SSC Pacific FY16 annual report on

PMRF Marine Mammal Monitoring

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14. ABSTRACT
This report documents SSC Pacific marine mammal monitoring efforts in FY16 for COMPACFLT at the Pacific Missile Range Facility (PMRF), including during U.S. Navy mid-frequency active sonar (MFAS) training. Data products (i.e., recorded hydrophone data, standard PMRF range products, and range craft deployed calibrated hydrophone data) were obtained and analyzed using custom detection, classification and localization tools described herein. Results of fully automated processing (i.e.. quick looks) are presented for all data collections throughout the fiscal year documenting relative abundance estimates for Blainville’s beaked whale foraging dives and the number of baleen whale call localizations for minke, humpback, and a combined category of fin, sei and Bryde’s whales. Metrics utilized were the number of Blainville’s beaked whale foraging dives per hour and the number of baleen whale call localizations per hour. In addition, similar analyses were conducted on recorded data from 2007 to 2011 for beaked whales, humpback whales, and minke whales (hydrophones then did not have sufficient low frequency bandwidth for the low frequency species). As expected, the humpback and minke whales showed a clear seasonal (November-May) presence at PMRF over the four year period as well as in 2016. The low-frequency baleen whale category also indicates a seasonal presence, but with detections occurring as early as September; these may be due to Bryde’s whales that may be present year-round and to date have been acoustically detected in August through October 2014 data. In contrast, beaked whales are present year-round. All species show clear decreases in vocal presence during training activity. However, no long-term trends in the occurrence of any species is evident; while there is some inter-annual variability (particularly in beaked whales) the overall number of detected and localized baleen whale calls or beaked whale groups remains consistent across 2007-2011. The occurrence for these species appears higher in 2016 compared to the 2007-2011, but the data have not been

normalized for the different spatial coverage from the different hydrophones recorded (e.g., coverage for beaked whales from 2007-2011 with only 13 hydrophones is much less than coverage with 62 hydrophones in 2016). Emerging capabilities are described, including additional automation in the areas of tracking baleen whale localizations and snapshot analyses of the resultant tracks for density estimation. The tracking and snapshot capabilities were implemented in custom Matlab® algorithms. Twenty-five minke whale tracks were generated over 98 hours (hr) of data from 17 to 21 February 2014 with the snapshot analysis and show a maximum of five individual minke whales present at once. The number of localized and tracked minke whales appeared to decrease during MFAS training as has previously been observed (Martin et al. 2015). At least two instances of potential behavioral responses (cessation of calling) have been identified for follow-on analyses including estimated exposure levels. Exposures were also analyzed as cumulative sound exposure levels (CSEL) on an individual minke whale tracked over a period of approximately 90 min of MFAS exposures at the onset of the SCC on 16 February 2016. This is a new capability which accounts for all acoustically localized MFAS transmissions from the custom C++ algorithm for a single ship on a single tracked whale. The CSEL was estimated at 148.7 dB re µPa2s on one minke whale from one MFAS ship over this time period. The whale ceased calling, potentially indicating a behavioral response to the MFAS exposures. The ship was from 20 km to 60+ km distant with the maximum non-cumulative sound exposure level of 137.3 dB re µPa2s, which is over 10 dB less than the CSEL when accounting for multiple pings. While the analysis presented here only considered the cumulative exposures from one ship, the methods are being extended for accumulating over pings from multiple MFAS ships. Several analyses were also conducted on validated Blainville's beaked whale detections, including a comparison of detection algorithms with NUWC and a density analyses using the combined datasets from both organizations, demonstrating the power of combining data (subsampled across 2011-2014). These analyses also support the idea of consistent occurrence patterns over time with some inter-annual variability, as the densities estimated from the combined datasets were found to be between 11.6 and 16.3 whales/440 km2 over all four years. Finally, the potential behavioral responses of groups of Blainville's beaked whales were assessed by examining changes in vocal behavior relative to received levels (RLs) at the group from MFAS, the distance between the source ship and the group, and the heading of the ship. Groups that responded by ceasing to vocalize at the onset of sonar had higher RLs than those that did not stop calling when sonar started. The source vessel was found to generally be closer to the group when groups responded to sonar versus those that didn't respond, and during periods of MFAS groups more often responded when the ship was approaching them than when it was headed parallel or away from them. Taken together, these results begin to tease out the contextual factors that contribute to whether or not a response occurs in Blainville's beaked whales to training activity that includes MFAS.The results of our passive acoustic monitoring efforts and the application of our detection and classification tools have been included in several publications that were submitted or published in 2016. These papers examine both the baseline behavior and habitat use of several whale species at PMRF and explore trends in these patterns over time, as well as assess behavioral responses to U.S.Navy training activity. Collaborative work occurred with R.W Baird and B. Southall under a NAVFAC contract to HDR Inc. for estimating exposure levels that nine tagged odontocetes were exposed to between 2013 and 2015. The effort made improvements to the received level estimation process compared to earlier work. Late in 2016 collaborative work began to perform similar effort with M. Deakos and J. Mobley for 2014-2016 aerial sighting data.

15. SUBJECT TERMS

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1 Executive Summary

This report documents Space and Naval Warfare Systems Center Pacific (SSC Pacific) marine mammal monitoring efforts in FY16 for COMPACFLT at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii, including during U.S. Navy mid-frequency active sonar (MFAS) training. Data products (i.e., recorded hydrophone data, standard PMRF range products, and range craft deployed calibrated hydrophone data) were obtained and analyzed using custom detection, classification and localization tools described herein.

Results of fully automated processing (i.e.. quick looks) are presented for all data collections throughout the fiscal year documenting relative abundance estimates for Blainville's beaked whale foraging dives and the number of baleen whale call localizations for minke, humpback, and a combined category of fin, sei and Bryde's whales. Metrics utilized were the number of Blainville's beaked whale foraging dives per hour and the number of baleen whale call localizations per hour. In addition, similar analyses were conducted on recorded data from 2007 to 2011 for beaked whales, humpback whales, and minke whales (hydrophones then did not have sufficient low frequency bandwidth for the low frequency species). As expected, the humpback and minke whales showed a clear seasonal (November – May) presence at PMRF over the four year period as well as in 2016. The low-frequency baleen whale category also indicates a seasonal presence, but with detections occurring as early as September; these may be due to Bryde's whales that may be present year-round and to date have been acoustically detected in August through October 2014 data. In contrast, beaked whales are present year-round. All species show clear decreases in vocal presence during training activity. However, no long-term trends in the occurrence of any species is evident; while there is some inter-annual variability (particularly in beaked whales) the overall number of detected and localized baleen whale calls or beaked whale groups remains consistent across 2007-2011. The occurrence for these species appears higher in 2016 compared to the 2007-2011, but the data have not been normalized for the different spatial coverage from the different hydrophones recorded (e.g., coverage for beaked whales from 2007-2011 with only 13 hydrophones is much less than coverage with 62 hydrophones in 2016).

Emerging capabilities are described, including additional automation in the areas of tracking baleen whale localizations and snapshot analyses of the resultant tracks for density estimation. The tracking and snapshot capabilities were implemented in custom Matlab® algorithms. Twenty-five minke whale tracks were generated over 98 hours (hr) of data from 17 to 21 February 2014 with the snapshot analysis and show a maximum of five individual minke whales present at once. The number of localized and tracked minke whales appeared to decrease during MFAS training as has previously been observed (Martin et al. 2015). At least two instances of

potential behavioral responses (cessation of calling) have been identified for follow-on analyses including estimated exposure levels.

Exposures were also analyzed as cumulative sound exposure levels (CSEL) on an individual minke whale tracked over a period of approximately 90 min of MFAS exposures at the onset of the SCC on 16 February 2016. This is a new capability which accounts for all acoustically localized MFAS transmissions from the custom C++ algorithm for a single ship on a single tracked whale. The CSEL was estimated at 148.7 dB re $\mu Pa^2 s$ on one minke whale from one MFAS ship over this time period. The whale ceased calling, potentially indicating a behavioral response to the MFAS exposures. The ship was from 20 km to 60+ km distant with the maximum non-cumulative sound exposure level of 137.3 dB re $\mu Pa^2 s$, which is over 10 dB less than the CSEL when accounting for multiple pings. While the analysis presented here only considered the cumulative exposures from one ship, the methods are being extended for accumulating over pings from multiple MFAS ships.

Several analyses were also conducted on validated Blainville’s beaked whale detections, including a comparison of detection algorithms with NUWC and a density analyses using the combined datasets from both organizations, demonstrating the power of combining data (subsampled across 2011-2014). These analyses also support the idea of consistent occurrence patterns over time with some inter-annual variability, as the densities estimated from the combined datasets were found to be between 11.6 and 16.3 whales/440 km^2 over all four years. Finally, the potential behavioral responses of groups of Blainville’s beaked whales were assessed by examining changes in vocal behavior relative to received levels (RLs) at the group from MFAS, the distance between the source ship and the group, and the heading of the ship. Groups that responded by ceasing to vocalize at the onset of sonar had higher RLs than those that did not stop calling when sonar started. The source vessel was found to generally be closer to the group when groups responded to sonar versus those that didn’t respond, and during periods of MFAS groups more often responded when the ship was approaching them than when it was headed parallel or away from them. Taken together, these results begin to tease out the contextual factors that contribute to whether or not a response occurs in Blainville’s beaked whales to training activity that includes MFAS.

The results of our passive acoustic monitoring efforts and the application of our detection and classification tools have been included in several publications that were submitted or published in 2016. These papers examine both the baseline behavior and habitat use of several whale species at PMRF and explore trends in these patterns over time, as well as assess behavioral responses to U.S.Navy training activity. Two papers were published that dealt with Blainville’s beaked whale group foraging dives. One paper examined baseline occurrence and foraging dive activity over a three-year period (2011-2013), and one documented the reduction in Blainville’s beaked whale dives in response to six U.S. Navy MFAS training events conducted over the same period. A third paper documented Bryde’s whale encounters observed from analyses of PMRF recorded data and assessed their movement and potential social behavior. Finally, a fourth paper was submitted for peer review publication on the behavior of acoustically tracked humpback whales with baseline PMRF recorded data collected between September and June (2011-2014) implementing new kinematic tools in the analyses to derive metrics used to determine baseline behavioral states. Understanding baseline vocal behavior and habitat use will allow us to better assess responses to sonar and other training activity in future analyses.

Collaborative work occurred with R.W Baird and B. Southall under a NAVFAC contract to HDR Inc. for estimating exposure levels that nine tagged odontocetes were exposed to between 2013 and 2015 (reported separately under R.W. Baird’s HDR effort). The effort made improvements to the received level estimation process compared to earlier work. Late in 2016 collaborative work began to perform similar effort with M. Deakos and J. Mobley for 2014-2016 aerial sighting data.

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3 List of Acronyms

BARSTUR – Barking Sands Tactical Underwater Range

BSURE – Barking Sands Underwater Range Expansion

COMPACFLT – Commander Pacific Fleet

DCLDE – Detection, classification, localization and density estimation

DCLTDE – Detection, classification, localization, tracking and density estimation. The SSC Pacific DCLTDE Laboratory is located in San Diego, CA

FY – Fiscal year

GPL – Generalized Power Law detection process

GVP – Group vocal period

HFM – High frequency modulated

IRIG – Inter-Range Instrumentation Group time code format for timing information

LMR – Living Marine Resources program

M3R – Marine Mammal Monitoring on Navy Ranges, a Naval Undersea Warfare Center program which consists of multiple computers in a system installed at U.S. Navy ranges for detecting and localizing marine mammals.

Matlab – Mathworks copyrighted scientific software environment

MFAS – Mid-frequency active sonar (1-10 kHz) primarily from surface ship sonar

NUWC – Naval Undersea Warfare Center, Newport, RI

OASIS – Ocean Acoustical Services and Instrumentation Systems (OASIS), Inc., Lexington, MA, United States, developer of Peregrine, a parabolic equation propagation model

ONR – Office of Naval Research

PAM – Passive acoustic monitoring

PCIMAT – Personal Computer Interactive Multisensor Acoustic Training

PMRF – Pacific Missile Range Facility, Kauai, HI

SCC – Submarine Commanders Course training event

SSC Pacific– Space and Naval Warfare Systems Center Pacific

4 Introduction

In fiscal year (FY) 2016 the Space and Naval Warfare Systems Center Pacific (SSC Pacific) Detection, Classification, Localization, Tracking, and Density Estimate (DCLTDE) Laboratory (San Diego, CA) automatically processed data recorded from bottom mounted hydrophones at the Pacific Missile Range Facility (PMRF) to detect and localize several species of marine mammals and estimate received levels (RLs) from mid-frequency active sonar (MFAS) transmissions. This ongoing passive acoustic monitoring (PAM) effort has focused on passive acoustic data collection and cataloging in addition to the baseline occurrence, habitat use, and density estimation of marine mammals at PMRF. In addition, this effort has focused on evaluating the occurrence, exposure, and response of marine mammals relative to the Submarine Commanders Course (SCC) training event. Estimation of marine mammal exposures from MFAS and possible subsequent behavioral reactions has been performed by analyzing data collected before, during, and after SCC training events held biannually in February and August since 2011.

Automated processing has progressed over the past several years such that when hydrophone data arrive at the DCLTDE laboratory, they are automatically processed for detecting and localizing marine mammal calls from fin whales (*Balaenoptera physalus*), sei whales (*Balaenoptera borealis*), Bryde's whales (*Balaenoptera edeni*), minke whales (*Balaenoptera acutorostrata*), sperm whales (*Physeter macrocephalus*), Blainville's beaked whales (*Mesoplodon densirostris*) and other beaked whales with frequency modulated echolocation clicks (e.g., Cuvier's beaked whale (*Ziphius cavirostris*) foraging clicks and Cross Seamount-type clicks) and a newly developed killer whales (*Orcinus orca*) high frequency modulated vocalization detector. In addition, MFAS detections are automatically processed and localized for exposure analysis efforts. Beaked whale dive groups were automatically detected and localized to the nearest hydrophone locations. Killer whales were automatically detected and future efforts will attempt to localize whales to the nearest hydrophone location, similar to beaked whales. All other species were localized as individuals when possible.

Descriptions of automated processing methods are briefly described herein with references to more detailed descriptions in previous reports and publications. Presence, occurrence, and relative abundance of species automatically processed are presented as a quick look for all available acoustic data recordings since the prior annual report (Martin et al. 2016). At the time of this report, FY16 data available for post-processing at the DCLTDE laboratory spanned from 28 August 2015 to 7 September 2016.

Utilizing recorded data, a test case analysis of MFAS exposures is provided with estimated RLs and potential behavioral responses for minke whales. In the San Diego laboratory, minke whales were automatically detected and localized using the C++ algorithms. The minke whale localizations were then semi-automatically tracked using Matlab® (R2014a, The Mathworks Inc., Natick, MA) algorithms, with kinematic processes tuned for the species' call rates and swim speeds. Animals received exposures to multiple MFAS transmissions that were expressed as a cumulative sound exposure level (CSEL), and the sonar equation was used for propagation modeling (future efforts will utilize more sophisticated propagation models to estimate the transmission losses).

A comparison of automatically detected Blainville's beaked whale dives was conducted between subsets of data (from March 2011, July 2011, January 2012, and February 2014) recorded by Naval Undersea Warfare Center (NUWC) and SSC Pacific. Finally, an analysis of individual group responses by Blainville's beaked whales to U.S. Navy training activities and MFAS is summarized.

5 Data Collection

Standard PMRF range data products have been obtained from PMRF for biannually-held Submarine Commanders Course (SCC) training events since February 2011. The PMRF standard data products have provided locations for all platforms from the start to finish of training events, but normally not between events. Recorded acoustic data from subsets of PMRF's bottom mounted hydrophones were also collected to support analysis for marine mammal vocalizations.

Two types of acoustic recordings were obtained in FY16. The standard recordings (Table 1) were full bandwidth recordings at the 96 kilohertz (kHz) native sample rate for 62 hydrophones. In addition, recordings at a reduced sample rate of 6 kHz (Table 1), referred to as decimated data, were collected on the 47 wide-band hydrophones. Decimated data collections (Figures 1-3) between August 2015 and September 2016 captured 34% of the total time between August 2015 and September 2016 while full bandwidth collections accounted for 13% of the same total time period. Decimated data provides higher data density and can record 16 times more data than a full bandwidth data collection on a similarly sized disk, but does not record the higher frequency data from Blainville's beaked whales, sperm whales, and killer whales.

A new capability was added in FY16 to decimate data collected at the 96-kHz sample rate, which essentially duplicates data below 6 kHz from the 47 wide-band hydrophones. Full bandwidth data were decimated in order to obtain baseline information on baleen species for comparison to observations made during training events. For baseline analyses, decimation ensures that all data are in a comparable format and enhances processing efficiency thereby reducing processing time for large data sets.

Table 1. Approximate number of hours of multiple channel hydrophone data since data collections started in 2003.

Number of hydrophones recorded	Sample rate (kHz)	Hours of acoustic recordings					
		Feb 2002-Sep 2006	Mar 2007-Jan 2011	Jan 2011-Aug 2012	Aug 2012-Sep 2014	Oct 2014-Aug2015	Aug 2015-Sep2016
24	44.1	730					
31	96		2901	2422			
62 (incl. all 41 BSURE replacements)	96				2288	1289	1268
47 (decimated data)	6				676	4357	2894

Collecting raw acoustic data has been pivotal in developing, testing, and improving new and existing automated algorithms that have processed thousands of hours of multi-channel data to date. In addition, a major benefit to collecting raw acoustic data is that it allows future reprocessing with additional emergent marine mammal species' DCLTDE algorithms, as demonstrated by processing historic data collected between 9 March 2007 and 11 January 2011 (Table 1) using the most recent automated processing algorithms. These data were recorded at the 96-kHz sample rate for 31 hydrophones (including six Barking Sands Tactical Underwater Range [BARSTUR] broadband hydrophones, four BARSTUR high-pass hydrophones, three Shallow Water Training Range [SWTR] high-pass hydrophones, and the 18 Barking Sands Underwater Range Expansion [BSURE] mid-pass hydrophones). Due to the frequency response of these 31 hydrophones (ranging from 100 Hertz [Hz] to 48 kHz), baleen whale low-frequency calls under 100 Hz (e.g., from fin, sei, blue [*Balaenoptera musculus*], and Bryde's whales) are not detectable. Species that are currently automatically detectable with these data include minke whales, humpback whales (*Megaptera novaeangliae*), Blainville's beaked whales, and sperm whales. The low-frequency baleen whale detector detects calls from multiple baleen whale species (e.g., fin, sei, Bryde's whales) to allow localization and tracking with manual verification efforts. When automated detection algorithms are developed and implemented for additional species in the future, historic data can be reprocessed for the additional species.

An issue (e.g., varying amplitudes and incorrect times) with the Inter-Range Instrumentation Group (IRIG) recorded time code signals was reported previously in the FY15 annual report (Martin et al. 2016). The issue was addressed during the August 2016 SCC, and efforts continue to resolve other ongoing IRIG issues.

During some of the SCC training events there has been an effort involving range support personnel to collect recordings from a calibrated near-surface hydrophone and time-depth data logger deployed over the side of a weapon retrieval vessel. This effort is intended to collect

MFAS signals near the surface in order to validate surface RLs estimated by Peregrine (Heaney and Campbell 2014) parabolic equation propagation modeling (Ocean Acoustical Services and Instrumentation Systems (OASIS), Inc., Lexington, MA).

Ongoing effort has included effort on transitioning from recording acoustic data on a Windows PC recorder (which has been utilized since collection began in February 2002), to a Linux packet recorder node included within NUWC's Marine Mammal Monitoring on Navy Ranges (M3R) architecture. Concurrent data collections on both recording systems occurred during the February and August 2016 SCCs at PMRF. The goal was to validate data collected on the M3R packet recorder node with the Windows PC recorder. Analysis of the concurrent collections revealed issues that are being worked on collaboratively with NUWC and SSC Pacific.

6 Automated Detection, Classification, and Localization Algorithms

Multiple algorithms are utilized in processing PMRF recorded data for marine mammal vocalizations and localization when possible. A custom C++ detection algorithm automatically processes for detections for beaked whales, sperm whales, baleen whales (minke and a low-frequency group of whales) with recent addition for detecting killer whale high-frequency modulated calls. A custom C++ localization algorithm localizes baleen and sperm whale detections. The two custom C++ algorithms, which also process for detection and localization of MFAS signals, currently run on both recorded data at approximately five times faster than real-time for native 96-kHz sample rate data and in real-time on the M3R system. A third custom Matlab algorithm processes for humpback whale song detections and localizations on recorded data only. These algorithms are briefly described below.

The custom C++ detection algorithm processes 62 hydrophone data at 96-kHz sample rate in addition to the 6 kHz decimated long term recordings. The algorithm is under configuration control, with the latest update (Baseline 3 dated October 20, 2016) adding a killer whale high frequency modulated (HFM) call detector and performing additional tests of the IRIG signal.

The custom C++ detection algorithm utilized the same front end processing for all species and was described in detail in Martin et al. 2015. The front end processing utilized 16k sample length fast Fourier transforms (FFTs) which provided improved signal to noise ratios compared to processing with shorter length FFTs such as in the M3R system (i.e., 2k sample FFTs). Decimated data were sampled at $1/16^{th}$ the full band rate with 1k FFTs for the same spectral bin resolution. Detection processing also required marine mammal vocalizations to have signal duration thresholds (e.g., the first stage of minke whale boing detection requires the call to be at least 0.8 seconds [sec] duration). Different frequency bands were utilized for various species' calls (e.g., low-frequency baleen calls were processed under 100 Hz and minke whale boing calls were processed from 1,350 to 1,440 Hz). Beaked and sperm whale detection processing was performed over the full 48-kHz bandwidth and required specific ratios of in-band energy (24-48 kHz for beaked whales and 3-10 kHz for sperm whales) to out-of-band energy (5-24 kHz for beaked whales and 20-48 kHz for sperm whales).

The new killer whale HFM algorithm was implemented given the previous sighting of killer whales in the area (Baird et al. 2012) and multiple observations of HFM signals in the 15- to 35-kHz band in recorded data. While the HFM signals have similarities to published information for the North Pacific killer whales (Simonis et al. 2012 and Filatova et al. 2012) there are some differences (e.g., some with longer durations). The most recent observation of the down-swept ultrasonic HFM calls occurred at PMRF on 10 February 2016 using manual methods. Subsequently, on 14 February 2016. local fishermen reported to R.W. Baird that they sighted (and provided a photograph) a single adult killer whale off the east side of Niihau that afternoon (R.W. Baird, Cascadia Research, personal communication). The new automated capability was later added to the baseline 3 C++ algorithm to detect the HFM signals in historical recorded data and will be refined in the future; the current version detects the stronger (over 30 decibels [dB] signal-to-noise ratio [SNR]), longer duration signals (required to be at least 0.37 sec in duration) having a down swept feature, as these could be detected with low false positive rates. HFM signals have been automatically detected (and manually verified) in PMRF full bandwidth data from 21 April 2011, 10 October 2014, 30 October 2014 as well as the 10 February 2016 data sets.

Classification processing was also performed within the custom C++ detection algorithm for minke and beaked whales. Minke whale boings were classified by reprocessing the detections to generate spectra with frequency resolution under 1 Hz for extracting features for classification (Martin et al. 2015). Beaked whale foraging echolocation clicks were classified by reprocessing the detections for high temporal resolution and requiring up-sweep frequency modulation fitting with literature for Blainville’s beaked whales (Johnson et al. 2006, Manzano-Roth et al. 2016, Henderson et al. 2016). Beaked whale inter-click intervals (ICIs) were also utilized for species classification. Current classification algorithms are for Blainville’s beaked whales only; however, algorithms for Cuvier’s beaked whales and the Cross Seamount beaked whale (McDonald et al. 2009) are in development.

The C++localization algorithm (described in Martin et al. 2015) was implemented in 2013 and is model-based, comparing observed and expected call arrival times. This algorithm localized baleen calls and sperm whale clicks by utilizing automatic detector start times across multiple hydrophones (with a minimum of four, and up to dozens of hydrophone detections included in individual localizations). This method was chosen over the more computationally intensive process of cross correlating multiple hydrophone pairs. The C++ localization algorithm was implemented in a situational display program which also provided an ability for detections and localizations to be replayed over time for situational understanding (including items such as ship positions and tagged animal positions) and has been employed on recorded data at the DCLTDE laboratory.

In addition to performing DCL for marine mammal vocalizations, the custom C++ algorithms also included capabilities to detect and localize active sonar transmissions in the mid-frequency band (1 to 10 kHz). This allowed for precise information on the locations and times of MFAS transmissions for use in estimating RLs on marine mammals and behavioral response analyses.

A Matlab algorithm utilizes the Generalized Power Law detection (Helble et al. 2012) and also performs model-based localization using cross correlation to determine relative arrival times. The Matlab algorithm was initially incorporated for detecting and localizing humpback whales using sequences of song units (Helble et al. 2015; Henderson et al submitted). Humpback whale localizations reported in the previous report (Martin et al. 2016), utilized configuration control version 1 of the Matlab algorithm. For this report, version 2 of the Matlab algorithm was utilized and included the ability to detect and localize other species (e.g., Bryde's whales, Helble et al. 2016) and also utilized hydrophones located on southern BSURE and BARSTUR. These hydrophones were not used previously due to concerns with hydrophone geometry and a shallower bathymetry. Automated results that utilized these hydrophones are currently being analyzed for quality and accuracy, however, initial investigations have revealed seemingly good tracks of humpback whales around southern BSURE although the amount of false positive scatter was high in the new southern arrays. Regression analysis comparing the results between the two versions is also in process. These three algorithms were utilized to automatically process PMRF data in the DCLDE lab as the data became available after performing backups for data integrity. Results provide insight into basic presence information on the range for species currently implemented in the algorithms (i.e., a 'quick look' analysis).

6.1 Automatic Processing Results for Presence, Occurrence and Relative Abundance

The quick look analysis provided relative species abundance as the number of automatically localized calls per hour for baleen whales (Figures 1, 2, 3, 5and 6) and automatically derived beaked whale group foraging dives per hour (Figure 4 and 7). Quick look results include false positives for all species. The localizations per hour metric for baleen whales has reduced false positives when compared to a detections per hour metric, as not all detections are localized. The beaked whale group foraging dives per hour metric was derived from periods of time that contained beaked whale foraging echolocation click detections. When foraging clicks were detected on either a single hydrophone or two to three closely spaced hydrophones, and were constrained in time to under 1 hr, the assumption was that a group of beaked whales were performing a foraging dive in the area. These quick look results provide the starting point for detailed analyses of datasets used for peer reviewed journal articles and presentations.

Quick look results were plotted on a log scale for baleen whale localizations per hour and a linear scale for the number of beaked whale group foraging dives per hour. If the number of localizations per hour for a dataset was below 0.1 the metric was plotted as 0.1, because spurious localizations that were spatially and temporally isolated may result in values over 0.1 in quick look analyses. Metrics were also normalized by the duration of a dataset to obtain the number of localizations or dives per hour. It is important to consider the effect of dataset duration (width of gray regions in Figures 1-7) when interpreting the normalized metric in order to understand the raw number of localizations or dives that occurred. When a single whale is present for a short period of time and calling infrequently (such as minke and Bryde's whales) the localized calls per hour can be well under 1, while if multiple whales that call often (e.g., multiple humpback whales singing) are present, localized calls per hour is typically over 100 calls per hour.

Two data collections in late May 2016 were not processed to date due to IRIG not being recorded. The acoustic data is present and changes to the baseline C++ algorithm are required to recover results from these periods.

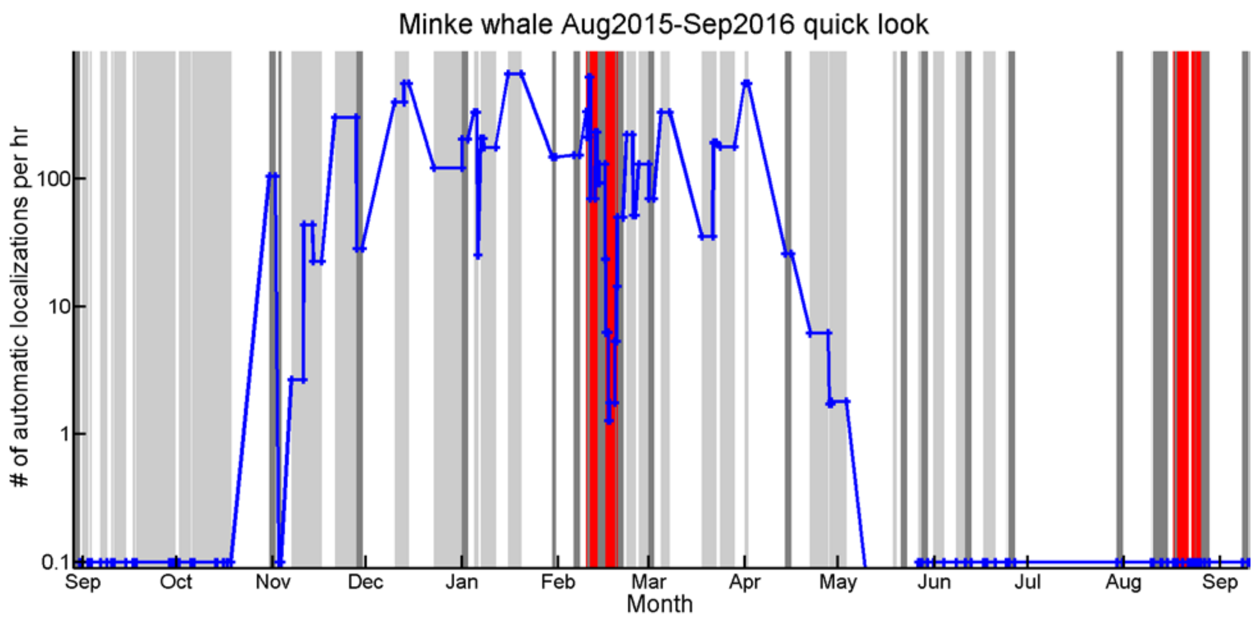

Figure 1. Quick look results of the number of automatically localized minke whale boing calls per hour, Sept 2015 to Sept 2016. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Red shaded regions were during phase A and B of the February and August SCCs when only full bandwidth data was collected. As automatically detected calls attributed to minke whales are also automatically classified, automatically processed minke whale results have few localized false positives.

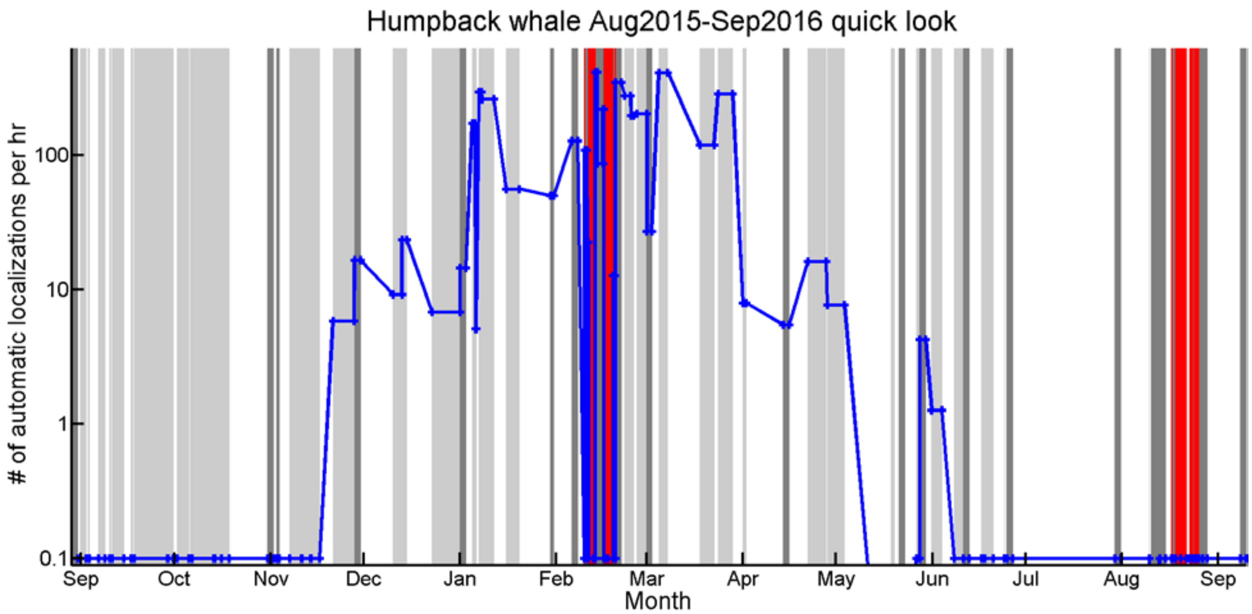

Figure 2. Quick look results of the number of automatically localized humpback whale vocalizations per hour Sept 2015 to Sept 2016. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Red shaded regions were during phase A and B of the February and August SCCs when only full bandwidth data was collected. However, humpback whale localizations during SCCs are not included in Figure 2 since false positive localizations have been observed during phase B of SCCs due to ship activity.

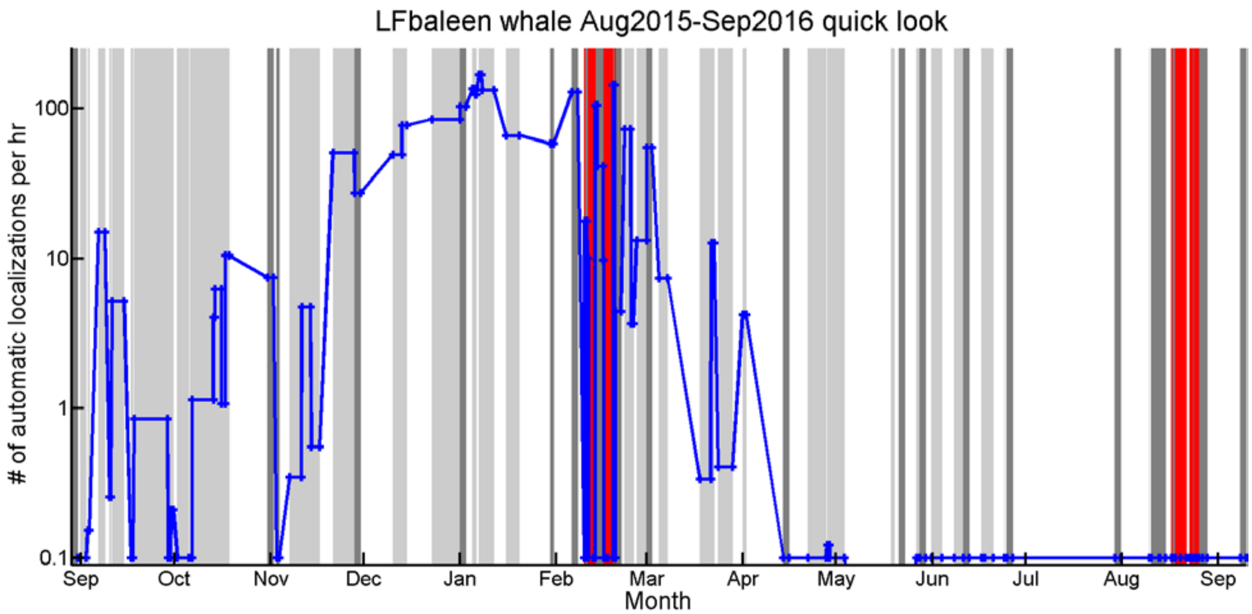

Figure 3. Quick look results of the number of automatically localized low-frequency baleen whale (not classified to species) calls per hour Sept 2015 to Sept 2016. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Red shaded regions were during phase A and B of the February and August SCCs when only full bandwidth data was collected. However, low-frequency baleen whale localizations during SCCs are not included in Figure 2 since false positive localizations have been observed during phase B of SCCs due to ship activity. Peaks outside of the expected seasonal presence could indicate localizations from low-frequency baleen species such as Bryde's whales, which may be present year round.

Species that emitted calls at more rapid rates had higher numbers of localizations for a single individual per unit time. For example, humpback whales produce song units every few seconds (Figures 2 and 6) and had more localizations per hour than minke whales (Figures 1 and 5). Thus, one should not compare the number of localizations across species without considering the species' call rates. A future goal is to provide the number of localized individual whales per hour for species that are localized as a more robust automated metric (see section 7.1 and 7.2.1 of this report). Notice that presence and abundance of migratory species (minke, humpback and some low-frequency baleen whales) shown in Figures 1-3, 5, 6, corresponds to expected seasonal migratory trends. Additional verification efforts have been performed when reporting on specific details (such as the estimated exposure analysis described later). Some peaks for low-frequency baleen localizations that have occurred out of the expected seasonal trend for migratory baleen whales have corresponded to the presence of Bryde's whales, which may be present year round (Martin and Matsuyama 2014, Helble et al. 2016). Automatically processed sperm whale detection and localization results were not included herein as this capability is still being refined.

The low-frequency (i.e.. under 100 Hz) baleen whale detection and localization process can detect multiple species' calls (e.g. fin, sei, Bryde's whales and potentially blue whale calls), but confusion exists in terms of automatic species classification. Rankin and Barlow (2007) documented calls from sei whales just north of Maui, with the majority of calls consisting of 39 Hz to 21 Hz downswept calls with 1.3-sec durations. The species identification was made by an experienced team of observers and was confirmed with biopsy samples. These types of calls had previously been thought to be attributed only to fin whales. Two other sei whale calls were also documented by Rankin and Barlow (2007), both sweeping down from 100 Hz to 44 Hz with 1-sec durations which are also similar to other *Balaenoptera* species' calls. When 20-Hz pulses were present in that data, the calls were assigned to fin whales. As to date these calls have not been attributed to any other species. In addition, low-frequency baleen and humpback whales' localizations during SCCs are not included in Figure 2 and 3 since false positive localizations have been observed during phase B of SCCs due to ship activity. Reporting false positive and spurious localizations during these periods may overestimate the number of localizations attributed to low-frequency baleen whales. Manual processes are currently involved for validation of species identification of low-frequency baleen whale detections and takes a significant amount of labor investigating the calls' waveforms, spectra, spectrograms, and temporal sequences.

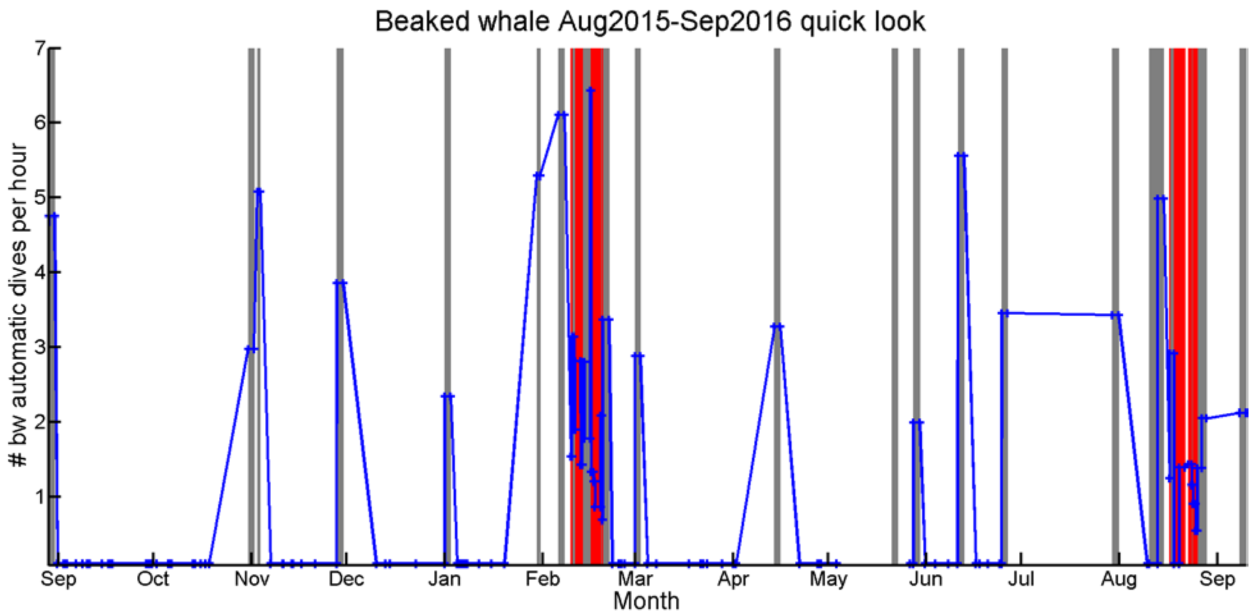

Figure 4. Quick look results of the number of automatically grouped beaked whale group foraging dives per hour Sept 2015 to Sept 2016. Gray shaded regions indicate availability of full bandwidth data (dark gray). Decimated data collections are not shown due to insufficient bandwidth for processing beaked whale clicks. White indicates periods of time when no data was collected. Red shaded regions were during phase A and B of the February and August SCCs when only full bandwidth data was collected. The false positive rate for automatically grouped beaked whale foraging dives has been shown to be a variable rate; for example, it was 3 to 42% of the total number of groups in 2013.

The beaked whale foraging click detector includes appreciable and variable false positives from other echolocating odontocetes even when utilizing a relatively high SNR requirement. The high detection SNR was utilized to help reduce false positives and to primarily detect clicks when beaked whales were scanning their echolocation beams towards a bottom hydrophone. This is justified as a group of three beaked whales in a 20-minute (min) dive vocal period can produce over 10,000 foraging clicks at three clicks per second. Characterization of the beaked whale foraging click detector has been done (Manzano-Roth et al. 2016) indicating that for a beaked whale click with a SNR over 25 dB the probability of detecting clicks was 0.39. The use of the automated beaked whale dive grouping in Figures 4 and 7 spatially and temporally organizes the detected clicks into beaked whale group dives. Manual validation of automatically detected and grouped beaked whale foraging group dives was performed during follow-on detailed analyses to ensure that false positives were removed (such as done in Manzano-Roth et al. 2016, Henderson et al. 2016). The overall number of dives per hour in Figure 4 is higher than has been reported in previous publications, and is much higher than the analysis of historical data presented below and in Figure 7. This is largely due to three factors. First, the 2016 analysis is using all 62 recorded hydrophones, whereas the 2007 to 2011 historical recorded data only had 13 hydrophones with bandwidth available for beaked whale clicks. Second, the data published previously on beaked whales were over the period 2011 through 2013 (Manzano-Roth et al. 2016, Henderson et al, 2016) which used 31 phones with the bandwidth needed for beaked whale clicks. Third, as mentioned above since this is an estimation of dives per hour based on non-validated data, it does include false positives that likely inflate the dive data. However, it could also be that there were more beaked whales detected at PMRF in 2016 than in previously analyzed years. A similar analysis conducted on 2015 data (Martin et al. 2016) demonstrated an increase in dives per hour in the latter half of the year, perhaps indicating an increase in beaked whale presence that has carried over into this year. As manual validation and analyses are conducted on this data, an examination of trends over time will be conducted.

Quick look analyses of the historic data collected between 9 March 2007 and 11 January 2011 is provided in Figures 5, 6, and 7 for minke, humpback, and beaked whales respectively. These automatically processed results are not directly comparable to results after 11 January 2011 since these historic data were collected using the old BSURE array of 18 hydrophones in two lines while the BSURE replacement hydrophones have a wider frequency response (respond under 100 Hz) and allow better localization since they have closer spacing.

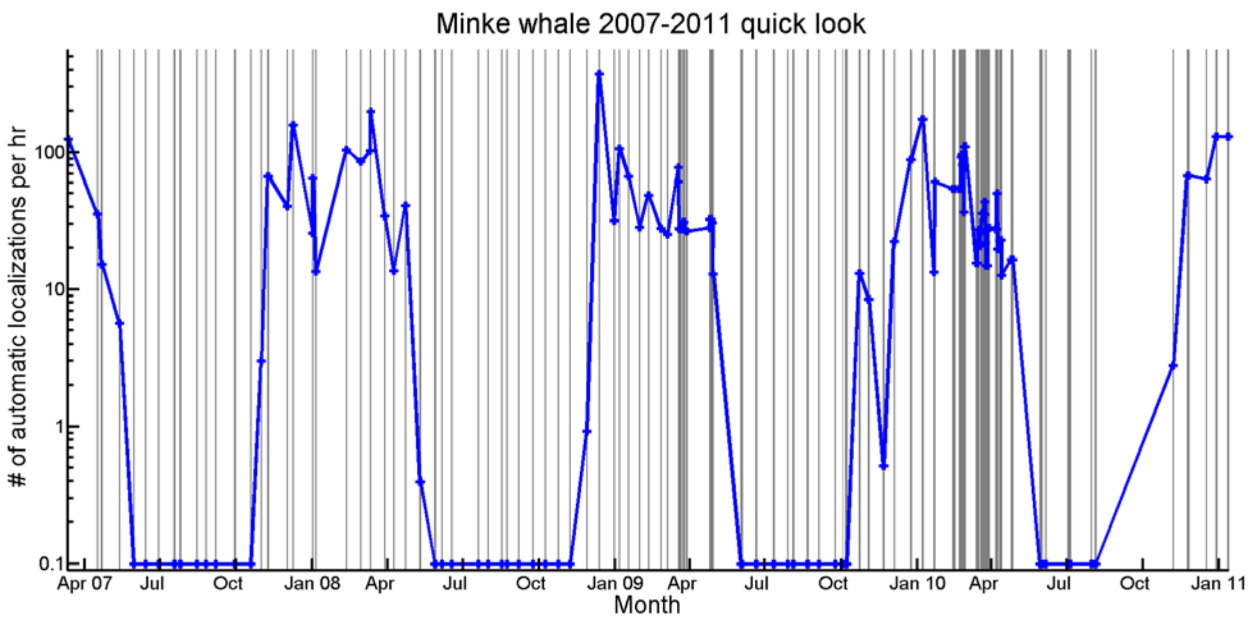

Figure 5. Quick look results of the number of automatically localized minke whale boing calls per hour in 2007 to 2011. Gray shaded regions indicate availability of full bandwidth data. White indicates periods of time when no data was collected. As automatically detected calls attributed to minke whales are also automatically classified, automatically processed minke whale results have few localized false positives.

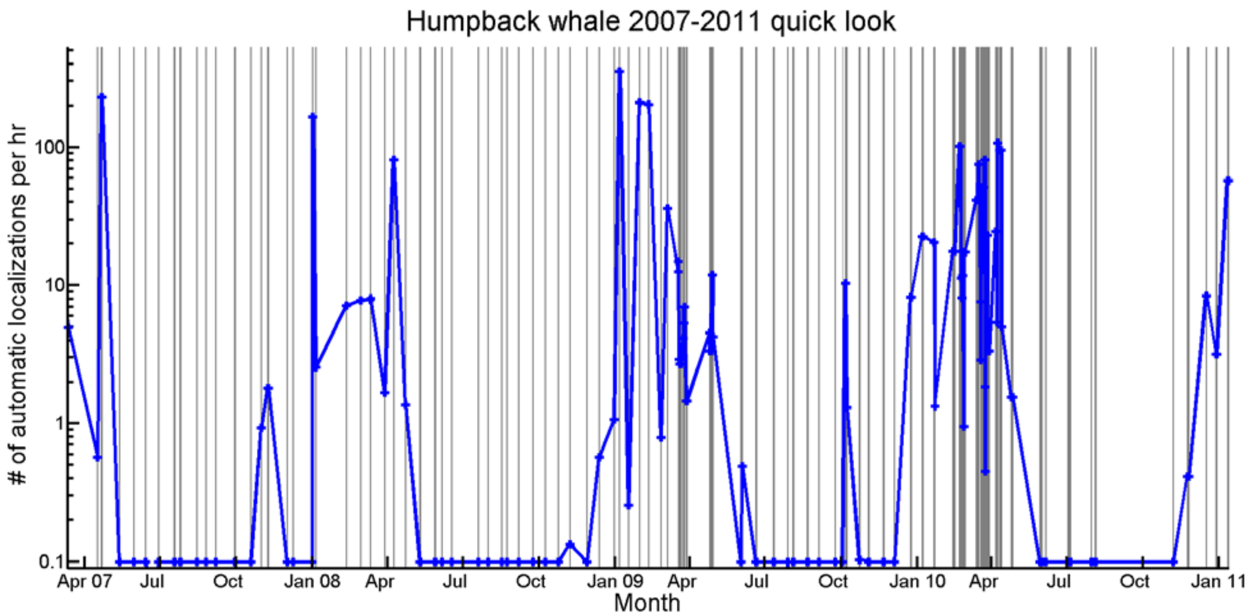

Figure 2. Quick look results of the number of automatically localized humpback whale calls per hour in 2007 to 2011. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Peaks outside of the expected seasonal presence could indicate localizations that are not humpback whales.

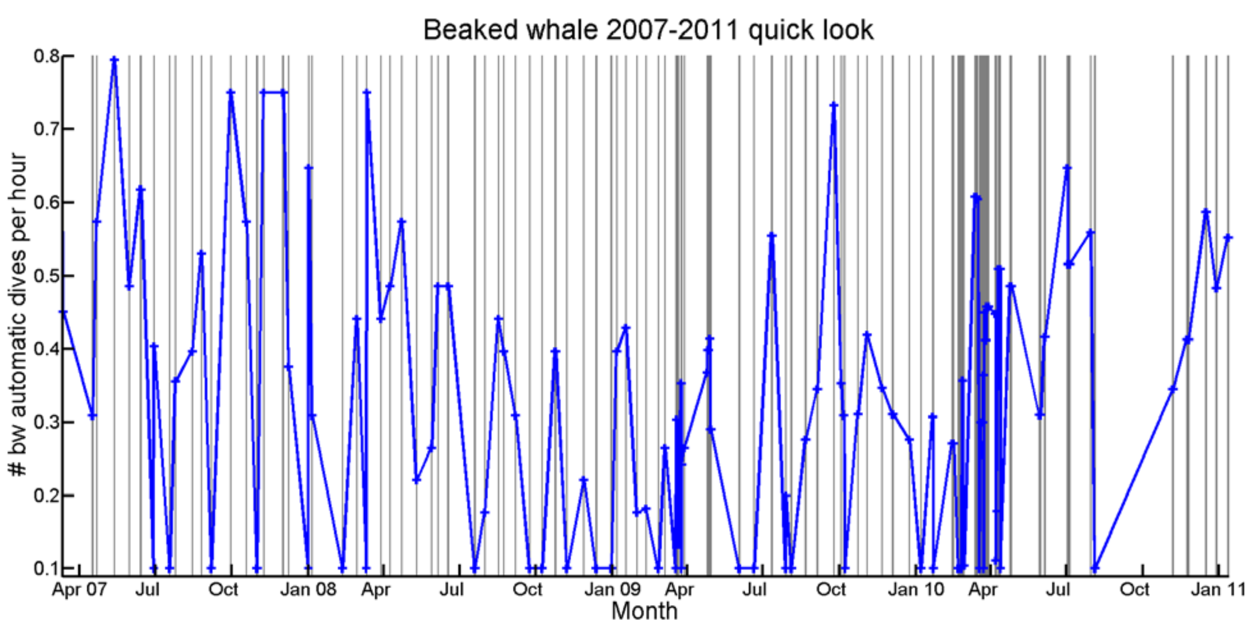

Figure 7. Quick look results of the number of automatically grouped beaked whale group foraging dives per hour in 2007 to 2011. Gray shaded regions indicate availability of full bandwidth data. White indicates periods of time when no data was collected.

7 Emerging Analysis Techniques

7.1 Semi-Automated Kinematic Tracking and Snapshot Analysis

Kinematic tracking of acoustic localizations was performed using a Matlab tracking algorithm developed under a previous ONR effort (Klay et al. 2015). The tracking algorithm used several parameter settings and performed spatiotemporal tracking of species localizations which were automatically generated by the custom C++ localization algorithm. Minke whale tracks are species specific, however the low frequency baleen category includes multiple species (e.g., fin, sei, and Bryde's whales) so tracks are not species specific. The tracking of the low frequency baleen group is termed track-before-classification as tracks are generated for species of whales which requires additional manual effort to determine the species. The tracking process could combine calls from multiple whales from the same processing algorithm output (e.g., minke whales or the low frequency baleen group of whales) as single tracks if their calls overlapped in both space and time. However, the cue rate output of the tracking algorithm would reveal the call rates having nearly twice the call rate expected from a single whale. The first stage of the tracking algorithm initiated tracks utilizing localizations that satisfied the user defined tracking parameters (i.e., minimum number of hydrophones utilized for a single localization solution, a minimum least square error between the modeled and actual time a signal arrived at a hydrophone) and occurred within the geographic boundaries of the defined study area. Localizations were added to a track when they occurred within a specified time of previous calls and were within the species-specific swim speed capabilities. Additional tracking parameters included a maximum coast time and a user defined minimum number of localizations (or calls) required for a track. The coast time was based on species-specific kinematics and was the maximum time allowed between successive localizations in a track. When the coast time was exceeded a new track was established. The minimum number of localizations required for a valid track filtered out tracks with small call counts as every localization is not tracked and many localizations result in spurious localization tracks with a single call count. In practice, good tracking parameters for minke whale boing tracking are 8 hydrophones for each localization, a least square error between the modeled and actual time a signal arrived at a hydrophone of 0.075 or less, and at least 8 calls localized calls for a valid track.

Tracking of localizations was implemented for automatically localized minke and low frequency baleen whales. Current semi-automated kinematic tracking allowed for counting individuals that were calling by utilizing snapshot analysis. This type of analysis provided an overview of a situation for a particular point in time and has been used to obtain density estimates of terrestrial animals (Buckland et al. 2001). For data collected at PMRF the first step of snapshot analysis added a random offset (between 60 and 300 sec) to the start of a data collection effort. From that point a snapshot would occur systematically every 10 min and times from all tracked localizations were checked to see if they occurred within a snapshot. If an individual whale track exists at the snapshot time that individual was tallied as present during the snapshot. Snapshots were aggregated every 60 min and the number of individuals present per hour was represented by the snapshot with the maximum number of individuals in an hour. This analysis is similar to the manual effort that was done to determine minke whale density estimates before, during, and after the February 2011-2013 SCCs (Martin et al. 2015). By automating this process, density estimates of calling baleen whales that are currently localized and tracked can readily be estimated using currently existing large baseline datasets. This also provides a more robust automatic metric (number of individual whales present per hour) than the number of localized calls per hour.

7.2 Minke Whale Exposures, Responses, and Estimated Received Levels

7.2.1 Automated Tracking during Anthropogenic Activity

An example of an application of automated kinematic tracking is as follows. The onset of the February 2014 SCC surface ship MFAS training occurred at 0700 on 18 February 2014 GMT and ended at 0226 on 21 February 2014. Figure 8 provides 25 minke whale tracks from the semi-automated Matlab tracking algorithm over this 98-hr period that includes more than one day of the weekend prior to the training. Over this period quite a few tracks were located west of the hydrophone array as shown in Figure 8, and four of the tracks included periods of rapid boing calling (nominally 2 or 3 per min) in addition to periods of the nominal boing call rate of one call every 5 or 6 min.

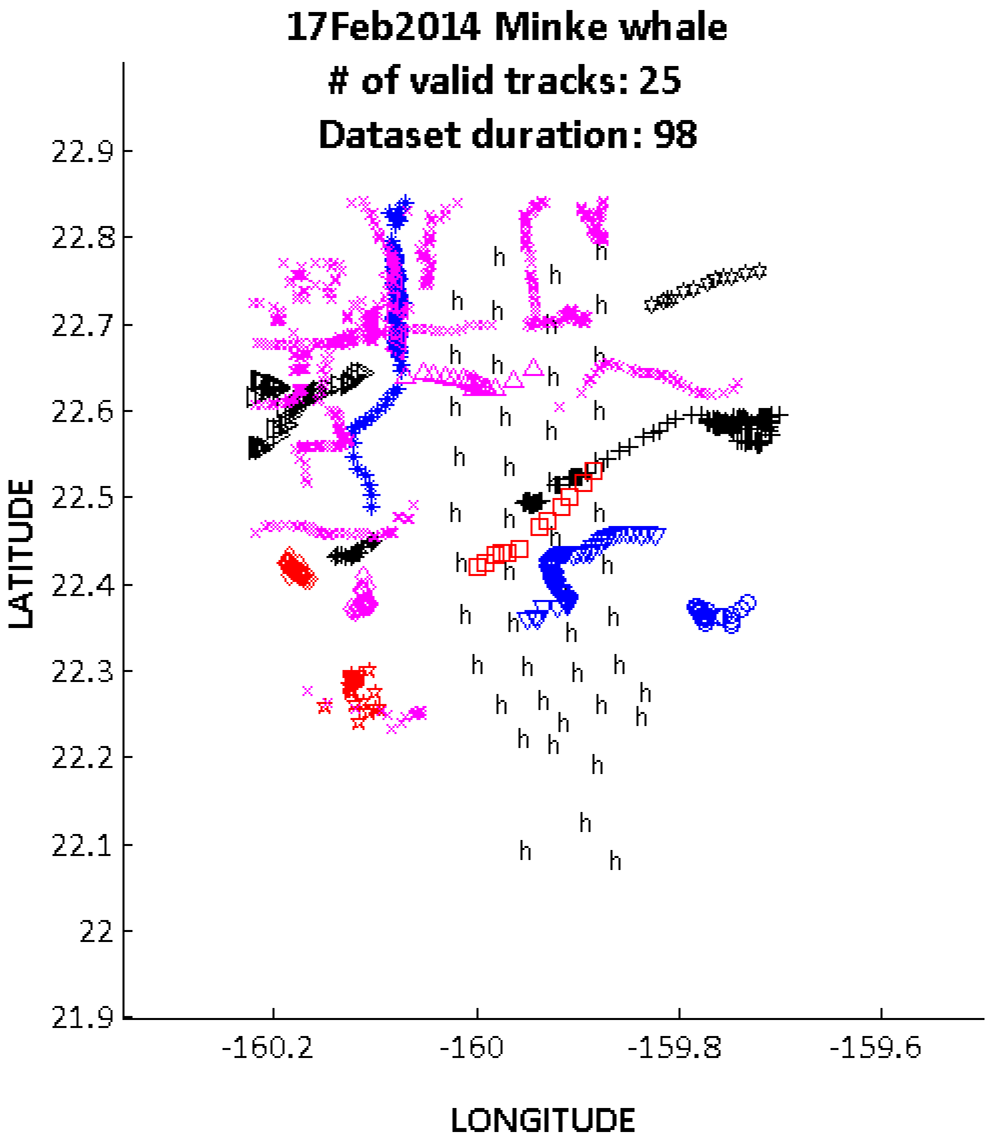

Figure 8. Minke whale tracks generated by the Matlab tracking algorithm over 98 hr of data from 17-21 February 2014. Symbols and colors change for the first 9 tracks, the remaining tracks are all shown with magenta x symbols. The "h" symbols are the approximate locations of the 47 broadband hydrophones used for baleen whale localization.

Figure 9 provides the snapshots per hour produced from the Matlab tracking algorithm over 4.5 days for these 25 tracks. Note the higher numbers of boing calling minke whales in the first day of data with a reduction during the periods of MFAS activity (represented by the gray vertical bars). This character is similar to what has been reported for minke whales for data from three training events in February of 2011, 2012 and 2013 (Martin et al. 2015). As previously mentioned, we are in the process of replacing the number of localized whale counts shown in

Figures 1 and 5 with counts of individual minke whales as determined by the tracking analysis output, and extending this metric to other localized whales.

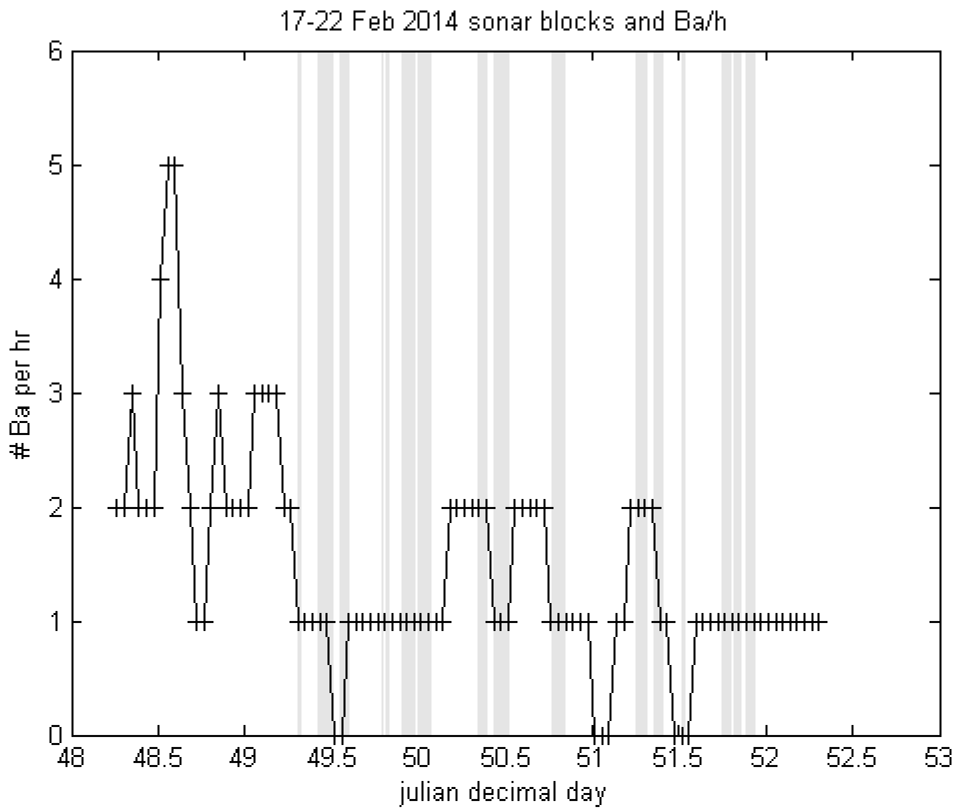

Figure 9. Snapshots per hour of individual minke whale counts over 98 hr of data (Ba/hour = the number of minke whale counts per hour). Time axis is in Julian decimal days for 17-21 February 2014. MFAS activity times are indicated by the gray vertical areas. The data include over a day prior to MFAS activity and several hours after MFAS activity.

Figure 10 provides details for minke whale track 12 that potentially ceased calling in response to the onset of the SCC. The left pane shows the latitude – longitude plan view of the minke whale track consisting of 73 calls over a period of 7+ hr beginning at the upper right and ending center left. The upper two plots on the right pane provide the inter-call-interval plotted against call number (top) and time in seconds from the beginning of the track (middle). The bottom plot on the right pane shows the derived estimated speed in m/s. The track changed at 0621 (39 min before the surface ship MFAS training portion of the SCC began, and 68 min before sonobuoy MFAS transmission) with an abrupt change of heading to the west with calls spatially grouped, indicating there was movement while not calling as compared with more evenly spaced localizations.

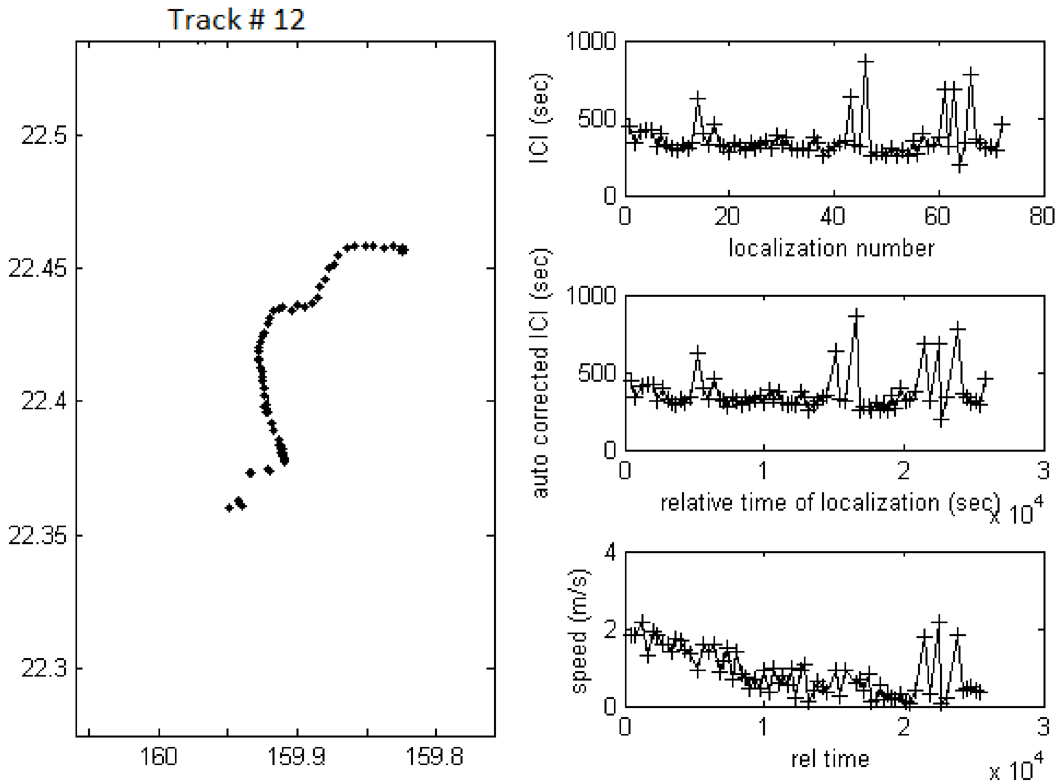

Figure 10. Minke whale track 12 between 0033 to 0745 on 18 February 2014. Track contained 73 calls at the nominal minke whale boing calling rate of 5 to 6 min (mean ICI 359.9 s) over 7.19 hrs of time. Estimated speed in m/s shown lower right. Track began near 22.45° N, 159.8° W and ended at 22.36° N 159.97° W

Figure 11 provides a contextual representation of anthropogenic activities occurring during track 12 on a latitude – longitude plan view. The tracked minke whale started vocalizing at 0033 on 18 February (upper right) and ended at 0745 after 73 calls. Ship tracks for the closest surface ship were available from 0707 to 0745. The anthropogenic activities related to U.S. Navy training are twofold: first, at 0729 active sonobuoy transmissions occurred for 4 min and 11+ kilometers (km) to the east of the whale, and second, at 0740 the closest point of approach of the surface ship to the minke whale was 2.2 km. One hypothesis is that the whale ceased calling in response to the approaching surface ship that was 2.2 km away and not transmitting MFAS. However, the sonobuoy MFAS transmissions could also be a contributor although they were over 11 km distant.

The whale changed behavior between 0621 and 0632, as indicated by a change in heading and call pattern. At the onset of the behavior change the travel speed slowed to near zero, followed by spatially clustered and separated calls. Call clusters were separated by estimated travel speeds between localizations on the order of 2 m/s. It is unclear if this is a 'normal' behavior (more baseline data needs investigated for the effect) or if it was brought about by some external events at around 0630. The raw acoustic data at the closest hydrophone to the whales' position at 0620 was investigated to see if the acoustic record could provide information that could be related to the whale's change of calling behavior. Around 0630 some higher frequency whistles (11-14 kHz) were observed (species uncertain), it is uncertain if those whistles could be related to the whales change in behavior between 0621 and 0632.

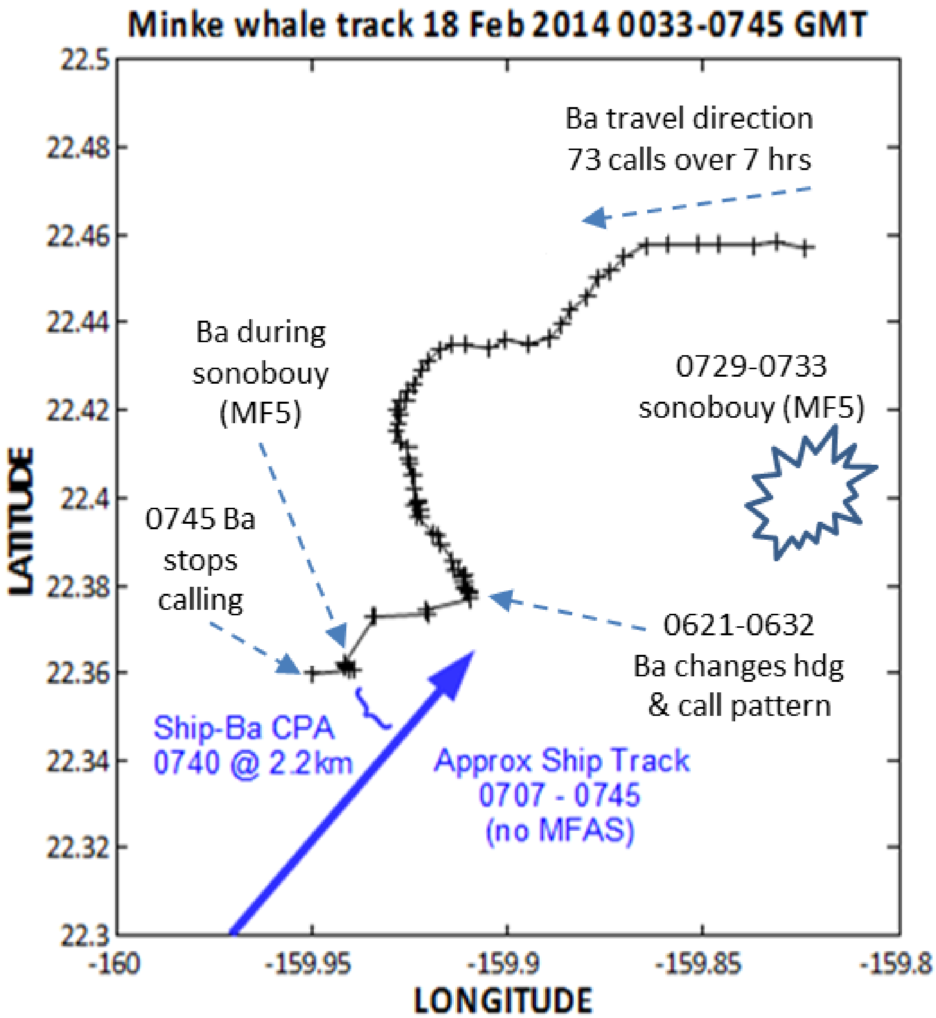

Figure 11. Details of minke whale track # 12 in context of sonobuoy MFAS transmissions and a surface ship approaching (heading ~45°) without MFAS activity. The closest point of approach of the surface ship and the minke whale occurred at 0740 with 2.2 km of separation. The minke whale's last call was at 0745. Sonobuoy active transmissions occurred between 0729 and 0733

A final figure investigating exposures in February 2014 (Figure 12) is also presented showing the timeline of this 98 hours of data with overlays of the 25 minke whale tracks' latitudes, with gray areas for periods of time with sonar activity, and red ellipses for the general latitudes of surface ship MFAS activity. This figure suggests that calling whales in the same latitudinal area as the MFAS activities reduce calling or move outside the area where MFAS is being used. Shortly after the start of Julian day 50 (19 February 2014) a minke whale (track 17) began calling soon after a sonar block stopped, suggesting that some minke whales remain in the area without vocalizing rather than departing the area when sonar activity begins.

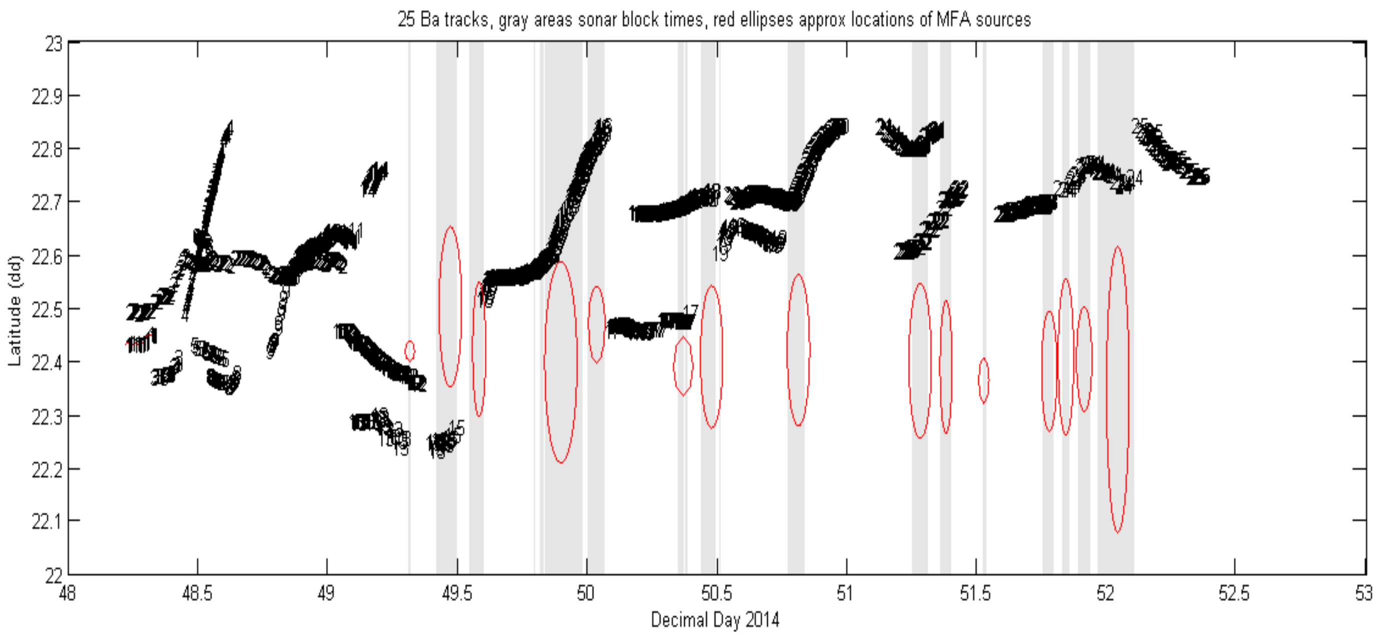

Figure 3. Timeline of 17 to 22 February 2014 (Julian day 48-53) with latitude values for 25 tracked minke whales plotted in black. Gray vertical areas indicate periods of MFAS activity. Red ellipses indicate latitudinal ranges of MFAS activities. Note that a minke whale track (17 of 25) starts almost immediately after the first sonar block (gray vertical bar) on Julian day 50 ends at a latitude of 22.45 deg.

7.2.2 Received Level Estimation

PAM using PMRF hydrophones is a powerful tool, however, all of the sensors are located on the seafloor. Propagation modeling is utilized to estimate RL at animal locations as no acoustic tags are on the animals. Various propagation models have been utilized (i.e., the U.S. Navy's Personal Computer Interactive Multisensor Acoustic Training (PCIMAT), Oasis's Peregrine, and the sonar equation). Propagation modeling was used to estimate the transmission loss (TL) for MFAS between sources and whale locations. The RL for a single source and ping is the source level (SL) minus the TL, however one must also account for other factors such as the beam patterns and frequencies of the sources and environmental parameters such as the sound velocity profile of the water column.

Source levels for various MFAS are available in the open literature (e.g., the U.S. Navy's AN/SQS-53C produces source levels of 235 dB re 1 µPa at 1 m and utilize 1-sec long pulses (Department of the Navy, 2013). PAM monitoring allows for the determination of times and locations when MFAS sources produce pings and whale locations when they are calling, which allows an estimation of the RL to which animals are exposed. Assuming MFAS produces 1-sec long pings, the magnitude of the sound exposure level (SEL) is equal to the RL, as the time period defined for SEL is 1 sec. To determine the RL from multiple MFAS sources, one can conceptually estimate the cumulative sound exposure level (CSEL) the animal receives from each ping from each source during monitored training events as the summation of the SEL magnitude (in units of $Pascals^2 \cdot s$) and converted to the conventional dB re $\mu Pa^2 \cdot s$ by taking $10\log_{10}$(accumulated SELs).

Work on determining the CSEL was performed in FY2016 for the onset of the surface ship portion of the February 2016 SCC. Figure 13 illustrates an encounter between 0357 and 0818 on 16 February 2016, where three minke whales were tracked in conjunction with surface ship MFAS activity.

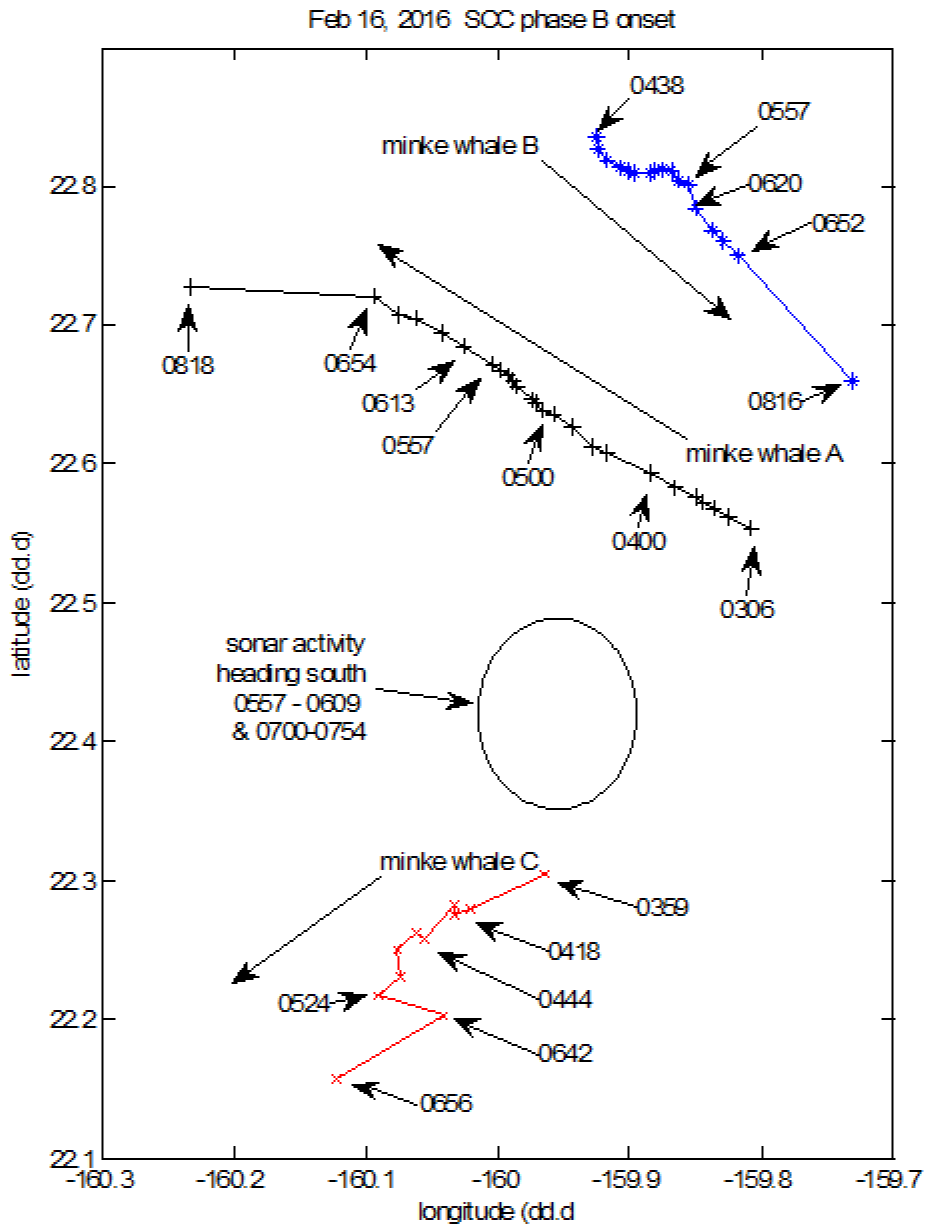

Figure 4. 16 February 2016 onset of surface ship MFAS training. Three minke whales localized and tracked between 0359 and 0818 GMT shown with some call times identified. The ellipse in the center is the approximate area of the MFAS activity between 0557 and 0754 GMT

One of the minke whales (whale C in the figure) was initially localized on the range then travelled south and off the range where localization accuracy is degraded (see whale C's localizations at 0524, 0642 and 0656 as an example). Whale A traversed the range headed northwest while whale B was traveling southeast from the northeastern portion of the range. Gaps are evident in the whale tracks over the MFAS periods of 0557 to 0609 and 0700 to 0754. Looking at only whale A (closest whale to MFAS) in a timeline (Figure 14) one sees that the

CSEL (red lines) begins at the same level as the SEL (black lines) of 137.3 dB re µPa ^{2}s at the onset of sonar activity at approximately day 47.25 (16 February 2016; 0557) which lasted for approximately 12 min. Even though the ship was more than 20 km from the whale, the CSEL increased to 146.7 dB re µPa ^{2}s during the 12-min duration. The second sonar activity ranged from 22 to 54 km away from whale A with the CSEL increasing to 148.7 dB re µPa ^{2}s. This type of analysis has potential in future efforts to establish a form of MFAS dose-response function for a cessation of calling response.

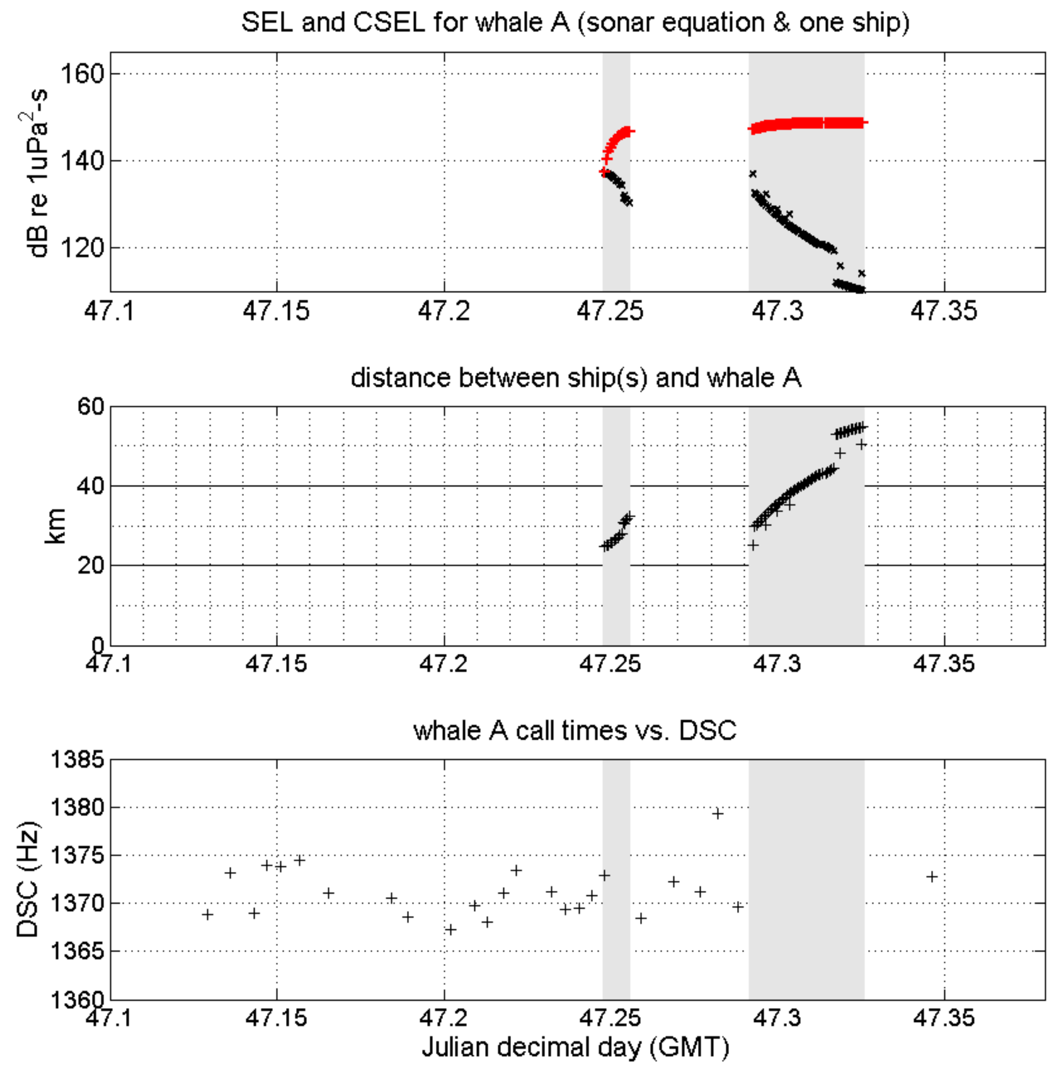

Figure 5. Estimated cumulative sound exposure level on whale A for the closest MFAS ship. All panels are scaled for the same time period (February 16, 2016 between 0224 and 0900 GMT) with vertical gray shaded areas indicating times that MFAS occurred. The upper panel shows the estimated CSEL (red lines) and SEL (black lines). The middle panel shows the distance between the closest ship and whale A while the lower panel shows whale A's dominant signal component (DSC) frequency with the plus symbols indicating times of calls (Martin et al. 2015)

7.3 Blainville's Beaked Whale Group Foraging Dive Analyses

Automated PAM processing has been utilized to detect beaked whale frequency modulated foraging clicks. A Matlab routine was utilized to automatically sort foraging click detections into beaked whale group foraging dives based on spatial and temporal patterns. Figure 4 provides the fully automated results for the beaked whale group foraging dives per hour for all FY16 full bandwidth recorded data available. However, these fully automated results were not validated (i.e., the clicks were not visually verified as Blainville's beaked whale clicks) and could contain significant differences when compared to validated results. These differences consist of the inclusion of false positive detections (mostly resulting from other cetacean clicks and occasionally from other noise sources), combining all beaked whale species' dives together, and incorrect automatic aggregations of hydrophones into a group dive, all of which are corrected during the manual validation process. Automatic detections are predominantly attributed to Blainville's beaked whales since they are the dominant beaked whale species detected with PAM at PMRF. However, clicks attributed to Cuvier's beaked whales have been detected, as have Cross Seamount types of FM foraging clicks (McDonald et al. 2009).

7.3.1 Comparison of NUWC and SSC Pacific Blainville's Beaked Whale Detections

In order to compare automated Blainville's beaked whale detections between SSC Pacific (algorithm 1) and NUWC (algorithm 2), data were examined between 2011 and 2014 to locate periods that were concurrently recorded by both algorithms. Four time periods were selected that ranged from just over one day (28.4 hr) to over four days (110.7 hr). Automated detections and group foraging dives were independently generated with tools and algorithms that each organization developed. The number of automatically generated beaked whale dives were compared to determine how many dives were detected by both algorithms and how many were only detected by one algorithm or the other (Table 2). The majority of the dives that were detected by algorithm 2 and not by algorithm 1 occurred on hydrophones that were not recorded by SSC Pacific in 2011 and 2012; this issue was largely resolved in the February 2014 data since this was after SSC Pacific increased the number of recorded hydrophones from 31 to 62 in August 2012. Dives that were detected by algorithm 2 on hydrophones not recorded by SSC Pacific were not considered "missed" dives in this analysis (but were considered "missed" for density estimation purposes, see next section and Table 3), but any dives that occurred on hydrophones that were recorded by SSC Pacific were considered "missed", unless they were manually checked (see below) and found to be false positives. Similarly, any of the validated beaked whale dives detected by algorithm 1 but not by algorithm 2 were considered "missed". All of the dives that were detected by algorithm 2 and missed by algorithm 1 were manually examined in random increments of 5 or 10 min to see if there were in fact Blainville's beaked whale dives that occurred at a signal-to-noise ratio below the threshold used by algorithm 1, or if those detections might have been false positives by algorithm 2. These are included in table 3 as algorithm 2 false positives if there were no beaked whales in the subsampled period; however, since the full time period of each dive was not examined manually these may not actually be true false positives as there could have been Blainville's beaked whale dives in the unexamined periods of the data. As all algorithm 1 Blainville's beaked whale dives were manually validated, we were also able to estimate the false positive rate for algorithm 1 detections; this is important to capture when assessing the capabilities of the algorithm. However, this rate is not carried forward in any density analyses as only the validated dives are used for analysis (i.e., 100% of the dives used in analysis are true beaked whale clicks so the false positive rate = 0). During the validation process after running algorithm 1, automatically sorted groups (e.g., clicks detected on hydrophones located within 6 km and 10 min of each other combined into one group dive) may also be adjusted into fewer groups (if more phones should be clustered) or more groups (if too many phones were clustered and should be separated); therefore the final number of group dive detections may differ from the raw automated detections not only by removing false positives but by adjusting the hydrophone clustering. The automatically detected group dives from algorithm 2 are not manually sorted afterwards; therefore the number of matching dives in this current analysis may be slightly off if a large cluster of hydrophones is called a single group by algorithm 2 but multiple groups by post-processing algorithm 1. This refinement in the comparison will be addressed in future efforts.

Results of this comparison demonstrate that algorithm 1 detected 66 to 86% of the Blainville's beaked whale foraging dives at PMRF, while algorithm 2 detected 67 to 85% of the dives (assuming the total number of dives between the two algorithms represents the "true" total number of dives on the range). Both algorithms co-detected between 50 and 62% of the dives. The number of detections made by algorithm 1 of the "true" number of dives increased to almost 90% in February 2014 when the number of recorded hydrophones doubled. This number is even greater (95%) if all of the possibly false positive detections by algorithm 2 are excluded from the count of "true" dives. This analysis was conducted assuming a zero false positive rate for algorithm 1 since only the manually validated dives were used. The true false positive rate for algorithm 2 is unknown, but is likely higher than the value used in this analysis as the groups that were manually checked did have several false positives. Similarly the true miss rate for both algorithms is unknown; however, by comparing and combining the datasets a closer approximation of the "true" number of dives that occurred can be used.

Table 2. A comparison of Blainville's beaked whale dive detections between algorithm 1 and algorithm 2. Note that the number of "true" dives does not reflect any possible false positive detections (e.g. all dives detected by algorithm 2 are included in that number)

Hours of recorded data	Mar 2011	Jul 2011	Jan 2012	Feb 2014
Algorithm 1 raw detections	63	79	171	178
Algorithm 1 validated detections	46	66	143	160
Algorithm 1/Algorithm 2 matches	35	51	113	98
Algorithm 2 unmatched raw detections	24	16	54	26
Algorithm 2 total detections	59	69	167	124
Total "true" dives detected	70	82	197	186
Algorithm 1 missed	1	0	3	5
Algorithm 1 false positive (raw)	17	13	28	18
Algorithm 1 false positive (validated)	0	0	0	0
Algorithm 2 missed	11	15	28	62
Algorithm 2 false positive	0	0	2	10

7.3.2 Density Estimation of Blainville's Beaked Whales

The Blainville's beaked whale dives that were detected by algorithm 1 and algorithm 2 were used in a density estimation analysis. Only dives detected on the southern hydrophones (BARSTUR and SWTR) were used for the density estimation, as the spacing of those hydrophones supports the assumption of detecting all occurring dives whereas the spacing on the northern phones may lead to some missed dives. The area of the southern phones (including a 3-km radius around each phone) is 440 square kilometers (km^2). The following density equation (Marques et al. 2009) was used:

$$\widehat{D} = \frac{n_c(1-c)S}{A\hat{P}T\hat{r}}$$

Where $\widehat{D}$ is the density of the whales, c is the probability of false positives, n_c is the number of dives, S is the mean group size, $\hat{P}$ is the probability of detecting a dive, $\hat{r}$ is the mean dive rate per hour, T is the total recorded time in hours, and A is the area in km^2. Initially the assumption was made that the false positive rate (c) for both detectors was equal to zero (all detections are true beaked whale dives), while the probability of detection ($\hat{P}$) was equal to one (all dives were detected). By assuming that all dives were detected when combining the data from both algorithms, we can compare the relative density estimations for the detections made by each algorithm on their own when continuing those assumptions across the analysis. Without knowing the true false positive rate of the algorithm 2 detections it is difficult to estimate the miss rate for algorithm 1, so an initial assumption of no false positives again helps compare the data across algorithms. The values used in the density estimation analysis are given in table 3. In a second density analysis, the combined datasets were used to estimate the false positive and miss rates for each detector (e.g. the detections found by algorithm 2 but missed by algorithm 1 provided the algorithm 1 missed rate, and the results of the manual analysis of subsampled raw data for the dives detected by algorithm 2 were used for the algorithm 2 false positive rate).

Table 3. Values used in the density estimation of Blainville's beaked whales at PMRF for dive detection data from algorithm 1, algorithm 2, and both algorithms combined. Shaded values were only used in the second analysis. Group size (s) and dive rate (r) taken from Baird et al. (2006).

	Mar 2011			Jul 2011			Jan 2012			Feb 2014		
	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2
n (#dives)	48	32	38	46	34	38	195	102	120	153	130	104
s (mean group size)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
r (dive time)	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
T (time)	33.1	33.1	33.1	28.4	28.4	28.4	99.9	99.9	99.9	110.7	110.7	110.7
A (area)	440	440	440	440	440	440	440	440	440	440	440	440
c = 0	0	0	0	0	0	0	0	0	0	0	0	0
c (prob false positives)	0	0	0	0	0	0	0	0.00	0.02	0	0	0.10
p = 1	1	1	1	1	1	1	1	1	1	1	1	1
p (prob detection)	1	0.67	0.79	1	0.74	0.83	1	0.71	0.83	1	0.85	0.68

The results of the density estimation analyses are given in Table 4. When the probability of false positives was assumed to be 0 and the probability of detecting all dives was assumed to be 1, the density of Blainville's beaked whales at PMRF was between 11.6 and 16.3 whales/440 km^2 when all dive data were combined. The density values derived for each algorithm independently were lower, with algorithm 1 estimated densities between 8.1 and 10 whales/440 km^2, and algorithm 2 density estimations between 7.9 and 11.2 whales/440 km^2. When the combined datasets were used to derive the detection probabilities for each algorithm, the density results changed slightly. The density estimations increased for each algorithm separately when accounting for the probability of detection, while it decreased slightly for algorithm 2 when the false positive rate was incorporated.

Table 4. Results of the density estimation for algorithm 1 data, algorithm 2 data, and combined, given in whales per 440 km^2. The first row used the assumptions that the probability of false positives (c) was 0 and the probability of detecting all dives (P) was 1. The second row used values for c and P derived from the comparison in detections between algorithms

	Mar 2011			Jul 2011			Jan 2012			Feb 2014		
	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2	combined	Algorithm 1	Algorithm 2
c=0, P=1	12.1	8.1	9.6	13.6	10.0	11.2	16.3	8.5	10.1	11.6	9.8	7.9
C(prob), P(prob)	12.1	12.1	12.1	13.6	13.6	13.6	16.3	12.1	11.9	11.6	11.6	10.5

7.3.3 Analysis of Blainville's Beaked Whale Foraging Groups with Navy Training Activity

For the 4th International Conference on the Effects of Noise on Aquatic Life (in July 2016), a detailed analysis was conducted of individual beaked whale group dives (Group Vocal Period, GVP) that occurred before, during, or after SCCs at PMRF. In this analysis, data from six SCCs that occurred in 2011-2013 were examined to identify changes in foraging behavior by individual Blainville's beaked whale groups that were detected within 30 min of the onset or cessation of sonar. This timeframe was used for analysis as the descent and ascent phases of beaked whale dives, during which little to no echolocation clicks are produced, make up just under half of the typical foraging dive (Tyack et al. 2006). If the vocal portion of the foraging dive can last between 20 to 60 min, then the ascent and descent portions can last 10 to 30 min each. Therefore by using a 30-min window we are assuming we would detect any dive that might start or stop within that time period. We did not compare the actual duration of the vocal periods in this study; as mentioned above we are only detecting the loudest clicks during each dive and therefore are likely missing clicks near the beginning or end of the dive. Since we are detecting clicks associated with foraging by all members of the group without counting individual animals, each detection is considered the GVP and represents a foraging dive conducted by one or more animals. In addition, RLs were estimated and the distance and bearing of the ship were calculated to determine if impacts differed based on the proximity and movement of the ship.

A behavioral response to the sonar was assumed to have occurred if the GVP ceased after sonar started (i.e., less than 5 min) or if the GVP did not begin until after sonar ceased (i.e.,. less than 30 min). Dives that occurred during periods of sonar were also examined on a case-by-case basis; however, generally it was assumed no response occurred for these dives as they co-occurred with sonar. At the start and end time of all dives, and at the time of a response if one occurred, the RL at the primary hydrophone was estimated using Peregrine at both 10-m depth (assuming the group was at the surface) and at 1,000-m depth (assuming the group was at foraging depth). The received level was also estimated at a radius of 6 km around the hydrophone at both the closest and furthest point from the source ship, as it was assumed a beaked whale group was within 6 km of a hydrophone when detected (following Ward et al. 2008; Zimmer et al. 2008). The bearing and distance of the source ship were also measured, as was the orientation of the ship to the primary hydrophone (although the sonar is modeled as omnidirectional, there is likely some vertical and horizontal beam pattern to the sonar in addition to the hull shadowing the source to the aft so the received level should be higher when the ship is approaching). The RLs, ship heading, and distance were examined using analyses of variance (ANOVAs) to compare these variables against groups that responded and did not respond during dives that occurred before, during, and after sonar periods. Paired t-tests were also used to compare responses within each time period.

Results of these analyses found there to be 100 Blainville's beaked whale GVPs that occurred during MFAS activity or within 30 min of onset or cessation. Twenty-four group dives occurred before sonar started; of these, 16 dives ended within 5 min of sonar starting (either before or after the onset, considered a response), four dives ended within 5 min of onset (before sonar started, no response) and four dives continued after sonar began (no response). Thirty-five group dives began after sonar ended; of these, 23 dives occurred within 15 min of sonar ended (considered a response by groups that were already diving but not actively foraging) while 12 dives occurred within 15 to 30 min of sonar ended (considered a response by groups that did not begin diving until the sonar ended). Finally, 37 group dives occurred during periods of sonar; seven of these groups may have responded by starting or ending their foraging dives when the source ship changed their orientation or proximity to the group, while 30 groups did not appear to respond. Figures 15-17 depict these responses in three different scenarios.

An unbalanced ANOVA did not find significant differences in the RLs when comparing all the above scenarios, but in paired t-tests within each period, there was a significant difference in RL for the groups that responded versus groups that did not respond in the "before" period ($T = -2.23$, $p = 0.04$; Figure 18). In other words, groups that were presumed to be foraging prior to the onset of sonar but ceased foraging when sonar began experienced higher RLs than those that did not cease foraging when sonar began. Although there were no significant differences in any period between groups that responded versus those that didn't respond to the proximity of the source vessel, the vessel was generally further away from groups that did not respond compared to the groups that did respond (Figure 19). Finally, when looking at the ship heading relative to the foraging groups (via the primary hydrophone), the ANOVA across all periods was not significant, but the paired t-test between groups that did and did not respond during periods of sonar found a significant difference ($T = -2.27$, $p = 0.03$; Figure 20), such that the vessel was approaching the groups that responded more frequently than groups that did not respond. To complete this analysis, regression models are planned that will test combinations of all of the above contextual variables that likely work in concert to cause a behavioral response in foraging beaked whales. These final analyses will be completed in early 2017 and submitted for publication in a peer-reviewed journal shortly thereafter.

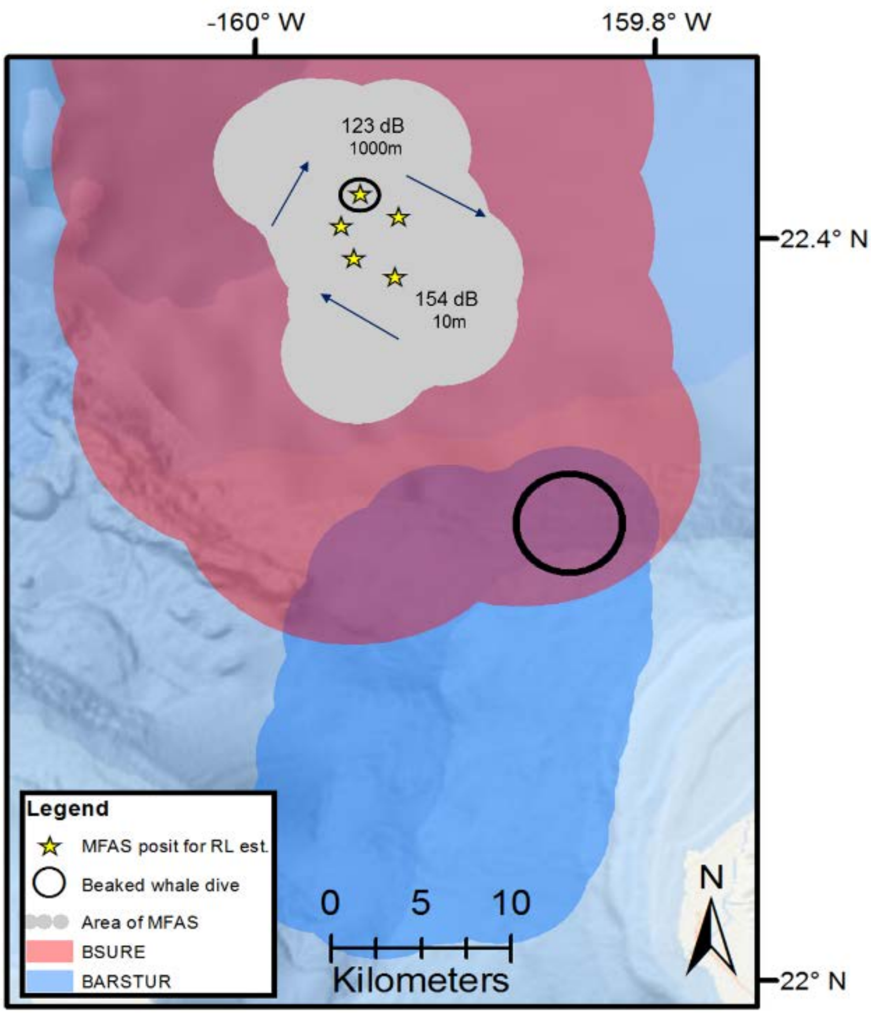

Figure 6. An example of a beaked whale group response to MFAS. In this case, the group (represented by the black circle) continued diving during a period of MFAS (clicks starting when ship was 21 km away) until the ship turned (at the location of the circled star), and began approaching the group at which time the group ceased emitting foraging clicks.

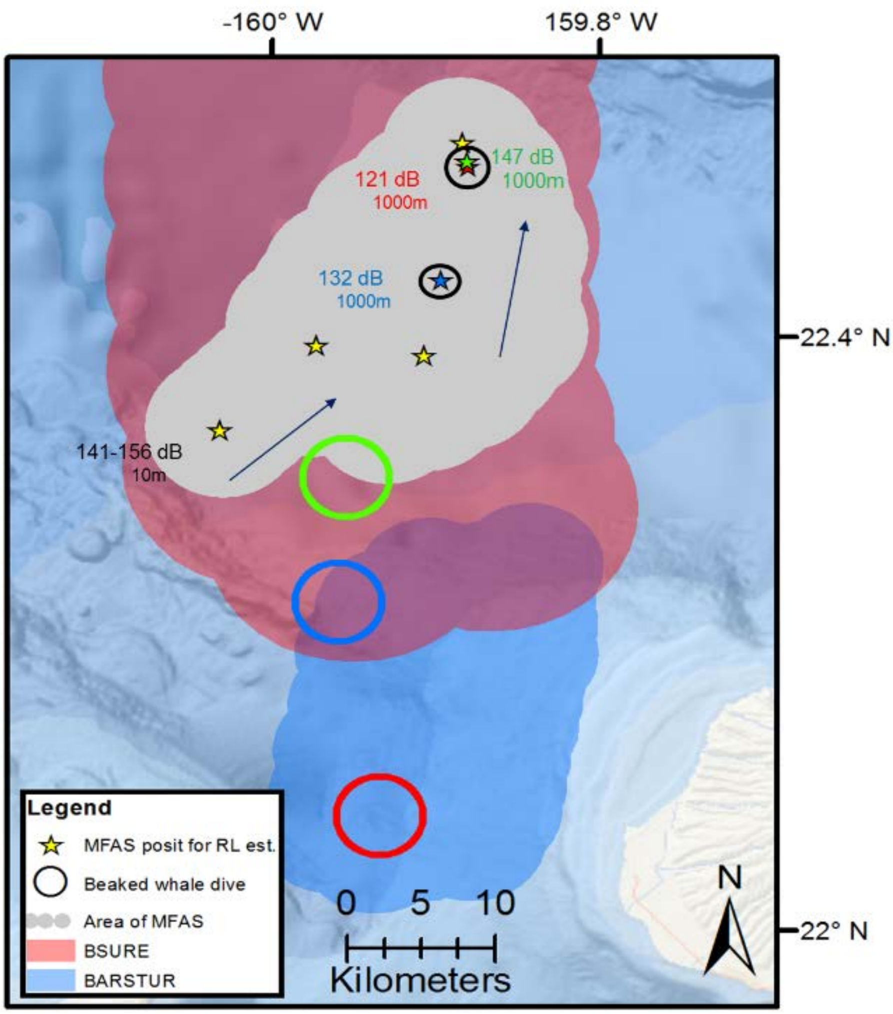

Figure 7. In this second example, three diving groups (represented by the three colored circles) all started vocalizing after a ship emitting MFAS turned their heading away from the dive locations and the distance between the ship and the hydrophones was 25-49 km. The stars circled in black correspond to the ship's position at the onset of each of the beaked whale group dives.

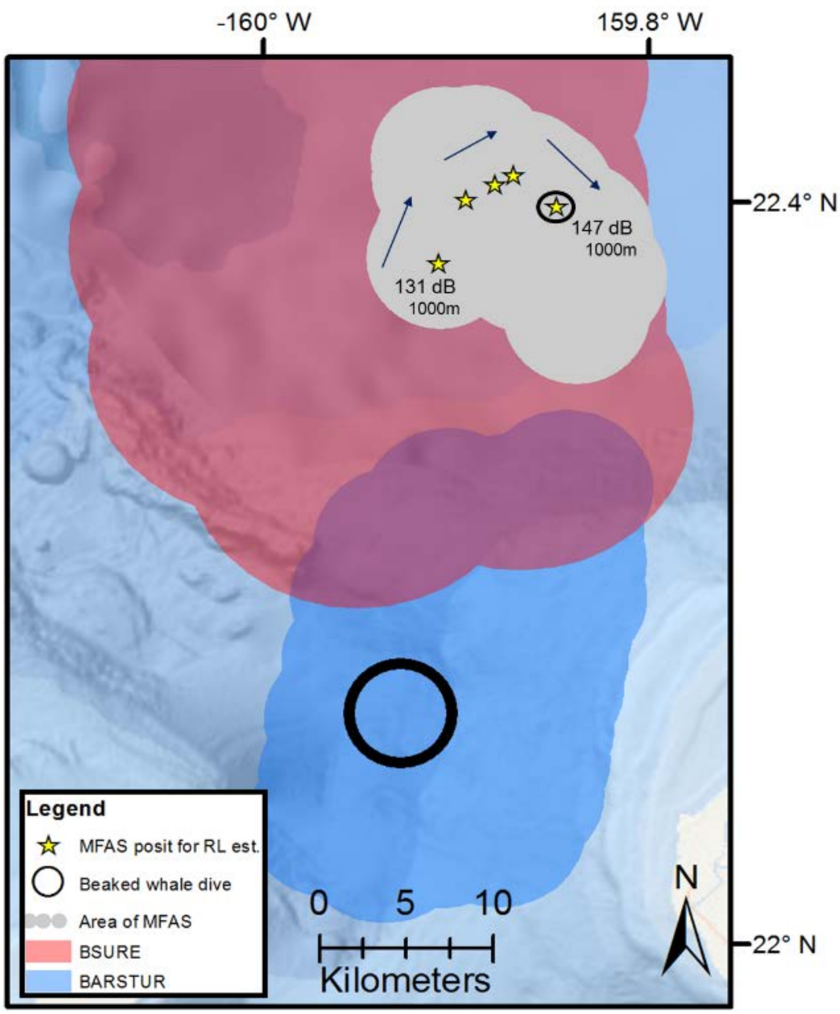

Figure 8. A third example of a response by a group of foraging Blainville's beaked whales. This group (represented by the large black circle) ceased producing foraging clicks when a ship emitting MFAS turned towards the group location (the black circled star) at a distance of 32 km.

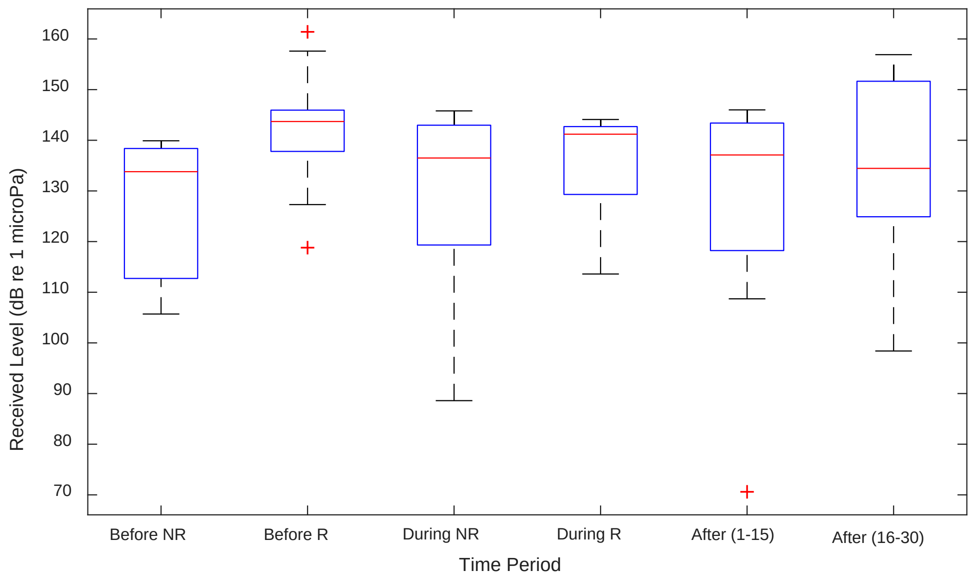

Figure 9. Comparison of RLs versus time period. Boxplots of groups that did respond ("R") or did not respond ("NR") in the periods before, during, or after MFAS. The ANOVA comparing all dives across all periods to the RL of the MFAS was not significant, but the paired t-test of the groups that did and did not respond to sonar in the before period was significant, such that the RL was higher for groups that did cease foraging in response to the onset of sonar compared to groups that continued foraging when sonar began.

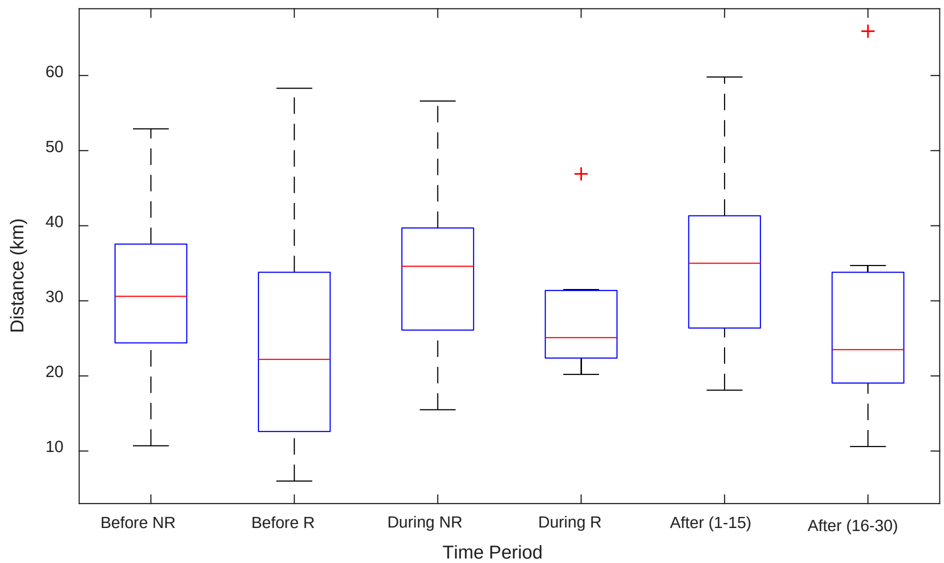

Figure 10. Comparison of distance between ship and group and time period. Boxplots of groups that did respond (“R”) or did not respond (“NR”) in the periods before, during, or after MFAS. None of the statistics comparing all dives across all periods to the distance of the source vessel were significant; however, in all time periods the vessels were generally further away from the groups that did not respond compared to the groups that did respond.

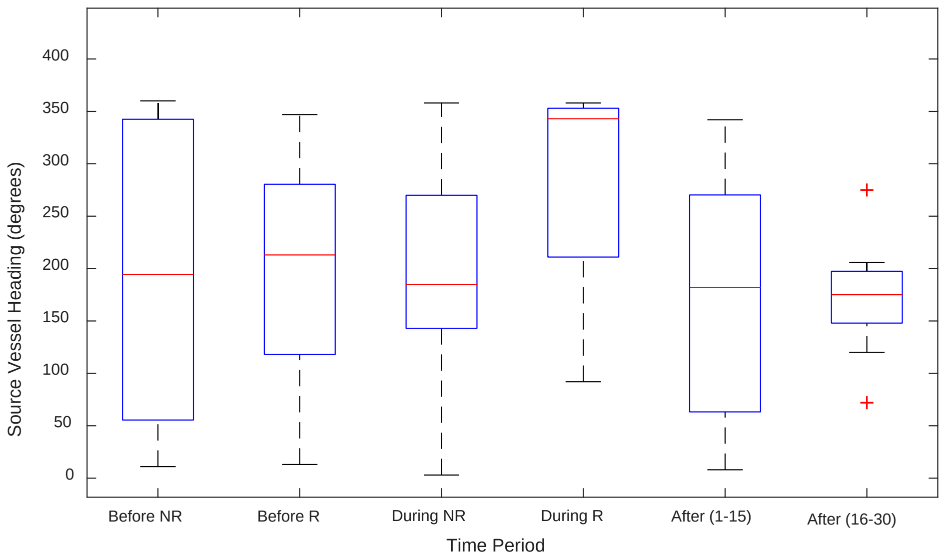

Figure 20. Comparison of source vessel heading and time period. Boxplots of groups that did respond ("R") or did not respond ("NR") in the periods before, during, or after MFAS. The ANOVA comparing all dives across all periods to the heading of the source vessel was not significant, but the paired t-test of the groups that did and did not respond to sonar in the during period was significant, such that the vessel was more frequently approaching the groups that did cease foraging compared to groups that continued foraging during periods of sonar.

8 Concurrent and Related Efforts

A current internal SSC Pacific Science and Technology effort (PI: E. Henderson) has the goal of attaching acoustic pingers to humpback whales to demonstrate that they can be tracked by pinger emissions using the bottom mounted range hydrophones at PMRF. This would provide indisputable confirmation of species, animal locations when they are not actively vocalizing, and evaluation of automated tracking accuracy, as well as some initial cue rate information and evidence for the amount of time individual whales spend on PMRF. If the tags can be successfully tracked, longer term attachments may allow an estimation of behavioral responses to Navy training activity as well.

An Office of Naval Research-funded project titled "Behavioral Response Evaluations Employing robust baselines and actual Navy training" (BREVE, PI: S.W. Martin) is a joint effort involving the National Marine Mammal Foundation, the Centre for Research into Ecological Environmental Modelling, and SSC Pacific. The primary goal is to develop and apply methods for determining baleen whale species' behavioral responses to actual Navy training using existing large data sets of PAM data from PMRF. A robust understanding of baseline behaviors for multiple baleen species (minke, fin, humpback, Bryde's, sei, and blue whales) will need to be established for comparison with behavioral observations during U.S. Navy training. Statistical methods developed for quantifying behavioral response for short-term controlled exposure experiments will be extended to long-term and larger-scale passive acoustic data to develop metrics of response and behavioral state estimates for baseline and exposure conditions.

A project funded by the U.S. Navy Living Marine Resources (LMR) program (PI: T. Helble) involves developing tools to help semi-automate processes involved in determining baseline marine mammal behaviors and behavioral reactions to ship-animal encounters. Currently, significant manual effort is required to fully investigate individual ship-animal encounters and perform manual investigation of acoustic signal characteristics in attempt to assign a track to a specific species. This project is directly applicable to the BREVE project and exposure analysis conducted in SSC Pacific's DCLDTE lab. These tools will enhance data analysis efficiency and repeatability and help eliminate subjectivity which is inherent to human analysis when analyzing marine mammal behavior which is highly variable.

Previous collaborative efforts with R.W. Baird, D. Webster, and B. Southall were performed on satellite tagged data from 2011 to 2013 (Baird et al. 2014). The previous work documented apparent indifference of bottlenose (*Tursiops truncatus*) and rough-toothed dolphins (*Steno bredanensis*) movements relative to MFAS, and movement of short-finned pilot whales (*Globicephala macrorhynchus*) from long distances towards increasing levels of MFAS activity. This type of analysis was deemed to be a powerful approach for observing large-scale movement patterns of species exposed to MFAS. Additional effort began mid-FY15 to analyze satellite tagged odontocete data from later in 2013 through February 2015. This work was completed in 2016 with estimated exposures to nine satellite-tagged odontocetes that coincided within an hour of MFAS activity (five short-finned pilot whales [Gm], three rough-toothed dolphins [Sb] and one false killer whale [Pc]). Improvements to the estimated RLs compared to the prior report include accounting for ARGOS satellite-tag positional errors and statistically representing the estimated RL over the range of possible positions. The statistical representations inform one when estimates are reasonable (e.g,, distribution of estimated RLs has unimodal character with low dB variations of estimates) and when they are not (e.g., multimodal estimated RL distributions and large variations). This effort is being separately reported collaboratively with R.W. Baird (first author) and B. Southall for submission to HDR.

9 Summary of FY16 Publications

The results of our passive acoustic monitoring efforts and the application of our detection and classification tools have been included in several publications that were submitted or published in 2016. These papers examine both the baseline behavior and habitat use of several whale species at PMRF and explore trends in these patterns over time, as well as assess behavioral responses to U.S. Navy training activity. By understanding baseline vocal behavior and habitat use, we will be more capable of assessing responses to sonar and other training activity in future analyses. In addition, we can develop detection, classification and localization tools and algorithms on baseline data that can then be applied to data recorded during training activity to determine whether or not a response may have occurred.

Two papers that dealt with Blainville's beaked whale group foraging dives were published in *Aquatic Mammals* as synergistic approaches to investigating Blainville's beaked whale behavior at PMRF both in the presence and absence of training activity. One paper examined baseline occurrence and foraging dive activity over a three-year period (2011-2013; Henderson et al. 2016), and found that while there were inter-annual differences in occurrence patterns, there was no seasonal trend. Dives occurred across the entire range, although seemed to preferentially occur along the slope region; this was borne out using a generalized additive model (GAM) that also determined that a diel pattern in dives occurred related to the lunar cycle. The second paper one documented the reduction in Blainville's beaked whale dives during periods of active sonar use in response to six U.S. Navy MFAS training events conducted over the same period (Manzano-Roth et al. 2016). While the number of dives per hour was reduced during these long, multi-day training activities, and the dives moved to the southern portion of the range and out to the edge of the range, the dives quickly returned to normal following each event and no response seemed to occur during shorter duration training events.

A third paper published in the *Journal of the Acoustical Society of America* documented Bryde's whale encounters observed from analyses of PMRF recorded data and assessed their movement and potential social behavior (Helble et al. 2016). This is the first paper to describe the occurrence of this Bryde's whale call type in Hawaiian waters, and found it to be similar to a call produced in other populations of Bryde's whales. Bryde's whales occurred on the range in August and September when no other baleen whales are present, and the animals seemed to be traveling in widely spaced groups and may use their vocalizations to maintain cohesion and spacing across long distances.

Finally, a fourth paper has been accepted for peer review publication on the behavior of acoustically tracked humpback whales with baseline PMRF recorded data collected between September and June (2011-2014) implementing new kinematic tools in the analyses to derive metrics used to determine baseline behavioral states (Henderson et al. submitted). Using metrics such as speed, duration, directivity, and path deviation that can be automatically derived from the localization data, the behavioral states of these singing humpback whales could be assessed and automatically categorized as Travel, Mill, or Drift Dive. These results provide new insight into different behaviors conducted by singing humpback whales, perhaps indicative of different strategies or social interactions. This analysis also provides baseline information on the occurrence and habitat use of these whales at PMRF and creates a method to compare the behavior of tracks recorded in the presence of MFAS to detect potential behavioral responses.

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