

3.2.1.1 Nearest Conspecific Analysis

In FY19, analyses were performed to characterize the bimodal call rate of acoustically tracked minke whales and investigate call rate as a function of distance between acoustically tracked conspecifics. Before the boing call was attributed to minke whales by Rankin and Barlow (2005), Thompson and Friedl (1982) collected recordings north of Oahu on a single bottom mounted hydrophone and noted varying call rates for the boing call from once every six minutes (termed "nominal") to once every 30 seconds (termed "rapid") when in contact with another boing source. Acoustically-tracked minke whales from recordings collected between 2016 and 2017 were utilized to characterize the minke whale call rate (red histogram in Figure 3). The peaks for these distributions are 27.6 seconds (SD = 3.4 seconds) and 346.6 seconds (SD = 36.9 seconds). Preliminary analysis of acoustically-tracked minke whales from recordings collected between 2002 and 2018 had peaks for the two distributions at 27.5 seconds and 345.5 seconds (blue histogram in Figure 3). The 16-year dataset was composed of more than six times as many tracks (1,829) compared to the single year dataset (288), and although the single year is a subset of the full dataset, similar peak inter-call-interval (ICI) values are maintained which highlights that the bimodal call rate is consistent over time.

The ICI for acoustically-tracked minke whales was also examined relative to the nearest acoustically tracked conspecific. This analysis was performed using a recently developed nearest conspecific tool which determines spatio-temporal overlap between tracked localizations. The data utilized for this analysis included recordings from 2016 and 2017 and had a total of 288 tracks composed of 19,662 localizations with full or partial spatio-temporal overlap with a conspecific (Figure 4). For each instance of nearest overlap the ICI and distance from the perspective of both tracks are captured and is reflected in the 39,324 points plotted in Figure 4. From the perspective of tracks at the rapid call rate of once every 30 seconds (i.e. the left cluster of points in Figure 4) the minimum distance to a conspecific is around 4-5 km and is from an interaction on October 29, 2016 (yellow points) where there was a minimum distance of 4.4 km between two rapid calling conspecifics. From the perspective of tracks at the nominal call rate of once every 6 minutes (i.e. the right cluster of points in Figure 4) there are not many points at this distance and instead the minimum distance to a conspecific is around 7-8 km and are primarily represented by blue and red points. Examination of rapid and nominal ICI distributions separately indicates that typical distances between conspecifics are > 10 km.

These data indicate that when conspecifics are more than approximately 10 km apart, there are many instances in which both overlapping tracks are likely calling at the nominal rate. When distances are lower than approximately 10 km, one or both overlapping tracks often exhibit rapid call rates. Larger separations for rapid calling animals could be due to cases where the nearest conspecific is outside the study area and therefore not included in the analysis, while the nearest conspecific within the study area is much farther away. Most of the instances of less than 10 km of separation between rapid calling whales was from one recording where the whales appeared to begin rapid calling when further apart and outside of the study area.

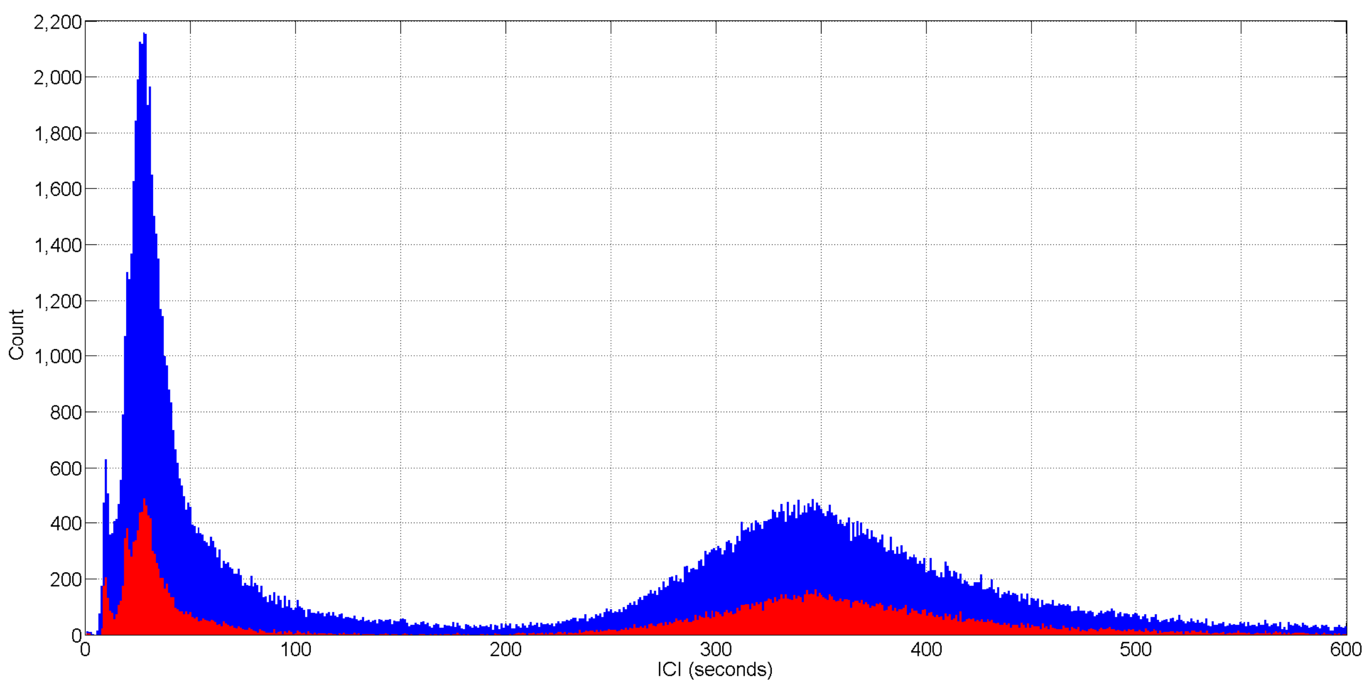

Figure 3: Call rate distributions for acoustically tracked minke whales utilizing recording for PMRF collected between 2016 and 2017 (red) with peaks for the two distributions at 27.61 seconds and 346.6 seconds. Preliminary examination of recordings collected between 2002 and 2018 (blue) have peaks for the two distributions at 27.52 seconds and 345.5 seconds.

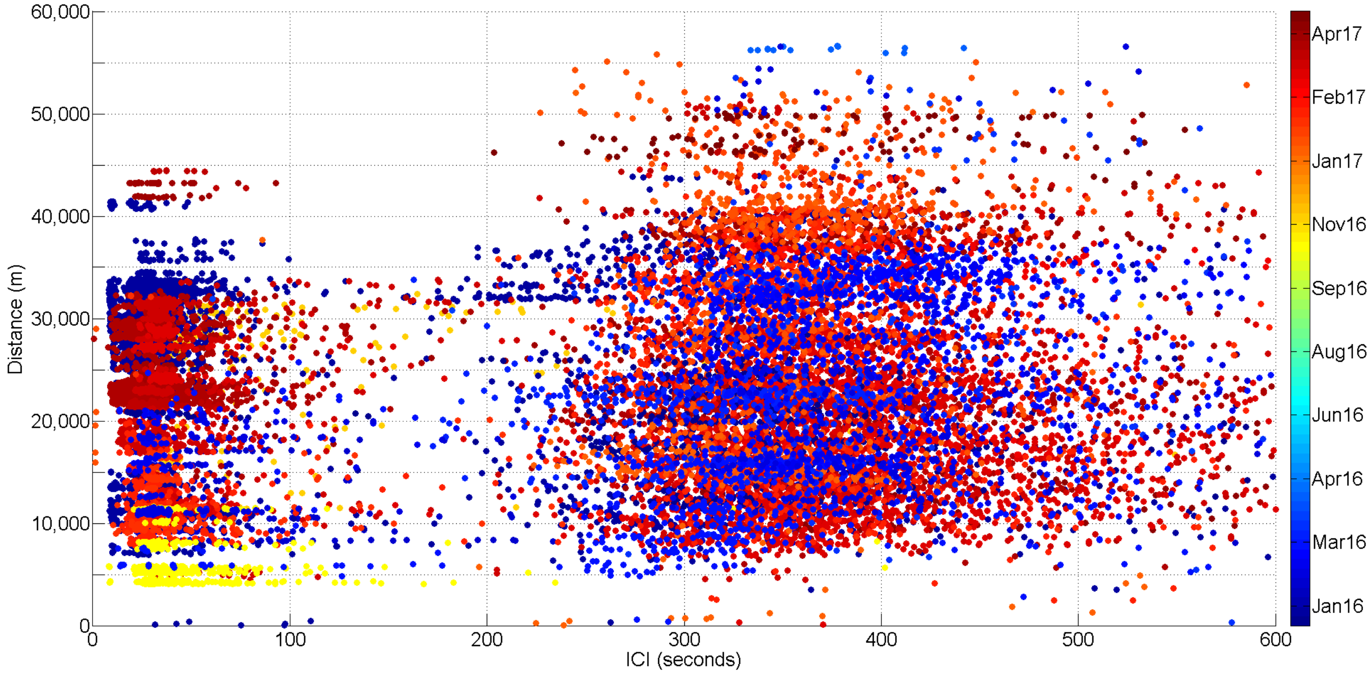

Figure 4: Tracked minke whale localizations from recordings collected between 2016 and 2017 with full or partial overlap with a conspecific (288 tracks composed of 19,662 localizations). Inter-call interval in seconds is on the x-axis and distance to the nearest conspecific in meters is on the y-axis. The color bar indicates the recording that the tracked localization is from and ranges from January 2016 (blue) to May 2017 (red).

3.2.2 Humpback Whales

Although the automated tracking algorithms were applied to all data in snapshots taken every 10 minutes for each hour of the day from recordings made between August 2018 to August 2019, humpback whale seasonal presence only occurred from November 2018 to April 2018. There was typically a maximum of one acoustic humpback track (based on song) present in a one-hour bin (Figure 5). There was a maximum of two acoustic humpback tracks present in the 10:00 and 11:00 HST hour bins on April 9, 2019. For comparison in Martin et al. (2019) humpback acoustic tracks were present from October 2017 to April 2018 with a maximum of two humpback tracks present for two consecutive one-hour bins in January 2018.

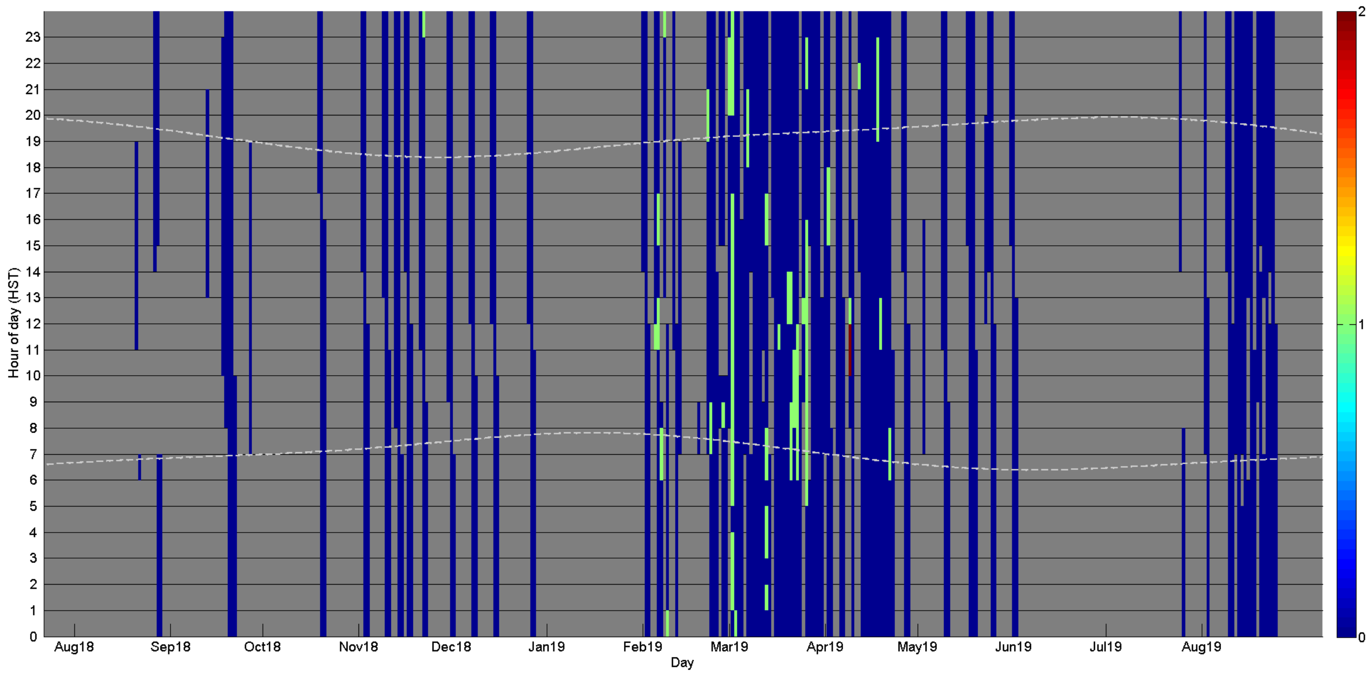

Figure 5: The maximum number of humpback whales in snapshots taken every 10 minutes for each hour of the day from August 2018 to August 2019 ranged from one (light green) to two (dark red). Dark blue regions indicate periods of effort when acoustic recordings were collected and 0 whale tracks were present. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

3.2.2.1 Humpback Whale Satellite and Pinger Tagging

Team members from NIWC Pacific and collaborators from HDR Inc. spent six days, March 21-26, 2019, tagging humpback whales off Kauai with both satellite tags and high-frequency active pinger tags. Sixty groups of humpback whales were encountered, with an estimated 118 individuals and a mean group size of two. Of those animals, 69 unique dorsal fins were distinguished via photo-identification methods, and 52 unique flukes were identified (most individuals had both dorsal fins and flukes photographed, but some had only one or the other). Dyads were the most common group composition encountered, but several mother-calf pairs or mother-calf-escort groups were also encountered, along with competitive pods and individual animals. Singers were localized using a custom-built bi-aural hydrophone array, improving our capabilities of finding and tracking singing whales.

Six Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET)-configured SPLASH10 tags enabled with FastLoc GPS (Wildlife Computers Inc.) were successfully deployed in 2019 (Figure 6). Unfortunately, two of the SPLASH10 tags seemed to malfunction, with one only providing three Advanced Research and Global Observation Satellite (ARGOS) locations northwest of Kauai (and no GPS positions) before ceasing transmissions (blue symbols), and the other providing highly inaccurate positions far to the east of Kauai for the first two days of transmission (yellow symbols) before beginning to provide locations near Kauai (whose accuracy are still uncertain given the poor initial data). Of the four tags that worked correctly for the duration of their attachment (Figure 6), one animal tagged in a dyad traveled to Niihau, past Middle Bank, and then returned to Niihau before the tag ceased transmitting (red symbols). Another animal, tagged as a secondary escort in a competitive pod, spent seven days near Niihau (orange dots). A primary escort (yellow-green symbols) and female (green symbols) were tagged in the same competitive pod as the secondary escort. These two animals remained together for at least four days after being tagged and traveled together to Oahu. The tag on the female stopped transmitting after four days, while the tag on the escort continue for an additional four days and showed the animal continue east to Penguin Bank. These tags add to the now three-year dataset of humpback whale movements near PMRF and where the animals go when they travel beyond Kauai (Henderson et al., 2018b).

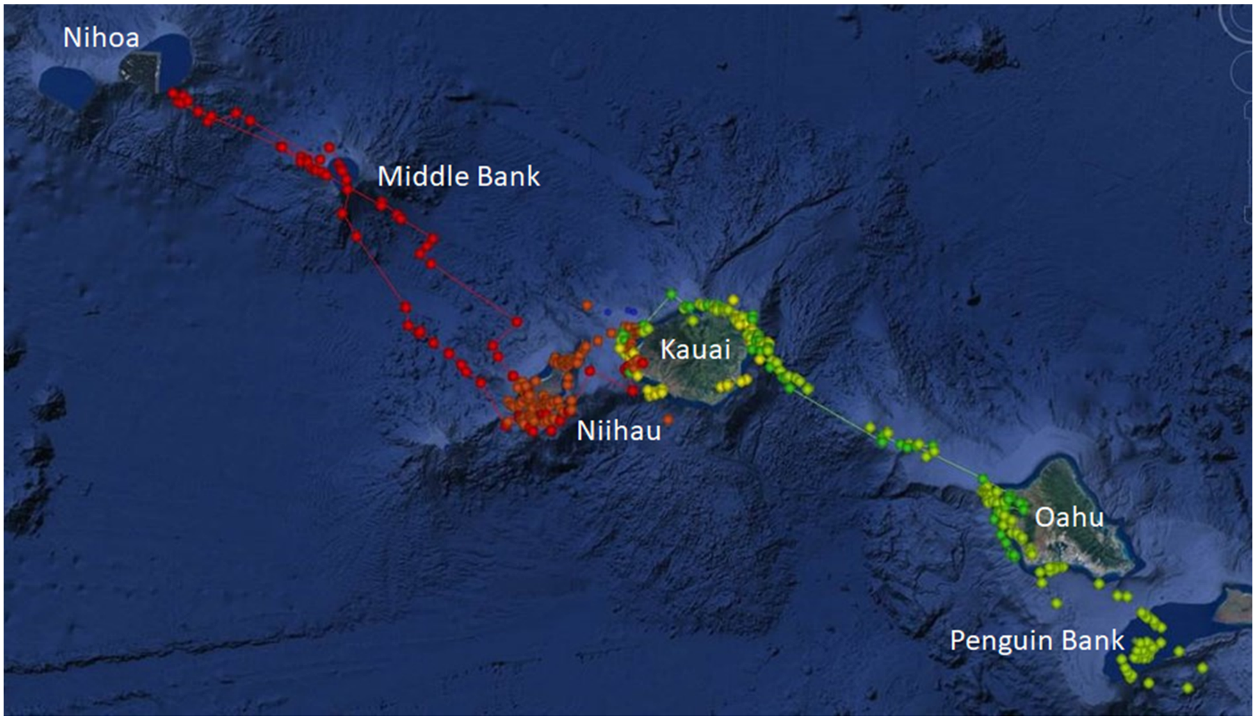

Figure 6: Positions of six humpback whales tagged in March 2019. Red track is 173790, Blue track is 179027, yellow track is 179030; orange track is 179030; yellow track is 179028; green track us 173791 (female).

Table 4: Tag deployment data for 2019

Tag ID	Time Deployed (HST)	Last Transmission (HST)	# Days transmitted	Age class	Group Information
173790	3/21/19 9:49	3/25/19 19:21	4.4	adult	Competitive pod of 6 animals
173791	3/25/19 10:13	3/30/19 5:30	4.8	adult	Competitive pod of 7 animals; female
179027	3/24/19 9:52	3/26/19 2:40	1.7	adult	Dyad (likely male)
179028	3/25/19 10:31	4/2/19 16:48	8.3	adult	Competitive pod of 7 animals; primary escort
179029	3/25/19 11:57	4/2/19 7:07	7.8	adult	Competitive pod of 7 animals; secondary escort
179030	3/25/19 11:26	3/29/19 15:35	4.2	adult	Competitive pod of 7 animals; secondary escort

Over the three years (2017-2019) that humpback whales were satellite tagged off Kauai, 15 of 19 total tagged animals continued west to Niihau, and six of those animals continued on northwest to additional islands and seamounts that make up the Hawaiian archipelago. While breeding behavior appears to have continued for these animals based on the tag-derived movement behavior, particularly at Niihau, it does appear that this westward movement may represent the beginning of the migration to Alaska. However, three whales did move east to Oahu: one female and two primary escorts. Palacios et al. (2019) found that most whales tagged off Maui also traveled generally in a northwest direction, with only one animal moving southeast. In addition, two whales tagged in Alaska entered the Hawaiian Islands near the Big Island. These combined study results seem to indicate that humpback whales generally move northwest through the main Hawaiian Islands during the breeding season, and that whales found off Kauai may be near the end of their time on the breeding grounds. However, some animals do move eastward towards the other main Hawaiian Islands instead (three from this study, one from Palacios et al. 2019, and two from Mate et al. 1998). Additional satellite tagging of humpback whales from different Hawaiian Islands would help to elucidate these large-scale movements. Of particular interest is the number of animals that cross PMRF, with the potential of exposure to Navy training activities. These results, combined with those from Henderson et al. (2018a), and Palacios et al. (2019), demonstrate that few animals spend time on the PMRF BSURE or BARSTUR hydrophones (only two animals from this study and possibly one from Palacios et al. 2019), and the few that do seem to transit the range or spend only a few hours on the range, indicating low likelihood or short durations of exposure to Navy training.

One high-frequency, 45 kHz active pinger tag was also successfully deployed on a primary escort in a competitive pod. Unfortunately, due to the aggressive activity of the animals in the group, the tag did not stay on for more than a few minutes. The animal was not near the Barking Sands Underwater Range Expansion (BSURE) or the Barking Sands Tactical Underwater Range (BARSTUR) hydrophones at the time, so we were unable to detect the tag for the brief period of attachment. While an active pinger tag would provide a mechanism to track whales if they were near the range hydrophones, and would allow us to get cue rate information, which is the number of calls produced over time, in addition to movement behavior, the results of this study demonstrate the difficulties in achieving that goal. First, getting a suction cup tag on a humpback whale off Kauai proved to be challenging due to both weather conditions and animal behavior (this proved to be more difficult than the satellite tags due to the required close proximity of the vessel to the animal). Second, of the 19 whales tagged over the three years of effort, only one of the satellite-tagged whales crossed the BSURE hydrophones when it began migrating north, and another two briefly passed over the BARSTUR hydrophones. None of the other satellite-tagged animals were located over the range (other than the nearshore Shallow Water Training Range (SWTR) portion of the range, which no longer has operational hydrophones). Therefore, the likelihood of successfully tagging a humpback whale with a pinger tag that then spent time over the recorded hydrophones is very low.

3.2.3 Low-Frequency Baleen Whales

The maximum number of automatically tracked individual calling low-frequency baleen whales (e.g. fin, sei, Bryde's, and blue) in snapshots taken every 10 minutes for each hour of the day from August 2018 to August 2019 are given in Figure 7 and utilized a study area focused on the hydrophone array. It is important to make the distinction that the track results in Figure 7 are from the C++ detection and localization algorithm described in Section 2.2.1 and the output from this process have been presented in prior annual reports. In Figure 7, the maximum number of low-frequency baleen whales present in a one-hour bin ranged from one to three whales between November 2018 and April 2019, with no apparent presence outside of this season, which would have been attributed to Bryde's whales (Martin and Matsuyama 2014, Helble et al. 2016, and Martin et al. 2019a).

The results in Sections 3.2.3.1 and 3.2.3.2 were processed using recorded data and the Generalized Power Law (GPL) detection and localization algorithms, which have previously been utilized to process humpback whale data. The low-frequency baleen whale classification Matlab tools developed under an LMR effort and described in Section 2.2.1 utilized GPL processed detection and localization results; this is the first time being included in the annual marine species monitoring report. All available data collected on hydrophones with the necessary frequency response to detect low-frequency baleen whale calls (i.e. since January 2011) were processed with the low-frequency classification tool, and using the best available scientific literature, calls were classified as fin, sei, fin and/or sei, Bryde's, and blue whales. Some calls (e.g. some from fin and sei whales) are similar between species and species classification could not be resolved without more visual and acoustic analysis. All tracks, call images, and call types are saved for future classification refinement.

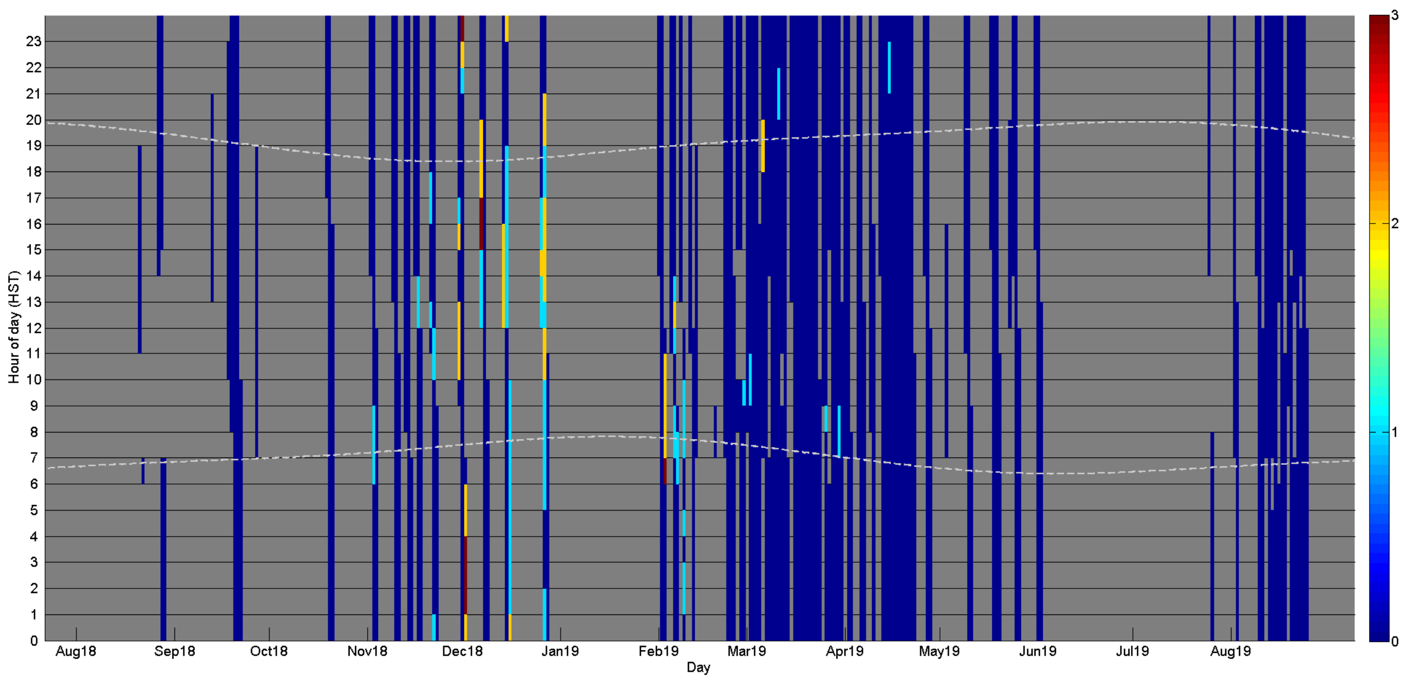

Figure 7: The maximum number of low-frequency baleen whales in snapshots taken every 10 minutes for each hour of the day from August 2018 to August 2019 ranged from one (light blue) to three (dark red). Dark blue regions indicate periods of effort when acoustic recordings were collected and 0 whale tracks were present. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

3.2.3.1 Bryde's, Fin, and Sei Whales

For the first time, all available full-bandwidth and decimated data with the necessary frequency response (i.e. data recorded on broadband hydrophones from January 11, 2011 to August 24, 2019) to detect Bryde's, fin, and sei whale calls were automatically processed, semi-automatically tracked, and automatically classified based on call templates (Table 5). Tracks were classified based on composition of varying call type percentage thresholds. Calls that could not be attributed to one of the six call types were classified as a seventh unknown call type for further investigation and potential reclassification. It is important to note that tracking is performed before classification to reduce processing time, since datasets can include an appreciable number of localizations that are not aggregated into a track. Current tracking methods utilize delta time, distance, and speed thresholds that are influenced by call rate; this preliminary effort (presented in Table 5) utilized tracking thresholds to capture species with a relatively lower call rate (e.g. Bryde's whales). Doing so artificially reduces the total number of tracks for species with higher call rates (e.g. fin and sei whales) by combining tracks that would otherwise be segmented since lower delta time, distance, and speed thresholds are used for species with higher call rates. Methods to resolve this will be further investigated and include utilizing a continuous animal movement model for tracking, or tracking localizations multiple times based on different species' call rates and resolving duplicate tracks.

Table 5: Low-frequency baleen whale track classification results from January 11, 2011 to August 24, 2019.

Call Type	Total tracks
Unknown	200
Fin A 20 Hz song	157
Fin A-B 20 Hz song	168
Fin or Sei non-song	334
Bryde's	110
Sei	138
40 Hz down sweep	11

Initial efforts to review the performance of the automated low-frequency baleen whale classifier have examined Bryde's tracks previously documented between August and October 2014 (Martin and Matsuyama, 2014; Helble et al., 2016) and in June 2018 (Martin et al., 2019a) with good agreement. The spectrograms in Figure 8 depict the 20 spectrogram templates (50 Hz to 10 Hz) that were utilized for classifying calls that comprised low-frequency baleen whale tracks. Fin whales produce song patterns that contain singlet or doublet form (Figure 8, panels 1-12). The songs have repeated interpulse-intervals (IPIs) that can vary by season, year, and region (Hatch et al., 2004, Koot et al., 2015, McDonald et al., 2006, Širović et al., 2017, Sukioka et al., 2015). Tracks containing song with a majority of calls from panels 6-8 in Figure 8 are classified as fin A 20 Hz song, and tracks containing greater than 25% of calls from panels 1-5 in Figure 8, and greater than 25% of calls from panels 6-8 in Figure 8 are classified as fin whale A-B 20 Hz song. Tracks with greater than 70% of calls from panels 16-18 in Figure 8 are classified as sei whales (Rankin and Barlow, 2007), and tracks with greater than 50% of calls from panels 13-15 in Figure 8 are classified as Bryde's whales. Tracks sometimes contained a mixture of calls that matched panels 1-12 and 16-20 in Figure 8, but with non-structured IPIs and no clear song. Because the tracks contained characteristics of both fin and sei whales, they were classified as fin/sei non-song. If more than 50% of the calls along a track did not match any of the known call types, the track was classified as unknown. Further manual analysis may help resolve some of the unknown track types and warrants further investigation. Because most acoustic recording systems cannot localize and track baleen whales in the North Pacific, the initial grouping of call types into tracks by NIWC Pacific provides a wealth of new information on low frequency call types and behaviors.

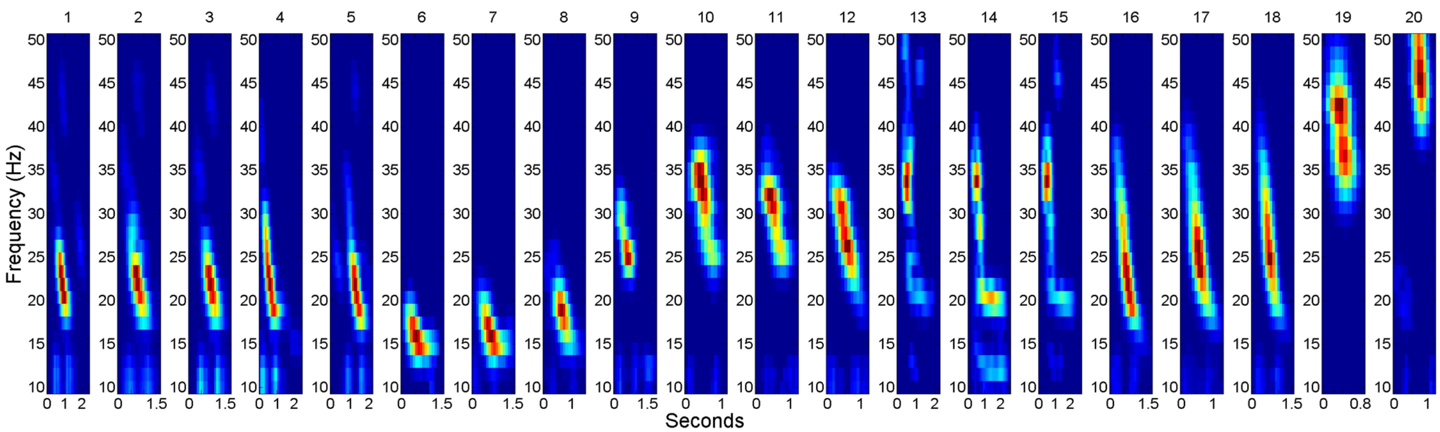

Figure 8: Spectrograms of the templates utilized for classifying low-frequency baleen whale calls. Calls traditionally attributed to fin 20 Hz type A are in panels 1 to 5, 20 Hz type B fin whale calls are in panels 6 to 8, fin and/or sei whale calls are in panels 9 to 12, Bryde's whale calls are in panels 13 to 15, candidate sei whale calls are in panels 16 to 18, and 40 Hz down sweep calls not classified to a species are in panels 19 and 20.

3.2.3.2 Blue Whales

For the first time, all full bandwidth and decimated data collections since January 11, 2011 were processed for blue whale calls using the Matlab GPL algorithms discussed in Section 2.2.1. There is a low level of occurrence of blue whale localizations at PMRF, as evidenced by automated processing results with only 23 of the 607 recordings over this period containing 20 or more localizations, and of those only one classified recording had 20 or more confirmed blue whale localizations (February 15, 2012). These localizations are not currently being tracked since the methods for localization are still being worked on. Initial manual investigation of automatically processed results found nine recordings with confirmed blue whale calls (Table 6). Localization accuracy can be affected by detecting calls far off the range due to high source levels, and from long call duration which causes calls to overlap in time and makes detecting start times difficult. Initial attempts at tracking blue whale localizations did not yield distinct or separate tracks and will be investigated more in future efforts. An example of blue whale calls that were localized and manually validated are depicted in Figure 9. The calls in the spectrogram are from a 10-minute data file collected on January 20, 2018 and displays the first 2 minutes and 25 seconds with frequency ranging from 0 to 100 Hz and the broadband hydrophone frequency response roll off evident below 15 Hz. The 40 to 20 Hz downsweep signals also depicted in Figure 9 are suspected to be from fin or sei whales.

Based on blue whale calls from Stafford et al. (2001) and Stafford et al. (2005) it is suspected that the first call in Figure 9 is a northeastern Pacific B call, and the second call is a northwestern Pacific call. It is important to note that the northeastern Pacific B call fundamental around 15 Hz appears weaker than the third harmonic at 45 Hz. This may be due to a 50 Hz high-pass filter applied to the hydrophones at PMRF which would attenuate the 15 Hz call more than the 45 Hz harmonic. Based on current literature it is unclear if the calls observed in Figure 9 are from one individual blue whale that might be switching the regional call type, or from two individual blue whales with different regional call types.

Table 6: Overview of automatically processed recordings that have been manually investigated and confirmed to contain blue whale calls

Recording	Dataset Duration (Hours)	Localizations	Localizations/hour
February 15, 2012	78	38	0.49
December 23, 2014	165.67	48	0.29
December 13, 2017	388.33	274	0.71
December 29, 2017	45.17	112	2.48
January 8, 2018	235.33	191	0.81
January 20, 2018	5	34	6.8
January 22, 2018	248.5	67	0.27
December 26, 2018	45.17	32	0.71
February 5, 2019	44.83	23	0.51

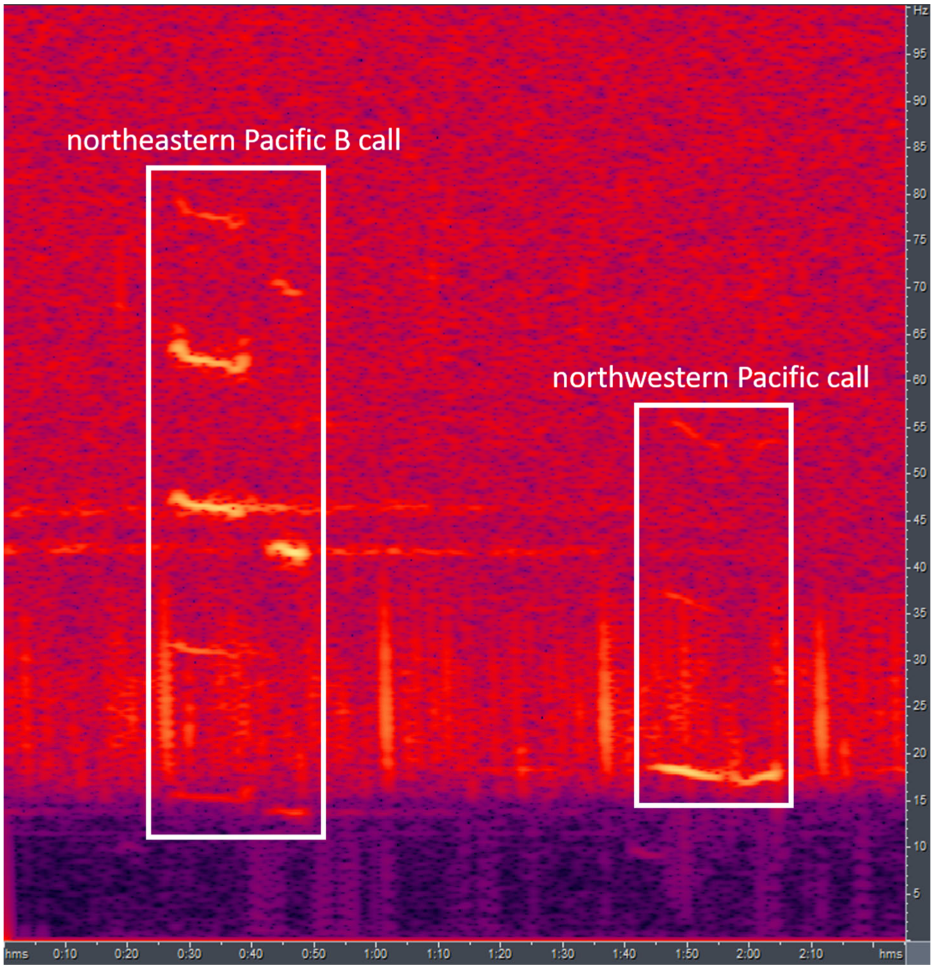

Figure 9: Recording from January 20, 2018 containing a blue whale northeastern Pacific B call and northwestern Pacific call that were automatically localized and manually validated. The x-axis ranges from zero to 2 minutes and 25 seconds and the y-axis ranges from 0-100 Hz.

3.2.4 Blainville's Beaked Whales

As has been done in previous years, four FY19 recordings with Blainville's beaked whales group foraging dives were randomly selected for manual validation. Automatically detected clicks that were automatically grouped into a dive were manually validated by systematically reviewing click spectrograms, spectra, and ICI to be Blainville's beaked whale clicks. The four FY19 manually validated recordings contained 306 validated true positive dives (90.5% true positive rate) and 32 validated false positive dives (9.5% false positive rate). This high true positive rate and low false positive rate are due to the Blainville's beaked whale detector being more refined than other relatively newer beaked whale detectors (i.e. Cuvier's and CSM beaked whales). FY19 Blainville's beaked whale results discussed in this section and summarized in Figure 10 and Table 7 were corrected by the true positive and false positive rates derived from manual sample validation.

The total number of Blainville's beaked whale dives that occurred during an hour of full bandwidth data collection was typically less than seven (Figure 10). There was a maximum of 10.53 dives (dark red) that occurred in a single one-hour bin on August 24, 2019 in the 23:00 HST hour bin. For dive data normalized by recording effort, Table 7 provides the monthly number of dives per hour of effort which ranged from 1.38 dives/hour in June 2019 to 2.62 dives/hour in August 2019. Between August 2018 and August 2019 there was an overall rate of 2.33 dives/hour. The total number of dives for all hours of effort in FY19 closely aligns with the 2.3 dives/hour reported in Martin et al. (2019a), however as a note, those dives were not corrected by FY18 sample validation true and false positive rates. Differences in dive rates are likely due to the natural variation in rates across months, seasons and years which has been reported by Henderson et al. (2016). The metric of total number of dives in a one-hour bin seen in Figure 10 is not influenced by the total duration of recording effort and provides finer temporal resolution, which can be particularly useful for analyzing presence before, during, and after training events. These results continue to demonstrate no clear seasonal or diel trends in Blainville's beaked whale abundance.

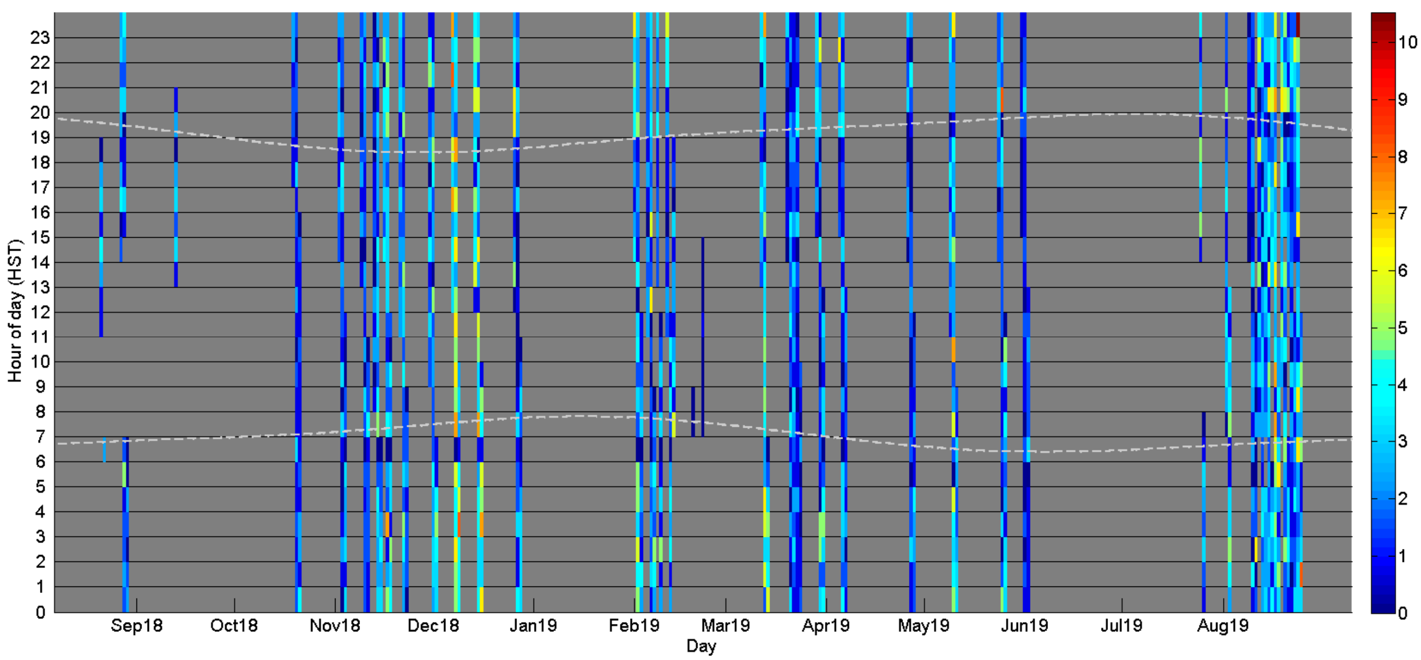

Figure 10: The total number of Blainville's beaked whale foraging dives per hour from August 21, 2018 to August 24, 2019 (corrected using validated rates). The total number of dives in a one-hour bin ranged from one (medium blue) to 14 (dark red). Results are from full bandwidth data collections only. Gray areas indicate periods when full bandwidth data were not available. The gray dashed line indicates sunrise and sunset times.

Table 7: FY19 Blainville's beaked whale sample validated corrected dive summary.

Date	Sum of Dives	Hours of Effort	Dives/Hour
2018	**1,199.76**	**499**	**2.40**
Aug	78.63	38.83	2.03
Sep	14.59	7	2.08
Oct	78.63	45.33	1.73
Nov	570.70	231.5	2.47
Dec	457.21	176.33	2.59
2019	**2,109.31**	**921**	**2.29**
Jan	N/A	0	N/A
Feb	346.15	156.33	2.21
Mar	378.57	177	2.14
Apr	149.97	90.67	1.65
May	226.98	90.5	2.51
Jun	62.42	45.33	1.38
Jul	42.15	16.5	2.55
Aug	903.07	344.67	2.62

3.2.5 Cuvier's Beaked Whales

All automatically detected clicks that were automatically grouped into a dive were manually validated by systematically reviewing click spectrograms, spectra, and ICI to be Cuvier's beaked whale clicks. The FY19 datasets contained 132 validated true positive dives (54.1% true positive rate) and 112 validated false positive dives (45.9% false positive rate). The total number of Cuvier's beaked whale dives that occurred during an hour of full bandwidth data collection was typically one or fewer, with a maximum of two dives (red) that occurred in multiple one-hour bins in November and December 2018, and February and April 2019 (Figure 11).

Table 8 provides the monthly number of manually validated dives per hour of recording effort, which ranged from zero dives/hour in September 2018 and June 2019, to 0.24 dives/hour in February 2019. Between August 2018 and August 2019 there was an overall rate of 0.09 dives/hour. This species also occurred on the range throughout the year with no clear diel trend, although there may be a slight increase in group dives during winter months since this was most frequently when two dives in an hour time bin occurred.

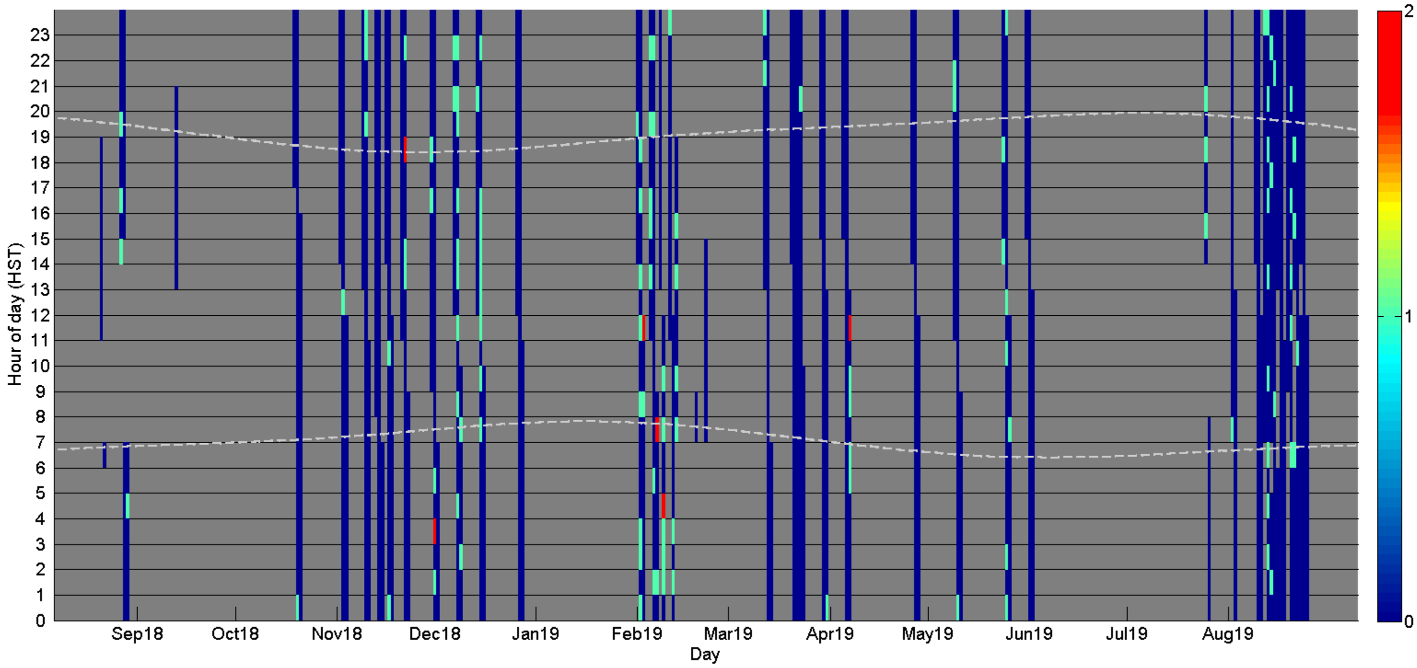

Figure 11: The total number of manually validated Cuvier's beaked whale foraging dives per hour from August 21, 2018 to August 24, 2019. Results are from full bandwidth data collections only. The total number of dives in a one-hour bin ranged from one (teal) to two (red). Gray areas indicate periods when full bandwidth data were not available. The gray dashed line indicates sunrise and sunset times.

Table 8: FY19 Cuvier's beaked whale manually validated dive summary

Date	Sum of Dives	Hours of Effort	Dives/Hour
2018	**45**	**499**	**0.09**
Aug	4	38.83	0.1
Sep	0	7	0
Oct	1	45.33	0.02
Nov	17	231.5	0.07
Dec	23	176.33	0.13
2019	**87**	**921**	**0.09**
Jan	N/A	0	N/A
Feb	38	156.33	0.24
Mar	4	177	0.02
Apr	6	90.67	0.07
May	11	90.5	0.12
Jun	0	45.33	0
Jul	3	16.5	0.18
Aug	25	344.67	0.07

3.2.6 Cross Seamount Beaked Whales

All automatically detected CSM clicks that were automatically grouped into a dive were manually validated by systematically reviewing click spectrograms, spectra, and ICI to be CSM beaked whale clicks. The FY19 datasets contained 160 validated true positive dives (26.8% true positive rate) and 437 validated false positive dives (73.2% false positive rate). The total number of manually validated CSM beaked whale dives that occurred during an hour of full bandwidth data collection (Figure 12) was typically one or fewer dives, with a maximum of two dives (red) that occurred in multiple one-hour bins throughout FY19.

Table 9 provides the monthly number of manually validated dives per hour of recording effort, which ranged from zero dives/hour in July 2019 to 0.18 dives/hour in October 2018. Between August 2018 and August 2019 there was an overall rate of 0.11 dives/hour. CSM dives occurred on the range in every month that had recording effort except for July 2019, which only had 16.5 hours of recording effort and zero CSM dives. Unlike Blainville's and Cuvier's beaked whales, there is a clear diel trend in the occurrence of CSM dives at night, with few instances of dives occurring immediately before sunset, and one instance of one dive occurring in a one-hour bin immediately after sunrise in February 2019.

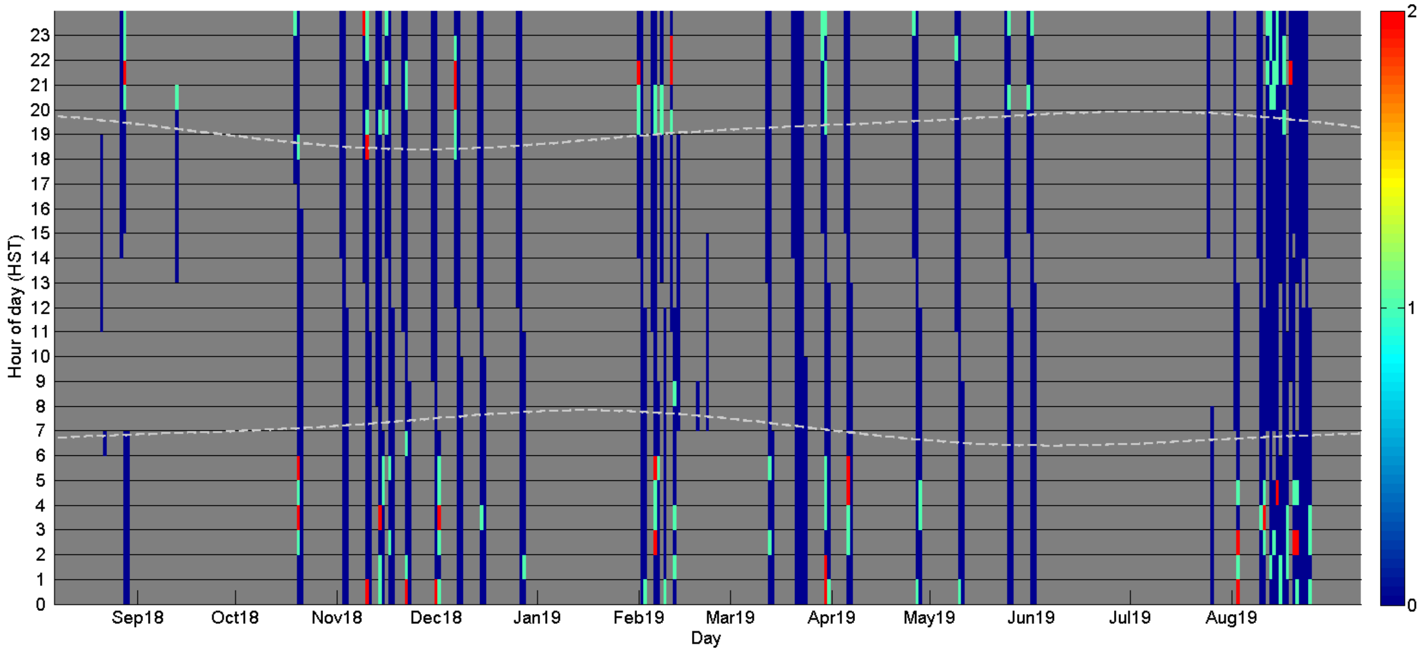

Figure 12: The total number of manually validated CSM dives per hour from August 21, 2018 to August 24, 2019. The total number of dives in a one-hour bin ranged from 1 (teal) to 2 (red). Results are from full bandwidth data collections only. Gray areas indicate periods when full bandwidth data were not available. The gray dashed line indicates sunrise and sunset times.

Table 9: FY19 CSM beaked whale manually validated dive summary

Date	Sum of Dives	Hours of Effort	Dives/Hour
2018	**58**	**499**	**0.12**
Aug	5	38.83	0.13
Sep	1	7	0.14
Oct	8	45.33	0.18
Nov	35	231.5	0.15
Dec	9	176.33	0.05
2019	**102**	**921**	**0.11**
Jan	N/A	0	N/A
Feb	25	156.33	0.16
Mar	16	177	0.09
Apr	10	90.67	0.11
May	4	90.5	0.04
Jun	2	45.33	0.04
Jul	0	16.5	0
Aug	45	344.67	0.13

3.2.6.1 Cross Seamount Long Term Dive Analysis

Between January 2007 and August 2018, a total of 540 CSM manually validated dives occurred during year-round baseline recordings. Of all the dives, the average dive rate was 0.1 dives/hour and occurred during night and dusk/dawn hours only, and the median ICI was 0.13 seconds. A majority of the dives were detected on hydrophones at depths between 648 to 1,526 m, slopes of 8.7% to 19.6% gradation; the hydrophone with the most detections was at 648 m, 8.7% slope (169 total dives).

Chi-Square tests were conducted to identify any dive trends in the data by comparing the results of expected values against observed values. Expected values are based on recording effort and the assumption used in all the tests was that there was an equal chance of detection across all seasons, months, time of day, lunar cycle, or baseline versus training event. The most significant dive trend indicated no dives occurred during the day, supporting previous studies. In addition, all the dives occurred at dawn, dusk, or nighttime between 16:00 to 07:00 HST (with a peak at 04:00 HST). A new trend that has not been previously reported demonstrated that CSM foraging dives were observed significantly less than expected during the full moon lunar phase and more dives occurred during the first quarter of the waning moon and the new moon.

3.2.7 Killer Whales

Due to relatively low levels of abundance and occurrence, all automatically grouped killer whale calls were manually validated by systematically reviewing call spectrograms and spectra to contain killer whale high-frequency modulated (HFM) calls. The results presented here do not include decimated data since those data do not have sufficient bandwidth (only up to 3 kHz) for the detectable portion of killer whale HFM calls (10-35 kHz). The total number of manually validated killer whale HFM calling groups that occurred during an hour of full bandwidth data collection was most often zero, with a maximum of one (Figure 13). There does not appear to be a clear seasonal presence, with killer whale HFM calling groups detected in early and mid-November 2018, early April 2019, late May 2019, and early June 2019. The results in Figure 13 may indicate a diel presence, with all detected calling groups occurring during daylight hours, with the exception of one calling group detected in November 2018 that occurred immediately before sunrise. Due to the overall low abundance of killer whale HFM calling groups at PMRF, all results since 2002 will be reanalyzed in FY20 to investigate diel presence.

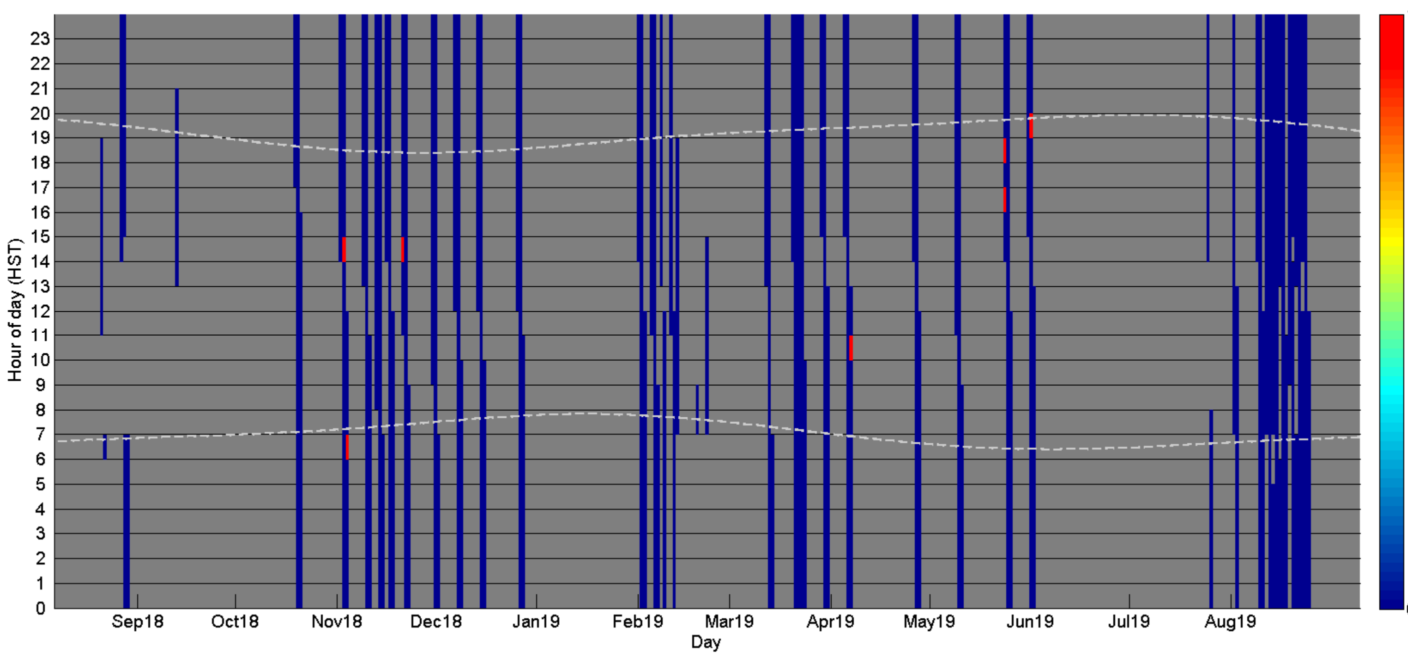

Figure 13: The total number of manually validated killer whale HFM calling groups per hour from August 21, 2018 to August 24, 2019. A maximum of one killer whale HFM calling group was present in a one-hour bin. Results are from full bandwidth data collections only. Gray areas indicate periods when full bandwidth data were not available. The gray dashed line indicates sunrise and sunset times.

Table 10: FY19 killer whale HFM manually validated group summary

Date	Sum of Groups	Hours of Effort	Groups/Hour
2018	3	**499**	0.006
Aug	0	38.83	0
Sep	0	7	0
Oct	0	45.33	0
Nov	3	231.5	0.013
Dec	0	176.33	0
2019	4	**921**	0.004
Jan	N/A	0	N/A
Feb	0	156.33	0
Mar	0	177	0
Apr	1	90.67	0.011
May	2	90.5	0.022
Jun	1	45.33	0.022
Jul	0	16.5	0
Aug	0	344.67	0

3.2.8 Sperm Whales

Since 2002, passive acoustic monitoring at PMRF has yielded minimum density estimates and disturbance analyses for various whale species, but the ability to do so for sperm whales has been limited. Such efforts have traditionally suffered from false positives and decreased localization accuracy with increased click density. Recent developments of the C++ detection and localization algorithms (described in more detail in Martin et al., [2019a]) and attempts were made to quantitatively and qualitatively assess improvements using archived 2014 data. Algorithm changes generated 2.4 times more detections (SD = 3.9) and 1.4 times more localizations (SD = 2.4) on average in this 2014 test year. Metrics indicating localization accuracy also improved. The number of detections per localization increased from a median of 5.5 (IQR = 5.2-5.8) to 7.0 (IQR = 6.0-8.3) and the percent of localizations theoretically capable of being tracked (i.e. those with at least eight contributing hydrophones) increased from 5.9% (IQR = 1.4%-11.6%) to 31.2% (IQR = 8.0%-46.9%). Visual comparison of new localizations indicates lower false positive rates, while other new software developments have enabled preliminary tracking efforts. Ultimately, track-level analyses should permit a more stable metric for minimum density estimates and disturbance tests and help establish baseline kinematics and behavior.

The maximum number of automatically tracked sperm whales in snapshots taken every 10 minutes for each month from February 2002 to August 2019 varied from zero to a maximum of eight individual sperm whale tracks in May 2016 (SD = 1.6 tracks) (Figure 14).

Despite substantial improvements to the automatic tracking process, the calling characteristics of sperm whales can still make discriminating individuals challenging under certain conditions. When whales are solitary, widely spaced, or slow-clicking males (producing clicks every 5-6+ seconds; Weilgart & Whitehead, 1988), tracking seems to be at least as reliable as it is for other species tracked with this software. However, sperm whales sometimes form close foraging groups, during which click rates are much more rapid (1-2 per second; Whitehead & Weilgart, 1990), which can cause the tracking software to attempt to link localizations from multiple individuals and create unpredictable behavior, of which the dataset in May 2016 with eight automatic tracks may be an example. Examination of the raw data certainly suggests multiple animals, but the unusual static and substantial calling behavior on this day may be causing tracks to split and recombine inaccurately. Future efforts will focus on attempting to resolve these unusual cases, perhaps by using individual-specific inter-pulse intervals (an intra-click characteristic unique to sperm whales; Bøttcher et al., 2018) to link localizations.

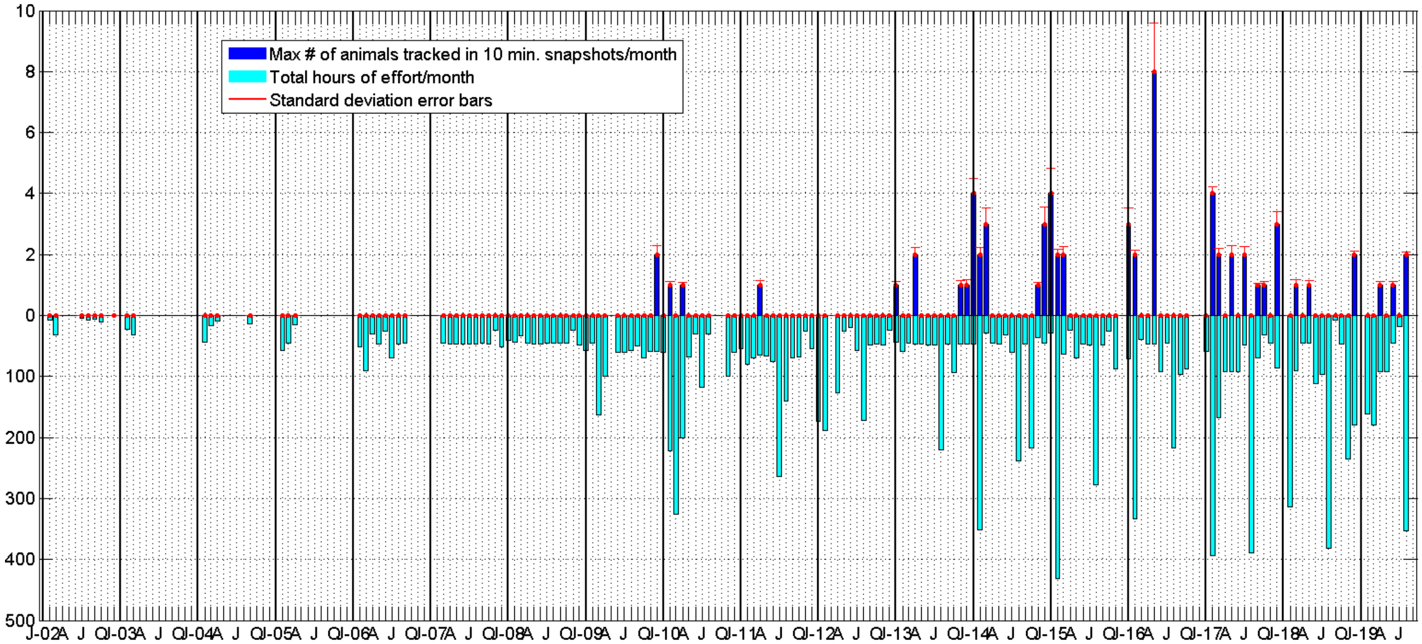

Figure 14: The maximum number of automated sperm whale tracks in a 10-minute snapshot per month from February 2002 to August 2019 (dark blue vertical bars) with the standard deviation of all snapshots in the month (red error bars). Hours of recording effort per month from 2002-2019 include full bandwidth data collections only (light blue vertical bars). The horizontal axis is gridded by month, with Januarys shown as solid black lines and calendar years indicated (e.g. J-02 indicates January 2002) and months of April, July, and October indicated with A, J, and O. If light blue bars exist but dark blue bars do not exist, then data were recorded for that month but no whales were tracked. If nothing is plotted for a month then no data were recorded.

3.3 Disturbance Analysis Results

For this reporting period, recordings were suspended prior to the February 2019 SCC due to emergent security concerns which precluded obtaining classified recordings; these concerns have since been resolved. The August 2019 SCC was also moved to SOAR and acoustic data were not available. Recordings from the August 2018 SCC were not available for analysis at the time of writing the FY18 report and accounts for approximately 61.2 hours of recording effort since the SCC ended early due to Hurricane Lane (August 15-28, 2018). Analysis of results from the August 2018 SCC are included as part of the Blainville’s beaked whale results presented in Section 3.3.2. The only other processed species results during the August 2018 SCC were for CSM beaked whales and were not further analyzed since no actual CSM dives occurred in the data. In addition, disturbance analyses were conducted on other previously recorded data for multiple species. Disturbance analyses can be applied to various species of whales acoustically detected at PMRF. Some species’ vocalizations allow for localizing and tracking calls from individuals (e.g. baleen whales and in some cases sperm whales) and so changes to kinematic behavior can be assessed, while other species are only localized to a radius around the hydrophone they are detected on (e.g. beaked whales and killer whales) and therefore only changes to the number of groups or spatial distribution of groups can be examined.

3.3.1 Minke Whale Spatial Distribution and Directed Movement

Progress on the ONR BREVE effort, which is being worked collaboratively with this monitoring effort, has shown progress in conducting behavioral response evaluation for data obtained from passive acoustic data in two main areas that will be briefly described below. Previous reports have documented methods developed to determine the whale-ship geometry and estimate the sound received levels that tracked whales experience from MFAS transmissions, along with contextual variables such as the distance to the ship(s) and the orientation of the whale relative to the ship (e.g. off the bow, beam, or stern quadrants). These previously developed methods, in conjunction with methods developed by the BREVE effort now allow for statistically determining behavioral responses of whales to U.S. Navy training activities; some of these responses are highlighted in this report.

The first area of progress involved demonstrating changes in the spatial distribution of minke whale acoustic presence and absence related to MFAS training by utilizing results from February 2014 and January and February of 2017. Full details of the analysis are available in a recent publication in Aquatic Mammals (Harris et al. 2019), but a brief summary of the analysis and results are presented herein. The results consist of acoustically generated whale tracks for minke whales covering temporal periods before, during, and after the portion of the SCC that contained surface ship MFAS training. For these three periods, the NARWHAL algorithm suite generated a total of 116 minke whale tracks for the 2014 data set, and 187 tracks for the 2017 data set. The before period of the 2017 data set contained more data and more tracks (over 19 days and 137 tracks) compared to the 2014 data set (over 11 days and 58 tracks). The during data were comprised of over 4 days for both years and contained similar numbers of whale tracks (19 tracks in 2014 and 23 in 2017). The After data consisted of 5 days for both years with a higher number of whale tracks in 2014 (43 tracks) compared to 2017 (32 tracks). The data were analyzed as a binary logistic regression using generalized estimating equations (GEEs) with "presence" coded as 1 and "absence" coded as 0 for each localized whale call within each acoustic track as the response variable. Presences were the individual call locations in each track with corresponding absences randomly assigned at the same time point from uniform distributions of latitude and longitude. Predictor variables shown to have significant results included: the phase of the study (before, during, and after); longitude; latitude; and year. Models were fit to the track data and were used to generate spatial prediction plots shown in

Figure 15 (from Harris et al., 2019). Minke whale acoustic presence was predicted over much of the study area in the before phase for each year, with differences observed between years. The spatial distribution of the probability of acoustic presence was different in the during phase compared to the before phase, with the blue dots shown in the during phases representing the center of ship locations where probabilities of presence were close to zero for both years. After phases for both years retained lower probabilities of presence, suggesting the return to baseline conditions may take more than 5 days. The results show a clear spatial redistribution of calling whales during U.S. Navy MFAS training; however, a limitation of passive acoustic monitoring is that one cannot conclude if the animals moved away or simply went silent (or a combination of the two). An expectation is that whales may initiate an avoidance response to the training activity and move away from the training activities.

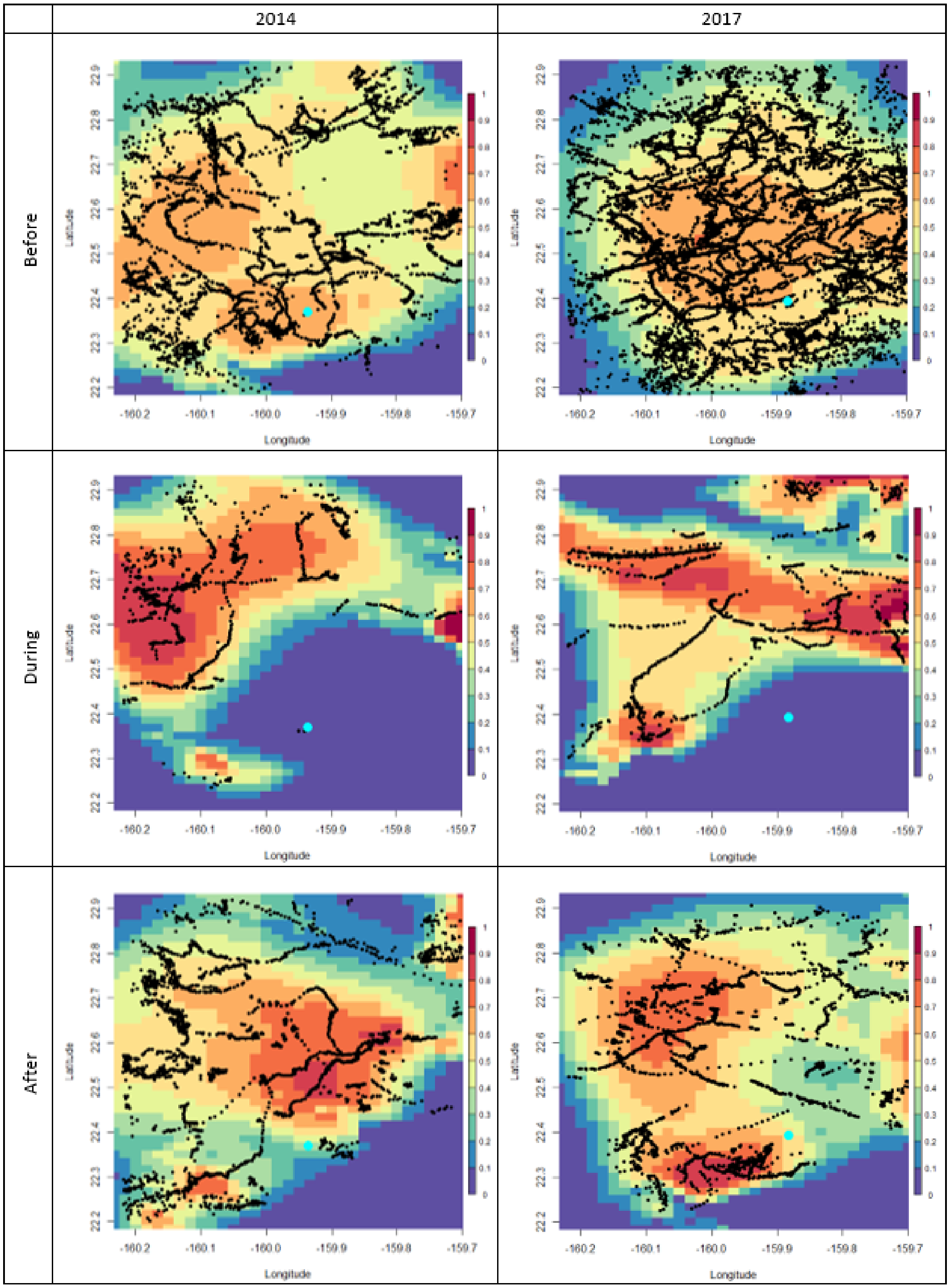

Figure 15: Figure from Harris et al. (2019) showing minke whale tracks (black) overlaying prediction surfaces from the selected model. The surfaces represent predicted probability of presence, with cool colors representing low probability of presence and hot colors representing high probability of presence. The left panels are for 2014 with the right panels representing 2017.

Top panels show the before periods, middle panels the during periods, and lower panels the after periods. The cyan dot represents the estimated mean center of ship activity for that year.

The second area of progress in the ONR BREVE effort demonstrates that minke whales responded to U.S. Navy training in terms of having more directed and higher speed movement during periods of MFAS activity (i.e. their kinematics). Both the whale speed and headings must be inferred from the passive acoustic call localizations with an understanding of the whale localization accuracies and time between calls. Only whale tracks within a defined 'kinematic' study area (essentially the area encompassing the hydrophone array) were utilized given the localization accuracy decreases as they occur further outside the hydrophone array. The behavioral change point analysis (bcpa) R package (Gurarie et al., 2009) was utilized for estimating whale track headings and speeds based on a moving average method using the call rates present during the tracks. This tool is required since in many situations the heading derived from one whale call location to the next can be misleading due to the error associated with each localization. Figure 16 illustrates a 16.86- hour long minke whale track which began on February 7, 2017 at 02:25 (UTC) near the western edge of the hydrophone array, moved north and slightly west, turned east and onto the hydrophone array, and then south down the middle of the array. A total of 164 calls were localized with a mean call interval of 372.4 seconds (SD = 96.96 seconds) which matches favorably with the minke whale boing call interval. The whale localizations are connected by black dashed lines, which would be the estimated whale heading based upon localized call-to-call locations, while the whale localizations (green, cyan, magenta and blue symbols) indicate the whale location error ellipses (due to the scale of Figure 16 the ellipses appear as small circles).

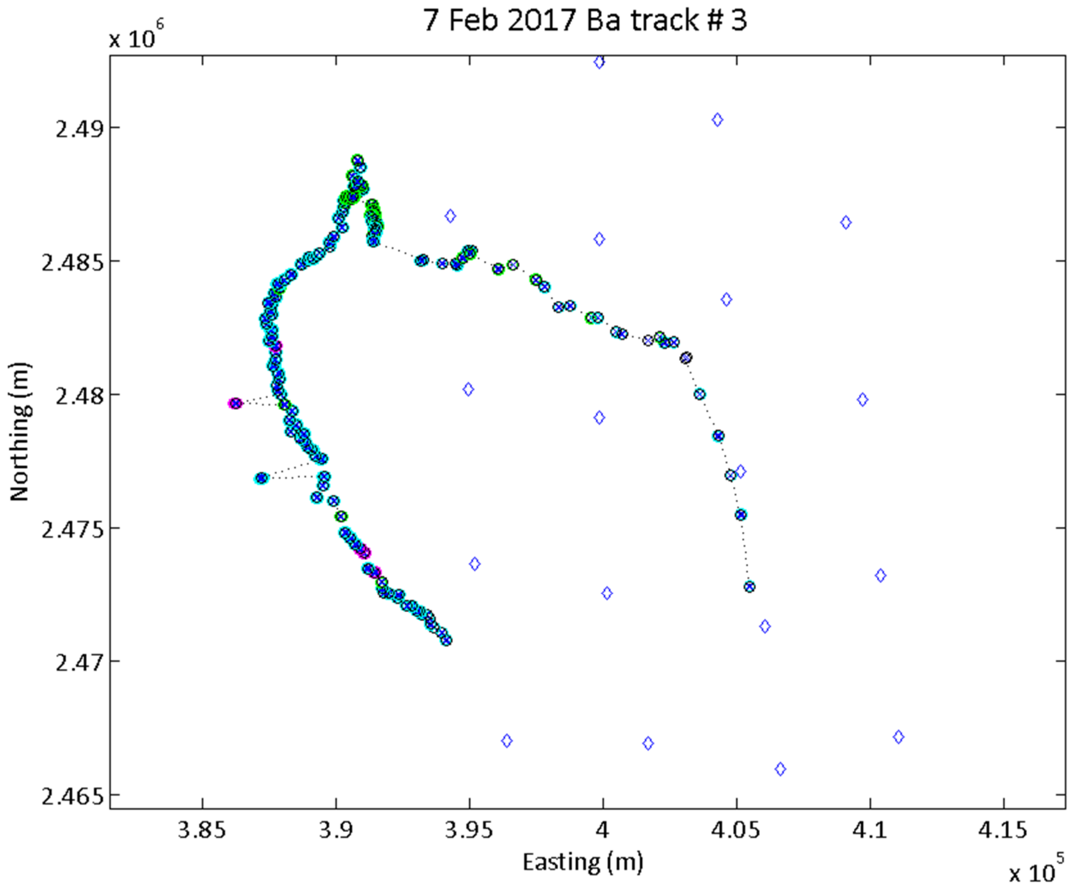

Figure 16: Example of a minke whale track from February 7, 2017. Blue diamond symbols indicate approximate hydrophone locations. Blue, green, cyan, and magenta colored location error ellipses (ellipses are not discernable at this scale, rather appear more circular) indicate the whale localizations which are connected by black dashed lines. The inner ellipse (blue) is estimated utilizing timing and geometry assuming direct path arrivals while the outer ellipses are estimated utilizing horizontal dilution of precision methods employed in satellite navigational geometric error analysis (also assuming direct path arrivals). Green indicates all contributions to each localization solution were within estimated direct path distances, cyan indicates at least one of the later (ninth or later) contributions to the localization solution were beyond estimated direct path distances, and magenta indicates one of the first eight contributors to the localization solution were beyond estimated direct path distances. The last six calls in the track (ending around 2.473×10^6 m northing and 4.05×10^5 m easting) are still at the nominal call rate, the larger distance separation indicates a higher speed (approx. 3 m/s).

Not visible in Figure 16 due to the scale of the plot are the bcpa estimated headings. Figure 17 provides a zoomed in view (50 m per division) of the portion of the track where the whale enters the hydrophone array and clearly shows four whale localizations with error ellipses (colored blue, green and cyan) with the bcpa derived whale headings shown as blue arrows at each localization, while the black dotted lines connect the centers of the error ellipses. The utility of the bcpa smoothed whale headings (blue lines with arrows) show a disagreement on the order of 180 degrees for the north eastern most location (the blue arrow points nearly east while the black dotted line connecting to the next localization center point is nearly west). The blue, inner error ellipses (one sigma) are derived from timing estimates and considered the hydrophone that contributed to the localization solution using an estimated timing error of 10 ms, while the green and cyan ellipses utilize the same 10 ms timing error and the geometric covariance matrix methods utilized in satellite navigational accuracy. The color of the outer ellipses is coded for the estimated contributions of indirect path arrivals (note the error ellipse analyses both assume direct path arrivals). For example, the westernmost magenta ellipse in Figure 16 had an indirect path detection from at least one of the first eight hydrophones contributing to the solution and is apparent due to it being 1.5 km off the apparent whale track line. In addition, the green ellipses indicate that all hydrophones contributing to the localization solution were within estimated direct path arrival distance while the cyan ellipses indicate that contributions starting with the ninth detection had at least one contribution that was estimated beyond direct path arrival distance (which biases the position and is currently not accounted for in the error ellipse analyses). This method shows promise in automatically identifying sources of positional error and improving the whale tracks by reducing outliers in the data. This represents a preliminary investigation to identify indirect path arrivals for improving the localization methods by either omitting them from the location and re-localizing, or extending the technology to a model-based method which accounts for both direct, and indirect path arrivals.

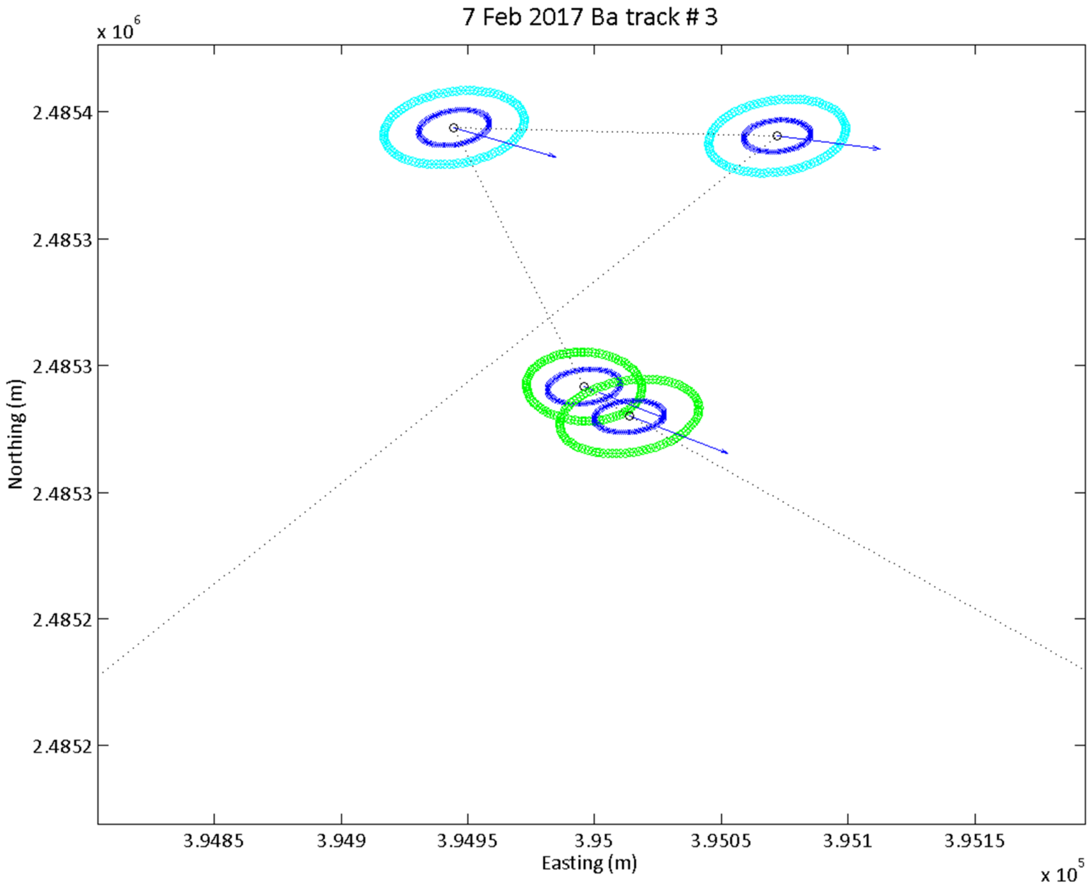

Figure 17: Zoom of four whale localizations from Figure 16 that are located just after the whale enters the hydrophone array. Each localization includes two estimated error ellipses, the inner ellipse (blue) is estimated utilizing timing and geometry assuming direct path arrivals while the outer ellipse (green and cyan in this case) are estimated utilizing horizontal dilution of precision methods employed in satellite navigational geometric error analysis (also assuming direct path arrivals). Dashed lines connect centers of the ellipse (localization to localization estimated heading) while the blue lines with arrows indicate the bcpa derived smoothed headings. Green indicates all contributions to each localization solution were within estimated direct path distances while the cyan colors indicate at least one of the later contributors to the localization solution were beyond estimated direct path distances.

Preliminary analyses of the bcpa derived minke whale headings and speeds of minke whales tracked before, during, and after the February 2014 and 2017 SCCs indicate that the whales are exhibiting statistically significant higher speeds with more directed movement during periods of MFAS activity compared to their movement patterns at other times (e.g. before and after periods). Additional effort is underway to determine if the directed movement is away from the MFAS sources, which would indicate a definitive movement response to the MFAS sources. Additional tools were developed to estimate the error ellipses for each whale call localization to support continuous time animal movement modeling. These tools are being transitioned to this monitoring effort as they become available.

3.3.2 Blainville's Beaked Whale Dives and Estimated Received Levels

Manually validated blainville's beaked whale group foraging dives were examined before, during, and after 16 SCCs at PMRF. It had previously been established that group foraging dives for multiple species of beaked whale decrease in the presence of hull-mounted MFAS (McCarthy et al. 2011; Manzano-Roth et al. 2016; Joyce et al. 2019), and recent results indicate that other types of MFAS impact beaked whale foraging dive behavior as well (Falcone et al. 2017; Watwood et al. 2019). The present study was the first to look at impacts of training activity that did not include MFAS with high source levels on Blainville's beaked whales.

Three types of analyses were conducted to look at the impacts of this training activity. First, received levels taken from the seafloor-mounted range hydrophones were binned into low- (10-999 Hz), mid- (1 – 10 kHz) and high- (20-48 kHz) frequency bands, and then integrated spectral densities per hydrophone for all half-hour periods during training that did contain beaked whale clicks were compared to integrated spectral densities for the half hour periods that did not contain beaked whale clicks. It was found that there was no significance in the integrated spectral densities of the low-frequency binned data with or without beaked whale clicks, but that for both the mid- and high-frequency bins, levels were actually significantly higher when clicks were present than when they weren't. The noise levels in the high frequency bins were partially driven by the beaked whale clicks themselves, but with the frequent occurrence of dolphin clicks also in the high frequency bin that could not have been the only driver of this result. These results may be related to the depth of the seafloor hydrophones, and that the shallower phones on the southern part of the range, where Blainville's beaked whales are more likely to occur, may also have higher levels of sound simply due to their closer proximity to noise sources. However, this needs to be looked at more closely to tease out the effects of hydrophone depth versus actual noise impacts to beaked whales.

A second analysis conducted was a change-point analysis of the number of manually validated dives per half hour period before, during, and after the SCC. The strongest change point was detected at the very start of the SCC, in the phase prior to the onset of hull-mounted MFAS, with a further decrease in foraging dives once MFAS was included in the training (Figure 18). This finding was further corroborated with a GAM of the spatial distribution of foraging dives across the range before, during, and after the SCC (also see Jacobson et al. 2019). This model found no change in the spatial distribution of dives during the first, non-MFAS phase of the SCC, but did find a 58% reduction in the number of foraging dives in that phase. There was both a spatial change to the distribution of dives and a further reduction in the number of dives during the MFAS phase of the SCC (Figure 19). These findings combined demonstrated that Blainville's beaked whale foraging dives decreased significantly at the onset of the SCC training events, even without the presence of hull-mounted MFAS.

A more detailed analysis needs to be conducted to determine what might be causing that strong behavioral change. One hypothesis is that the Blainville's beaked whales found on or near PMRF are somewhat resident, and have learned that the activity at the start of each SCC indicates that hull-mounted MFAS will be occurring, and therefore move out of the area prior to the onset of the MFAS. While that hypothesis would be difficult to test, other periods of training activity at PMRF that are similar to both the non-MFAS phase and the MFAS phase of the SCCs could be recorded, and the foraging behavior of Blainville's beaked whales could be examined in a similar manner. This would help to better understand the impact of a variety of training activities on Blainville's beaked whales, beyond just the large-scale SCC events.

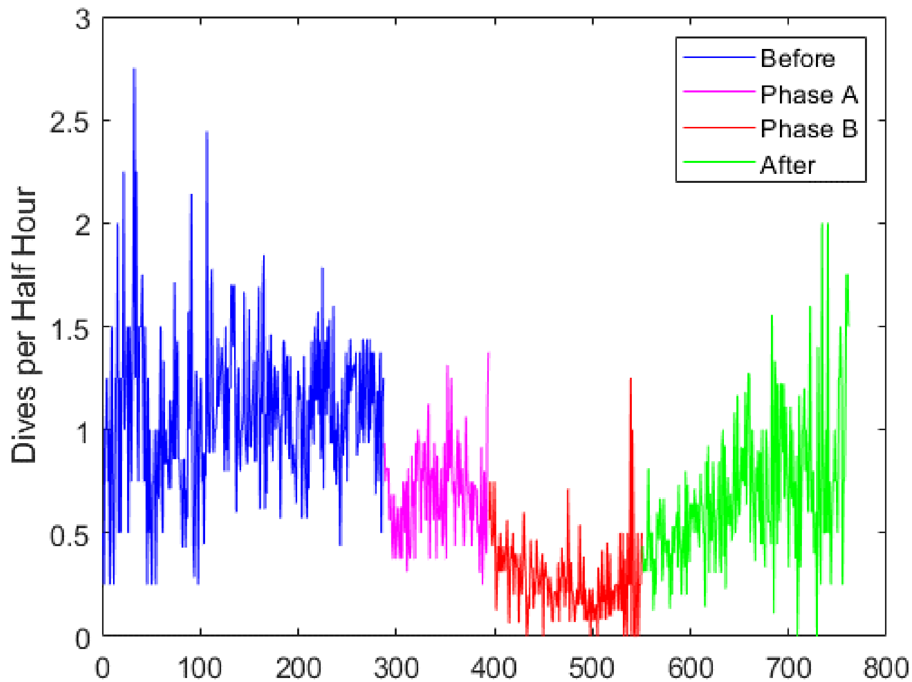

Figure 18: The number of dives per hour of Blainville's beaked whale dives during the before, phase A, phase B, and after periods of the sixteen SCCs from 2011-2018. A clear decrease in the number of dives occurs at the onset of phase A, and a continued decrease in dives occurs throughout the SCC. However, the number of dives begins to increase as soon as the SCCs are completed.

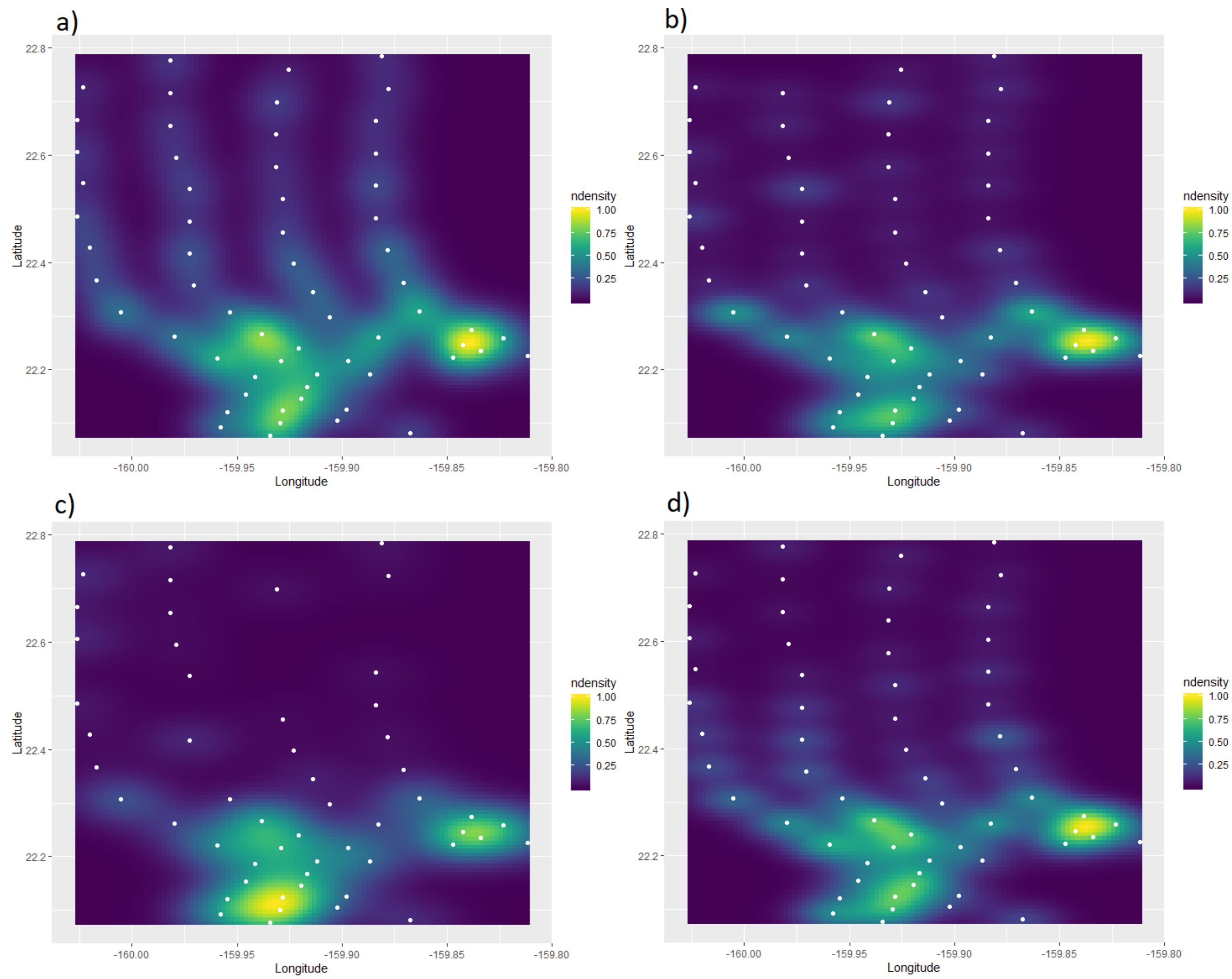

Figure 19: Blainville's spatial density maps for the different periods of 16 SCCs showing before (panel a), phase A (panel b), phase B (panel c), and after (panel d). The kernel density (0-1) is relative to each respective period only and these maps serve to compare spatial movement across periods rather than the absolute number of dives across periods. Maps are scaled to the same latitude and longitude extent with approximate hydrophone locations indicated with white dots if dives were detected on them.

3.3.3 Cross-Seamount Beaked Whale Dives

A total of 545 manually validated CSM dives detected between January 2007 and August 2018 (Section 3.2.6.1) were categorized as baseline. These dives were compared to 95 CSM dives that occurred during SCCs between February and August 2011 to 2018 to investigate potential dive rate differences for baseline periods and during SCCs. The during period was defined as the day the SCC started until the day the SCC ended (including both phase A and phase B), the between period included weekends and days when the SCC did not occur, and the before and after periods encompassed seven days both before and after the start and end of the SCC. The during periods had an average dive rate of 0.1 dives/hour versus the baseline rate of 0.14 dives/hour (Figure 20). The hydrophones with most of the CSM detections in the during phases were at depths shallower than 1,000 m, which shows a spatial redistribution compared to baseline periods, when they were found in depths up to 1,526 m. There was a statistically significant deviation from expected dive rates over a more fine-scale division of the SCCs (before, during, between, and after), with fewer dives observed in the during phase than expected, but almost equal amounts of dives observed as expected in the after and between phases.

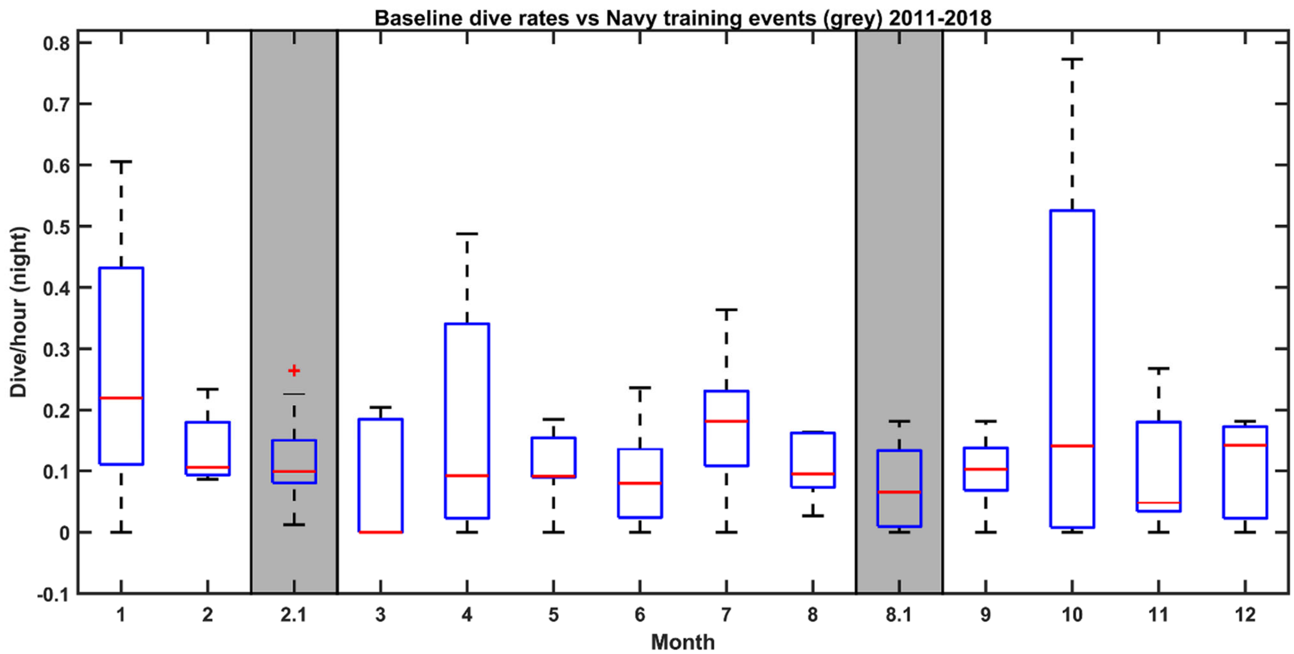

Figure 20: Box and whisker plot from Manzano-Roth et al., 2019. The median number of pooled CSM dives/hour for data pooled across months is indicated by the red central lines. The bottom and top edges of the blue boxes indicate the 25th and 75th percentiles of the data, the black whiskers extend to the minimum and maximum data points, and outliers are plotted as a red cross. Months numbered 2.1 and 8.1 indicate the during period results for February and August 2011 to 2018 which is also indicated with gray shaded bars. Remaining months indicate results for baseline period data pooled across months from January 2007 to August 2018.

3.3.4 Baleen Whale Response to Broadband Explosive Noise in Kauai

Three events consisting of explosive impulse sounds were opportunistically recorded at PMRF on March 10, 2017. Automated tracks were generated (and manually validated with spectrograms and known calling behavior) for three minke whales and one suspected fin whale (based on an A-B calling behavior) calling within the hydrophone array during the events. Figure 21 depicts the four whale tracks that overlapped with the opportunistically recorded explosive events and indicates each whale's position closest in time to the explosive event and the direction from where the source would be perceived. Call rates, swim speeds, and headings were estimated for each tracked animal before and after the explosive events. General observations of whales during the explosive events included a slight increase in call rate for all three minke whales, heading adjustments for all whales, and a slight increase in swim speed for two whales. However, high inter- and intra-variability in baseline behavior and limited sample size make it difficult to attribute any apparent changes to actual responses, especially with single, short duration events and for whales with long inter-call intervals.

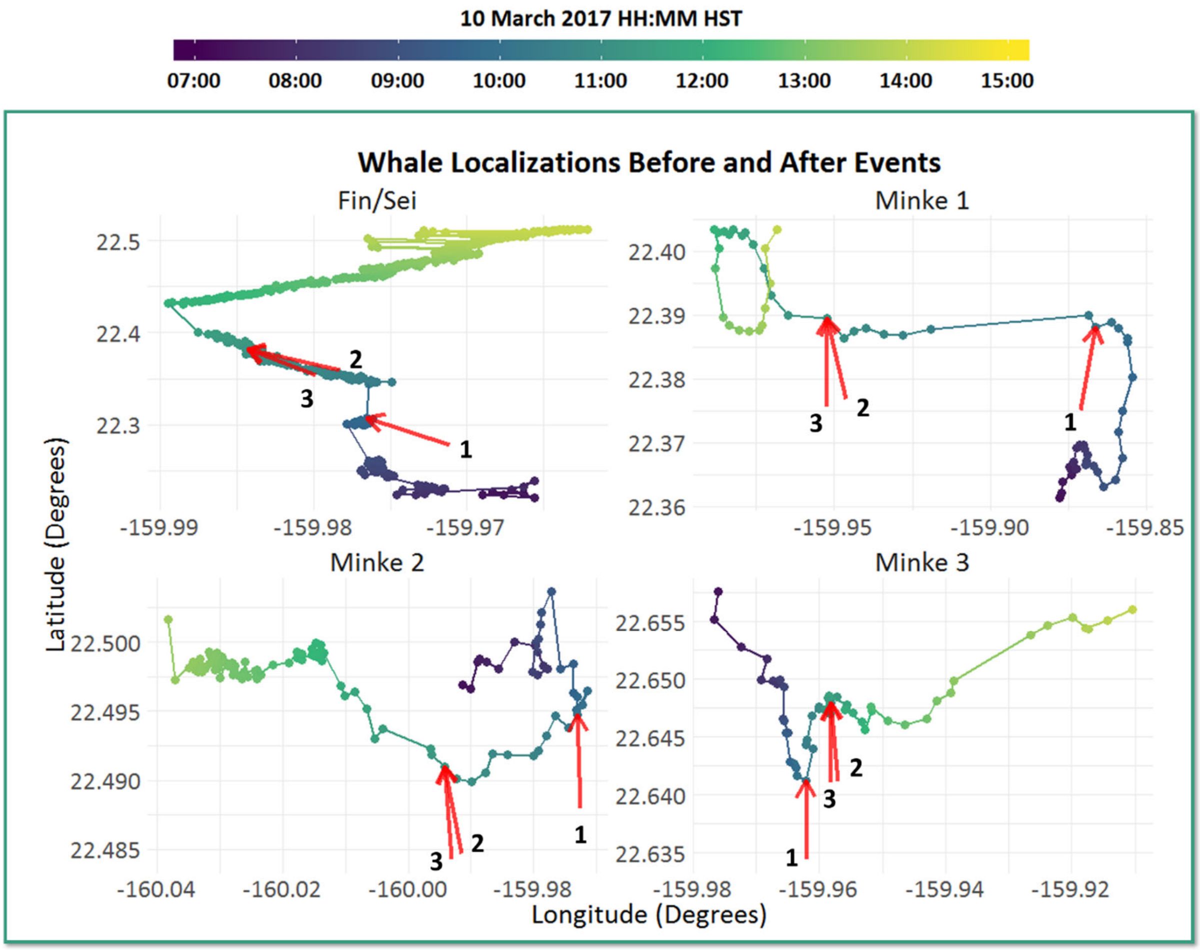

Figure 21: Figure from Alongi et al., 2019a. Whale tracks from three hours before the first explosive event to three hours after the last. Red arrows indicate the last call detected before each event and the direction from where the source would be heard.

3.4 Noise Analysis Results

An initial analysis of whale detections relative to environmental conditions was undertaken in FY19 as part of the kick-off of the ONR (Code 322, Marine Mammals and Biology) funded effort referred to as E-BREVE (Environmentally-influenced Behavioral Response EValuations). As the metrics and results from that analysis will be applied to monitoring data in the future, some of the initial results are included herein. Figure 22 compares minke whale tracks with weather conditions at PMRF in January 2017 (a period during which it was previously determined that a storm occurred that increased ambient noise levels and had concurrent decreased whale detections [Martin et al. 2019a]). The significant wave height in meters was calculated for all waves with periods less than or equal to 10 seconds. The significant wave height is the 30-minute average of the highest 1/3 waves at the buoy; these waves make up the wind-waves or "seas" and are formed from local wind conditions. The wave heights were measured by the Waverider Buoy off the north coast of Kauai at 22.285°N, 159.574°W and were furnished by the Coastal Data Information Program, Integrative Oceanography Division, operated by the Scripps Institution of Oceanography (https://cdip.ucsd.edu/). Wind speed was modeled at 10 m above the sea surface with 0.5° spatial resolution and approximately 6-hour time resolution by the Navy Global Environmental Model. Modeled values were averaged within the area of the PMRF hydrophone array for each 6-hour time period. Whale tracks during known periods of U.S. Navy training (e.g. the end of January 2017 in Figure 22) were not included in the analysis to determine the potential impact of environmental induced noise level increase due to the possible confounding impact of anthropogenic noise on the presence of whale tracks.

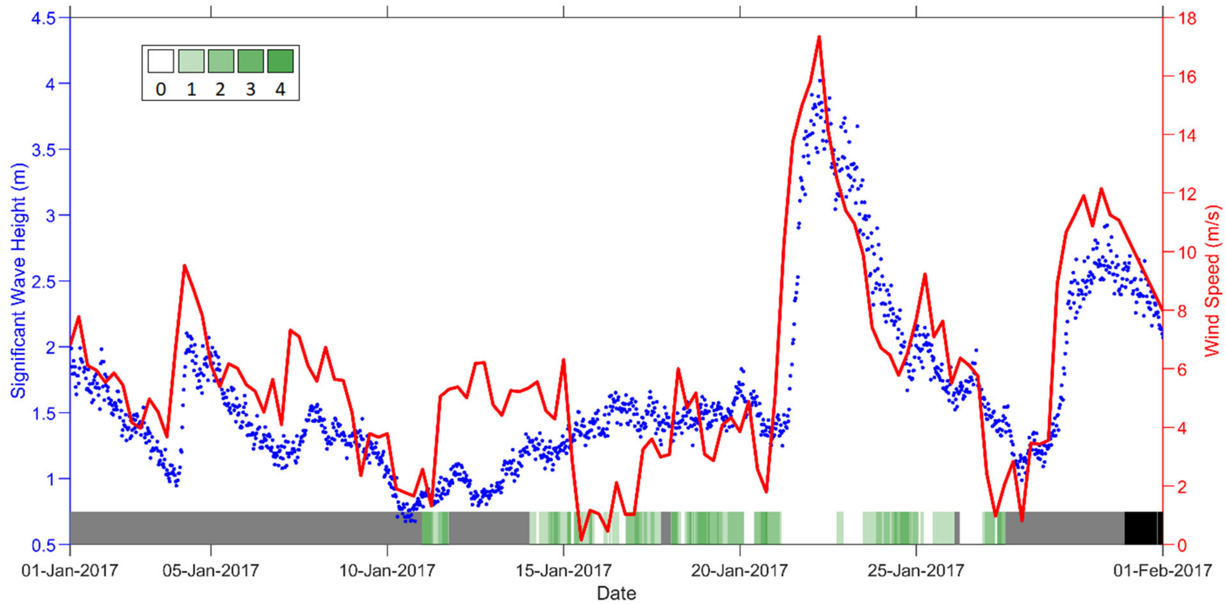

Figure 22: Minke whale track occurrence relative to wave height. Wave height (m) is indicated by blue dots corresponding values on the left y-axis, and wind speed (m/s) is indicated by the red line corresponding to values on the right y-axis. The number of minke whale tracks is scaled based on the intensity of the green shading at the bottom of the plot (range from 0 to 4), with more animals represented by darker green colors. White portions of the bar indicate full-bandwidth data collection but no minke whale tracks, while gray portions indicate no full-bandwidth data collection effort, and the black portion indicates when a known U.S. Navy training activity occurred and any whale tracks during that time are not depicted.

Using these environmental data, an investigation has begun on how minke whales respond to wind-wave events. In the plotted example for January 2017, preliminary analysis suggests that minke whales may decrease calling during wind-wave events. This work will continue in FY20.

In addition to cessation of calling, baleen whales may shift the source levels of their calls as background noise levels increase. In a study of this effect (called the Lombard Effect), it was found that minke whales that were acoustically tracked on PMRF increased the source levels of their boing calls during periods with increased background noise (Helble et al., 2020). This research is significant in that it reports the first ever source levels for minke whales, and also contains the largest (to date) sample size for conducting a marine mammal Lombard study (41,159 vocalizations).

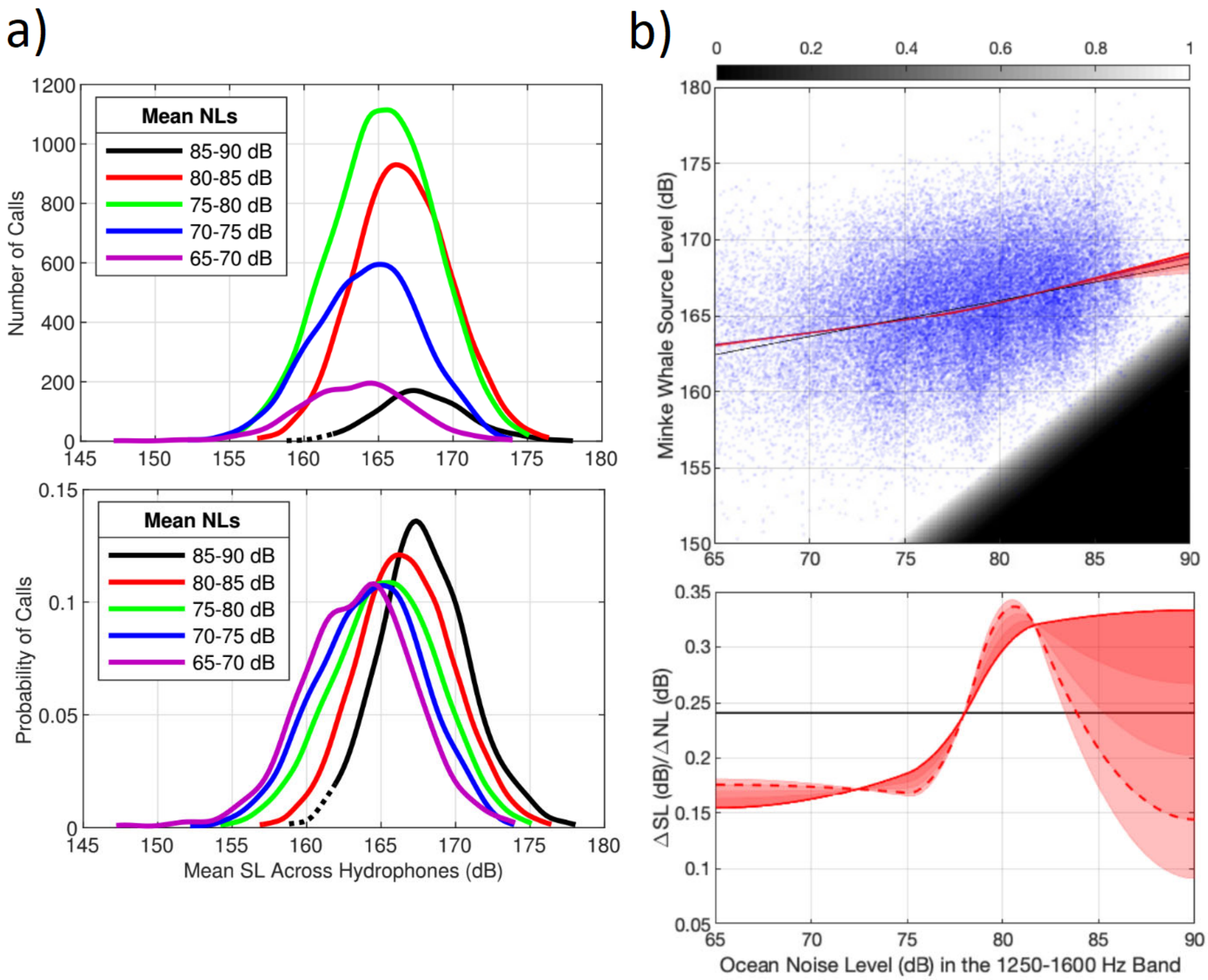

Figure 23: a) Figure from Helble et al., 2020. Overlapping fitted histograms of estimated minke whale source levels (SL) for given noise level (NL) bands restricted to a horizontal distance between 1-10 km from the contributing hydrophone. The colors indicate the different noise level bins measured in dB re 1µPa over the 1,250-1,600 Hz band. The magenta line indicates calls produced during noise levels of 65-70 dB (magenta line), 70-75 dB (blue line), 75-80 dB (green line), 80-85 dB (red line), and 85-90 dB (black line), with all noise levels in dB re 1µPa. The dotted portion indicates portions of the histogram that could be suppressed due to masking. b) Figure from Helble et al., 2020. The upper scatter plot depicts minke whale source level and noise level restricted to a distance 1-10 km from the measuring hydrophone. The grayscale indicates the estimated probability of localization averaged over all subarrays. The white region indicates that nearly all calls will be localized while the black region indicates that most calls will be masked. The black line represents a linear fit to the data, and the red line is fitted using a GAM. The red levels of shading represent the results of the GAM with simulated calls in the masking zone for the decay constant b = (1,2,3,4) with the dashed line representing b = 2. The slopes of the fits, ΔSL (dB)/ΔNL (dB), are shown in the lower plot. All NL values are in units of dB re 1 µPa and SL values are in units of dB re 1 µPa at 1 m.

Overlapping fitted histograms of estimated minke whale source levels (SL) for given noise level (NL) bands restricted to a horizontal distance of 1-10 km from the center hydrophone are given in the left panel of Figure 23. Source levels were measured in dB re 1µPa at 1 m. The portion of the histogram that could be suppressed due to masking is represented by the dotted portion of each histogram. The histograms were fit to the data using non-parametric kernel smoothing distributions evaluated at 100 evenly spaced points covering the range of data for each noise level bin. The total number of calls in each noise bin are given in the upper plot of the left panel (Figure 23), while the lower plot is normalized by the total number of calls in each bin. The mean source level in the 65-70 dB re 1 μPa noise bin was 163.42 dB re 1 μPa with a variance of 14.27 dB re 1 μPa, while the mean source level in the 85-90 dB re 1 μPa bin was 167.90 dB with a variance of 9.28 dB re 1 μPa. The mean source level of the minke whale boing calls increased significantly over these noise levels and the variance decreased significantly between the 3 upper noise level bins.

All of the estimated minke whale source levels and noise levels were restricted to a distance of 1-10 km from the measuring hydrophone (given in the right panel of Figure 23). The estimated probability of localization was averaged over all subarrays, and assumed random distribution of calls between 1-10 km from the measuring hydrophone (as indicated by the grayscale portion of the plot, where the white background indicates that nearly all calls will be localized, while the black background indicates that most calls will be missed). The data were fit using two different methods: a linear fit (indicated by the black line in the right panel of Figure 23), and a GAM (indicated by the red line in the right panel of Figure 23). The linear fit had a slope of 0.24 dB increase in minke whale boing call source level per 1 dB increase in background noise level, while the GAM model indicated that the maximum response was 0.34 dB increase in SL per 1 dB increase in NL (Figure 23, right panel, bottom plot). These results indicated that minke whales may experience a drastic decrease in their communication space as noise levels increase since they are unable to fully compensate for the increase in background noise level. This analysis will be continued by similarly investigating how humpback whale calls shift in source level in various background noise conditions. Preliminary results suggest that humpback whales also increase their call intensity in increased background noise levels, although their increase in source level is greater than minke whales; however, they still do not fully compensate for the increased noise level.

The noise analysis tool was also used this year to develop a data integrity addendum to the C++ algorithms used to process for whale detections (see Sections 2.2.1 and 2.2.4). So far, this new algorithm has only been parameterized and implemented for the decimated data, so current hydrophone profiles (describing archived spectral averages and standard deviations) are limited to below 3 kHz. The algorithm successfully identified periods of known hydrophone outages – such as an 11-phone drop-out starting in August 2017 (see Martin et al., 2019a) – and unusual electrical or mechanical noise, such as when the BSURE phones exhibited odd electrical behavior in July 2015. It also managed to isolate a dataset this FY in June where all hydrophones except one were non-responsive. Once developed for the full-bandwidth of each phone, this tool could be essential for more accurately quantifying effort. It will help identify when a lack of whale detections is real or due to electrical or mechanical failure and eliminate periods of recording where the non-natural noise may generate false positives in the detectors.

4 Concurrent and Related Efforts

- The FY17-20 ONR BREVE effort works collaboratively with the COMPACFLT effort. The thrust of the BREVE effort is to show behavioral responses of baleen whales relative to actual Navy MFAS training (i.e. the February and August SCC events). The BREVE effort has developed new tools being transitioned to the COMPACFLT effort in the following areas: tracking of whales; localization error ellipse estimation using two separate approaches; automating disturbance analyses; and recently efforts to identify erroneous localizations due to multipath contributions to localizations. Efforts on BREVE have shown for the February 2014, and January and February 2017 data sets (Baseline, Before, During and After SCC training), a difference in the spatial distribution of boing calling minke whales. In addition, the tracked minke whales' speeds increase, and their movement becomes more directed during MFAS periods. As the project concludes in FY20 the focus is twofold, including analysis of a third data set (January-March 2015) and investigating if the faster and more directed movement is related to the MFAS ship geometry which would indicate faster more directed movement as a behavioral response to the U.S. Navy MFAS activities.

- Dr. Robin Baird is separately funded by COMPACFLT to tag marine mammals prior to the bi-annual SCC training events. NIWC Pacific and SEA Inc. (Dr. Brandon Southall) are also funded to work collaboratively with Dr. Robin Baird to document MFAS exposures on tagged whales and investigate if there are detectable behavioral responses of the tagged whales to the MFAS activities. NIWC Pacific's main portion of the effort is focused on estimating the received level at which the animals are exposed. During this period, collaborative work focused on analysis of tagged animals from 2016-2018 utilizing primarily the same methods utilized in prior efforts (Baird et al., 2017, Baird et al., 2019). Future work will look at data from all years for the most frequently tagged species (rough-toothed dolphins and short-finned pilot whales) and utilize newer methods involving continuous movement models and estimating received levels in a more robust way by extending to full 3D sound fields vice the previous 2D methods.

- The ONR E-BREVE effort aims to investigate how whale behavior is influenced by natural environmental variables including background noise, weather, and climate oscillations. So far, minke whale and humpback whale call source levels have been investigated how they change with background noise levels, and how calling behavior changes during high wind and wave activity. The results from E-BREVE will help to contextualize baleen whale response to Navy sonar (BREVE project).

- Another related project funded by LMR (PIs: Dr. Elizabeth Henderson at NIWC Pacific and Susan Jarvis at NUWC Newport) is an evaluation of existing Navy sonar detectors and their performance on different sonar signal types recorded by different instruments in varied environments. The ultimate goal of the project is to either modify an existing detector or develop a new detector or suite of detectors that can be shared with the bioacoustics community, such that all organizations tasked with detecting sonar as part of a behavioral response assessment are using the same algorithms and tuning recommendations. This would help ensure data consistency across organizations and analyses, and provide some assurance that sonar metrics and potential impacts are reported commensurably. In addition, unclassified descriptions of Navy sonar signals will be compiled and shared across the bioacoustics community as well, so that in addition to analyzing the data in a similar manner, the results can be described consistently as well to provide clarity when evaluating potential sonar impacts. While the current NIWC Pacific sonar detector does a good job of detecting hull-mounted MFAS signals, its detection capabilities of additional sonar signals could be improved and therefore NIWC Pacific would be a beneficiary of the results of this LMR effort. The updated detector could be applied to existing and future PMRF raw data to assess the presence and potential impacts of additional sonar signals, thereby increasing the breadth of our impact and disturbance analyses.

- Using context to improve marine mammal classification is a multi-disciplinary project with team members from San Diego State University, The University of St Andrews, The National Oceanic and Atmospheric Administration, the University of Hawaii, and NIWC Pacific. The goal is to develop new methods to provide context-sensitive, species-level classification of marine mammal vocalizations. The methods used incorporate automated localization of calls into classification frameworks, use contextual information such as neighboring detections to inform classification decisions, and exploit recent developments in deep learning that enable classifiers to incorporate contextual information into the learning process. Dr. Tyler Helble is a team member providing expertise in context-based classification and transitioning relevant software to the post-doctoral students on this project.

5 FY19 Publications from Navy Funded Monitoring

Harris, C.M., Martin, S.W., Martin, C.R., Helble, T.A., Henderson, E.E., Paxton, C.G.M., Thomas, L. 2019 (spatial analysis pub) 2019. Changes in the Spatial Distribution of Acoustically Derived Minke Whale (*Balaenoptera acutorostrata*) Tracks in Response to Navy Training. Aquatic Mammals, 45(6), p.661-674

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6 FY19 Presentations from Navy Funded Monitoring

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