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14. ABSTRACT
Beaked whales (family Ziphiidae) consist of at least 21 different species in six genera with relatively little known about many of the species. Research on this family of odontocetes has increased in the last two decades as a result of a mass stranding event of beaked whales in the Bahamas in 2000 in association with a U.S. Navy training event1. Results of this research have identified echolocation click characteristics for several species from different areas of the world based upon both tag data and passive acoustic monitoring data2,3. Acoustic characteristics have been reported for the following species, all of which have been visually validated: Blainville's (Mesoplodon densirostris), Cuvier's (Ziphius cavirostris), Gervais' (Mesoplodon europaeus), Baird's (Berardius bairdii), Longman's (Indopacetus pacificus), Deraniyagala's (M. hotaula), and Stejneger's (M. stejnegeri) beaked whales as reported in the literature4–7,22. 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 50 kHz. Longman's beaked whales in Hawai'i have also been reported to use lower frequency clicks with no appreciable frequency modulated (FM) characteristics6,22. Other beaked whale click types have been described, but have not been associated to a single beaked whale species yet; these include a click type recorded at Cross Seamount and in Hawaii8,21-22, two click types recorded off southern California22, and one click type recorded in the Gulf of California22.
Manzano-Roth et al.21 reported on the presence of Blainville's-like clicks and Cross Seamount-like clicks on the Pacific Missile Range Facility (PMRF) before, during, and after a U.S. Navy training event in February 2012, and estimated the received levels of mid-frequency active sonar (MFAS) on beaked whales whose dives coincided with MFAS. This report seeks to update that information with data associated with five additional training events from February and August

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2011-2013 as well as the February 2012 training event already reported. This report analyzes the changes in dive counts before, during, and after these training events, including the period with MFAS activity, to assess the impact of MFAS on dive behavior. This report focuses solely on detections from Blainville's beaked whales, as these are the dominant species recorded at PMRF. Data that includes the Cross Seamount-like clicks are part of an ongoing analysis and will not be addressed in this report.

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Impacts of U.S. Navy training events on beaked whale foraging dives in Hawaiian waters: Update

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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. Research on this family of odontocetes has increased in the last two decades as a result of a mass stranding event of beaked whales in the Bahamas in 2000 in association with a U.S. Navy training event[1]. Results of this research have identified echolocation click characteristics for several species from different areas of the world based upon both tag data and passive acoustic monitoring data[2,3]. Acoustic characteristics have been reported for the following species, all of which have been visually validated: Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), Gervais' (*Mesoplodon europaeus*), Baird's (*Berardius bairdii*), Longman's (*Indopacetus pacificus*), Deraniyagala's (*M. hotaula*), and Stejneger's (*M. stejnegeri*) beaked whales as reported in the literature[4–7,22]. 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 50 kHz. Longman's beaked whales in Hawai'i have also been reported to use lower frequency clicks with no appreciable frequency modulated (FM) characteristics[6,22]. Other beaked whale click types have been described, but have not been associated to a single beaked whale species yet; these include a click type recorded at Cross Seamount and in Hawaii[8,21-22], two click types recorded off southern California[22], and one click type recorded in the Gulf of California[22].

Manzano-Roth et al.[21] reported on the presence of Blainville's-like clicks and Cross Seamount-like clicks on the Pacific Missile Range Facility (PMRF) before, during, and after a U.S. Navy training event in February 2012, and estimated the received levels of mid-frequency active sonar (MFAS) on beaked whales whose dives coincided with MFAS. This report seeks to update that information with data associated with five additional training events from February and August 2011-2013 as well as the February 2012 training event already reported. This report analyzes the changes in dive counts before, during, and after these training events, including the period with MFAS activity, to assess the impact of MFAS on dive behavior. This report focuses solely on detections from Blainville's beaked whales, as these are the dominant species recorded at PMRF. Data that includes the Cross Seamount-like clicks are part of an ongoing analysis and will not be addressed in this report.

II. METHODS

A. Data collection

PMRF, located off the west coast of Kauai, Hawaiʻi (Figure 1), hosts a variety of U.S. Navy 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. Navy systems. PMRF has supported U.S. Navy funded monitoring of marine mammal acoustics 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 training events in February and August, 2011 and 2012. 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 10 minutes of data. 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 the southern area to over 10 km in areas farther offshore.

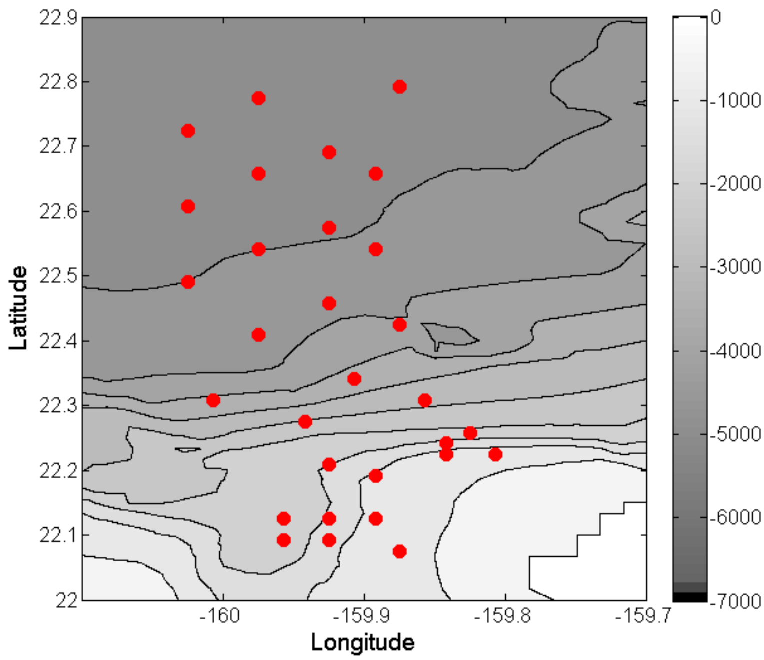

FIG. 1. Approximate locations of the 62 recorded seafloor hydrophones used in this study at the Pacific Missile Range Facility, Kauai, Hawai‘i. 1000m depth contours are in grey. Note: the figure axes are not to scale.

B. Acoustic detection, classification and verification

1. Beaked whale click detection and validation

Manzano-Roth et al.[21] provided a detailed description of the automatic click detector used in this analysis. Briefly, beaked whale foraging clicks were automatically detected using a custom C++ algorithm which processes disk files of raw hydrophone data for frequency modulated clicks. 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. Detected beaked whale clicks reports are automatically saved along with optional time series and spectrograms for later validation. Automatically detected beaked whale foraging clicks are manually validated by experienced analysts to ensure the clicks have the appropriate characteristics. A custom MATLAB routine allows rapid review of the time series and spectrogram of individual automatic click detections and a histogram of inter-click intervals (ICIs) over a ten minute period. Each beaked whale dive detection was treated as a group of beaked whales, as these animals typically dive in groups (mean group size 3.6±3)[10].

2. Beaked Whale Dives

The number of clicks identified by the detector for a beaked whale dive is a result of 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. Orientation of the animal relative to the hydrophone affects the apparent source levels of the clicks due to their directional nature and spectral content. 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. Ultrasonic signals, such as beaked whale foraging clicks, were assumed to not be detected on seafloor hydrophones at distances much over 6 km due to transmission loss. The 6 km maximum detection distance was selected based upon Zimmer, who reported a maximum detection distance of 4 km for hydrophones located close to the surface[18], and Ward who reported a maximum detection distance of 6.5 km for bottom mounted hydrophones at the Atlantic Undersea Test and Evaluation Center (AUTEC)[19].

Concurrently detected beaked whale foraging dives on adjacent hydrophones less than 6 km apart were considered the same dive; while this assumption could potentially bias the number of dives, it provided the most conservative estimate of dive counts. The hydrophone with the most manually validated beaked whale clicks for a dive was termed the closest hydrophone under the assumption that it was the closest hydrophone to the group of foraging beaked whales. The lack of detected clicks pre-dive and post-dive also provides supporting behavior typical of beaked whales. This process was felt to provide a high confidence in detecting a beaked whale foraging dive present near the closest hydrophone. This allowed a useful metric for the number of beaked whale dives detected per unit time, which were compared before, during and after U.S. Navy training events involving MFAS activity.

3. 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 events including AN/SQS-53C, AN/SQS 56 sonar, sonobuoys, and other sources. The focus of this analysis was on the MFAS activity from the surface ship activities. However, all signals within the MFAS bandwidth being processed were detected in order to know precisely when 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.

III. RESULTS

A. Data collection

Passive acoustic data were collected continuously for 31 hydrophones over 60 days (1615.7 hours) 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. About 396.2 hours of total data were collected for the periods before the training events, 669.9 hours during the training events, and 402.6 hours after the training events. The training events consisted of an initial portion (335.2 hours) with no MFAS from the sonar sources (termed phase A) and a later portion (334.7 hours) with MFAS activity (termed phase B). There were also two weekend “between” periods in February and August of 2013 (144.1 hours), such that a weekend occurred between the initial no-sonar portion of the training event and the later portion with sonar activity, during which no training took place. 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; 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 positions was not a major issue. Over all six training events, there were 127 periods of MFAS lasting 12 to 161 min (mean 63 min), for a total duration of 122.1 hours, or 36.5% of the total phase B period. These exposures took place equally day and night across the three-day period.

B. Acoustic detection, classification and verification

Figure 2 demonstrates the characteristics of a typical 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.

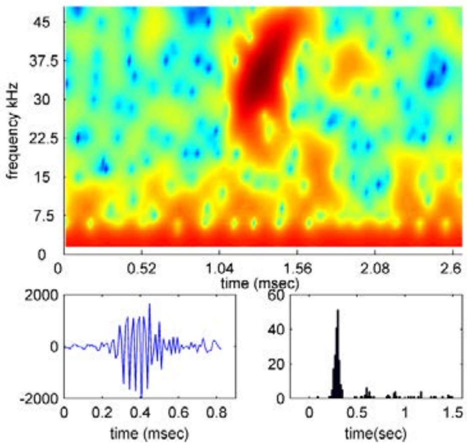

FIG. 2. Spectrogram (0 to 48 kHz over 2.6 s) of a beaked whale click. Time series (amplitude in counts over 0.8 ms) of the same beaked whale click (lower left). Histogram of the ICI (0 to 1.6 s) of the beaked whale clicks in the previous 10 minutes (mode value 0.312 s) (lower right).

When the data from all six training events was combined, 562 Blainville's beaked whale dives were detected before the training periods, 404 during all phase A periods, 158 during all phase B periods (with MFAS), 332 after the training events, and 119 over the two weekend periods in 2013 (Table I), which equates to an overall mean of 1.4 dives per hour before, 1.2 dives per hour during phase A, 0.5 dives per hour during phase B, 0.8 dives per hour After, and 0.8 dives during the two between periods. A chi-square goodness of fit test showed that these dive counts are significantly different than expected ($\chi^2 = 191.6$, $p < 0.0001$); in other words, there are far more dives in the before period and fewer dives in the other periods than expected when the proportions are compared.

While sonar was present 20 – 67% of the time during the phase B sampling periods, the number of dives detected during sonar training generally represented about 25 – 40% of the total dive count during that time period (158 beaked whale dives during pooled phase B periods, 50 co-occurred with MFAS activity). The number of dives recorded during MFAS was generally proportional to the amount of time MFAS activity occurred during phase B. The exceptions to this were August 2012, when only 2 dives co-occurred with sonar (~10%), and August 2013 when only 4 dives co-occurred with sonar (27%). However, more of the dives 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.

TABLE I. Blainville's beaked whale dive detection data from the combined before, during phase A, during phase B (with MFAS), and after periods relative to the training events on PMRF in February and August 2011 - 2013.

	Before	Phase A	Phase B	After
Hours of data	396.2	335.2	334.7	405.6
Validated dives detected	562	404	158	332
Dives per hour	1.4	1.2	0.5	0.8

When the data from each of the six training events is analyzed separately (Table II), the overall pattern still holds, with a reduced number of dives detected in phase A and a further reduction in phase B. Chi-square goodness of fit tests indicated that the number of dives 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 dives began to increase immediately after the training events were completed, as evidenced by the increase in dive rates in the After period, although 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. However, analyses of baseline beaked whale presence on the range has shown full recovery within a week or two[23], and the dives counts increased even during the two weekend periods in 2013 (Table II).

In addition, chi-square tests conducted across training events also showed significant differences, indicating that seasonal and inter-annual differences in occurrence patterns also exist. For example, a comparison of the total number of dives that were recorded across all six training events against the expected number of dives (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 dives 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 dives during phase B (χ^2 = 8.9, p = 0.11); in this case all the dive counts were similarly low.

TABLE II - Blainville's beaked whale dive detection data from the before, during phase A, between phases, during phase B (with MFAS), and after periods over all six training events for the original 31 hydrophones. Asterisks indicate analysis of additional data in progress.

Training Event	Period	Duration (hours)	Dive Count	Dives per Hour	Sonar Duration (hours)	# dives with sonar
Feb 2011	Before	89.65	87	0.97		
	Phase A	43.96	21	0.48		
	Phase B	69.61	36	0.52	21.38	12
	After	77.25	72	0.93		
Aug 2011	Before	71.00	140	1.97		
	Phase A	78.92	214	2.71		
	Phase B	64.08	42	0.66	22.52	15
	After	48.00	85	1.77		
Feb 2012	Before	94.84	166	1.75		
	Phase A	54.60	67	1.20		
	Phase B	62.62	30	0.48	16.50	8
	After	90.50	59	0.65		
Aug 2012	Before	92.29	107	1.25		
	Phase A	50.35	36	0.71		
	Phase B	64.49	21	0.33	12.87	2
	After	55.33	47	0.89		
Feb 2013	Before	28.60	37	1.29		
	Phase A	52.42	23	0.44		
	Between	71.89	56	0.78		
	Phase B	38.59*	14	0.36	25.09	12
	After	22.32	6	0.27		
Aug 2013	Before	19.78	25	1.26		
	Phase A	54.91	43	0.78		
	Between	72.20	63	0.87		
	Phase B	35.30*	15	0.42	23.78	6
	After	112.17	64	0.57		

C. 31 vs 62 hydrophone comparison

In 2013, an additional 31 hydrophones were recorded. Table III shows the increase in the number of dives detected using the additional hydrophones. These differences are on the order of 30 % – 70% greater when all 62 hydrophones were used compared to only 31 hydrophones. However, the overall trends are still the same, with fewer dives in phases A and B, and an increase in dives between the phases and after the training event.

Table III – A comparison of Blainville's beaked whale dive 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	31 hydrophones		62 hydrophones	
		Dive count	Dives per hour	Dive count	Dives per hour
Feb 2013	Before	37	1.33	75	2.62
	Phase A	23	0.44	33	0.63
	Between	56	0.78	126	1.75
	Phase B	14	0.36	24	0.62
	After	6	0.27	19	0.85
Aug 2013	Before	25	1.26	35	1.77
	Phase A	43	0.78	85	1.55
	Between	63	0.87	113	1.57
	Phase B	15	0.42	24	0.68
	After	63	0.57	146	1.30

IV. DISCUSSION

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. Recent work by Baumann-Pickering et al.[22] supports this classification. This classification is also supported by the number of Blainville's beaked whale sightings that have been made on PMRF through boat-based and aerial visual surveys [24]. 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)[20]. Previous analyses have also demonstrated the presence of the Cross Seamount beaked whale[21]; further analyses are being conducted on the seasonal and inter-annual occurrence patterns of that species.

The data presented here demonstrate that beaked whale dives continued to occur at PMRF while MFAS activity was occurring, although in reduced numbers. Blainville's dives were detected across the range before the training event, predominantly in the south-central portion of the range. During the training event, the overall number of dives decreased, and the dives occurred more in the southern portion of the range, and an increase in detections on the edge hydrophones occurred as well. The southern portion of the range has more closely-spaced hydrophones, which allows for increased detections of beaked whale clicks. The southernmost hydrophones are also 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[9]. Therefore the beaked whales may be concentrating in an area of preferred foraging habitat during the training events, as well as moving away from the ship traffic and sonar noise.

The inclusion of an additional 31 hydrophones in 2013 led to an increase in up to 70% more dives detected on the range than with the original 31 hydrophones. The new additions reduce the inter-hydrophone spacing such that almost every hydrophone is within 6 km of at least one other hydrophone. While this increases the likelihood of recording beaked whale dives that occur on the range, the northern hydrophones are 4.5 km deep, and are still separated by > 6 km from most neighboring hydrophones. Therefore the spatial coverage across the range, while improved, is still not complete.

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 periods could be the after periods for other training activities. 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.

Acknowledgments

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