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Impacts of U.S. Navy Training Events on Blainville's Beaked Whale (*Mesoplodon densirostris*) Foraging Dives in Hawaiian Waters

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Abstract

Blainville's beaked whales (*Mesoplodon densirostris*) were detected in recorded acoustic data collected before, during, and after February and August U.S. Navy training events in 2011, 2012, and 2013 at the Pacific Missile Range Facility in Kauai, Hawaii. Beaked whale clicks were automatically detected and manually verified to ensure they fit characteristics of foraging echolocation clicks. Verified foraging click detections were spatially and temporally clustered to represent group vocal periods (GVPs) of beaked whale foraging dives. More GVPs were detected before training events than during or after the training events, and GVPs were detected more on hydrophones at the edges and in the southern portion of the range during sonar activity. However, there were also interannual differences in GVP counts across training event phases, indicating that baseline variability in Blainville's beaked whale GVPs must be distinguished from reduced foraging dive activity during training events with sonar activity to understand the true impact of sonar.

Key Words: Navy activity, mid-frequency active sonar, Blainville's beaked whales, *Mesoplodon densirostris,* beaked whale behavior, Hawaii beaked whales, beaked whale group vocal periods

Introduction

Beaked whales (family Ziphiidae) consist of at least 22 different species in six genera with relatively little known about many of the species (Jefferson et al., 2015). Incidents of mass stranding in association with U.S. Naval activities have attracted research of this odontocete family (D'Amico et al., 2009). The mass stranding following a U.S. Navy training event in the Bahamas in 2000 resulted in an investigation of the event with an emphasis on the two species involved: Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales (England et al., 2001). The investigation concluded that there is a need for the Navy to understand the effects of its activities during testing and training, and to monitor the populations that inhabit Navy ranges in compliance with the Marine Mammal Protection Act and the Endangered Species Act while not jeopardizing national security.

Beaked whale foraging dive behavior has been identified using data from a variety of tags (Baird et al., 2006, 2008; Johnson et al., 2006; Tyack et al., 2006). Blainville's and Cuvier's beaked whales utilize foraging echolocation clicks (Johnson et al., 2004), with frequency modulation characteristics and relatively consistent inter-click intervals (ICIs). These two species are known to only produce foraging clicks while at depths greater than 200 m during foraging dives. Blainville's beaked whale group vocal periods (GVPs) are approximately 23 to 33 min (Johnson et al., 2006), while the group foraging dives are on average 47 min in duration but can last up to 57 min and have mean foraging dive intervals of 92 min (Tyack et al., 2006). The foraging dive vocalizations include two types of echolocation clicks: (1) foraging clicks used to find prey and (2) 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 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 were 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 Hawaii, with similar findings.

Further research has identified echolocation click characteristics for several beaked whales from different areas of the world based upon both tag data and passive acoustic monitoring data (Zimmer et al., 2005; Johnson et al., 2006). Acoustic characteristics also have been reported for the following species in the North Pacific: Deraniyagala's (*Mesoplodon hotaula*), Baird's (*Berardius bairdii*), Cuvier's, and Longman's (*Indopacetus pacificus*) beaked whales (Baumann-Pickering et al., 2010, 2013; Zimmer et al., 2005; and Rankin et al., 2011, respectively). A common characteristic of many of the reported beaked whale species' foraging clicks are short duration signals (< 1 ms), with frequency-modulated sweeps from as low as 15 kHz to over 100 kHz (McDonald et al., 2009; Baumann-Pickering et al., 2014). Longman's beaked whales in Hawaii have also been reported to use clicks that extend below 15 kHz with no appreciable FM characteristics (Rankin et al., 2011).

Given the available information on beaked whale click characteristics, a variety of beaked whale click detection methods have been developed to 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). Passive acoustic monitoring methods for beaked whales can be used to estimate density based on acoustic click (cue) counting techniques (Marques et al., 2009) and group foraging dive counting (Moretti et al., 2010).

Density estimation at the Atlantic Undersea Test and Evaluation Center (AUTEC) located in the Bahamas found reduced foraging dive activity during training involving mid-frequency active sonar (MFAS) activity as compared to before the training events (Moretti et al., 2010; McCarthy et al., 2011; Tyack et al., 2011). These efforts demonstrated that Blainville's beaked whales appeared to depart an area where MFAS is occurring and gradually return over a 2 to 3 d period after sonar activities cease. This is supported by the behavior of a satellite-tagged beaked whale that moved an average of 54 km away from the center of the range during MFAS activity and then over the next several days slowly returned to using the center of the range (Tyack et al., 2011).

Several behavioral response studies have also been conducted to investigate the responses of beaked whales and other cetaceans to simulated and real Navy sonars (e.g., DeRuiter et al., 2013; Goldbogen et al., 2013; Stimpert et al., 2014; Miller et al., 2015; Sivle et al., 2015). These studies have demonstrated that beaked whales are sensitive to sonar and respond by ceasing their foraging behavior, conducting long silent dives while moving away and avoiding the sound source for long periods of time. However, incidental real U.S. Navy sonar occurred while one of the Cuvier's beaked whales was tagged in southern California waters; received levels were similar to those from the simulated sonar exposure, but no response was observed (DeRuiter et al., 2013). This could indicate that behavioral responses may be contextually mediated, and that proximity to the sound source may play a more important role than received level alone.

While similar to the work conducted at the AUTEC Naval Range, this study differs in detection methodology and is in a different geographic area. This paper describes the methods utilized to acoustically detect Blainville's beaked whale group vocal activity during MFAS activity at the Pacific Missile Range Facility (PMRF) and analyzes the differences in GVP characteristics before, during, and after MFAS activity to assess the potential impact of MFAS on this species' vocal behavior. Since Blainville's beaked whales only produce echolocation clicks during their deep foraging dives, GVPs will be used to represent beaked whale deep foraging dives throughout the following analyses and discussion.

Methods

Data Collection

PMRF, located off the west coast of Kauai, Hawaii (Figure 1), hosts a variety of U.S. Navy training events every year and has a hydrophone array 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 for over a decade before and after training events. More recently, it has become possible to obtain ship locations and recorded acoustic hydrophone data during training events to support marine mammal monitoring efforts for analysis.

Acoustic data from 31 hydrophones, along with an analog time code signal, were provided for before, during, and after training events in February and August 2011, 2012, and 2013, while an additional 31 hydrophones were sampled in February and August of 2013. 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 approximately 10 min of data. The recorded time code signal allowed precise alignment of acoustic data with ship positions in post-event analysis.

Spacing between the hydrophones used in the data collection varies from less than 1.6 km in one cluster area in the south and nearshore to more than 10 km in areas farther offshore. Water depths vary from 650 m to over 4,700 m, with a steep slope just off the island of Kauai that progresses to a more gradual slope and then a relatively flat bottom in deeper waters. There were 62 recording hydrophones utilized in this study, with three different frequency responses (~50 Hz to 48 kHz, ~100 Hz to 48 kHz, and ~10 to 48 kHz), depending on the date of installation of the hydrophone line array (Figure 1).

Acoustic Detection, Classification, and Verification

Automatic Beaked Whale Click Detection and Classification—Beaked whale foraging clicks

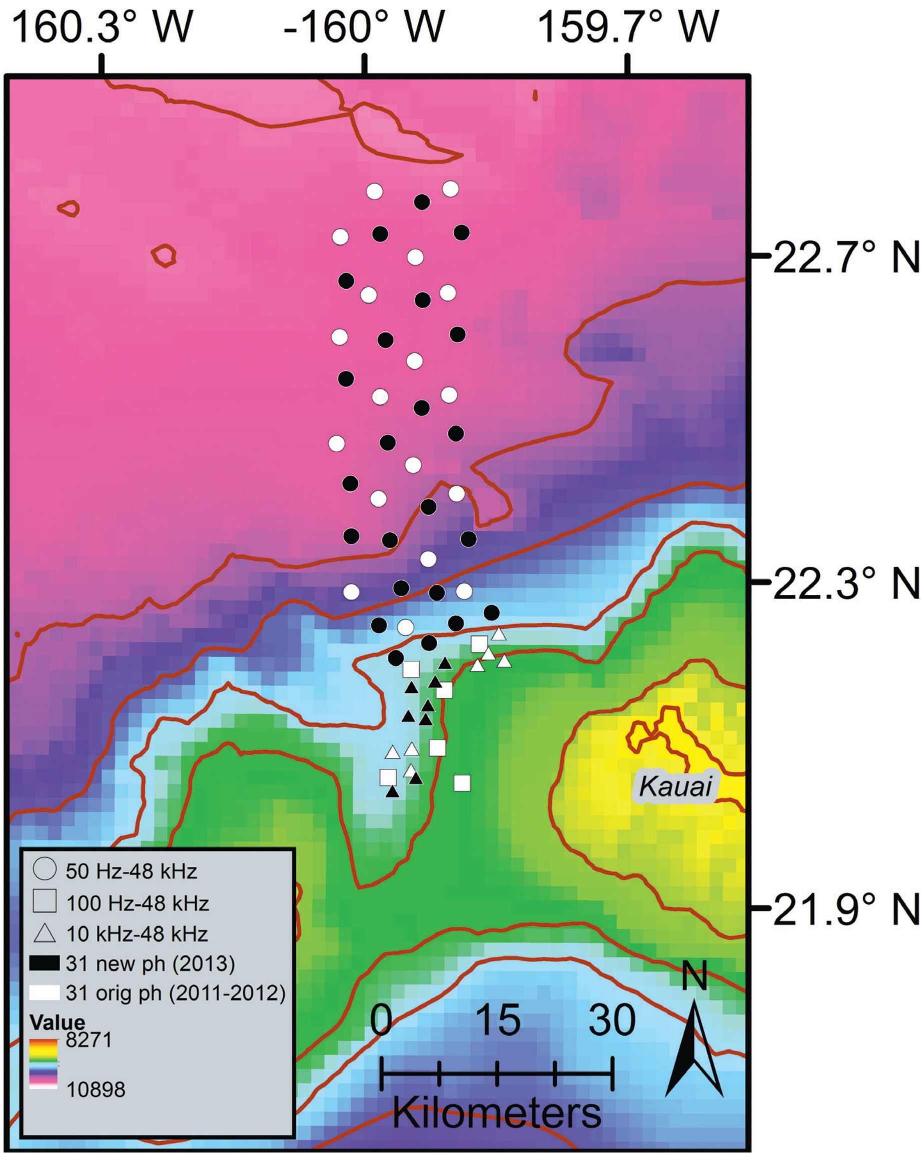

Figure 1. Approximate locations of the 62 recorded hydrophones used during this study at the Pacific Missile Range Facility (PMRF) in Kauai, Hawaii. The original 31 hydrophones are shown in white, while the 31 hydrophones added in 2013 are shown in black. The symbol of the hydrophone location represents the frequency response band. Bathymetry contours adapted from Amante & Eakins (2009).

were automatically detected using a custom C++ algorithm that processes recorded raw hydrophone data for frequency-modulated clicks. The algorithm has a first stage detection that processes the 96 kHz sampled data with 16,384-point FFTs, with 93.75% overlap. The first stage detection employs thresholds for both the signal level in the click band of 28 to 44 kHz over the background level and the ratio of the in-band mean level compared to the 5 to 28 kHz out-band mean level. When a signal passes the first stage detection process, it is then processed through a second stage (using a 64-point FFTs, with 98% overlap) to determine how much frequency modulation (FM) is in the click. Multiple species of beaked whales, notably Blainville's and Cuvier's, are somewhat unique in that their foraging clicks are on the order of 250 to 300 μs in duration and exhibit over 10 kHz of FM. The FM is utilized as a feature for beaked whale clicks bounded by a lower sweep threshold of 40 kHz/ms and bounded by an upper 140 kHz/ms sweep threshold. Clicks that meet the second stage FM requirement are identified as beaked whale clicks.

Thresholds in both stages were purposely set high to reject more false positives at the expense of detecting fewer actual beaked whale clicks. The logic for this is that if a group of beaked whales are actually diving in the area, there will be multiple animals, each producing thousands of foraging clicks in a typical foraging dive. Thus, even considering the relatively narrow beam pattern of Blainville's foraging clicks (Shaffer et al., 2013), there should be hundreds of opportunities to detect clicks when individuals are looking toward a bottom-mounted hydrophone. So, while the probability of detecting a single click may be small, the probability of detecting a GVP is high.

The beaked whale foraging click detection algorithm operates both with real-time and recorded data inputs, and works approximately 10 times faster than real-time when processing recorded data. The algorithm provides outputs, including the start time of the detections, the hydrophones that had detections, duration, sweep rate and optional file outputs of the detection spectrogram, and time series for verification purposes.

Manual Verification of Automated Detections

By utilizing time series waveforms, spectrograms, and spectra of the clicks, automatically detected signals were manually verified as individual beaked whale foraging clicks. Analysts ensure that the waveforms, spectrograms, and spectra fit with published results for beaked whales (e.g., Baumann-Pickering et al., 2014). In addition, the ICIs are evaluated for consistency with published intervals for different beaked whale species (e.g., approximately 0.3 s for Blainville's and 0.4 s for Cuvier's whales [Johnson et al., 2004; Zimmer et al., 2005]). A final species confirmation checked that the detected GVP was consistent with published dive vocal periods for the species (Zimmer et al., 2005; Johnson et al., 2006; Tyack et al., 2006). When all of these factors are in agreement, one can be very confident in the manual verification process in declaring detection of a beaked whale GVP.

Performance Characterization of Automated Detector

The performance of the automated detector was assessed to determine the actual probability of detecting a beaked whale click. Automated beaked whale detector performance was quantified by comparing automatic detections to manually obtained detections for a random sample of recorded data files from all 3 y of data. Average signal levels for manual and automatic detections were calculated by computing a 64-point FFT centered on the signal with a Hanning window and averaging the spectrum in the beaked whale foraging click band. The average noise level was calculated in a similar manner but averaged over a 1 s long noise sample for each file. Automatic detections that were within 1.5 ms of a manual detection were considered correct detections, and manual detections without a corresponding automatic detection were considered missed opportunities.

Blainville's Beaked Whale GVPs and MFAS Dive Group Vocal Periods—Group sizes for Blainville's beaked whales in Hawaiian waters are reported as 3.6 whales per group (Baird et al., 2006). Multiple animals in a group provide more opportunities to detect beaked whale clicks from a group dive. The number of clicks detected for a beaked whale dive is related to the distance of individual whales from the hydrophone, the number of animals in a group, the beam pattern of the foraging clicks, and the orientation of the animal with respect to the hydrophone. The distance of the animal from a hydrophone determines how much propagation loss is experienced (i.e., spreading losses and absorption of sound in the sea water). 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 (also see Hildebrand et al., 2015).

The hydrophones utilized in this analysis have in some cases very wide separation and can be over 4 km deep, which cannot guarantee detection of all beaked whale GVPs on the range. Therefore, the number of clicks detected and the estimated GVP durations may be less than what could be recorded on an acoustic tag. For this analysis, concurrently detected beaked whale GVPs on adjacent hydrophones less than 6 km apart are considered the same GVP. While this assumption could potentially bias the number of GVPs, it provides the most conservative estimate of GVPs. The hydrophone with the most manually verified beaked whale clicks for a GVP was termed the primary hydrophone and was considered the closest to the group of foraging beaked whales. The lack of detected clicks before and after a GVP also provided evidence of typical beaked whale foraging dive behavior. Although individual GVPs may be located a large distance from the primary hydrophone and have an apparent short duration, decreased high-frequency content due to absorption, and few clicks detected, the overall count of all the GVPs may be indicative of changes before, during, and after MFAS training events.

Mid-Frequency Active Sonar and Navy Training Events

MFAS in the frequency range of 1 to 10 kHz was present during each training event. A *Matlab* (Mathworks, Natick, MA, USA) based detector was developed to detect MFAS transmissions in order to know precisely when the sonar signals were present. The detection threshold was set such that the majority of these sonar pulses were detected with very few false positives, and manual inspection was performed to verify MFAS activity.

Data collection was separated into three time periods—Before, During, and After—throughout the Submarine Commander's Course (SCC) training events from February and August 2011 to 2013. The Hawaii Southern California Training and Testing Activities Final Environmental Impact Statement/Overseas Environmental Impact Statement (HSTT EIS/OEIS) provides more information regarding the SCC training scenarios (U.S. Department of the Navy, 2015). The amount of data analyzed depended on the availability of recordings from PMRF; therefore, data in the Before period of the SCC training event was recorded for 1 to 4 d prior to commencement, and data from the After period started at the end of the training event and lasted up to 1 to 4 d. As described in Martin et al. (2015), all training events took place in the During period of the data collection, and each training event was separated into Phases A and B. Phase A occurred in the initial portion of the training events and focused mainly on submarine-on-submarine scenarios, without MFAS from surface ships. Phase B occurred after Phase A and included MFAS from surface ships, sonobouys, and dipping sonars. For the SCC training events, surface ship MFAS activity is defined when a ship begins noncontinuous MFAS pulsed transmissions. Both Phases A and B also include range support platforms such as helicopters and surface ships for recovering exercise torpedoes and performing range safety- related tasks.

Results

Data Collection

Passive acoustic data were collected for 31 hydrophones over a total of 1,649 h in February and August of 2011, 2012, and 2013 (Table 1). In February and August of 2013, there were 62 hydrophones recorded. Only the original 31 hydrophones were used for the overall analysis but are also later compared against using all 62 hydrophones. There were 396.2 h of total data collected for the Before periods and 405.6 h in the After periods. Phase A, without MFAS from surface ships, consisted of 335.2 h; and Phase B, with MFAS pulse activity from surface ships in the 1 to 10 kHz bandwidth, consisted of 367.9 h. There were also two weekend periods separating Phase A and Phase B training ("Between phase") in February and August of 2013 (144.1 h). Over all six training events, there were 127 periods of MFAS activity lasting 12 to 161 min (mean of 63 min), for a total duration of 122.1 h or 33.2%

Table 1. Blainville's beaked whale (*Mesoplodon densirostris*) group vocal period (GVP) detection data from the combined Before, during Phase A, during Phase B (with MFAS), and After periods relative to the training events on Pacific Missile Range Facility (PMRF) in February and August 2011-2013

	Before	Phase A	Between	Phase B	After
Hours of data	396.2	335.2	144.1	367.9	405.6
Verified GVP detected	562	404	119	158	333
GVPs per hour	1.4	1.2	0.8	0.4	0.8

of the total Phase B period. The MFAS activity took place equally day and night in Phase B.

Both phases of the training event consisted of multiple event scenarios with different objectives. Ship GPS positions were obtained for the time period of each scenario. While the number of ships and movement of ships is not considered in this analysis, most activity took place in the center of the range, although it could occur anywhere on the range. There were similar levels of submarine activity for all exercises during Phase A, but for Phase B, February 2011 had the most surface ship activity, while August 2012, February 2012, and February 2013 had equal but less activity than February 2011, followed by August 2013. August 2011 had the least amount of surface ship activity.

Acoustic Detection, Classification, and Verification

Figure 2 demonstrates the characteristics of a typical click classified as a 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 s. In the process of verifying beaked whale clicks,

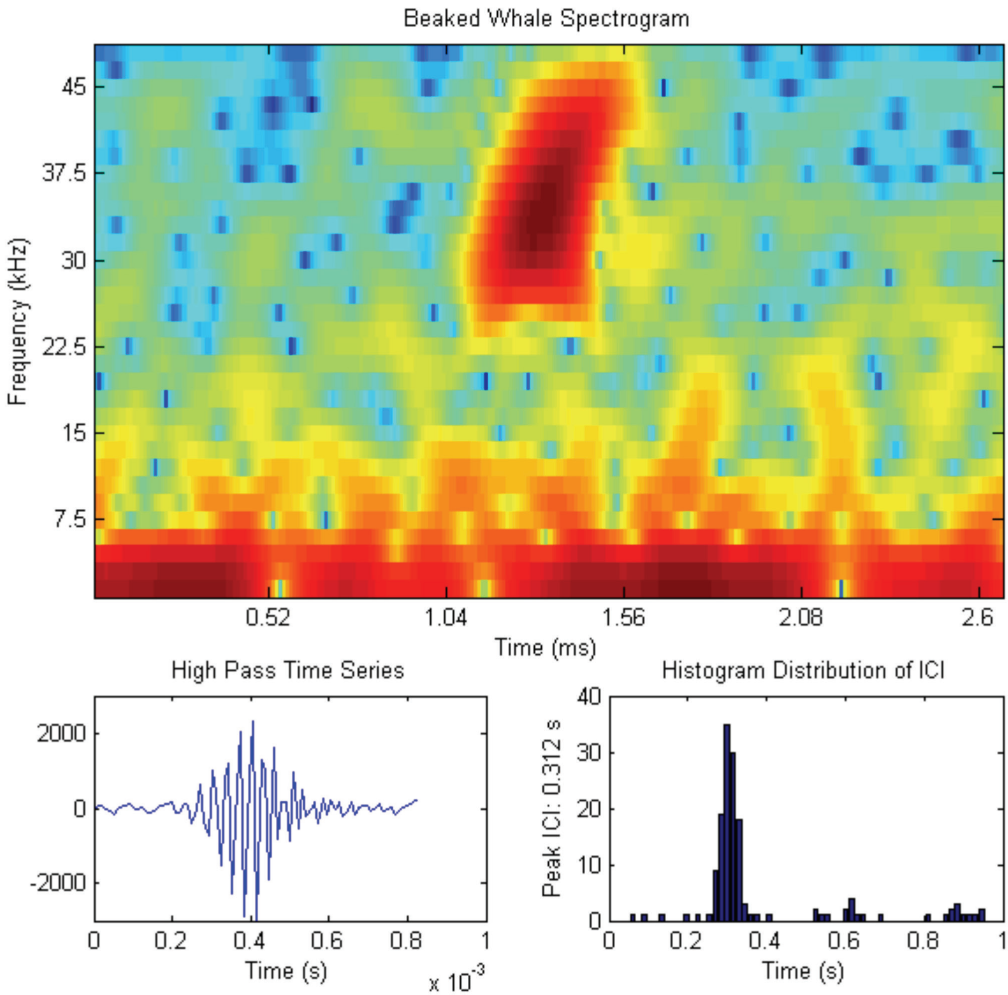

Figure 2. Spectrogram (0 to 48 kHz over 2.6 ms; 64-point FFT, overlapped 99%) of a beaked whale click from the pre-event data (top); time series (amplitude in counts over 1 ms) of the same beaked whale click (lower left); and histogram of the distribution of the inter-click interval (ICI) (0 to 1 s) of the beaked whale clicks in the previous 10 min (peak value 0.3 s) (lower right).

a few GVPs were observed to have different click characteristics reminiscent of the beaked whale clicks detected at Cross Seamount by McDonald et al. (2009). These were removed as they were out of the scope of this analysis, but they will be examined in future efforts.

A random sample of 22 data files from 17 hydrophones representing different water depths and distances from shore was utilized for performance characterization from the February 2011, 2012, and 2013 datasets and were not concurrent with Phase A or Phase B. Of the manual detections with signal-to-noise-ratios (SNR) under 15 dB, very few signals were automatically detected. A total of 2,787 clicks were manually detected, and 1,229 had at least a 15 dB SNR or higher. Of those, 485 were automatically detected. For a SNR over 25 dB, the standard level used in this detector, the probability of detecting clicks was 0.39. The 1 s average noise level in the band reduced the "noise" level over instantaneous levels but was utilized as it was similar to the normalization process the automatic detector utilized. The false positive rate was assumed to be zero since false positives were removed during manual verification.

Blainville's Beaked Whale GVP and MFAS

When the data from all six training events were combined, 562 Blainville's beaked whale GVPs were detected before the training events (Before period), 404 during all Phase A periods, 158 during all Phase B periods (with MFAS), 333 after the training events (After period), and 119 over the two weekend periods (Between period) in 2013 (Table 1), which equates to an overall mean of 1.4 GVPs per hour of effort Before, 1.2 GVPs per hour during Phase A, 0.4 GVP per hour during Phase B, 0.8 GVP per hour After, and 0.8 GVP per hour during the two Between phases. A chi-square goodness of fit test showed that these GVP counts are significantly different than expected (χ^2 = 191.6, $p < 0.0001$); in other words, there are more GVPs in the Before period and fewer GVPs in the other periods than expected when the proportions are compared.

It was hypothesized that GVPs that did occur during Phase B might take place preferentially between periods of MFAS. While pulsed MFAS activity was present 20 to 53% of the time during the Phase B periods, the number of GVPs detected during MFAS activity generally represented about 25 to 40% of the total GVP count during that time period (158 beaked whale GVPs during pooled Phase B periods; 50 co-occurred with MFAS activity). Therefore, the number of GVPs recorded concurrently with MFAS was generally proportional to the amount of time MFAS activity occurred during Phase B, and GVPs were not occurring more often between periods of MFAS. The exception to this was August 2012, when only two GVPs co-occurred with MFAS activity (~10%). While GVPs did co-occur with sonar, more of the GVPs during Phase B were detected on hydrophones on the edge of the range than expected (χ^2 = 7.76, p = 0.0053), indicating that beaked whales may be moving to the edges or off of the range during sonar activity. Alternatively, beaked whale groups in the center of the range may be going quiet, while groups on the edges of the range may continue foraging. This would also account for the decrease in overall GVPs as well as the shift in GVP locations.

When the data from each of the six training events were analyzed separately (Table 2), the overall pattern still generally holds, with a reduced number of GVPs detected in Phase A and a further reduction in Phase B. Chi-square goodness of fit tests indicated that the number of GVPs per sampling period (relative to the amount of time sampled) within each training event were significantly different than expected for all six training events (χ^2 ranged from 18.53 to 82.66; p ranged from 0.001 to < 0.0001). In most cases, the GVPs began to increase within days after the training events were completed as evidenced by the increase in GVP rates in the After period, and the GVP counts increased even during the two weekend periods in 2013 (Table 2). While in none of the years was there a long enough time frame sampled post-training to reach the number of detections prior to each training event, analyses of baseline beaked whale presence on the range have shown full recovery within a week or two (Henderson et al., 2013, 2016).

Chi-square tests conducted to compare training events across years showed significant differences, indicating that seasonal and interannual differences in occurrence patterns existed. For example, a comparison of the total number of GVPs within each period (e.g., all Before GVPs) that were recorded across all six training events against the expected number of GVPs (given the sampling effort) showed significant differences (χ^2 = 268.25, $p < 0.0001$). When each sampling period was examined across all six training events, the Before, Phase A, and After periods all had significantly different numbers of GVPs than expected (χ^2 = 39.88, 212.06, and 75.19, respectively; p = 0.0012, < 0.0001, and < 0.0001, respectively), indicating interannual variability within each training event period. Interestingly, there was no significant difference in the number of GVPs during Phase B (χ^2 = 8.9, p = 0.11); in this case, all the GVP counts were similarly low.

The distribution of GVPs across the range in each of the training event periods was also examined using ANOVA tests to compare GVP counts across hydrophones. In all years, the results were significant (p values ranged from 0.008 to < 0.001), with the GVPs more concentrated in the southern portion of the range during Phase B than during any other period (Figure 3). Diel GVP patterns were also examined for all years combined, with the expected GVPs per hour of the day (normalized by effort) compared to the observed GVPs per hour using a Chi-square goodness of fit test. The number of GVPs per hour did not vary significantly for all combined Before periods ($\chi^2 = 1.60$, $p = 0.44$), but were significantly different for the Phase A ($\chi^2 = 28.95$, $p < 0.001$), Phase B ($\chi^2 = 10.97$, $p = 0.03$), and After ($\chi^2 = 9.95$, $p = 0.02$) periods. Overall, there were fewer GVPs than expected in those periods, with slightly more GVPs than expected in the morning and afternoon hours.

31 vs 62 Hydrophone Comparison

Beginning in 2013, an additional 31 hydrophones were recorded. Table 3 shows the increase in the number of GVPs detected using the additional hydrophones. These differences demonstrate an increase in GVPs detected on the order of 30 to 70% greater when all 62 hydrophones were used compared to only 31 hydrophones. Still, the overall trends remain the same, with fewer GVPs in

Table 2. Blainville's beaked whale GVP detection data from the Before, during Phase A, during Phase B (with MFAS), Between, and After periods over all six training events for the original 31 hydrophones

Training event	Period	Duration (h)	GVPs	GVPs per hour	Sonar duration (h)	# GVPs with sonar
February 2011	Before	89.7	87	1.0		
	Phase A	44.0	21	0.5		
	Phase B	69.6	36	0.5	21.4	12
	After	77.3	72	0.9		
August 2011	Before	71.0	140	2.0		
	Phase A	78.9	214	2.7		
	Phase B	64.1	42	0.7	22.5	15
	After	48.0	85	1.8		
February 2012	Before	94.8	166	1.8		
	Phase A	54.6	67	1.2		
	Phase B	62.6	30	0.5	16.5	8
	After	90.5	59	0.7		
August 2012	Before	92.3	107	1.2		
	Phase A	50.4	36	0.7		
	Phase B	64.5	21	0.3	12.9	2
	After	55.3	47	0.9		
February 2013	Before	28.6	37	1.3		
	Phase A	52.4	23	0.4		
	Between	71.9	56	0.8		
	Phase B	62.6	14	0.2	25.1	12
	After	22.3	6	0.3		
August 2013	Before	19.8	25	1.3		
	Phase A	54.9	43	0.8		
	Between	72.2	63	0.9		
	Phase B	44.5	15	0.3	23.8	6
	After	112.2	64	0.6		

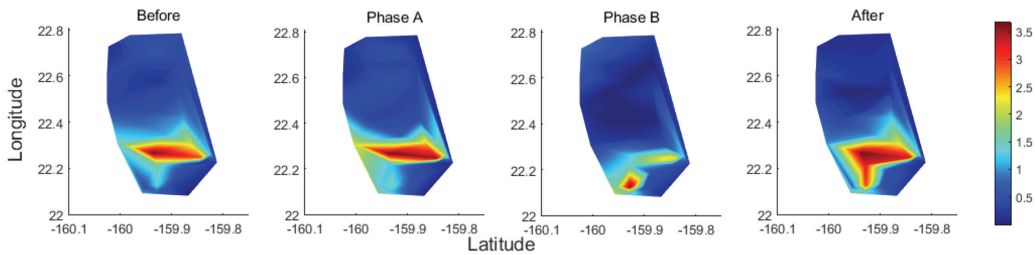

Figure 3. Maps of the distribution of Blainville's beaked whale GVPs (normalized as the number of GVPs per hydrophone per hours of effort) across the range for all training event periods combined (Before, Phase A, Phase B, and After) for 2011-2013, showing an overall reduction in GVPs and a shift in distribution of GVPs to the southern and edge hydrophones during Phase B

Table 3. A comparison of Blainville's beaked whale GVP detection data from the combined Before, during Phase A, during Phase B (with MFAS), and After periods in 2013 with 31 vs 62 hydrophones

Training event	Period	GVPs (31 phones)	GVPs per hour (31 phones)	GVPs (62 phones)	GVPs per hour (62 phones)
February 2013	Before	37	1.3	75	2.6
	Phase A	23	0.4	33	0.6
	Between	56	0.8	126	1.8
	Phase B	14	0.2	24	0.4
	After	6	0.3	19	0.9
August 2013	Before	25	1.3	35	1.8
	Phase A	43	0.8	85	1.6
	Between	63	0.9	113	1.6
	Phase B	15	0.3	24	0.5
	After	63	0.6	146	1.3

Phases A and B, and an increase in GVPs between the phases and after the training event.

Discussion

The data presented herein demonstrate that beaked whale GVPs continued to occur at PMRF during MFAS activity, although in reduced numbers. Tyack et al. (2011) showed that at AUTEC, beaked whale GVPs deviated from normal dive patterns when exposed to anthropogenic sound (e.g., simulated and actual Navy sonar, simulated killer whale calls, and a pseudorandom noise). Likewise, at PMRF, dives could potentially still be occurring without vocalizations, animals could have moved off the range or concentrated their diving in a smaller area of the range, or a combination of the above could have occurred. However, for this study, only GVPs detected on the range could be accounted for using passive acoustics.

Blainville's beaked whale GVPs were detected across PMRF before the training events, and predominantly in the area concentrated near the 22.3° N latitude portion of the range. During the training events, the overall number of GVPs decreased and were detected mostly south of the 22.2° N latitude, while there were also increased detections on the edge hydrophones compared to before the training events. The hydrophones between 22.1° and 22.3° N latitude 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; Henderson et al., 2016). Therefore, while beaked whale GVPs were more spread across the range before the training events, the beaked whales may be concentrating in an area of preferred foraging habitat as well as moving away from the ship traffic and sonar noise during the training events.

It is also possible that beaked whales in the center of the range are simply going quiet but not leaving the area; however, given the behavior of the tagged Blainville's beaked whale at AUTEC (Tyack et al., 2011), and the behavior of tagged Cuvier's and Baird's beaked whales and northern bottlenose whales (*Hyperoodon ampullatus*) in response to sonar (DeRuiter et al., 2013; Stimpert et al., 2014; Miller et al., 2015; Sivle et al., 2015), this seems unlikely. In almost all cases of tagged beaked whales exposed to simulated or real Navy sonars, the whale ceased echolocating, turned away from the sound source, and conducted very long, deep dives with shallow ascent rates as they avoided the sound source. The response was even more severe for a Blainville's beaked whale exposed to killer whale vocalization playbacks, leading to the hypothesis that cetaceans, and beaked whales in particular, are demonstrating an anti-predator response to sonar (Tyack et al., 2011; Curé et al., 2015). Therefore it is most likely that the decreased detection of GVPs in the center of PMRF is an indication that animals are moving to the edges and outside of the range rather than going silent. Since the proximity of the sound source seems to play a role in the occurrence and severity of the response (e.g., DeRuiter et al., 2013), this movement to the south and edges of the range may be sufficient to reduce further responses by Blainville's beaked whales at PMRF, which may be why dives continue during Phase B, and even during periods of MFAS activity. Responses by individual groups of beaked whales to MFAS, with the bearing and distance of the sound source, will be examined in greater detail in the future to determine what contextual variables contribute to a behavioral response.

Baird et al. (2008) found that deep foraging dives by tagged Blainville's and Cuvier's beaked whales in Hawaii 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 (Arranz et al., 2011; Hazen et al., 2011). In contrast, Au et al. (2013) found a distinct diel pattern to beaked whale foraging dives in the same region, and Baumann-Pickering et al. (2014) found Blainville's beaked whale acoustic activity to be highest early morning to mid-day. The beaked whales at Cross Seamount also display a strong diel pattern, with foraging dives occurring at night (McDonald et al., 2009; Baumann-Pickering et al., 2014). During this study, GVPs occurred equally day and night before the training events but seemed to shift slightly to have morning and afternoon peaks during and after the training events.

This analysis was conducted under the assumption that the Before periods represented a baseline of behavior; however, while training events are not continuously ongoing, there is appreciable activity at the range. To address this issue, true baseline data need to be identified and used to compare with behavior during training events to really capture any behavioral responses to MFAS and the concurrent increase in ship traffic (e.g., Henderson et al., 2016). The relatively large separation between hydrophones utilized in this analysis, as well as the deeper depths of the hydrophones in the northern portion of the range, may result in detecting only a fraction of or completely missing a beaked whale GVP. Therefore, the GVP durations were not analyzed, and only GVP counts were utilized. In addition, with many GVPs 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 GVP, and, therefore, absolute click counts were also not analyzed.

PMRF has roughly 200 bottom-mounted hydrophones; however, most are located close to shore and in shallower water and so may not be in preferred beaked whale habitat. It may be possible in the future to record on more hydrophones, which will decrease the spatial separation between hydrophones in some locations and increase the likelihood of detecting more of the GVPs on the range. Additional efforts in progress include calculating the density of Blainville's beaked whales, estimating sonar exposure levels from MFAS sources for beaked whales detected by various methods (i.e., passive acoustics, sighted by observers, and tagged animals), and examining the other beaked whale clicks detected at PMRF. All of these additional analyses represent an ongoing examination into the habitat use of this region by beaked whales before, during, and after training events as well as during baseline periods.

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