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14. ABSTRACT
Beaked whales (family Ziphiidae) were automatically detected post exercise in recorded acoustic data collected before, during and after a February 2012 U.S. Naval training event at the PMRF, Kauai, Hawaii. Manual validation of the detections was performed to ensure they fit known characteristics of beaked whale foraging echolocation clicks, including waveform, spectrum, inter-click-intervals, and dive vocal period durations. Received levels, being the received sound pressure level in dB per 1 micropascal (µPa) rms, are estimated utilizing the U.S. Navy's standard personal computer interactive multi-sensor analysis tool for dive groups detected during MFAS transmissions.
A total of 289 beaked-whale-like dives were detected over the study period. Two hundred fifty-eight of these were composed of clicks that resemble Blainville's foraging clicks, while 31 dives were composed of clicks more similar to those observed near Cross Seamount. Statistical differences in dive rates of both type occurred after the initiation of the Navy training event. Differences are also observed in the diel occurrence patterns and spatial distribution of the dives. Receive levels for the 10 beaked whale dives detected during MFAS activity at distances from potentially as close as 13 km to over 52 km have estimated RLs varying from 52 to 137 dB re 1 µPa (mean 109 dB, standard deviation [s.d.] 22 dB) while the animals were presumed to be at depth foraging. RLs that are estimated assuming the animals were at/near the sea surface, average 40.1 dB higher than those estimated at foraging depth due to ducted propagation varying from 134 to 162 dB re 1 µPa (mean 151 dB, s.d. 9 dB).

15. SUBJECT TERMS

Beaked whale, mid-frequency active sonar (MFAS), passive acoustic monitoring, Pacific Missile Range Facility (PMRF)

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Impacts of a U.S. Navy training event on beaked whale dives in Hawaiian waters

September 30, 2013

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Abstract

Beaked whales (family Ziphiidae) were detected in acoustic data collected before, during and after a February 2012 U.S. Navy training event at the Pacific Missile Range Facility, Kauai, Hawai'i. Validation of the detections was performed to ensure they fit characteristics of beaked whale foraging echolocation clicks. Two hundred fifty eight detected dives were composed of clicks that resembled Blainville's beaked whale (*Mesoplodon densirostris*) clicks, while 31 detected dives were composed of clicks similar to those of an unknown odontocete reported near Cross Seamount. Statistical differences were found in the dive rates, diel occurrence patterns and the spatial distribution of the dives. The received levels (RL) of sound (in dB re 1 µPa) from the AN/SQS-53C sonar for each dive group detected during the training event are estimated utilizing the U.S. Navy's standard personal computer interactive multi-sensor analysis tool (PCIMAT). Ten dives occurred during MFAS activity at distances between 13 km to over 52 km. RLs for the dives vary from 52 to 137 dB (mean 109.3 dB, s.d. 22 dB) while the animals were presumed to be at foraging depth and vary from 134 to 162 dB (mean 150.6 dB, s.d. 9 dB) near the sea surface.

I. INTRODUCTION

Beaked whales (family *Ziphiidae*) consist of at least 21 different species in six genera with relatively little known about many of the species. Both Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) species were among the species which stranded in association with a U.S. Navy training event in the Bahamas in 2000 (Hogarth and Johnson 2001). This resulted in an emphasis on beaked whale research, especially on the two species involved in the 2000 stranding. Results of this research have identified echolocation click characteristics for these two species from different areas of the world based upon data from instrumentation tags attached to the whales (Zimmer et al. 2005, and Johnson et al. 2006). Both of these species were found to utilize foraging echolocation clicks with frequency modulation characteristics and relatively consistent inter-click-intervals (ICIs). Acoustic characteristics have also been reported for the following species: Gervais' (*Mesoplodon europaeus*), Baird's (*Berardius bairdii*), and Longman's (*Indopacetus pacificus*) beaked whales as reported in the literature (Gillespie et al. 2009, Dawson et al. 1998 and Rankin et al. 2011, respectively). A common characteristic of many of the reported beaked whale species foraging clicks are short duration signals (< 0.4ms) with frequency modulated sweeps from as low as 15 kHz to over 50 kHz. Longman's species in Hawai'i have also been reported to use lower frequency clicks with no appreciable FM characteristics (Rankin et al. 2011). Beaked whale-like acoustic signals have been detected in the Pacific at Palmyra Atoll with suggestion towards a new species based both upon skulls that are not similar to existing species and differences of the acoustic characteristics of the signals (Baumann-Pickering et al. 2010). Acoustic signals recorded at Cross Seamount, located approximately 290 km south of Oahu, Hawai‘i, (McDonald et al. 2009) have also shown frequency modulation characteristics but with longer durations (~ 1 ms), wider bandwidth (20 to over 90 kHz) and shorter inter-click-intervals (ICIs) (mean 0.11 s, s.d. 0.035 s for highest signal levels) than normally reported for beaked whales. McDonald et al. suspect that the clicks detected at Cross Seamount may be geographic variants of Cuvier’s, Longman’s or Blainville’s beaked whales, or from another beaked whale species not known to occur in the region.

Beaked whale foraging dive behavior has been identified for Blainville’s and Cuvier’s species using various tag data and reported in the literature (Tyack et al. 2006, Johnson et al. 2006, Baird et al. 2006, and 2008). These two species are known to only produce foraging clicks while at depths greater than 200 m during foraging dives, with dive vocal durations approximately 30 to 57 min per dive (Johnson et al. 2004, Tyack et al. 2006). The interval between foraging dive’s vocal periods is on the order of 2 hours or more (Tyack et al. 2006, Tyack et al. 2011). The foraging dive vocalizations include two types of echolocation clicks: foraging clicks for finding prey and rapid buzz clicks for short range prey capture. Foraging echolocation clicks can be generally characterized as short waveforms (0.175 to 0.4 ms upswept pulses) with relatively flat spectrums between 30 kHz and 50 kHz, source levels over 200 dB re 1 μPa and mean ICIs on the order of 0.3 to 0.5 s (Johnson et al. 2004, Moretti et al. 2010). Shallower dives are observed between the foraging dives with no click activity present. Much of these dive and click characteristics come from data from other regions of the world, however Baird et al. (2006; 2008) reported dive characteristics for both Blainville’s and Cuvier’s species off the island of Hawai‘i, with similar findings.

Given the available information that exists for the acoustic click characteristics of beaked whales, a variety of different beaked whale click detection methods currently exist which enable automated processing of passive acoustic data to detect these clicks (Yack et al. 2010). The use of automated detectors for beaked whale clicks allows large volumes of data to be processed from many sources (e.g. survey vessel towed hydrophones, long term acoustic recording packages and U.S. Navy training ranges’ hydrophones cabled to shore). Extension of passive acoustic monitoring methods for beaked whales includes density estimation based upon click (cue) counting techniques (Marques et al. 2009) and acoustically determined beaked whale foraging dive counting based on density estimation methods (Moretti et al. 2010).

The acoustically determined beaked whale dive count method of density estimation also shows reduced dive activity and abundance at the Atlantic Undersea Test and Evaluation Center (AUTEC) located in the Bahamas (Moretti et al. 2010, McCarthy et al. 2011 and Tyack et al. 2011) during mid-frequency active sonar (MFAS) activity as compared to before the training events. These efforts demonstrated that Blainville’s beaked whales appeared to depart an area where MFAS is occurring and gradually return after a two to three day period after sonar activities cease. The studies at AUTEC reported four samples of AN/SQS-53C MFA sonar activity ensonifying Blainville’s beaked whales at distances from 14.7 to 19 km with estimated received sound pressure levels (SPLs) of 127 to 133 dB re 1 μPa rms. These reports also included 13 other sources of mid-frequency sonar exposures (AN/SQS-56 equipped U.S. Navy ships and foreign ship sonars). When pooling all sources of sonar, Blainville's beaked whale received levels ranged from 101 to 157 dB re 1 µPa (mean 128 dB, s.d. 15 dB). While this study is similar to the work at AUTEC conducted on naval ranges, this study differs in detection methodology and is in a different area. This paper describes the methods utilized to acoustically detect beaked whale group vocal activity coincident with MFAS activity at the Pacific Missile Range Facility (PMRF) and to estimate the sound pressure levels the whales would be exposed to both near the sea surface and at a presumed dive depth. Finally, this report analyzes the differences in dive characteristics before, during, and after MFAS activity to assess the impact of MFAS on dive behavior.

II. METHODS

A. Data Collection

PMRF, located off the west coast of Kauai, Hawaiʻi (Figure 1), hosts a variety of U.S. Naval training events every year and has on the order of two hundred hydrophones mounted on the seafloor and cabled to shore to support performance analysis for U.S. Naval systems. PMRF has supported U.S. Navy funded monitoring of marine mammal acoustics of for over a decade when training events are not occurring. In some cases it is possible to obtain data during training events to support marine mammal monitoring efforts; in those cases, ship locations and recorded acoustic hydrophone data can be provided post-event for analysis.

Acoustic data from 31 hydrophones, along with an analog time code signal, were provided for before, during, and after a training event in February, 2012. The 31 hydrophones was a limitation of the data acquisition system used to record the data at that time. The hydrophone recordings were simultaneously sampled at a rate of 96 kHz using 16 bit analog-to-digital converters. The data were stored as sequential data files, each containing 10 minutes of data. A two terabyte drive allowed continuous recording of the 31 hydrophones for about three and a half days. The recorded time code signal allowed precise alignment of acoustic data with ship positions in post-event analysis.

Figure 1 shows the approximate locations of the 31 hydrophones recorded and utilized in this analysis. Spacing between the hydrophones used in the data collection varies from under 1.6 km in one cluster area to over 10 km in areas farther offshore. Hydrophones were clustered into five groups as indicated in Figure 1 for a spatial analysis (cluster 1: phones 40, 33, 24, 34, 41, 10; cluster 2: 1, 2, 132, 133, 135; cluster 3: 200, 212, 191, 180, 37, 21; cluster 4: 182, 193, 203, 215, 205, 184, 195; cluster 5: 188, 197, 209, 219, 207, 186, 217). Water depths vary from 650 m to over 4700 m with a steep slope just off the island of Kauai that progress to a more gradual slope in deeper waters. Recorded hydrophones have three different frequency responses: ~50 Hz to 48 kHz, ~100 Hz to 48 kHz, and ~10 kHz to 48 kHz.

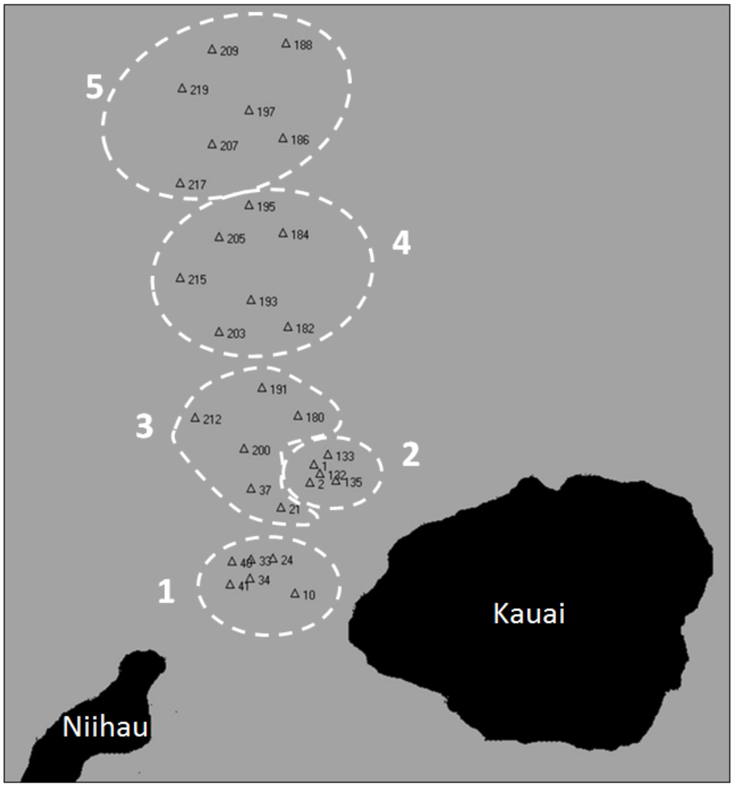

Figure 1: Approximate locations of the 31 recorded hydrophones used in this study at the Pacific Missile Range Facility, Kauai, Hawai'i. Hydrophone clusters used for spatial analysis are circled in white.

B. Acoustic Detection, Classification and Verification

Beaked Whale Clicks

Beaked whale foraging clicks were automatically detected using a custom C++ algorithm which processes disk files of raw hydrophone data for frequency modulated clicks. This program is able to perform detections over 100 times faster than a previous MATLAB (Mathworks, Natick, MA) program (Yack et al. 2010). The beaked whale detection program operates both with real-time data input and approximately10 times faster than real-time when processing recorded data. The C++ beaked whale foraging click detector provides outputs for: the start time of the detections, the detection hydrophone identifier, and optional file outputs of the detection spectrogram and time series for validation purposes. Histograms of the inter-detection intervals (start time to start time) over several minutes of time provides insight into the inter-click-intervals (ICIs) for the species being detected. While the automated detector may be reporting correct click detections along with detections from multiple individuals and false positive click detections, the peak of the histogram is often a good indicator of the ICI for single individuals.

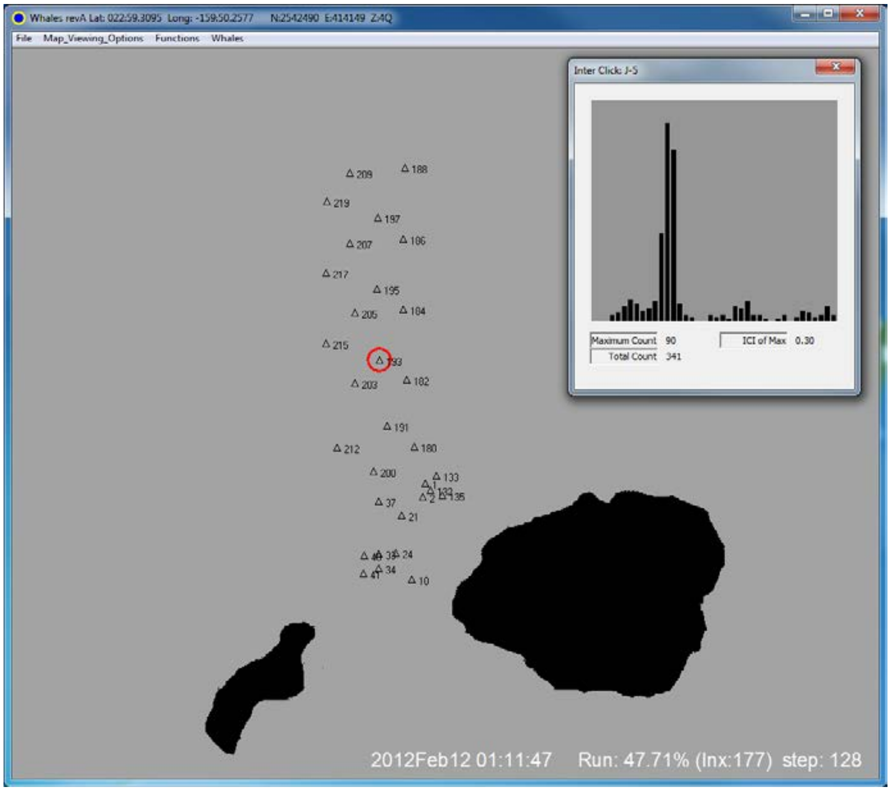

Figure 2: Custom display showing the hydrophone locations on the range with a single dive detected on phone 193 indicated by small red circle. Clicking on the phone with the detections pops up an ICI histogram (insert) for that phones automatic detections (peak IDI for this case of 0.3s). Data is from 12 Feb 2012 at 01:11 GMT.

Detected beaked whale clicks reports are automatically saved along with optional time series and spectrograms for later validation. In addition, the click detections are displayed with a custom C++ display program (Figure 2). This display provides an interactive spatial/temporal situational display with operator controls for: zooming into specific areas with higher spatial resolution; a time step factor for scrolling forward or backwards in the data; the duration of the analysis window for summing the click detection count (default 10 min); and when clicking on a hydrophone label, a histogram of the detection intervals over the analysis window duration. The number of automatic beaked whale FM clicks detected in the temporal analysis window is visually indicated by circles whose diameter is inversely proportional to the number of clicks and color coded proportional to the number of clicks detected (e.g. the largest blue circle requires > 3 click detections while the smaller red circle, as shown in Figure 2, can have hundreds of click detections). Labels for the hydrophones also optionally indicate the number of automatically detected clicks appended to the hydrophone identifier. During analysis, GPS positions of the AN/SQS-53C ship are also overlaid to visualize how close the ship was to the beaked whale detections, and the ship heading with respect to the hydrophone(s) with beaked whale detections. The current time (GMT) is shown at the bottom of the figure, along with reference to the file number for results currently being displayed and the current step size in seconds.
Automatically detected beaked whale foraging clicks are manually validated by experienced analysts to ensure the clicks have appropriate characteristics of beaked whale foraging clicks. A custom MATLAB routine allows rapid review of the time series and spectrogram of individual

automatic click detections and a histogram of ICIs over a ten minute period. Each beaked whale dive detected is treated as a group of beaked whales.

Beaked Whale Dives

Group sizes for Blainville's and Cuvier's beaked whales in Hawaiian waters are reported as 3.6 and 2.6 whales per group respectively (Baird et al. 2006). Multiple animals in a group provide more opportunities to detect beaked whale clicks from a group dive (which can be useful for tuning the detector to reduce false positives at the expense of reduced detections of foraging clicks). The number of clicks detected for a beaked whale dive is related to the distance of individual whales from hydrophones, the number of animals in a group, the beam pattern of the foraging clicks, and the orientation of the animal with respect to the hydrophones. The distance of the animal from a hydrophone determines how much propagation loss is experienced (spreading losses and absorption of sound in the seawater). Ultrasonic signals, such as beaked whale foraging clicks, were assumed to not be detected on bottom hydrophones at distances much over 6 km due to transmission loss. The 6 km maximum detection distance was selected based upon Zimmer et al. (2008), who reported a maximum detection distance of 4 km for hydrophones located close to the surface, and Ward et al. (2008) who reported a maximum detection distance of 6.5 km for bottom mounted hydrophones at AUTEC. Orientation of the animal relative to the hydrophone affects the apparent source levels of the clicks due to their directional nature and spectral content.

Beaked whale group dive vocal periods are on average 47 minutes in duration, but can range from 30 minutes to 57 minutes (Johnson et al. 2004; Tyack et al. 2006). Both Blainville's and Cuvier's beaked whales will also spend between 66 to 155 min in the upper 50 m of the water column after a foraging dive and in preparation for the next deep dive (Baird et al. 2006). The hydrophones utilized in this analysis have in some cases very wide separation and some depths over 4 km, such that one cannot guarantee detection of all beaked whale dives on the range. Therefore, the number of clicks detected and the estimated dive vocal period durations may be less than what was actually produced, as could be determined by an acoustic tag on an animal. Concurrent detected beaked whale foraging dives on adjacent hydrophones less than 6 km apart are considered the same dive; while this assumption could potentially bias the number of dives, it provides the most conservative estimate of dive counts. The hydrophone with the most manually-validated beaked whale clicks for a dive was termed the 'hot' phone and was considered the closest to the group of foraging beaked whales. The lack of detected clicks before and after a dive vocal period also provides supporting behavior typical of beaked whales. A spatial analysis was also performed utilizing the mean dive vocal period durations (with standard deviations). Although individual dives may be located a large distance from a 'hot' hydrophone and have an apparent short duration, reduced high frequency content due to absorption and few clicks detected, the overall mean for all the dives may be indicative of changes before, during and after MFAS operations.

Mid-Frequency Active Sonar

MFAS is considered to be in the frequency range of 1 to 10 kHz. Various MFAS sound sources were present during the training event including MFAS from the AN/SQS-56 sonar. However, as the capability to detect the AN/SQS-56 sonar was still in development, the focus of this analysis was on the MFAS activity from the AN/SQS-53C sonar system. A MATLAB based detector was developed to detect the nominal 3 kHz MFAS transmissions in order to know precisely when the sonar signals are present. The detection threshold was set such that the majority of these sonar pulses were detected with very few false positives. Manual inspection was performed to verify MFAS activity, to allow subsequent estimation of sound pressure levels received for each coincident beaked whale dive (see Section D).

C. Localization

Beaked whale group foraging dives were localized in post-event processing, and were assumed to be somewhere within the maximum detection distance (6 km is utilized) from the 'hot' hydrophone. This process is felt to provide a high confidence in detecting a beaked whale foraging dive present near the 'hot' hydrophone. This allows a useful metric for the number of beaked whale dives detected per unit time, which were compared before, during and after a U.S. Naval training event involving AN/SQS-53C MFAS activity.

D. Estimating Received Sound Pressure Levels

In order to estimate the SPLs received by the beaked whales (estimated received level, *RL*), the following items were required: ship position at the time of the beaked whale foraging dives, location of the 'hot' hydrophone, environmental information (e.g. wind speed, bottom type, sound velocity profile), and an acoustic propagation model. Ship positions were provided as GPS ship locations updated every second during the training event. The ship position for the *RL* estimates was chosen by finding the closest point of approach (CPA) of the ship transmitting MFA sonar signals to the 'hot' hydrophone within the detected foraging dive time period. The ship and hydrophone locations are used with a propagation model to estimate the transmission loss from the ship to the animal or group of animals.

The Personal Computer Interactive Multi-sensor Analysis Tool (PCIMAT) is a standard U.S. Navy tool which utilizes propagation modeling to estimate transmission loss (TL). The acoustic propagation model utilized within PCIMAT was the Comprehensive Acoustic System Simulation (CASS) model. The model includes historic sound velocity profiles (by year, month, time) for the area, detailed bathymetry of the area, and selectable bottom type, wind speed, and sea state. Acoustic source inputs to PCIMAT include frequency, and depth. In this case the nominal levels of AN/SQS-53C sonar were used; these included a frequency of 3 kHz, a depth of 7.5 m, and a source level of 235 dB re 1 μPa rms. The receiver (beaked whale) depths utilized were both 10 m (at/near surface) and 1 km (while foraging). Environmental parameters included a wind speed of 10 kts and Open Ocean as the surface boundary. The bathymetry and bottom-loss inputs were from the PCIMAT databases. For most of the RL estimates, the bottom-loss was from clay sediment. The detected beaked whales *RL* range is found by subtracting the maximum and minimum TL from MFAS source level. PCIMAT is used to find the MFAS estimated TL by taking the maximum and minimum TL from the ship's CPA to the 'hot' phone +/- 6 km (the maximum detection distance.) Thus, for each beaked whale dive vocal period detected simultaneously with MFA sonar activity there are four estimated *RL*s for the animals: the maximum and minimum when the animals were at presumed foraging depth, and the maximum and minimum as if the animals were near the surface. Model validation is felt to be very important; however, there were no acoustic sensor data available near the sea surface during the training event to enable validating sound fields in the surface duct. Therefore, *RL*s are reported using both historic, and *in situ*, sound velocity profiles (SVPs).

III. Results

A. Data Collection

Passive acoustic data were collected continuously for 31 hydrophones over 11 days (269.3 hours) from February 10 to February 21, 2012. About 61.6 hours of data was collected before the training event, and 90.5 hours after the training event. The training event consists of an initial portion (54.6 hours between 13 to15 February) with no MFAS from the AN/SQS-53C sonar ('Phase I') and the later portion (62.6 hours between 15 and18 February) with MFAS activity ('Phase II'). Both phases of the training event consist of multiple event scenarios with different objectives. Ship GPS positions were obtained for the time period of each scenario; ship positions were not available for the periods of time between scenarios. However, nearly all MFAS activity occurred during scenarios and the lack of continuous ship position was not a major issue (for this training event only ~ 2 minutes of MFAS was present without GPS ship positions at the official end of the training event). Overall, there were 17 instances of MFAS lasting 12 to 95 min (mean 62 min, s.d 27.4 min), for a total duration of 990 minutes, or 26.4% of Phase II. These exposures took place equally day and night across the three-day period.

B. Acoustic Detection, Classification and Verification

Figure 3 demonstrates the characteristics of a typical suspected Blainville's beaked whale click, including the frequency upsweep (~ 27 to 45 kHz) over the nominal 0.3 ms duration (top spectrogram). The time series (lower left) has several cycles of amplitude modulated frequency upsweep character, while the histogram (lower right) demonstrates a strong ICI mode of 0.3 ms. In the process of validating beaked whale clicks, a few dives were observed to have different click characteristics. Figure 4 demonstrates the characteristics of the different click type; it has a longer duration of about 0.6 ms, an ICI mode of 0.14 ms, and the energy of the FM sweep starts lower (~20 kHz) and extends beyond the Nyquist frequency of the recorded data. This click is believed to be similar to those detected on a High Frequency Recording Package (HARP) located at Cross Seamount (MacDonald et al. 2009; Bauman-Pickering et al. 2011), and is hereafter referred to as the Cross Seamount (CSM)-like click.

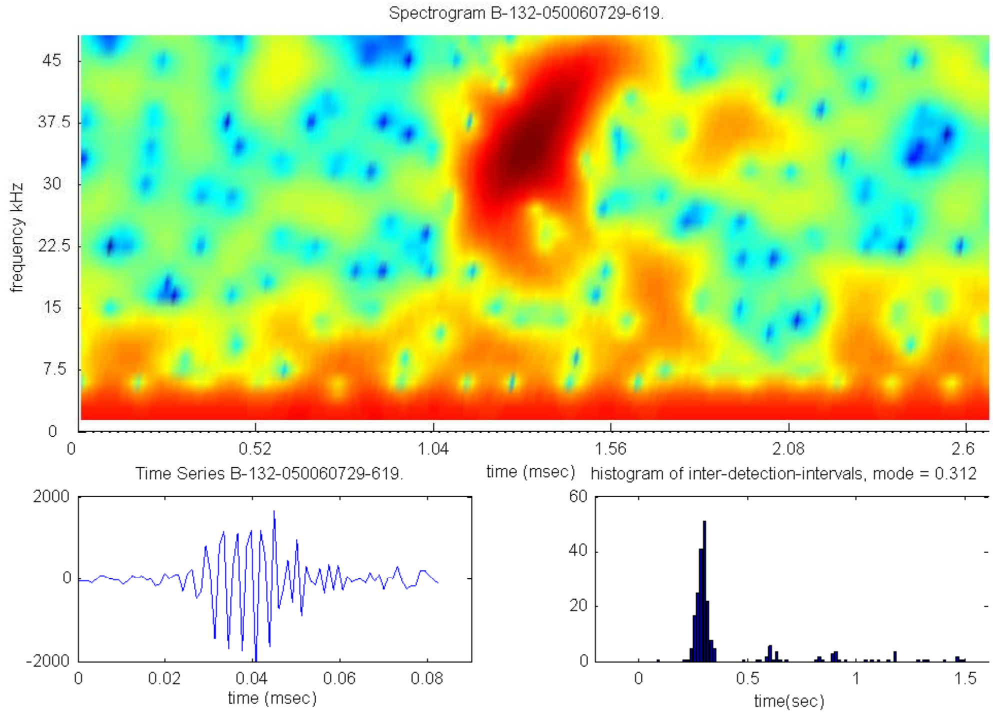

Figure 3: Spectrogram (0 to 48 kHz over 2.6 ms) of a beaked whale click from the pre-event data (top). Time series (amplitude in counts over 0.8 ms) of the same beaked whale click (lower left). Histogram of the ICI (0 to 1.6 s) of the beaked whale clicks in the previous 10 minutes (peak value 0.3 s) (lower right).

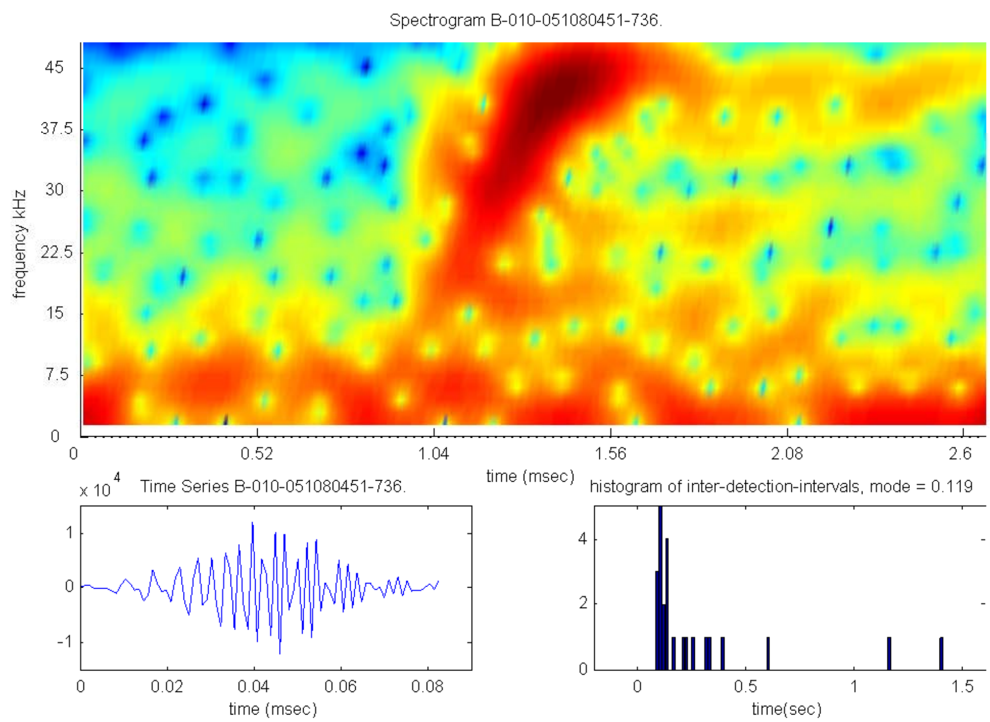

Figure 4: Spectrogram (0 to 48 kHz over 2.6 ms) of a Cross Seamount-like beaked whale click from the pre-training event data (top). Time series (amplitude in counts over 0.8 ms) of the same click (lower left). The

lower right histogram of the ICI (0 to 1.6 s) is of the beaked whale clicks detected in the previous 10 minutes (peak 0.18s).

Figure 5 (upper plots) shows a typical CSM-like click as recorded by a HARP with a 200 kHz sample rate (used with permission from McDonald and Hildebrand). The lower plots of Figure 5 also show this same click after low pass filtering and decimated to a 96 kHz sample rate to simulate reception on a PMRF hydrophone. The simulated click appears similar to the CSM-like clicks shown in Figure 4. The ICI's for these CSM-like clicks detected at PMRF are variable but consistently smaller than those for suspected Blainville's clicks. McDonald et al. (2009) reported average inter-pulse intervals for the CSM-like clicks of 0.11s (s.d. 0.035 s) for a subset of signals with the highest levels.

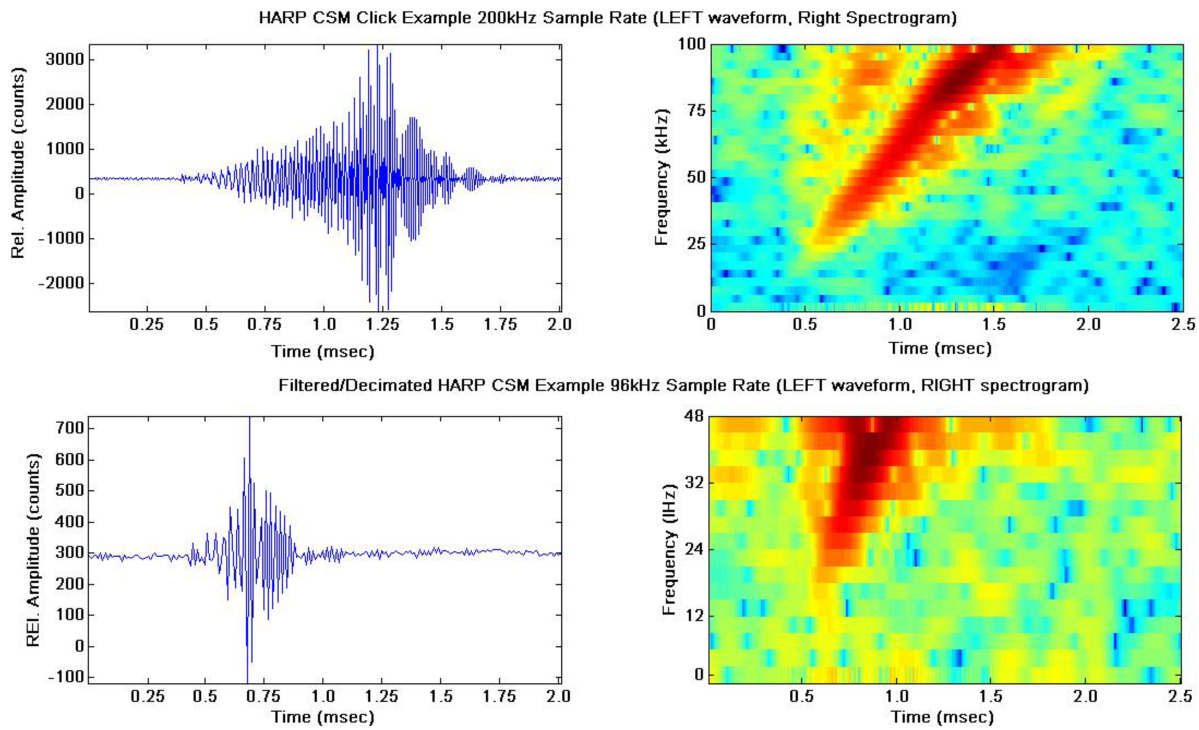

Figure 5 – Upper plots are a sample waveform and spectrogram of a Cross Seamount frequency modulated click as collected by HARP (courtesy of McDonald and Hildebrand). Lower plots show apparent reduced duration and bandwidth when filtered/decimated to simulate reception on PMRF hydrophones. Note the spectrogram axes are different – top goes to 100 kHz while bottom goes to 48 kHz.

During the study period, 102 Blainville's-like beaked whale dives were detected before the training, 67 during Phase I, 30 during Phase II (with surface ship MFAS), and 59 after the training event (Table 1), which equates to 1.7 dives per hour before, 1.2 dives per hour during Phase I, 0.5 dives per hour during Phase II, and 0.7 dives per hour after. A chi-square goodness of fit test indicates that the differences in the observed number of Blainville's-like beaked whale dives across these periods were highly significant (χ^2 = 54.9, df = 3, p<0.001). In addition, in a pair-wise chi-square comparison all periods were significantly different than expected from each other ($p \leq 0.0002$) except for before versus Phase I which approached significance (X^2 = 3.65, p = 0.056) and Phase II versus after (X^2 = 1.69, p = 0.19). In other words, based on the number of dives before the training events, there were fewer dives during and after the training events than expected, and there were fewer dives during Phase II and after the training events than during Phase I.

While the daytime and nighttime periods were evenly sampled during Phase II and after the training events, the before and Phase I periods were not (Table 2). An initial chi-square analysis indicated that the overall number of dives detected during the day versus at night did not change significantly before, during both phases, and after the training events ($\chi^2 = 3.006$, df = 3, p=0.4). However, a chi-square goodness of fit test was conducted to compare the expected number of dives per time of day (TOD) to the observed number of dives per TOD. The results indicate that for the before and Phase II periods, there was no significant difference between the observed and expected number of dives per TOD. However, during phase I the number of dives per TOD was significantly different than expected ($X^2 = 46.9$, df = 23, p = 0.002), and after the training the number of dives per TOD approached significance ($X^2 = 32.5$, df = 23, p = 0.09). These TOD patterns can be seen in Figure 6. Before and during Phase I dives are present day and night, but with a distinct peak at twilight. During Phase II there were still dives day and night, but the twilight peak is gone, and after the training events there were more dives at night than during the day.

Blainville's-like clicks were often detected on more than one hydrophone at a time. The dive vocal period duration was assumed to be cumulative across phones, such that if one dive was recorded on multiple hydrophones, the duration was counted from the first click detected to the final click detected on any of the hydrophones recording that dive. An ANOVA showed that dive vocal durations were significantly different between periods relative to the training event (F = 26.54, p<0.001), with the shortest dives occurring before the training events; however the number of clicks detected were not significantly different across the four periods (Table 1).

Of the 30 beaked whale detections that occurred during Phase II, only seven co-occurred with MFAS activity (Table 3). An ANOVA revealed that there were no significant differences in the duration or number of clicks detected between the dives that occurred with MFAS and those that did not during this period. However, the TOD was significantly different (F = 5.98, p = 0.02), with the dives that co-occurred with MFA occurring more in the latter half of the day (afternoon and evening), while those that didn't occurred throughout the day and night.

Table 1 – Blainville's-like beaked whale dive detection data from the before, during, and after periods relative to the training event on PMRF.

	Before	Phase 1	Phase 2 (with MFAS)	After
Hours of data	61.6	54.6	62.6	90.5
Percent of recording time	22.9%	20.3%	23.3%	33.6%
Total validated dives detected	102	67	30	59
Dives per hour	1.7	1.2	0.5	0.7
Mean (s.d.) dive vocal period duration in min	18.2 (± 10.5)	20.8 (± 13.2)	20.6 (± 14.3)	19.9 (±6.3)

Mean (s.d.) number of click detections per dive	211 (±337)	282 (± 463)	261 (±353)	294 (±367)

Table 2: A comparison of daytime vs nighttime dives for the before, during Phase 1, during Phase 2, and after periods of the PMRF activity.

	Before	Phase 1	Phase 2 (with MFAS)	After
Number of daytime hours in period	34 (56%)	25 (45%)	31 (49%)	45 (49%)
Number of nighttime hours in period	27 (44%)	30 (55%)	32 (51%)	46 (51%)
Number of daytime dive detections	52 (51%)	33 (49%)	15 (50%)	22 (37%)
Number of nighttime dive detections	50 (49%)	34 (51%)	15 (50%)	37 (63%)
Number of dives per hour (daytime)	1.5	1.3	0.5	0.5
Number of dives per hour (nighttime)	1.9	1.1	0.5	0.8

Table 3: A description of beaked whale foraging dives that co-occurred with sonar, including dive number, date, time (GMT), phones detected on, phone with greatest FM detections ('hot'), number of auto beaked whale FM detections, and the peak in the ICIs. Dives 1, 2, and 5 are the Cross Seamount-like clicks.

Dive Number	Zulu Day	Zulu time Start (HHMM)	Zulu time End (HHMM)	Detection hydrophone numbers	# auto detections	ICI peak (sec)
1	16	0738	0823	135	95	.134
2	16	1115	1147	24	151	0.165
3	16	2036	2054	219	14	.275
4	17	0443	0503	41	66	.302
5	17	0534	0545	135	33	0.207
6	17	0545 0552	0615 0554	40 41	300 19	.279 .298
7	17	0741 0747 0800 0817	0759 0806 0824 0824	40 41 34 33	180 72 899 54	.275 .299 .31 0.3
8	17	0951 0955	1006 1006	33 40	198 30	0.292 .299
9	17	2110 2115	2123 2124	1 132	102 38	.287 .297
10	18	0110	0121	21	122	.332

As compared to the Blainville's-like clicks, the CSM-like clicks were only detected in five dives before training, seven dives during Phase I, 14 dives during Phase II (with MFAS), and five dives after the training event (Table 4). Although there were far fewer dives detected, the difference in the number of dives before and after the training event versus during the training event, particularly Phase II, is still significant (χ^2 = 8.39, df = 3, $p<0.05$), with the most dives detected during Phase II with MFAS. The dive durations were similar to those from the Blainville's-like dives, but the numbers of clicks detected per dive were far fewer during the training event. Also in contrast, almost all CSM-like dives were only detected on a single hydrophone and were almost exclusively detected at night (only two daytime detections occurred; Table 4).

Table 4 – Cross Seamount-like beaked whale dive detection data from before, during, and after the training event on PMRF

	Before	Phase I	Phase II (with MFAS)	After
Total dives	5	7	14	5
Mean (s.d.) dive vocal period duration in min	20.9 (±10.7)	14.8 (±13.3)	21.5 (±23.2)	26.4 (±24.9)
Mean (s.d.) number of click detections per dive	165 (±110)	50.3 (±60.5)	58.4 (±67.8)	291 (±101.3)
Mean (s.d.) ICI in sec	0.12 (±0.08)	0.15 (±0.6)	0.16 (±0.04)	0.13 (±0.02)
Number of daytime dive detections	1 (20%)	0	1 (7%)	0
Number of nighttime detections	4 (80%)	7 (100%)	13 (93%)	5 (100%)

A spatial analysis also revealed that the distribution of Blainville's-like beaked whale detections changed over time. Detections before the training event were distributed across the range, with most detections occurring in the south-central region of the range (Cluster 3; Figure 7). However, during Phase I most detections occurred in the southwest and central portions of the range and during Phase II (with MFAS) most detections occurred in the southwest and southeast corners of the range (Clusters 1 and 2; Figure 7) while the training event occurred mostly in the central part of the range (Cluster 3 and 4).Although the detected beaked whales returned to the central portion of the range after the training event, detections still largely occurred on the southern portion of the range rather than the central or northern regions. A two-way ANOVA was conducted to examine if there was a relationship between TOD and where dives were occurring (e.g. if the animals were moving offshore at dusk and onshore at dawn). However, it did not reveal a significant relationship between the spatial distribution of the dives and the TOD in which they occurred (e.g. if the animals were moving offshore at dusk and onshore at dawn) although a two-way ANOVA revealed that the TOD relative to the cluster location approached significance (F(TOD) = 2.23, p(TOD) = 0.085; F(Cluster) = 1.11, p(Cluster) = 0.35). The CSM-like clicks were only detected in the southern portion of the range (Figure 7); however, their distribution expanded across phones throughout the study period rather than contracting like the Blainville's-like dives.

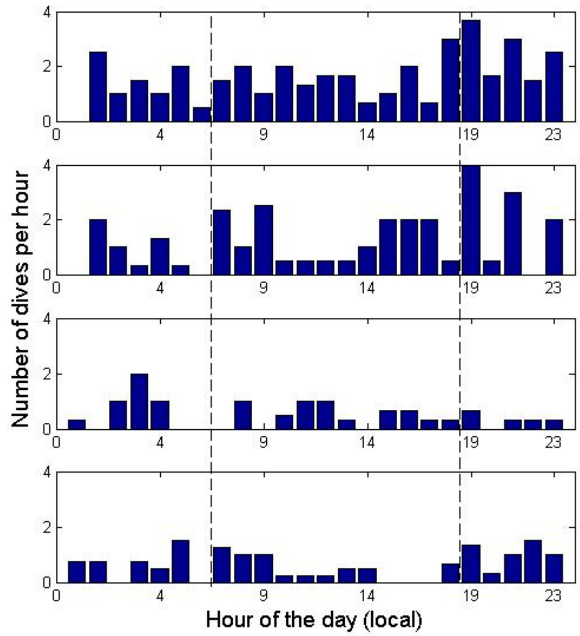

Figure 6– Observed rates of Blainville's-like dive detections throughout the day (top - before, second – Phase I, third – Phase II, and bottom – after). Detections are binned by the hour of the day (local time) in which they began; the dotted lines indicate the times of sunrise and sunset during this period. Data has been normalized by number of hours sampled.

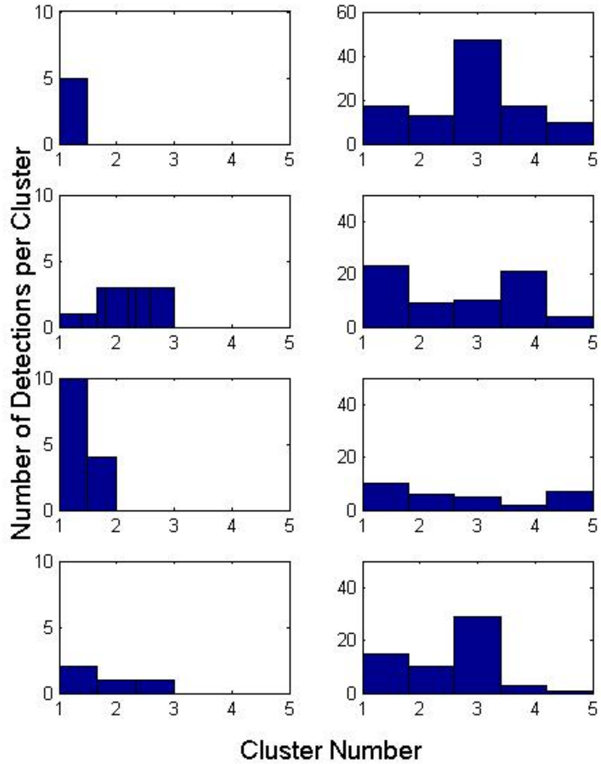

Figure 7 – Histograms of Cross Seamount-like beaked whale dive detections (left column) and Blainville's-like beaked whale dive detections (right column) for the four time periods: before (top), Phase I (second), PhaseII (with MFAS) (third), and after (bottom) the training event on PMRF.

C. Estimating *RL*s

Table 5 provides the estimated *RL*s and CPAs for the ten dives that co-occurred with MFAS activity. For each dive and assumed animal depth, a minimum and maximum *RL* and CPA was estimated to account for the location uncertainty of the group of animals relative to the nearest hydrophone position, using a 6 km detection radius. Estimated CPAs ranged from 13 to 52 km, with a mean of 31.6 km (±6.7 km).

Estimated *RL*s at 1 km depth span from 52.0 to 136.7 dB re 1 µPa with the average min/max across dives of 93/126 dB re 1 µPa (s.d. 22.0 dB). The estimated RLs for the dives near the surface (10 m depth) similarly span from 134.0 to 162.2 dB re 1 µPa with the average min/max across the ten dives of 143/158 dB re 1 µPa (s.d. 9.0 dB) . The *RL*s near the sea surface average 41 dB higher than those at the presumed foraging depth. Ducted propagation near the surface is a common condition in this area and is an important consideration when estimating exposure levels on marine mammals.

Table 5: Estimated *RL*s that beaked whale dive groups were exposed to for ten dives occurring during MFA sonar activity in Feb 2012. *RL*s are estimated for animals at depth foraging and near the surface for a 6 km radius uncertainty from the 'hot' phone. Note 1: Limited by bathymetry, SPL for the maximum distance

were taken at the max depth of 600 m. Note 2: Cross Seamount-like beaked whale dive detections. Note 3: Bathymetry has a steep upslope up to 20 km followed by slight depression to 40 km.

Dive #	Day in Feb	'Hot' Hydrophone numbers	Zulu Time of CPA (HHMM)	CPA distance Max/Min MFA ship to beaked whales (km)	Min/Max estimated *RL* @ 1 km depth (dB re 1 μPa)	Min/Max estimated *RL* @ 10 m depth (dB re 1 μPa)
1[1,2]	16	135	0738	22/34	52.0/118.8	150.6/161.5
2[1,2]	16	24	1141	21/33	66.3/130.9	134.0/157.5
3	16	219	2050	31/43	116.2/136.7	147.7/159.1
4	17	41	0503	40/52	101.2/117.9	145.7/154.5
5[1,2]	17	135	0546	28/40	102.6/116.7	145.8/157.5
6[3]	17	40	0551	27/39	106.0/128.8	104.1/155.1
7[3]	17	34	0741	23/35	92.1/127.6	138.1/159.5
8	17	33	1006	24/36	109.7/129.3	144.2/158.0
9[1]	17	1	2110	13/25	96.6/133.3	136.7/162.2
10[1]	18	21	0115	27/39	83.1/120.9	144.5/159.1

Figure 8 shows the comparison of *RL*s using historic SVPs to *in situ* SVPs. *In situ* SVP's were obtained at various locations and times throughout the training event. The *in situ* SVP at the closest in time to the dive and distance to beaked whale detection with MFA was used utilized for the *in situ* SVP modeling for each *RL* calculation. For the 1 km depth data shown in Figure 8, the average *RL* using the historic SVP was 109.3 dB but the average *RL* using the *in situ* SVP was 80.6 dB, which is a difference of 28.7 dB due to the two different sound velocity profiles. Near the surface, the *RL*s for the historic SVP profiles average is 150.6 dB and *in situ* SVP profiles *RL*s average is149.5 dB, a difference of only 1.1 dB. The *in situ* SVPs measurements were limited by the expendable bathythermograph maximum depth of 750 m, and was combined historic SVP below 750 m to the seafloor. The observed differences in running the model are that historical SVPs have been averaged to a smoother curve, while the *in situ* SVPs have more variability throughout the water column and that the propagation model is able to use multiple historic SVPs if available, but can the user can only input one *in situ* SVP per propagation scenario. The *in situ* SVPs were also measured between 2 to 23 km, an average of 10.6 km (s.d. 6 k m) away from the actually ship locations. The mentioned discrepancies could account for the large differences in *RL* at the beaked whale foraging depth.

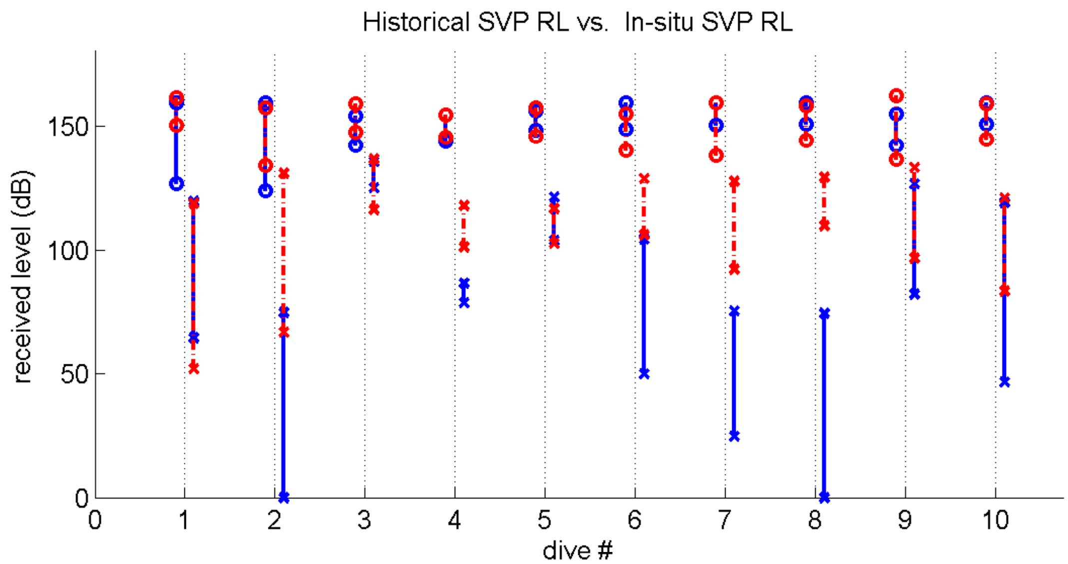

Figure 8: Estimated max/min RLs using historic versus *in situ* sound velocity profiles at 10 m and 1 km depth for each dive from Table 5. At 10 m depth: red circles are RLs from Historic SVP, blue circles are RLs from In-Situ SVPs. At 1 km depth: red x's are RLs from Historic SVP, blue x's are RLs from In-Situ SVPs.

V. DISCUSSION

The data presented here demonstrate that beaked whale dives continued to occur at PMRF while MFAS activity was occurring at estimated distances of 13 to 52 km between the MFAS ship while transmitting and the animals. *RL*s are similar to other reported findings for animals at depth foraging, but an average of 40 dB higher near the sea surface due to ducted propagation (to represent animals returning to the surface to breathe). Differences were found in the dive vocal period duration, dive rate, and spatial distribution of dives across the range. There also was a diel shift after the training event, with more dives occurring at night than prior to or during the activity.

The observed acoustic characteristics of most detected clicks do appear to fit best with reported information for Blainville's species, and so have been cautiously classified as such. However, much is still unknown about beaked whale species in Hawaiian waters and in general. Blainville's, Cuvier's, and Longman's species are known to be present in Hawaiian waters, but it is possible that additional species could also be present (e.g. Ginkgo-toothed, Baird's, Hubb's and pygmy) (Macleod et al. 2006). The clicks that resemble those acoustic signals recorded at Cross Seamount (McDonald et al. 2009) could be from species known to be in the area using different echolocation strategy for different prey possibly in a more reverberant environment, or from another species.

Tyack et al. (2011) and McCarthy et al. (2011) reported that in similar training events in 2007 and 2008 at the AUTEC range, four instances of continued foraging with AN/SQS-53C MFA sonar exposures ranging from 14.7 to 19 km with RLs of 127 to 133 dB re 1 µPa (rms). Results here for 10 instances of beaked whale dives occurring during AN/SQS-53C MFAS activity are similar in terms of distances to dives (closest dive was somewhere between 13 to 25 km) and estimated RLs (the closest dive maximum of 133 dB re 1 µPa (rms)) for animals at a presumed foraging depth of 1km. However, when considering ducted propagation at PMRF, animals in this closest dive would have been exposed to levels somewhere between 137 and 162 dB re 1 µPa (rms) if they were at the surface at the time. This suggests that for beaked whales in the Hawai‘i area animals are likely exposed to higher levels than observed at AUTEC due to the surface ducted propagation and the amount of time the whales are in the upper 50 m of the water column. Based on tag data off the island of Hawai‘i, Baird et al. 2006 reported that Blainville's have been observed to spend up to 155 min periods in the upper 50 m of the water column while Cuvier's are documented to spend a 66 min period in the upper 50 m of the water column. Therefore, to improve this analysis and get more accurate *RL* estimates, one could consider typical beaked whale dive profiles and include average periods of time spent in the ducted region. This data could then be integrated into a dose type exposure for a dive with contributions from multiple MFAS transmissions and considering both the ducted region and at-depth region *RL*s.

How well the acoustic propagation model matches actual conditions is always a consideration when using models. Here the U.S. Navy standard PCIMAT model was utilized with high fidelity bathymetry, historical sound velocity profiles and bottom type models embedded. Surface ducted propagation is predicted by PCIMAT using both historical and *in situ* sound velocity profiles. Changes in sound velocity profiles can have a large impact on modeled sound levels at depth, however historic and *in situ* sound velocity profiles for the surface ducted propagation are in close agreement. The *in-situ* profile used in dive 2 showed an additional weak sound channel at about 500 m depth that was not present in the historical SVPs, which could have affected the modeling *RL* differences at the foraging depth. The ray trace of the *in-situ* SVP used in dive 7 and 8 had more downward and focused refracting rays than the historical SVP. Data from hydrophones in the ducted region were not available to allow validation of the levels in the predicted ducted propagation region. Behavioral response studies utilize acoustic tags on animals to unambiguously measure the received levels at the animal's location. It would be worthwhile to see how well PCIMAT-modeled exposures fit with exposure levels measured during behavioral response studies as an attempt at model validation.

Although the suspected Blainville's beaked whale dives occurred across the range prior to the training activity, they were still predominantly located in the southern portion of the range (water depths under approximately two km), as were the CSM-like beaked whale dives. Clusters 1 and 2 consist of hydrophones spaced more closely together which leads to an increased number of hydrophones detecting each dive, which was the case for the Blainville's like beaked whale dives. However, the CSM-like clicks were also predominantly heard on those hydrophones and were almost never recorded on more than one hydrophone at a time. Therefore, the Blainville's-like beaked whale dives may consist of more animals or widely spaced animals, whereas the CSM-like beaked whale dives may have fewer animals, or animals clustered more closely together. The CSM-like dives may also have shorter detection ranges due to lower apparent source levels as received by the 48 kHz limited bandwidth hydrophones (as Figure 5 illustrates the band limited version of the click is ~ 16 dB lower in level than the original). The southernmost hydrophones are located in the portion of the range with the steepest slopes, which agrees with water depths and steep bathymetry typically associated with beaked whale foraging dives (Tyack et al. 2006). Twelve of the Blainvilles' like dives (including 2 during MFA sonar activity) occurred in water depths of approximately 4.7 km with a relatively flat bottom which is nearly a km deeper than the maximum water depth that Cuvier's beaked whales were sighted off the island of Hawai'i (Baird et al. 2006).

Blainville's-like dives were detected across the range before the training event, predominantly in hydrophone cluster 3, which is located in the south-central portion of the range. During the training events, the overall number of dives decreased, and the dives occurred more in the southern portion of the range (although there was also an increase in Cluster 4 during Phase I). As mentioned, Clusters 1 and 2 have more closely-spaced hydrophones, which allows for increased detections of beaked whale clicks. While there is a chance that the increased dive durations observed during the training event represents a Lombard effect of increased clicking in the presence of higher background noise, the most parsimonious explanation is that more clicks are being detected on the more closely spaced hydrophones as the beaked whales shift their habitat use away from the training activity. These durations do not represent the true full duration of beaked whale dives; rather, they signify the duration these dives were detected on the bottom-mounted hydrophones. Work at AUTEC has demonstrated that seafloor hydrophones only detect a portion of beaked whale dives, while tags are able to capture the full dive and all associated clicks (Ward et al. 2011). With that said, the mean of about 20 minutes of detection per dive as measured here does match the portion of dives in which clicking occurs, estimated to be about 20-30 minutes (e.g. Madsen et al. 2005; Tyack et al 2006).

Baird et al. (2008) found that deep foraging dives by tagged Blainville's and Cuvier's beaked whales in Hawai'i occurred at similar rates both day and night, with similar dive durations (48 to 68 min). Other tagged beaked whales have also shown no diel difference in foraging patterns (Hazen et al. 2011; Arranz et al. 2011). In contrast, Au et al. (2013) found a distinct diel pattern to beaked whale dives in the same region. Additionally, Au et al. found a similar trend for all odontocete species in Hawaiian waters, and previous work by Benoit-Bird and Au (2009) demonstrated that the diel vertical migration of the mesopelagic community also has a horizontal, inshore-offshore component that is mirrored by spinner dolphins (*Stenella longirostris*). Therefore the diel pattern in the foraging clicks recorded by Au et al. (2013) on bottom-mounted acoustic recorders may be a result of that inshore-offshore movement rather than a true crepuscular peak in foraging behavior. During this study, dives occurred equally day and night before and during the training events, although there was a peak in dive activity at twilight before and during Phase I that doesn't occur during Phase II, when MFAS was present. However, after the training events dives rates shifted to occur more at night. Since the training and MFAS occurred both day and night this shift seems counter-intuitive as an avoidance response. In contrast, the CSM-like clicks occurred predominantly at night (fitting with McDonald et al. 2009 results), and the most dives occurred during the MFAS portion of the training event. If the Blainville's-like beaked whales are moving off the range during training activity, it may be that the CSM-like beaked whale is taking advantage of that open niche to forage in more parts of the range. However, this change in click frequency and ICI could also result from a change of prey, with a corresponding change in echolocation strategy. In that case, these clicks could also be from the same species of beaked whale as the Blainville's-like clicks, and the change in click pattern could indicate a shift foraging strategy.

This analysis was conducted under the assumption that the "before" period represented a baseline of behavior; however while training events are not continuously ongoing, there is fairly constant activity at the range. Therefore our "before" period could be the "after" period for another activity. In order to address this issue true baseline data needs to be identified and used to compare with behavior during training events to truly capture any behavioral responses to MFAS and an increase in ship traffic. In addition, dive vocal period durations and click detections were analyzed as though the full dive vocal period was detected. The relatively large separation between hydrophones utilized in this analysis, as well as the deeper depths of the hydrophones in the offshore clusters (4 and 5), may result in detecting only a portion of a beaked whale group's vocal period. Therefore the dive vocal period durations presented here represent minimum estimates rather than absolute values. However, with many dives occurring over widely spaced hydrophones or at the edge of the range, and with highly directional beam patterns and high attenuation rates inherent to echolocation clicks, it is more than likely that many clicks were missed during each dive.

PMRF has on the order of 200 bottom-mounted hydrophones; however, most are high pass filtered and located close to shore. In August of 2012 thirty-one additional hydrophones were recorded for analysis to decrease the distance between phones and increase the capabilities for localization and detection. Thus, analysis for training events after Aug 2012 will have access to 62 phones, which should provide better foraging dive detection. Efforts are also in progress to automatically detect and localize MFAS activity from both the AN/SQS-56 and AN/SQS-53C shipboard sonars, which will streamline analysis processes and enable analysis for periods of MFAS activity if GPS ship positions are unavailable. All of these additional analyses are currently underway, thus this work represents an effort snapshot of an ongoing examination into the habitat use of this region by beaked whales, and the impact of ships and MFAS on their behavior.

VI. CONCLUSION

Passive acoustic monitoring is a valuable method for monitoring marine mammal vocal activity for potential effects of MFAS training events. This effort provides results at PMRF in Hawaiʻi showing both similarities and differences to results reported for AUTEC (McCarthy et al. 2011, Moretti et al. 2009, and Tyack et al. 2011). Similarities to these prior reported studies are found relative to the distances that beaked whale dive vocal activity ceases even though different beaked whale click detection methodology is utilized. This report does highlight an important consideration when investigating *RL*s: levels are an average of 41dB higher near the sea surface when ducted propagation is present. Thus, if beaked whale groups remain at PMRF during MFAS activity, they will be exposed to higher levels than one would estimate if only considering their location at depth while vocalizing.

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