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FY16 annual report on PMRF Marine Mammal Monitoring

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ADMINISTRATIVE INFORMATION

The work described in this report was performed for Commander, U.S. Pacific Fleet (COMPACFLT) by the Maritime Surveillance Branch (Code 56470) of the Biosciences Division (Code 71500), Space and Naval Warfare Systems Center Pacific (SSC Pacific), San Diego, CA. Additional Support was provided by the National Marine Mammal Foundation (NMMF).

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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, Hawai'i, including during U.S. Navy mid-frequency active sonar (MFAS) training. Data products (both recorded hydrophone data, standard PMRF range products, and range craft deployed calibrated hydrophone data) were obtained and analyzed.

Results of fully automated processing are presented for all data collections throughout the fiscal year in terms of the beaked whale foraging dives per hour and the number of baleen whale and sperm whale passive acoustic localizations on and near the range. In addition, data from 2007 through 2010 was automatically processed for beaked whales, humpback whales and sperm whales, and plots of these results are presented as well. These "quick look" results provide information regarding these species' presence and occurrence throughout the PMRF range with qualitative relative abundance and help identify other datasets for further investigation and validation (such as Bryde's (*Balaenoptera edeni*) whale calls in the summer). Currently, validation efforts require additional manual and semi-automated processes and these quick look results typically provide the starting point for refined analyses of datasets used for peer reviewed journal articles and presentations.

Two papers that dealt with Blainville's beaked whale (*Mesoplodon densirostris*) group foraging dives were published in Aquatic Mammals in November 2016 and are included as appendices. One paper examined baseline 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 published in the Journal of the Acoustical Society of America in December 2016 documented Bryde's whale encounters observed from analyses of PMRF recorded data. Finally, a fourth paper has been 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) using kinematic analysis to derive metrics used to determine basic behavioral states. Due to copy write restrictions full-text publications are not included.

Collaborative work occurred with R. 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. 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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ACRONYMS AND DEFINITIONS

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 transferring 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 Incorporated registered trademark, 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

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1. INTRODUCTION

1.1 OVERVIEW

In Fiscal Year (FY) 2016 the SSC Pacific Detection, Classification, Localization, Tracking, and Density Estimate (DCLTDE) Laboratory (San Diego, CA) automatically processed data recorded on bottom mounted hydrophones at the Pacific Missile Range Facility (PMRF) to detect and localize several species of marine mammals and estimate received levels 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.

1.2 HISTORY

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 whale (*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.

1.3 PROCESSING METHODS

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 August 28, 2015 to September 7, 2016.

Utilizing recorded data, a test case analysis of MFAS exposures is provided with estimated received levels 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, United States) 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 propogation 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 NUWC and SSC Pacific. Finally, an analysis of individual group responses by Blainville's beaked whales to Navy training activity and sonar is summarized.

2. DATA COLLECTION

2.1 DATA COLLECTION METHODS

Standard PMRF range data products have been obtained from PMRF for biannually held 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 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. All unreported data currently available spanned from 28 August 2015 to 7 September 2016.

		Hours of Acoustic Recordings					
Number of Hydrophones Recorded	Sample Rate (kHz)	February 2002 to September 2006	March 2007 to January 2011	January 2011 to August 2012	August 2012 to September 2014	October 2014 to August 2015	August 2015 to September 2016
24	44.1	730					
31	96		2901	2422			
62 (includes all 41 BSURE replacements)	96				2288	1289	1268
47 (decimated data)	6				676	4357	2894

There is no data for areas shown in cyan.

2.2 DATA COLLECTION BENEFITS

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 March 9, 2007 and January 11, 2011 (Table 1) using the most recent automated processing algorithms. These data were recorded at the 96 kHz sample rate for 31 hydrophones (including 6 BARSTUR broadband hydrophones, 4 BARSTUR high-pass hydrophones, 3 Shallow Water Training Range (SWTR) high-pass hydrophones, and the18 BSURE mid-pass hydrophones). Due to the frequency response of these 31 hydrophones (ranging from 100 Hz to 48 kHz), baleen whale low frequency calls under 100 Hz (e.g., from fin, sei, blue, and Bryde's whales) are not detectable. Species that are currently automatically detectable with these data include minke whales, humpback whales, 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 with the Inter-Range Instrumentation Group (IRIG) time code amplitudes varying was reported previously in the FY15 annual report (Martin et al., 2016). The issue was attributed to hardware failure and was resolved during the August 2016 SCC when personnel were present at PMRF. Data collected with faulty IRIG typically exhibits an IRIG signal that has amplitude fluctuations and signal levels that are weak or saturated, and in some cases incorrect time information. Hours of acoustic recordings exhibits some variation compared to what was reported in the prior annual report (Martin et al., 2016). Some files with faulty IRIG time code were unable to be processed until the recent development of a program that is able to resolve faulty IRIG time code.

During some of the SCC training events there has been an effort involving range support personnel to collect recordings from a calibrated 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 received levels estimated by Peregrine parabolic equation propagation modeling (Ocean Acoustical Services and Instrumentation Systems (OASIS), Inc., Lexington, MA, United States).

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 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.

3. AUTOMATED DETECTION, CLASSIFICATION, AND LOCALIZATION ALGORITHMS

3.1 OVERVIEW

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.

3.2 ALGORITHMS

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.

UDPListen.exe utilized the same front end processing for all species and was described in detail in Martin, Martin, Matsuyama, and Henderson (2015). The front end processing utilized 16k sample length 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 FFT's). Decimated data were sampled at 1/16th the full band rate with 1k FFT's 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 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 1350 to 1440 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 had been included in UDPListen.exe baseline 3 processes in response to both the previous sighting of killer whales in the area (Baird et al., 2012) and multiple observations of high frequency modulated (HFM) signals in the 15 to 35 kHz band in recorded data. While the HFM signal 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. Subsequently, on 14 February 2016 local fishermen reported to R. Baird that they sighted (and provided a photograph) of a single adult killer whale off the east side of Niihau that afternoon (pers. comm. R. Baird). This new capability to detect the HFM signals will be refined in the future; the current version detects the stronger (over 30 dB SNR), longer duration signals (required to be at least 0.37 s in duration) having a down swept feature, as these could be detected with low false positive rates. Using this UDPListen.exe baseline 3 version of the killer whale HFM detector, killer whale 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. Refinements to the HFM detector are planned in the future to detect the shorter duration HFM signals and reduce the SNR while keeping false positives low.

Classification processing was also performed within UDPListen.exe for minke and beaked whales. Minke whale boings were classified by reprocessing the detections to generate sub-hertz spectra for extracting features for classification (Martin et al., 2015). Beaked whale foraging echolocation clicks were classified by reprocessing 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 Martin, Manzano-Roth, and Matsuyama, 2016a). Beaked whale inter-click intervals (ICIs) were also utilized for species classification.

A separate C++ model-based localization algorithm (C3D.exe described in Martin et al., 2015) was implemented in 2013. 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. C3D.exe 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 UDPlisten.exe and C3D.exe 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 received levels on marine mammals and behavioral response analyses.

A MATLAB® algorithm is also employed for Generalized Power Law (GPL) detection (Helble et al., 2012) and model-based localization using cross correlation to determine relative arrival times. The MATLAB® GPL detection algorithm was initially incorporated for detecting and localizing humpback whales using sequences of song units (Helble, Ierley, D'Spain, and Martin 2015; Henderson 2016b). Humpback whale localizations reported in the previous report (Martin et al., 2016), utilized version 1 of the GPL algorithm. For this report, version 2 of the GPL algorithm was utilized and included the ability to detect and localize other species (e.g., Bryde's whales; Helble, Martin, Ierley, and Henderson, 2016) and also utilized hydrophones located on southern BSURE. 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 versions 1 and 2 of the GPL algorithm is also in process.

3.3 AUTOMATIC PROCESSING RESULTS FOR PRESENCE, OCCURRENCE AND RELATIVE ABUNDANCE

Upon receiving acoustic data recordings at the DCLTDE laboratory and creating backups for data integrity, automated processing was performed to establish basic presence information for species on the range and with currently implemented automated algorithms (i.e., a "quick look" analysis). The quick look analysis provided relative species abundance as the number of automatically localized calls per hour for baleen whales (Figures 1, 2, 4, and 6) and automatically derived beaked whale group foraging dives per hour (Figure 3 and 5). 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 one hour, the assumption was that a group of beaked whales were performing a foraging dive in the area. These quick look results typically provide the starting point for refined 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 1–6) 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 can be upwards of 100 calls per hour.

Data collection periods in late May 2016 without data points were for datasets with IRIG not being recorded. The acoustic data is present and changes to the baseline C++ algorithm are required to recover results from these periods.

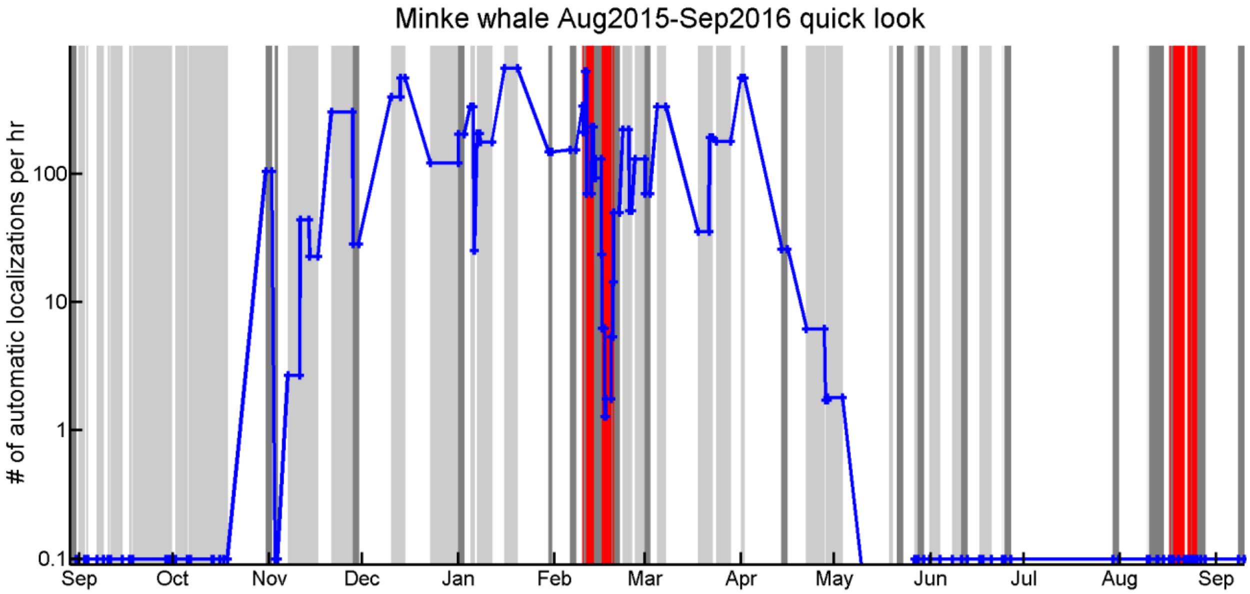


Figure 1. Quick look results of the number of automatically localized minke whale boing calls per hour. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Red shaded regions were during 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.

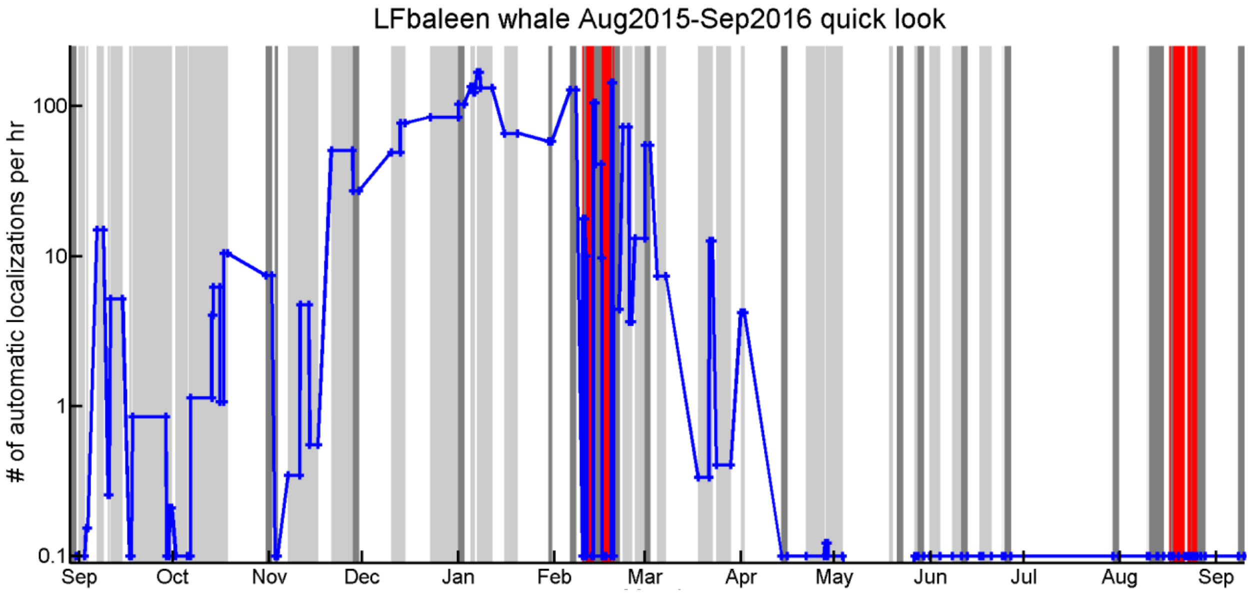


Figure 2. Quick look results of the number of automatically localized low-frequency baleen whale calls per hour. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Red shaded regions 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 are 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 (Figure 6) and had more localizations per hour than minke whales (Figures 1 and 4). 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 4.1 and 4.2.1 of this report). Notice that presence and abundance of migratory species (minke and some low frequency baleen whales) shown in Figures 1–2, corresponds to expected seasonal migratory trends. An additional manual verification effort has 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 down swept calls with 1.3 second 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 second 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 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. 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. Therefore, it is important to remember that these are quick look results and likely contain false positives, spurious localizations, and localizations attributed to multiple species.

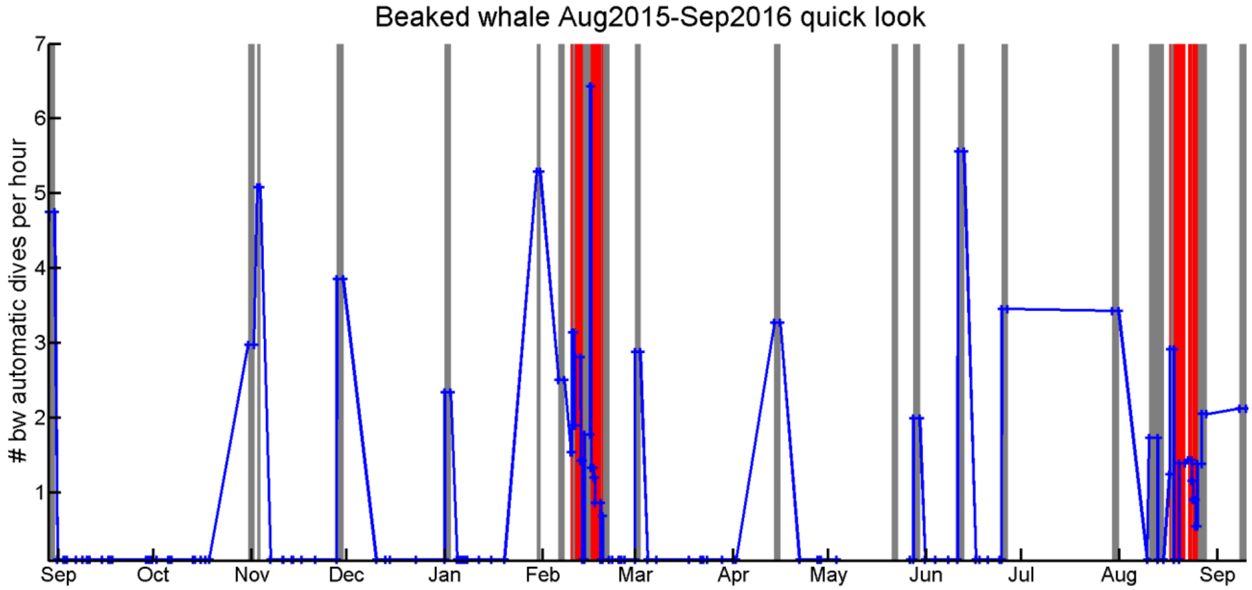


Figure 3. Quick look results of the number of automatically grouped beaked whale group foraging dives per hour. Gray shaded regions indicate availability of full bandwidth data (dark gray). Decimated data collections are not shown due to insufficient bandwidth for processing beaked whale clicks. White 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 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 3 and 5 helps spatially and temporally organize the detected clicks into beaked whale 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 and Henderson et al., 2016).

Quick look analyses of the historic data collected between March 9, 2007 and January 11, 2011 is provided in Figures 4, 5, and 6 for minke, beaked, and humpback whales respectively. As with the FY15 data (Martin et al., 2016), automatically processed sperm whale detections and localizations were not included herein as this capability is still being refined. These automatically processed results are not directly comparable to the FY16 results above since these historic data were collected using the old BSURE array of 18 hydrophones in two lines. The BSURE hydrophones were replaced in late 2010 by forty-one BSURE replacement hydrophones which have a wider frequency response and allow better localization.

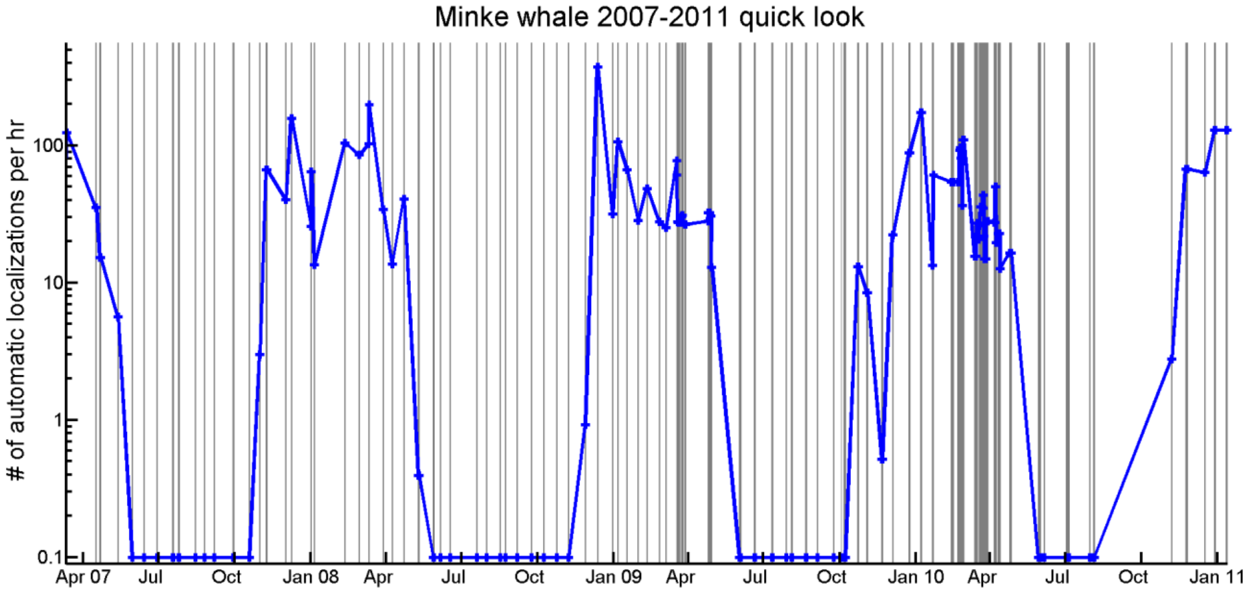


Figure 4. Quick look results of the number of automatically localized minke whale boing calls per hour. Gray shaded regions indicate availability of full bandwidth data. White indicates periods of time when no data was collected. As automatically detected calls attributed to minke whales are also automatically classified, automatically processed minke whale results have few localized false positives.

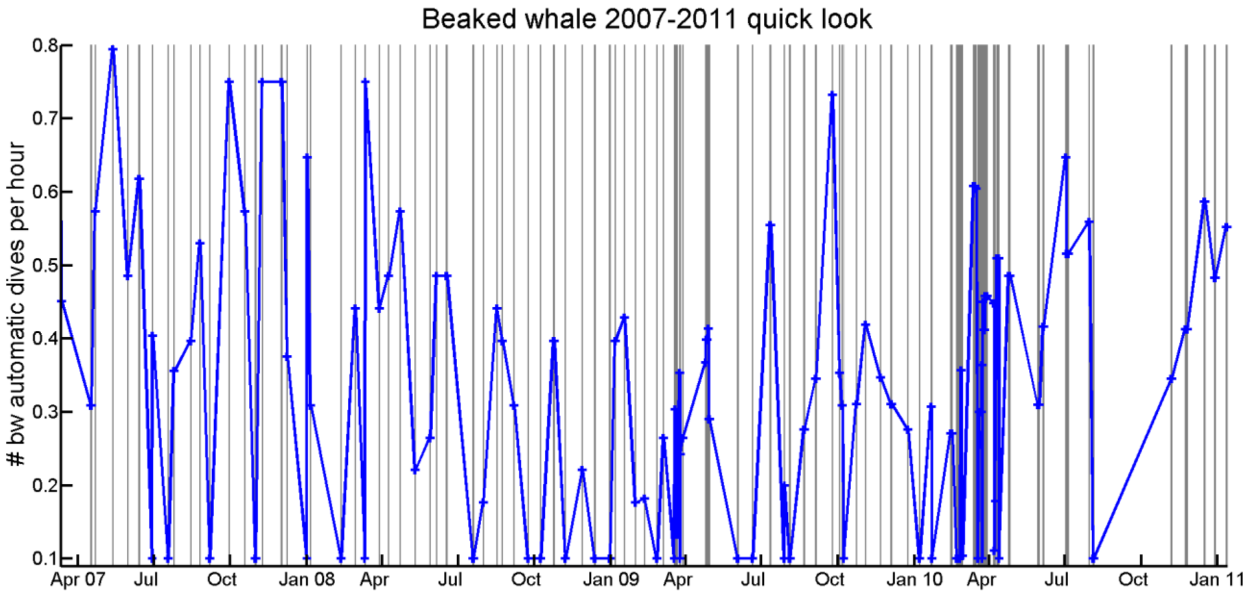


Figure 5. Quick look results of the number of automatically grouped beaked whale group foraging dives per hour. Gray shaded regions indicate availability of full bandwidth data. White indicates periods of time when no data was collected.

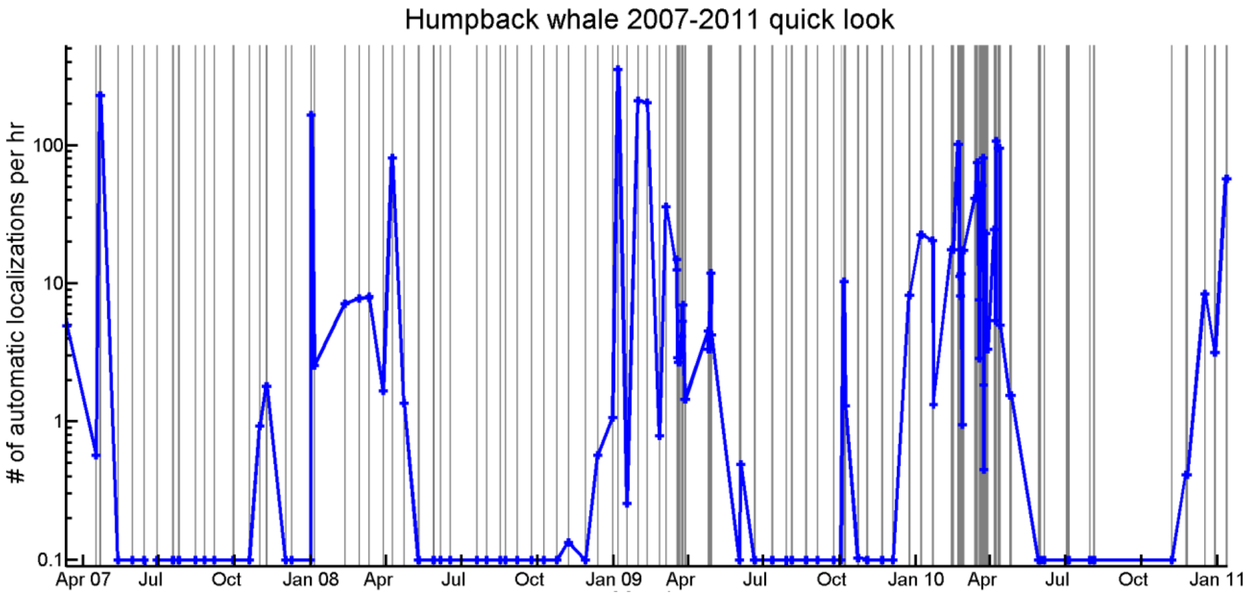


Figure 6. Quick look results of the number of automatically localized humpback whale calls per hour. Gray shaded regions indicate availability of full bandwidth data (dark gray) or decimated data (light gray). White indicates periods of time when no data was collected. Peaks outside of the expected seasonal presence could indicate localizations that are not humpback whales.

4. EMERGING ANALYSIS TECHNIQUES GROUPS STUDIED

4.1 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 C3D.exe. Minke whale tracks are species specific, however the low frequency baleen category includes multiple species (i.e., 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 (i.e., 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 for a valid track.

Tracking of localizations was implemented for automatically localized 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 minutes 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 minutes 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, and data collected around the time of later February SCCs. This also provides a more robust automatic metric (number of individual whales present per hour) than the number of localized calls per hour.

4.2 MINKE WHALE EXPOSURES, RESPONSES, AND ESTIMATED RECEIVED LEVELS

4.2.1 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 7 provides twenty-five minke whale tracks from the semi-automated MATLAB® tracking algorithm over this 98 hour 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 7, and four of the tracks included periods of rapid boing calling (nominally 2 or 3 per minute) in addition to periods of the nominal boing call rate of one call every 5 or 6 minutes

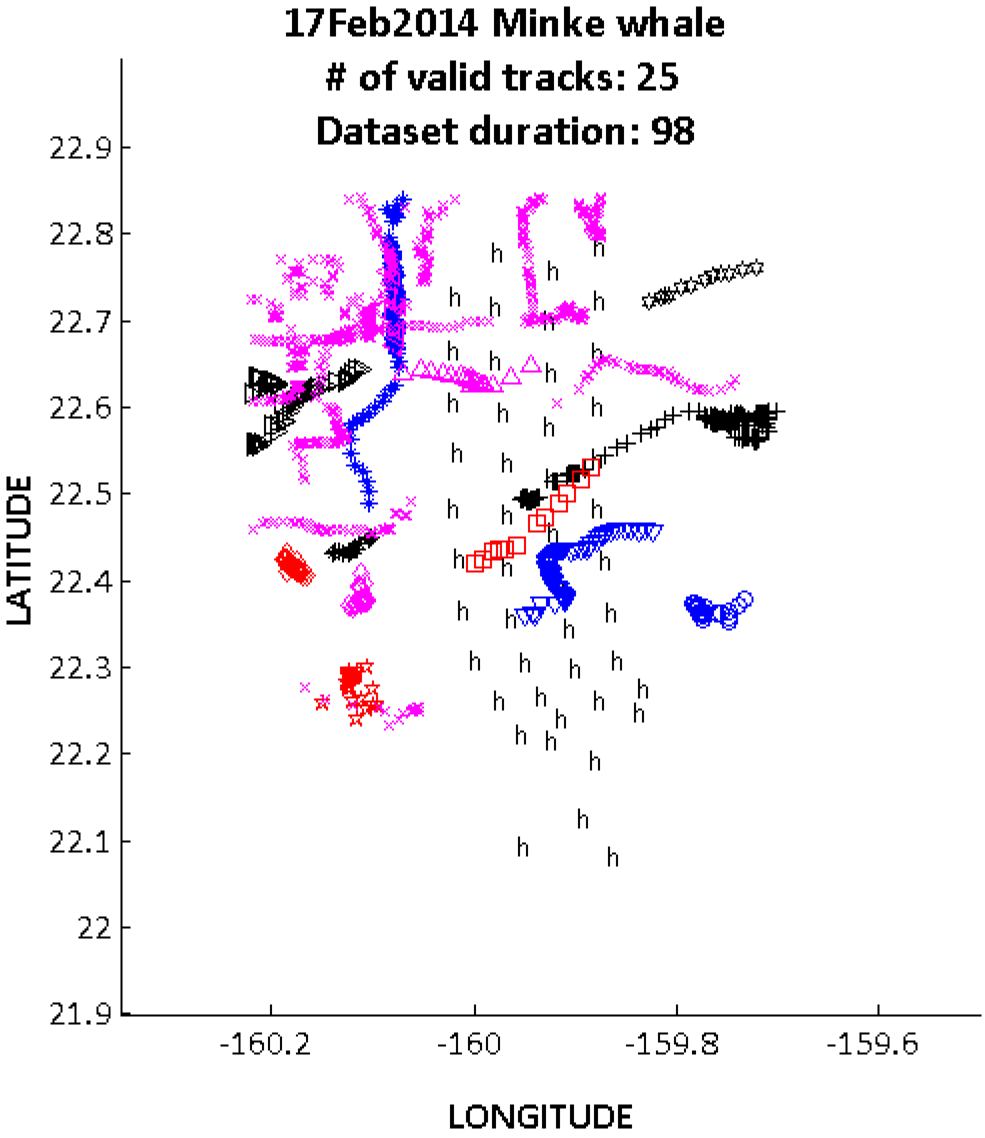


Figure 7. Minke whale tracks generated by the MATLAB® tracking algorithm over 98 hours of data from 17–21 February 2014. Symbols and colors change for the first 9 tracks, the remaining tracks

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 8 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 incorporating the tracking snapshot analysis outputs of counts of individual minke whales as a metric to replace the number of localized whale counts shown in Figures 1 and 4, and extending this metric to other localized whales.

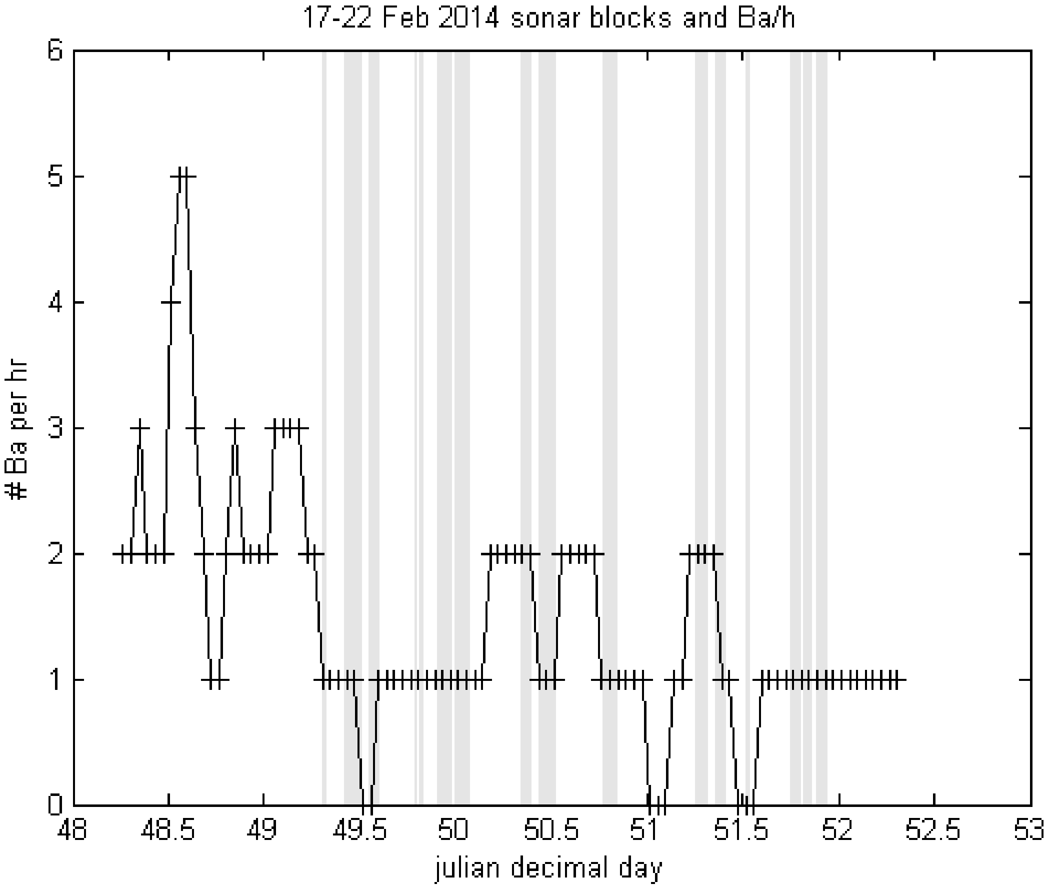


Figure 8. Snapshots per hour of individual minke whale counts over 98 hrs of data. Time axis is in Julian decimal days for 17–21 February 2014. MFAS activity times are indicated by the gray vertical areas. The data include over a day prior to MFAS activity and several hours after MFAS activity.

Figure 9 provides details for minke whale track 12 that potentially ceased calling in response to the training activity. The left pane shows the latitude – longitude plan view of the minke whale track consisting of 73 calls over a period of 7+ hrs beginning at the upper right and ending center left. The right upper two plots in Figure 9 provide the inter-call-interval plotted against call number (top) and time in seconds from the beginning of the track (middle). The lower right panel shows the derived estimated speed in m/s. The track changed at 0621 (39 minutes before the surface ship MFAS training portion of the SCC began, and 68 minutes 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.

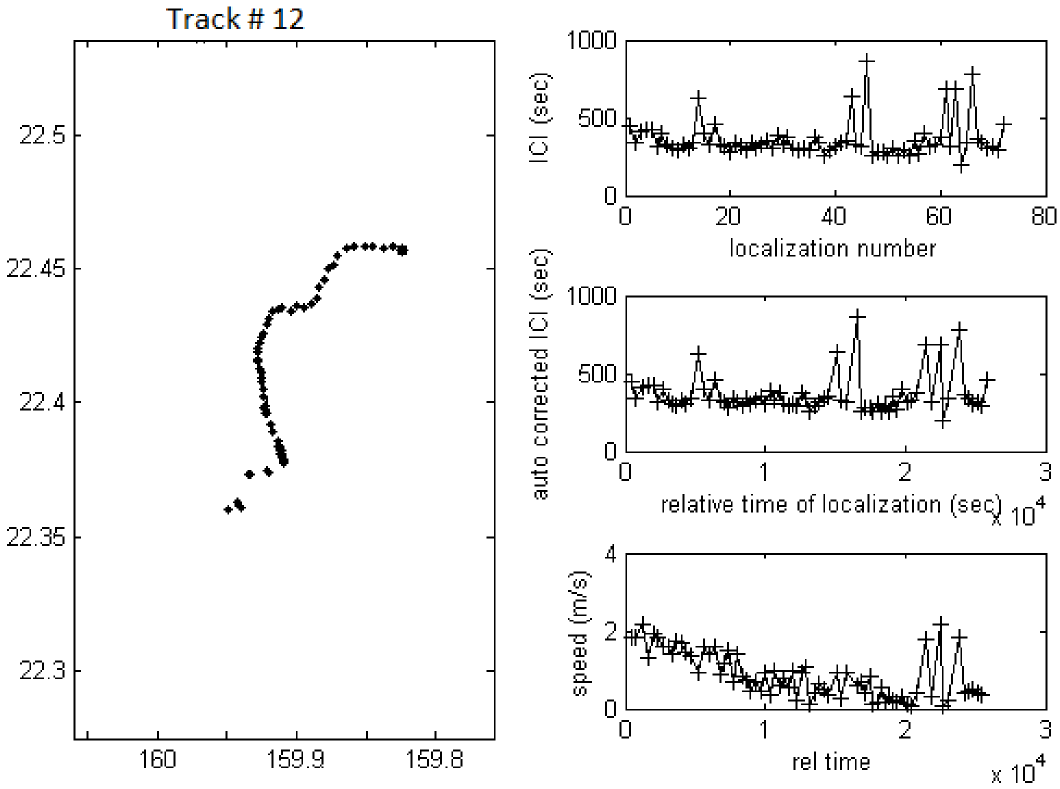


Figure 9. Minke whale track 12 between 0033 to 0745 on 18 February 2014. Track contained 73 calls at the nominal minke whale boing calling rate of 5 to 6 minute (mean ICI 359.9 s) over 7.19 hrs of time. Estimated speed in m/s shown lower right. Track began near 22.45° N, 159.8° W and ended at 22.36° N 159.97° W

Figure 10 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 Navy training are twofold: first, at 0729 active sonobuoy transmissions occurred for 4 minutes and 11+ 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 travel speeds on the order of 1.6 to 2 m/s and during this movement the whale was not calling. 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.

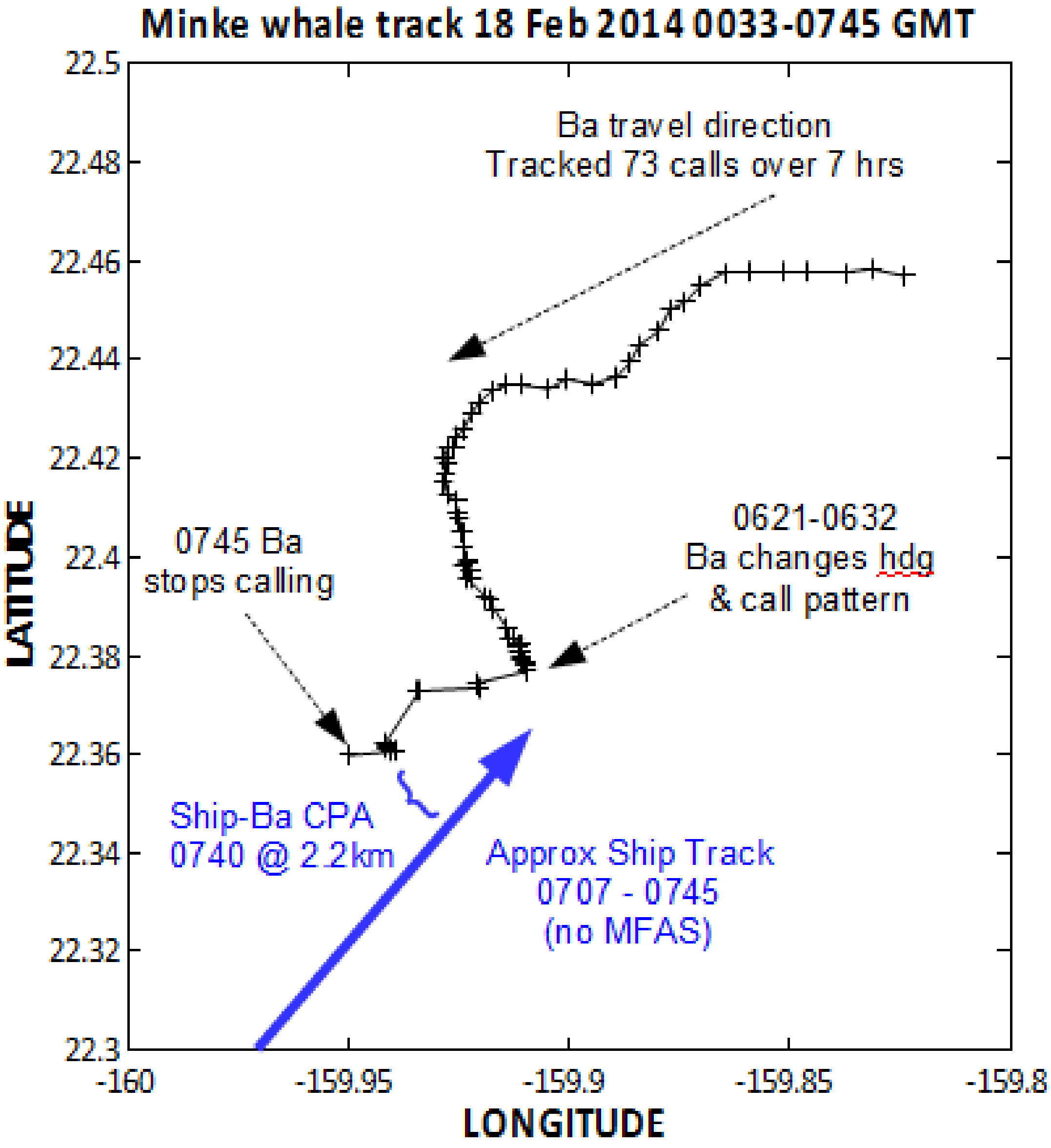


Figure 10. Details of minke whale track # 12 in context of sonobuoy MFAS transmissions and a surface ship approaching (heading ~45°) without MFAS activity. The closest point of approach of the surface ship and the minke whale occurred at 0740 with 2.2 km of separation. The minke whale's last call was at 0745. Sonobuoy active transmissions occurred between 0729 and 0733

A final figure investigating exposures in February 2014 (Figure 11) 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 appears to indicate 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 after cessation of calling and resume calling rather than departing the area when sonar activity begins.

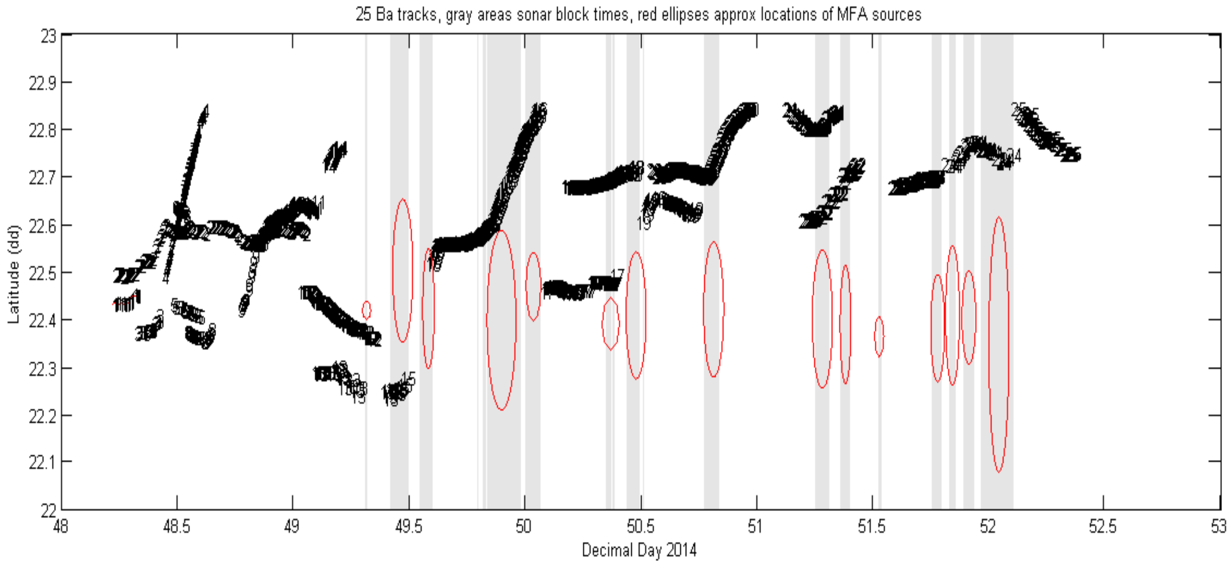


Figure 11. Timeline view between 17 to 22 February 2014 (Julian day 48–53) with latitude values for 25 tracked minke whales plotted in black (with track number as symbols). Gray vertical areas indicate periods of MFAS activity. Red ellipses indicate latitudinal ranges of MFAS activities. Note that minke 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.

4.2.2 Received Level Estimation

Passive acoustic monitoring (PAM) of PMRF hydrophones is a powerful tool, however all of the sensors are located at the seafloor. Propagation modeling is utilized to estimate the received level at animal locations as no acoustic tags are on the animals. Various propagation models have been utilized (i.e. the U.S. Navy's PCIMAT, Oasis's Peregrine, and the sonar equation). Propagation modeling was used to estimate the transmission loss for MFAS between sources and whale locations. The received level for a single source and ping is the source level minus the transmission loss, 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 mid-frequency active sonars 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 meter 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 received level to which animals are exposed. Assuming MFAS produces 1 sec long pings, the magnitude of the sound exposure level (SEL) is equal to the received level, as the time period defined for SEL is 1 sec. To determine the received level 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·s) and converted to the conventional dB re µPa^2·s by taking $10\log_{10}$(accumulated SELs).

Work on determining the CSEL was performed in FY2016 for a portion of the onset of the surface ship portion of the February 2016 SCC. Figure 12 illustrates an encounter between 0357 and 0818 on

16 February 2016, where three minke whales were tracked in conjunction with surface ship MFAS activity.

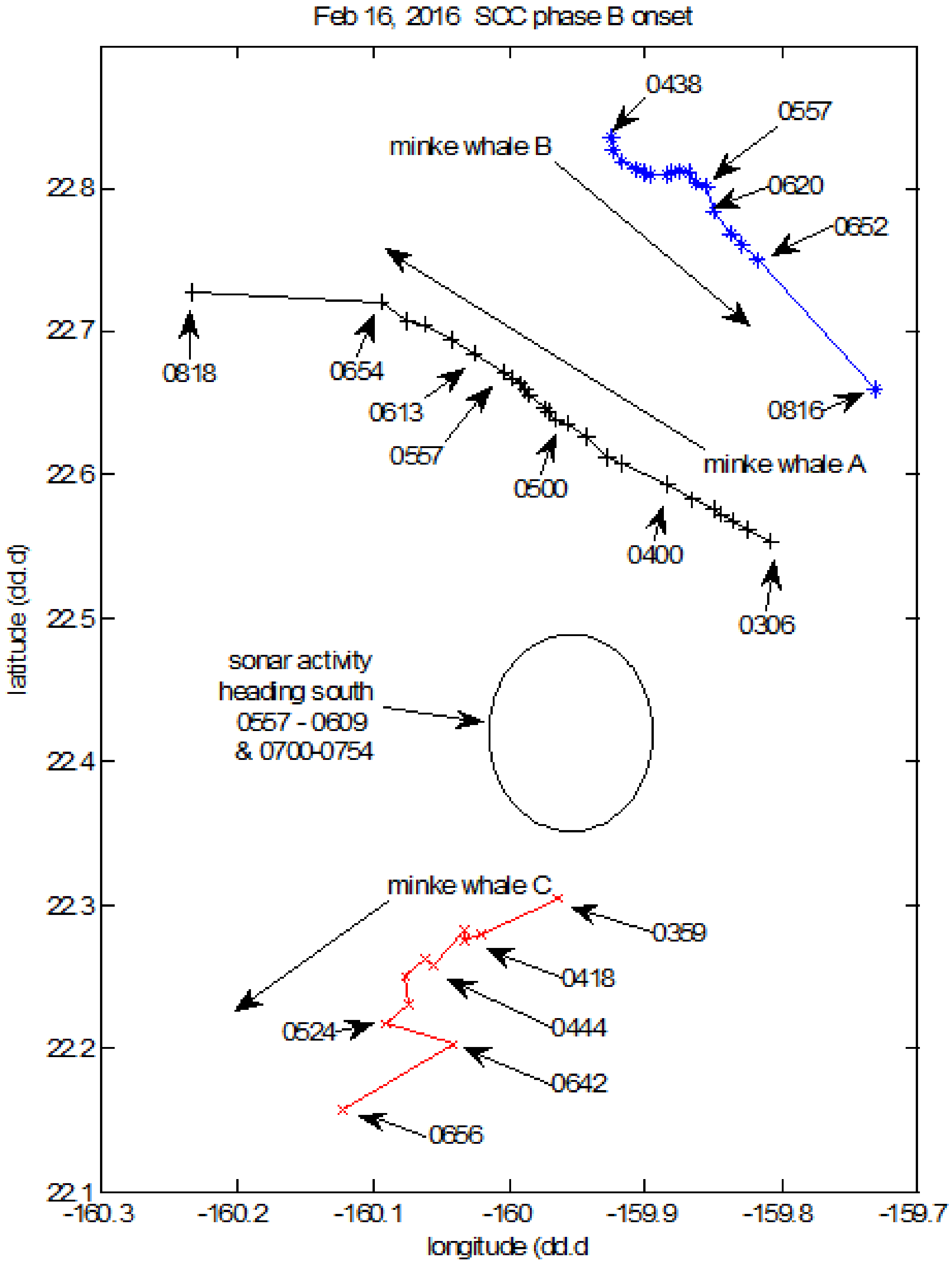


Figure 12. Onset of surface ship MFAS training, 16 February 2016. Three minke whales localized and tracked between 0359 and 0818 GMT shown with some call times identified. The ellipse in the center is the approximate area of the MFAS activity between 0557 and 0754 GMT

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 NW while whale B was traveling SE from the north east 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 13) 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 minutes. Even though the ship was over 20 km from the whale, the CSEL increased to 146.7 dB re µPa ^{2}s during that time. 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.

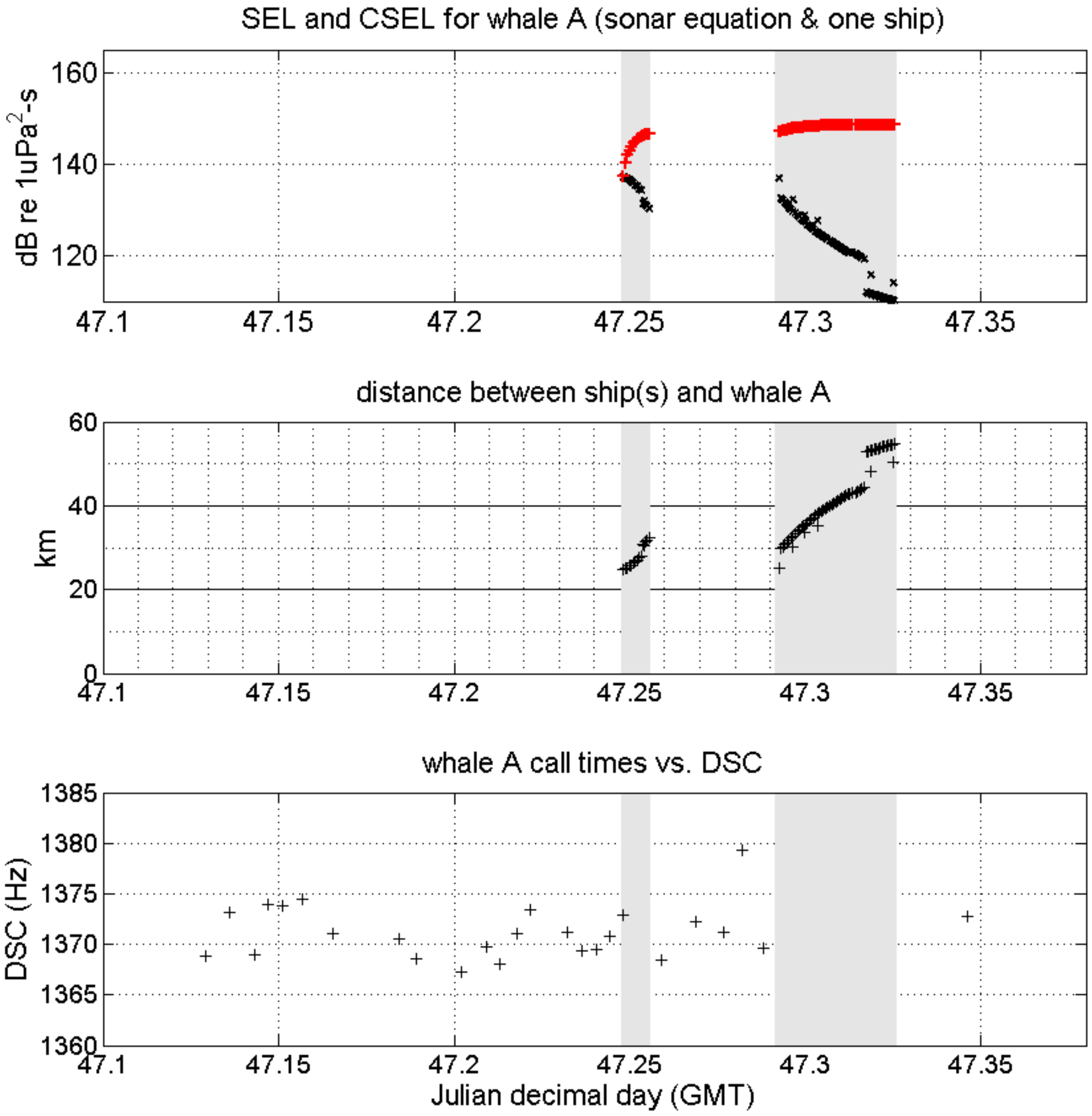


Figure 13. Estimated cumulative sound exposure level on whale A for the closest MFAS ship. All panels are scaled for the same time period (16 February 2016 between 0224 and 0900 GMT) with vertical gray shaded areas indicating times that MFAS occurred. The upper panel shows the estimated CSEL (red lines) 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 (Martin et al., 2015) frequency with the plus symbols indicating times of calls

4.3 BLAINVILLE'S BEAKED WHALE GROUP FORAGING DIVE ANALYSES

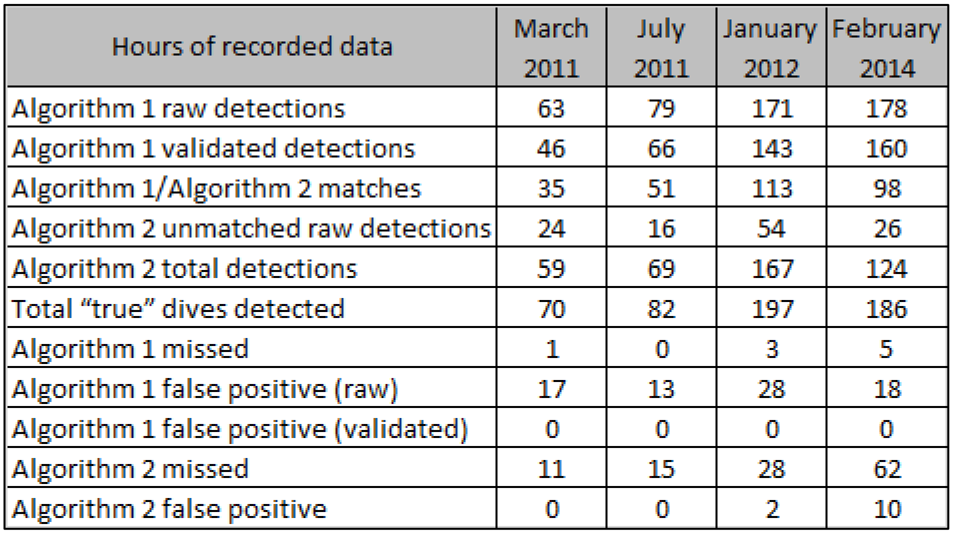
Automated PAM processing has been utilized to detect beaked whale frequency modulated foraging clicks. A MATLAB® routine was utilized to automatically sort foraging click detections into beaked whale group foraging dives based on spatial and temporal patterns. Figure 3 provides the fully automated results 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 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 clicks, 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 (*Ziphius cavirostris*) have been detected, as have Cross Seamount types of FM foraging clicks (McDonald et al., 2009).

4.3.1 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 hours) to over four days (110.7 hours). 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". 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 five or ten minutes 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 66-86–% of the Blainville’s beaked whale foraging dives at PMRF, while algorithm 2 detected 67–85% 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	March 2011	July 2011	January 2012	February 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

4.3.2 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 km^2. The following density equation (Marques, Thomas, Ward, DiMarzio, and Tyack; 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.

	March 2011			July 2011			January 2012			February 2014		
	Combined	Algorithm 1	Algorithm 2	Combined	Algorithm 1	Algorithm 2	Combined	Algorithm 1	Algorithm 2	Combined	Algorithm 1	Algorithm 2
n (number of 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 rate/hour	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 (hour)	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/km2)	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 (probability of false positives)	0	0	0	0	0	0	0	0	0.02	0	0	0.1
p = 1	1	1	1	1	1	1	1	1	1	1	1	1
p (probability of detection)	1	0.67	0.79	1	0.74	0.83	1	0.71	0.83	1	0.85	0.68

Cyan shaded values were only used in the second analysis.

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

	March 2011			July 2011			January 2012			February 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	11.2	16.3	8.5	10.1	11.6	9.8	7.9
C (probability), P (probability)	12.1	12.1	12.1	13.6	13.6	13.6	16.3	12.1	11.9	11.6	11.6	10.5

4.3.3 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 minutes 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 minutes, then the ascent and descent portions can last 10 to 30 minutes each. 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, received levels 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 five minute) or if the GVP did not begin until after sonar ceased (i.e. less than 30 minute). 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 received level at the primary hydrophone was estimated using Peregrine at both 10m depth (assuming the group was at the surface) and at 1000m 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. 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 received levels, ship heading, and distance were examined using 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 minutes of onset or cessation. Twenty-four group dives occurred before sonar started; of these, 16 dives ended within 5 minute of sonar starting (either before or after the onset, considered a response), four dives ended within 5 minute 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 minute of sonar ended (considered a response by groups that were already diving but not actively foraging) while 12 dives occurred within 15–30 minute 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 14–16 depict these responses in three different scenarios.

An unbalanced ANOVA did not find significant differences in the received levels when comparing all the above scenarios, but in paired t-tests within each period, there was a significant difference in received level for the groups that responded versus groups that did not respond in the “before” period (T = -2.23, p = 0.04; Figure 17). In other words, groups that were presumed to be foraging prior to the onset of sonar but ceased foraging when sonar began experienced higher received levels 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 18). 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 19), 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.

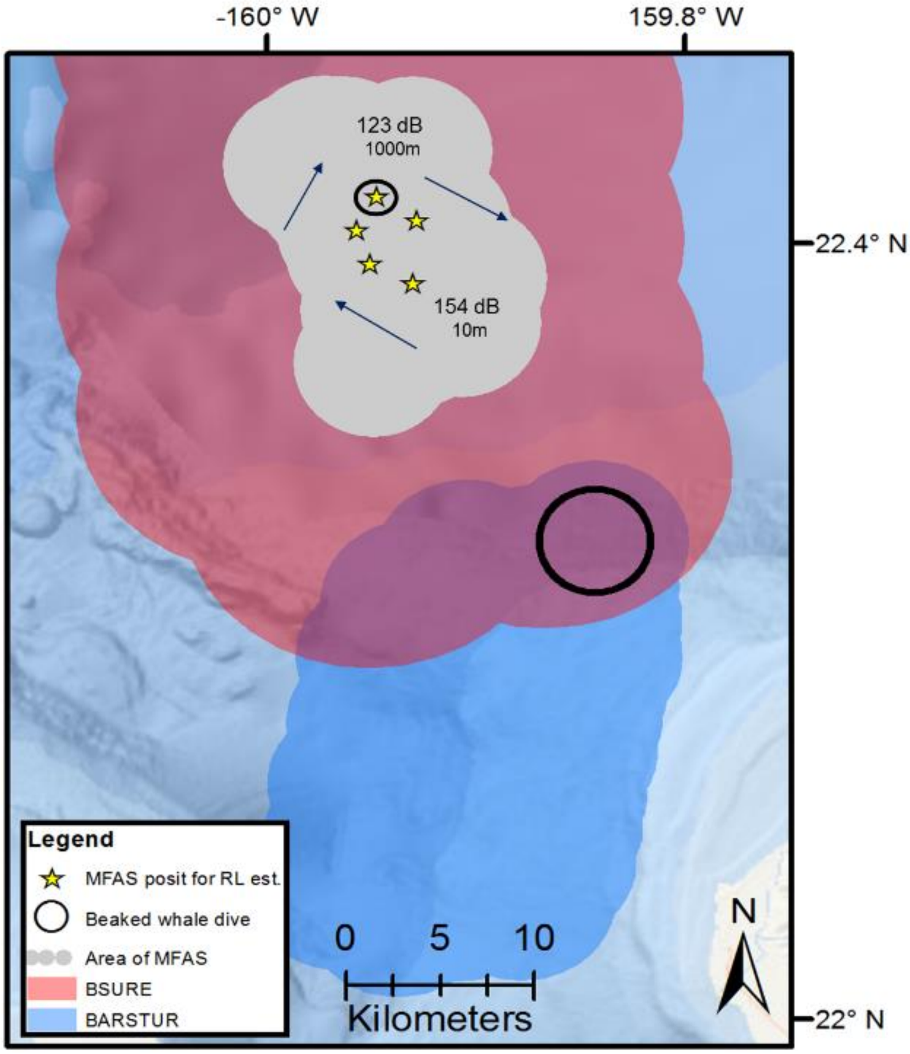


Figure 14. An example of a beaked whale group response to MFAS. In this case, the group (represented by the black circle) continued diving during a period of MFAS (clicks starting when ship was 21 km away) until the ship turned (at the location of the circled star), and began approaching the group at which time the group ceased emitting foraging clicks

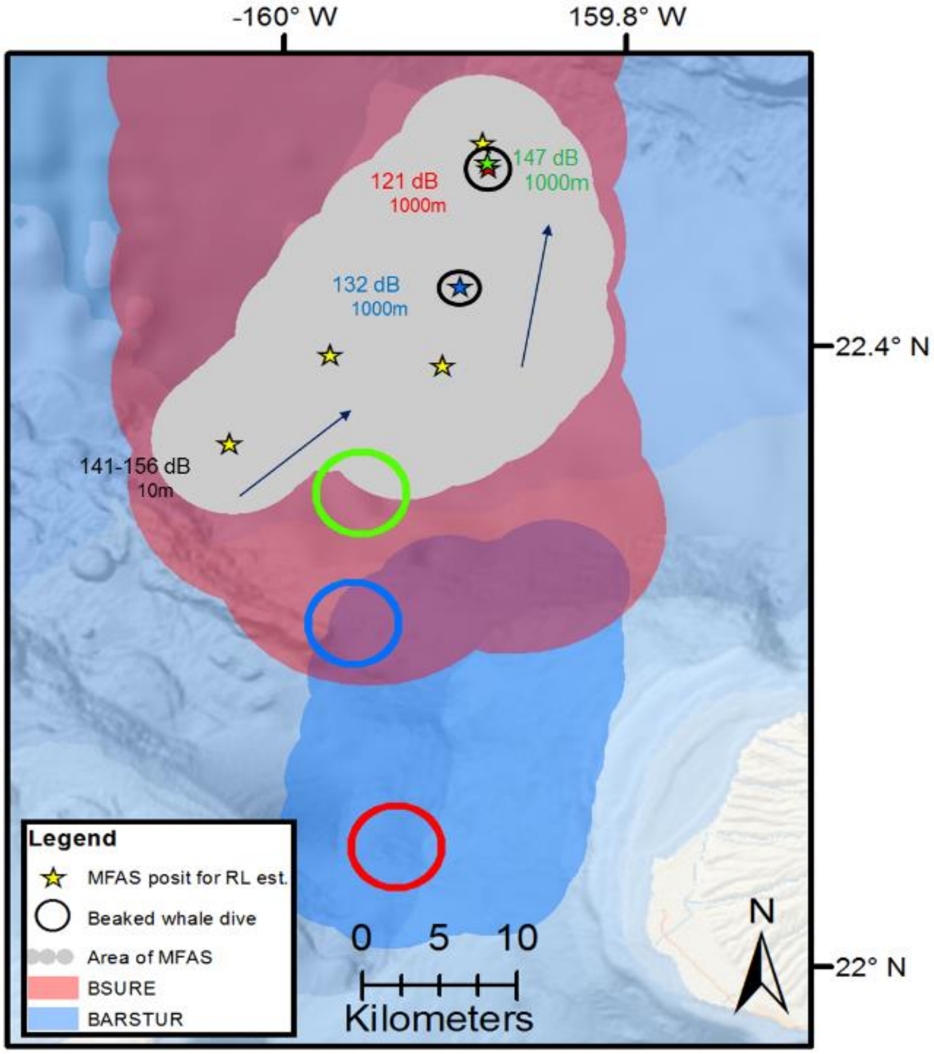


Figure 15. In this second example, three diving groups (represented by the three colored circles) all started vocalizing after a ship emitting MFAS turned their heading away from the dive locations and the distance between the ship and the hydrophones was 25–49 km. The stars circled in black correspond to the ship's position at the onset of each of the beaked whale group dives.

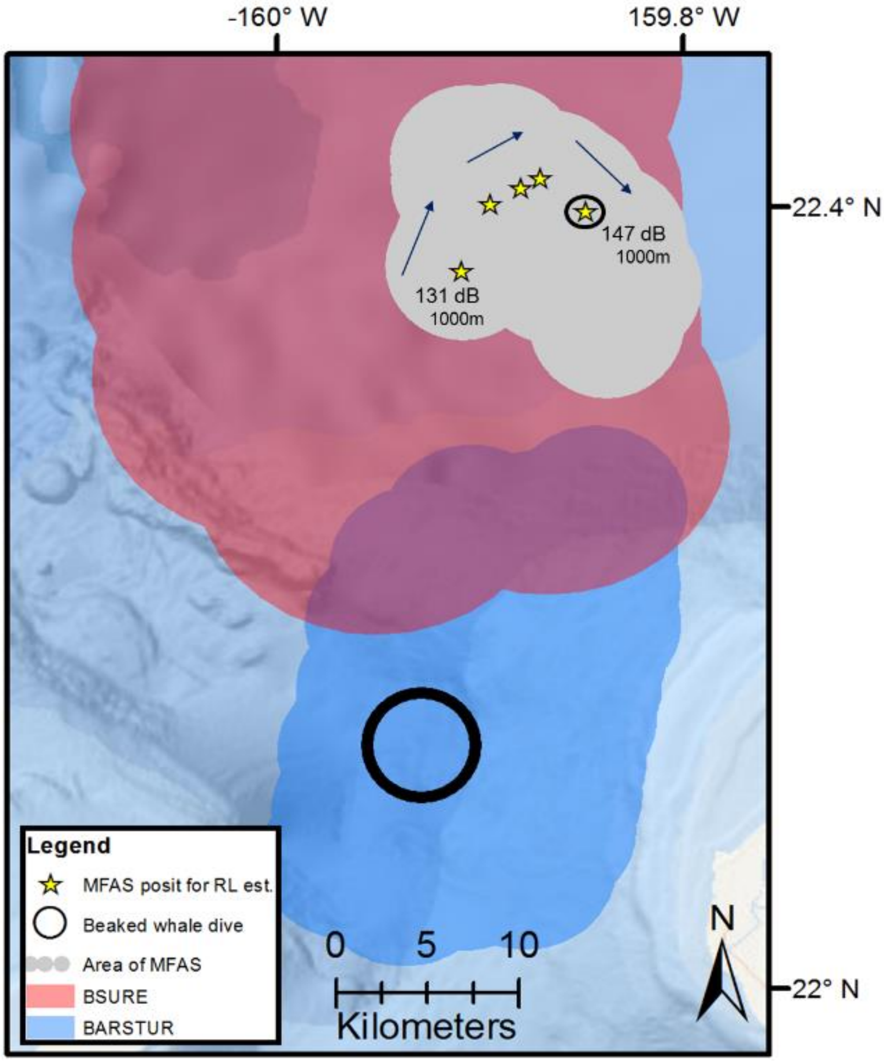


Figure 16. A third example of a response by a group of foraging Blainville's beaked whales. This group (represented by the large black circle) ceased producing foraging clicks when a ship emitting MFAS turned towards the group location (the black circled star) at a distance of 32 km.

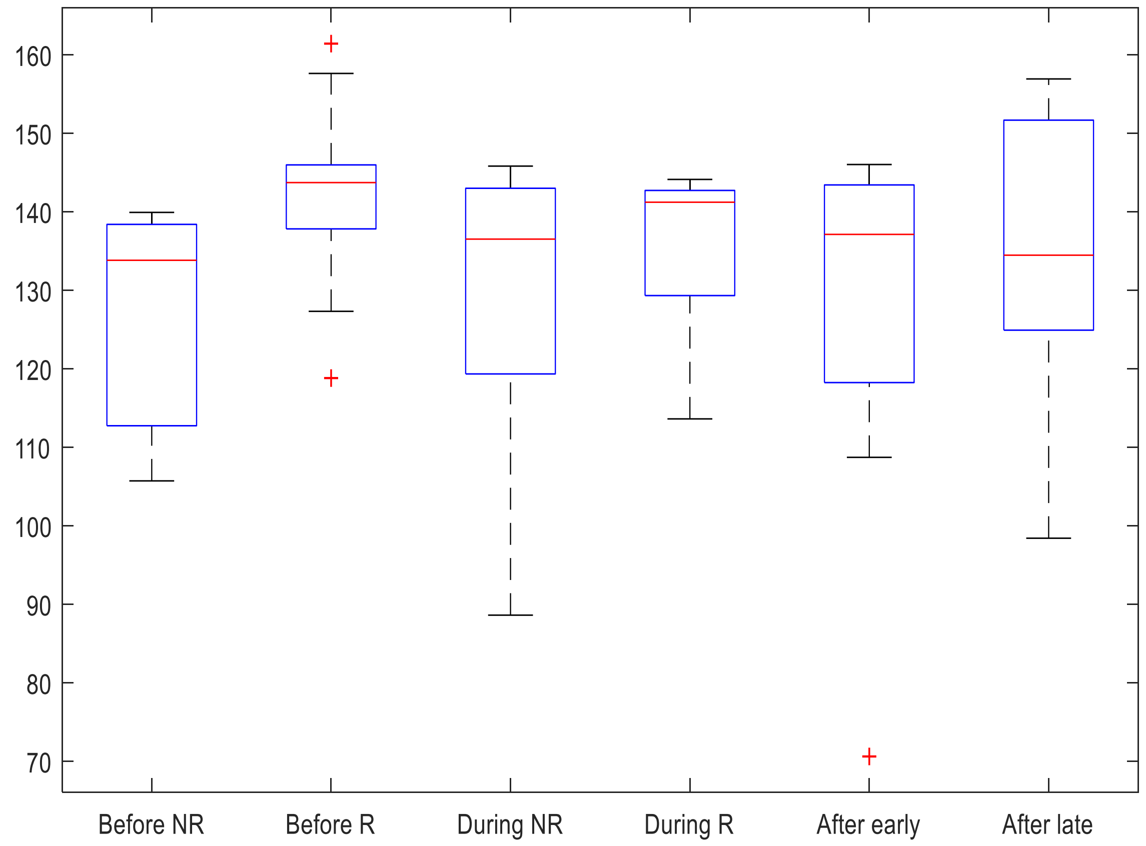


Figure 17. Boxplots of groups that did respond (“R”) or did not respond (“NR”) in the periods before, during, or after MFAS. The ANOVA comparing all dives across all periods to the received level of the MFAS was not significant, but the paired t-test of the groups that did and did not respond to sonar in the before period was significant, such that the received level was higher for groups that did cease foraging in response to the onset of sonar compared to groups that continued foraging when sonar began.

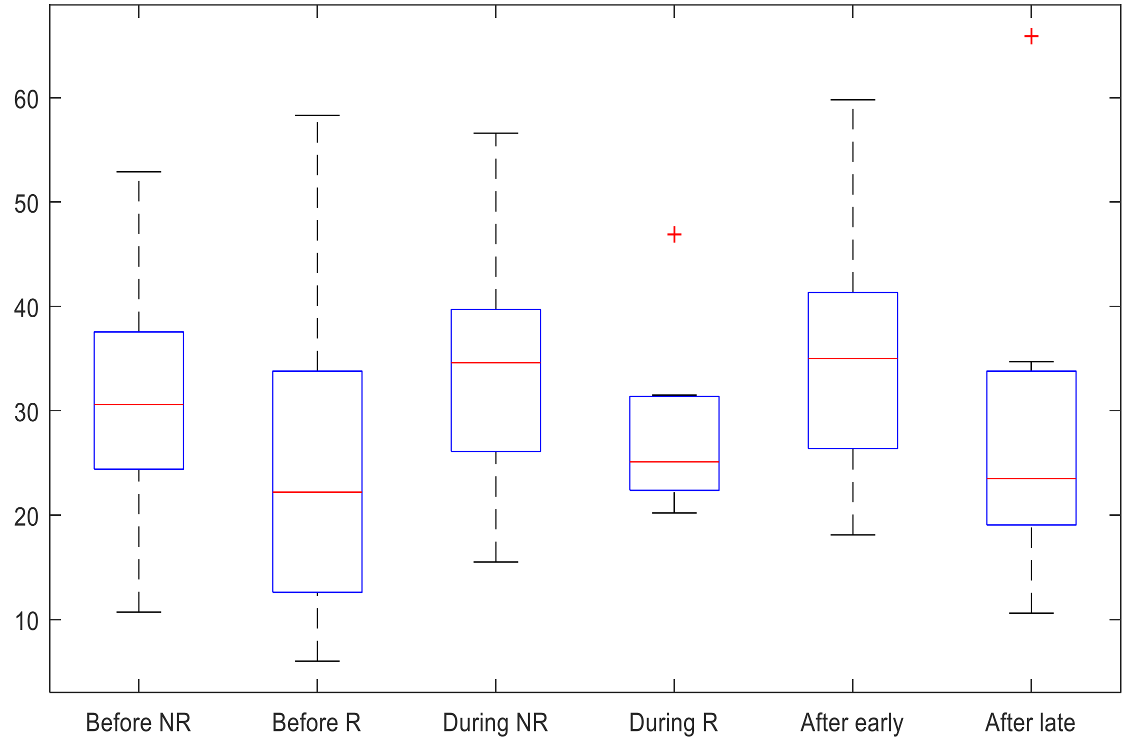


Figure 18. Boxplots of groups that did respond (“R”) or did not respond (“NR”) in the periods before, during, or after MFAS. None of the statistics comparing all dives across all periods to the distance of the source vessel were significant; however, in all time periods the vessels were generally further away from the groups that did not respond compared to the groups that did respond.

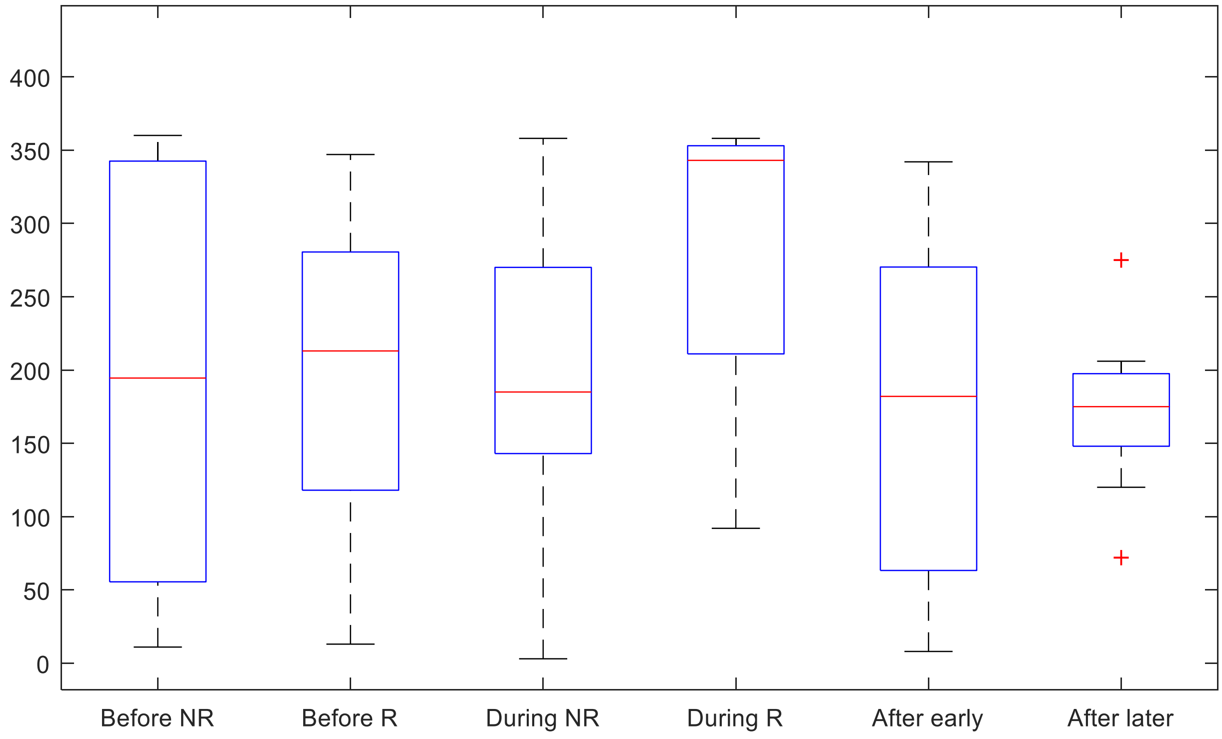


Figure 19. Boxplots of groups that did respond (“R”) or did not respond (“NR”) in the periods before, during, or after MFAS. The ANOVA comparing all dives across all periods to the heading of the source vessel was not significant, but the paired t-test of the groups that did and did not respond to sonar 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.

5. 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 ONR funded project titled “Behavioral Response Evaluations Employing robust baselines and actual navy training” (BREVE, PI: S. 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 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 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. Baird, D. Webster, and B. Southall were performed on satellite tagged data from 2011 to 2013 (Baird, Martin, Webster, and Southhall; 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 received levels compared to the prior report include accounting for ARGOS satellite tag positional errors and statistically representing the estimated received level over the range of possible positions. The statistical representations inform one when estimates are reasonable (e.g. distribution of estimated received levels has unimodal character with low dB variations of estimates) and when they are not (e.g. multimodal estimated received level distributions and large variations). This effort is being separately reported collaboratively with R. Baird (first author) and B. Southall for submission to HDR.

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APPENDIX A
OCCURRENCE AND HABITAT USE OF FORAGING BLAINVILLE'S BEAKED WHALES (MESOPLODON DENSIROSTRIS) ON A US NAVY RANGE IN HAWAI'I. AQUATIC MAMMALS

A.1 SUPPORTING ARTICLE REFERENCE

Appendix A – Henderson, E.E., S.W. Martin, R.A. Manzano-Roth, and B.M. Matsuyama. 2016. Occurrence and habitat use of foraging Blainville's beaked whales (*Mesoplodon densirostris*) on a US Navy range in Hawai'i. Aquatic Mammals 42(4): 549-562.

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APPENDIX B
IMPACTS OF A U.S. NAVY TRAINING EVENT ON BEAKED WHALES DIVES IN HAWAI'IAN WATERS. AQUATIC MAMMALS

B.1 SUPPORTING ARTICLE REFERENCE

Appendix B – Manzano-Roth, R.A., E.E. Henderson, S.W. Martin, C.R. Martin, and B.M. Matsuyama. 2016. Impacts of a U.S. Navy training event on beaked whales dives in Hawai'ian waters. Aquatic Mammals 42(4): 507-518.

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APPENDIX C
SWIM TRACK KINEMATICS AND CALLING BEHAVIOR ATTRIBUTED TO BRYDE'S WHALES ON THE NAVY'S PACIFIC MISSILE RANGE FACILITY. JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA

C.1 SUPPORTING ARTICLE REFERENCE

Appendix C – Helble, T. A., S.W. Martin, G. R. Ierley, and E.E. Henderson. 2016. Swim track kinematics and calling behavior attributed to Bryde's whales on the Navy's Pacific Missile Range Facility. Journal of the Acoustical Society of America 140 (6): 4170-4177.

C.2 WEB LINK

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APPENDIX D
IDENTIFYING BEHAVIORAL STATES AND HABITAT USE OF ACOUSTICALLY TRACKED HUMPBACK WHALES IN HAWAI'I. MARINE MAMMAL SCIENCE

D.1 SUPPORTING ARTICLE REFERENCE

Appendix D – Henderson, E.E., T.A. Helble, G.R. Ierley, and S.W. Martin. (Submitted). Identifying behavioral states and habitat use of acoustically tracked humpback whales in Hawai'i. Marine Mammal Science.

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14. ABSTRACT

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, Hawai'i, including during U.S. Navy Mid-Frequency Active Sonar (MFAS) training. Data products (both recorded hydrophone data, standard PMRF range products, and range craft deployed calibrated hydrophone data) were obtained and analyzed.

Results of fully automated processing are presented for all data collections throughout the fiscal year in terms of the beaked whale foraging dives per hour and the number of baleen whale and sperm whale passive acoustic localizations on and near the range. In addition, data from 2007 through 2010 was automatically processed for beaked whales, humpback whales and sperm whales, and plots of these results are presented as well.

15. SUBJECT TERMS
Marine mammal monitoring; Naval undersea warfare; GVP; LMR; M3R; NUWC; OASIS

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