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Occurrence and Habitat Use of Foraging Blainville's Beaked Whales (*Mesoplodon densirostris*) on a U.S. Navy Range in Hawaii

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Abstract

Blainville's beaked whales (*Mesoplodon densirostris*) were detected through passive acoustic monitoring recordings of the hydrophones at the Pacific Missile Range Facility (PMRF) off Kauai, Hawaii, from 2011 through 2013. Group vocal period (GVP) detections were analyzed for temporal (intra- and inter-annual and diel) and spatial (depth, slope, and range extent) patterns. A habitat model was developed using those parameters as predictor variables in Blainville's beaked whale foraging dive distributions. No monthly or annual trends in GVP rates were found, but there was some diel periodicity found in GVP rates related to the lunar cycle. In addition, a strong relationship was found between bathymetric features and GVP rates, with most dives occurring over steep slopes and depths between 2,000 and 3,000 m. While GVPs occurred across the range throughout each year, they were concentrated in those areas of preferred habitat. GVP rates were also compared against Navy training activity to assess whether foraging behavior was affected by active sonar or explosive sounds. Similar to other Navy ranges, biannual multi-day training events did decrease GVP rates, but all of the other training activity did not appear to affect GVP rates over sampling periods of a week to a month. These results are the first description of baseline foraging behavior for Blainville's beaked whales at PMRF and provide some insight into the habitat use patterns related to both the natural environment and anthropogenic impacts.

Key Words: Hawaii, foraging dives, habitat use, echolocation clicks, Blainville's beaked whale, *Mesoplodon densirostris*

Introduction

Beaked whales and the effects of Navy sonar have come under more scrutiny in the last 25 y (Simmonds & Lopez-Jurado, 1991; Ketten, 2005; Cox et al., 2006; D'Amico et al., 2009; Faerber & Baird, 2010). Prior to this period of intensive study, this was a relatively unknown family of cetaceans, with several species described only from skulls or stranded animals. In the last two decades of research, new beaked whale species have been discovered (Dalebout et al., 2002, 2014; Baumann-Pickering et al., 2010); new vocalizations have been recorded and, in some cases, attributed to likely candidate species (McDonald et al., 2009; Baumann-Pickering et al., 2010, 2013; Rankin et al., 2011); and more information has been gleaned on the better known species, including Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), and Baird's (*Berardius bairdii*) beaked whales, and northern bottlenose whales (*Hyperoodon ampullatus*) (Hooker & Baird, 1999; Hooker & Whitehead, 2002; Johnson et al., 2006, 2008; Falcone et al., 2009; Wahlberg et al., 2011; Dunn et al., 2013; Schorr et al., 2014; Stimpert et al., 2014; Miller et al., 2015). The majority of this new information has come through tagging, passive acoustic monitoring, behavioral response studies, and photo-identification. However, several of these studies have taken place over short-term periods, on the order of hours to days, and may represent snapshots of behavior rather than long-term trends.

Blainville's beaked whales are the most widely distributed of the *Mesoplodon* species, second only to Cuvier's beaked whales in global distribution (MacLeod et al., 2006), and are found in tropical and temperate waters in all ocean basins except the Arctic and Mediterranean. Despite this nearly global distribution, few studies of occurrence and habitat use have been conducted on this species due to their low visibility and long dive times (Barlow, 1999). Visual surveys (MacLeod & Zuur, 2005; Claridge, 2006) and habitat modeling (Hazen et al., 2011) have been conducted in the Bahamas off Great Abaco Island, while passive acoustic monitoring has been conducted using bottom-mounted hydrophones at the Atlantic Undersea Testing and Evaluation Center (AUTEC), a Navy range frequently used for active sonar training (McCarthy et al., 2011; Tyack et al., 2011). In the Bahamas studies, Blainville's beaked whales were strongly associated with depths between 136 and 1,310 m and slopes from 6 to 30%, and remained within several km of shore. Some photo-identified animals have been resighted over time, indicating some possible residency to the area (MacLeod & Zuur, 2005; Claridge, 2006).

Similarly, another resident population of Blainville's beaked whales has been photo-identified and tagged off the west coast of the island of Hawaii, with 40% of the animals observed more than once and resights up to 21 y apart (Baird et al., 2004, 2006a, 2008, 2009; McSweeney et al., 2007; Schorr et al., 2009; Baird, 2016). These Blainville's beaked whales were associated with depths between 880 and 1,455 m and slopes between 0 to 41%, remaining within 50 km of the island (Baird et al., 2006a; Schorr et al., 2009). Tagged animals dove to depths between 800 and 1,484 m to forage (Baird et al., 2006a), presumably on cephalopods and deepwater fish (MacLeod et al., 2003) not associated with the scattering layer as they conducted these deep foraging dives equally both day and night (Baird et al., 2008).

For this study, acoustic data were recorded a few days each month using the instrumented range hydrophones at the Pacific Missile Range Facility (PMRF) off the island of Kauai in the Hawaiian archipelago from 2011 to 2013, as well as before, during, and after U.S. Navy training events in the same years (Manzano-Roth et al., 2016). This dataset provides the ability to examine long-term trends in Blainville's beaked whale foraging behavior and habitat use on a broad spatial scale. This information is crucial to the estimation of behavioral responses to active sonar and other anthropogenic activity at the range. By parsing out natural variations in foraging dive behavior, the changes that occur in response to Navy active sonar can be more accurately identified.

The goals of this study were to (1) describe diel, seasonal, and inter-annual trends in Blainville's beaked whale foraging dives; and (2) associate these trends with bathymetric and temporal features and anthropogenic noise events (i.e., sonar and explosive sounds) to identify features that potentially correlate with foraging dives in order to (3) assess the habitat use of Blainville's beaked whales at PMRF.

Methods

Acoustic Recordings and Analysis

PMRF is located off the northwest coast of the island of Kauai, Hawaii (Figure 1), and has over 200 seafloor-mounted hydrophones that support a wide variety of U.S. Navy training and testing activities throughout the year. A subsample of the range hydrophones at PMRF have been recorded since 2003, with an increase to at least 2 d a month in 2006 and the addition of the before, during, and after periods of a biannual Navy training event since 2011 (Manzano-Roth et al., 2016). The period during training events will not be utilized in this analysis of baseline behavior, but the before and after periods have been included. From January 2011 through August 2012, 31 hydrophones were

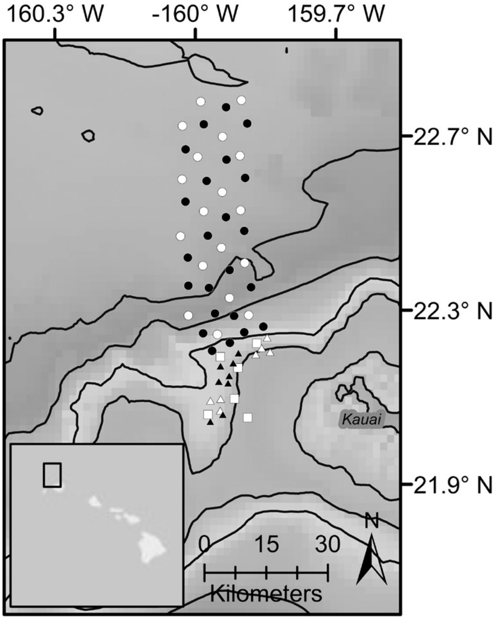

Figure 1. Approximate locations of the 62 recorded hydrophones used during this study at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. The original 31 hydrophones are shown in white, while the 31 hydrophones added in 2013 are shown in black. The symbol of the hydrophone location represents the frequency response band, with triangles representing 10 kHz to 48 kHz, squares representing 100 Hz to 48 kHz, and circles representing 50 Hz to 48 kHz. Depth contours in 1,200 m intervals are shown in grey.

sampled and that number was doubled to 62 recorded hydrophones from late August 2012 through December 2013 (Figure 1). However, only data from the first 31 hydrophones will be examined in these analyses in order to be consistent across years. These broadband hydrophones, with frequency responses ranging from 50 Hz to 48 kHz to 10 kHz to 48 kHz, were sampled at 96 kHz using 16-bit analog-to-digital converters. The sampled portion of the range varies in depth from 429 to 4,877 m, with a mean depth of 2,945 m.

The recording process and automated detector used for analysis have been described in detail in Manzano-Roth et al. (2016) and will only be briefly summarized here. A custom-built C++ algorithm was used to automatically detect Blainville's beaked whale foraging clicks. Blainville's beaked whale clicks have a frequency upsweep from 27 to 45 kHz over a 0.3 ms duration, with a typical ICI of around 0.3 s (Baumann-Pickering et al., 2014; Manzano-Roth et al., 2016). A high signal-to-noise ratio threshold was used to reduce the likelihood of false positives. In a performance assessment conducted on a subset of data taken from all 3 y, the probability of detecting an individual click was around 39% (Manzano-Roth et al., 2016). However, all automated detections were manually validated, leading to a final false positive rate of zero, while the likelihood of detecting a group vocal period (GVP) remains high due to the spacing of the hydrophones (1.6 to 10+ km apart, with at least one neighboring hydrophone within 6 km). These GVPs were assumed to represent deep foraging dives as Blainville's beaked whales do not click during their shallower bounce dives near the surface (Johnson et al., 2004); therefore, the terms *GVP* and *foraging dive* will be used interchangeably. Both terms are intended to represent dives by one to several individuals as Blainville's beaked whales are typically found in groups of up to 11 individuals (range 1 to 11, mean 3.7; Baird, 2016) and have been shown to dive synchronously (Baird et al., 2006a). When clicks were detected on more than one hydrophone in an area and were deemed to have come from the same group, the hydrophone with the most detections was designated as the *primary* hydrophone. Only the primary hydrophone was used for all temporal and spatial analyses.

Habitat Use Analysis

All detected and validated Blainville's beaked whale GVPs from the original 31 hydrophones were compiled and normalized by recording effort to assess diel, monthly, and inter-annual trends in foraging dive behavior. In addition, depth data were taken from the National Oceanic and Atmospheric Administration's National GeoPhysical Data Center's ETOPO2 2-min global relief database (www.ngdc.noaa.gov/mgg/fliers/06mgg01.html). Depth values were selected within a 3-km radius around each hydrophone to determine the minimum, maximum, and mean depth values for each hydrophone area. These data were used to calculate the maximum percent slope of each hydrophone area, calculated as maximum–minimum depth/6,000 m*100.

Chi-square goodness-of-fit tests were used to assess the number of normalized GVPs detected across diel, monthly, and inter-annual temporal scales to determine if there were significant trends across those time periods. Kendall's rank test was used to look for correlation between depth, slope, and dive counts. A Generalized Additive Model (GAM) was fit to all temporal and spatial data in order to develop a model that best described the spatio-temporal habitat use of Blainville's beaked whales at PMRF. Blainville's beaked whale GVPs were grouped into 1 h bins based on the start time of the GVP, and then GAMs were developed as a function of temporal and spatial variables (Year, Month, Start Hour, Lunar Phase, Depth, and Slope) using the mixed GAM computational vehicle (mgcv) package in *R* software, Version 3.2.3 (Hastie & Tibshirani, 1990; Wood, 2006; R Core Team, 2014). To select predictor variables for inclusion in each model, a likelihood-based smoothness selection method was applied with the restricted maximum likelihood (REML) criterion (Patterson & Thompson, 1971; Wood, 2006). Each predictor variable was tested for inclusion in the model using a smoothing function defined by a cubic regression spline with shrinkage. The best model was selected after sequentially dropping the single term with the highest nonsignificant *p* value and then refitting the model until only significant terms were included and the REML score and explained deviance were maximized.

Training Activity at PMRF

Multi-day training events occur at PMRF every February and August that utilize multiple types of active sonars, including hull-mounted sonars, and typically utilize more mid-frequency active sonar than training that occurs throughout the rest of the year. The number and spatial occurrence of foraging Blainville's beaked whale GVPs that occur before, during, and after these events has already been studied in detail (Manzano-Roth et al., 2016). However, there are a number of other, smaller training and testing events that take place at PMRF throughout the year that may utilize a variety of active sonars or generate explosive sounds during a portion of the event (see U.S. Department of the Navy, 2013, for more details). The hours of all training events that took place at PMRF from 2011 through 2013 that may have emitted active sonar or explosive sounds were tallied. These were compared against the number of beaked whale GVPs each month using a Spearman's rank test to determine if there was any effect on the number of Blainville's beaked whale foraging dives throughout the year from these shorter events. In addition, to assess patterns at smaller temporal scales, all training hours within 7 d of a baseline recording were summed and normalized into a per hour metric based on the number of days of training and then compared to the number of GVPs per hour in the subsequent recording period. This was conducted both with and without the inclusion of a time lag term to account for the number of days between training and acoustic recording periods, giving more weight to training events that had occurred just before the recording period. A Spearman's rank test was also used for this analysis.

Results

Temporal Foraging Dive Patterns

There was a total of 2,328.8 h of hydrophone data recorded over the 3-y period, with 2,958 Blainville's beaked whale GVPs detected on 31 hydrophones (Table 1). There were almost twice as many GVPs detected on all 62 hydrophones after August 2012. Overall, there were a mean of 39.4 GVPs per recording (4 to 125 GVPs total) and 1.3 GVPs per hour of effort (1.3 to 3.3 GVPs per hour) on 31 hydrophones, and 54 GVPs per recording (9 to 108 GVPs total) and 2.1 GVPs per hour of effort (0.7 to 3.7 GVPs per hour) on 62 hydrophones.

The number of detected GVPs per recording period was significantly different than expected ($\chi = 494.57$, $p < 0.0001$), indicating broad intra-annual variability in GVP occurrence patterns, although this number varied greatly within and across years (Figure 2). On a monthly basis, GVP counts ranged from 11 to 226 on 31 hydrophones, with a mean of 84.5 and a median of 66 (0.5 to 2.3 GVPs per hour; Figure 3). The observed number of GVPs per month for all years combined was significantly different than expected given the level of effort ($\chi = 57.64$, $p < 0.0001$), indicating within-year seasonal variation. There was no clear pattern to this intra-annual variation, although there seemed to be an increase in GVPs in spring and again in late summer (Figure 3). The observed number of GVPs per year for all months combined was also significantly different than expected given the level of effort ($\chi = 54.97$, $p < 0.0001$), with more GVPs than expected in 2011 and fewer than expected in 2013 (Figure 2).

Finally, although the apparent diel pattern in Blainville's beaked whale GVPs was slight when looking at the overall number of dives per hour over 24 h, the normalized number of GVPs per hour was significantly different than expected ($\chi = 47.13$, $p = 0.002$), with a small decrease in GVPs during crepuscular periods (Figure 4).

Spatial Foraging Dive Patterns

Blainville's beaked whale foraging dives did not occur evenly across the range ($\chi = 2{,}375.43$, $p < 0.0001$). Strong differences in the number of GVPs detected on each of the 31 hydrophones across each month were demonstrated (Figure 5). The majority of GVPs (68%) occurred on hydrophones located on the southern portion of the range where the depth increases rapidly from 600 to 3,000 m along a steep slope. The hydrophones in this region of the range are located 9.8 to 32 km from the island of Kauai. Blainville's beaked whale GVPs were weakly correlated with depth (Rho = -0.22, $p = 0.09$), with a peak in GVPs occurring between 2,000 and 3,000 m (Figure 5), although GVPs occurred at all depths from 648 to 4,716 m. GVPs were also strongly correlated with slope (Rho = 0.42, $p = 0.001$), with a peak in dives around 15% grade, although this occurred at all slopes from 1 to 23%. Depth and slope were

Table 1. Recording effort and number of detected and validated Blainville's beaked whale (*Mesoplodon densirostris*) foraging dives or group vocal periods (GVPs) at the Pacific Missile Range Facility (PMRF) by year

	31 hydrophones			62 hydrophones		
Year	Recording effort (h)	GVP count	GVPs per hour	Recording effort (h)	Dive count	Dives per hour
2011	733.9	1,088	1.5	NA	NA	NA
2012	849.8	1,089	1.3	180.5	453	2.5
2013	745.1	781	1	745.1	1,490	2.0
Total	2,328.8	2,958	1.3 (mean)	925.6	1,943	2.1 (mean)

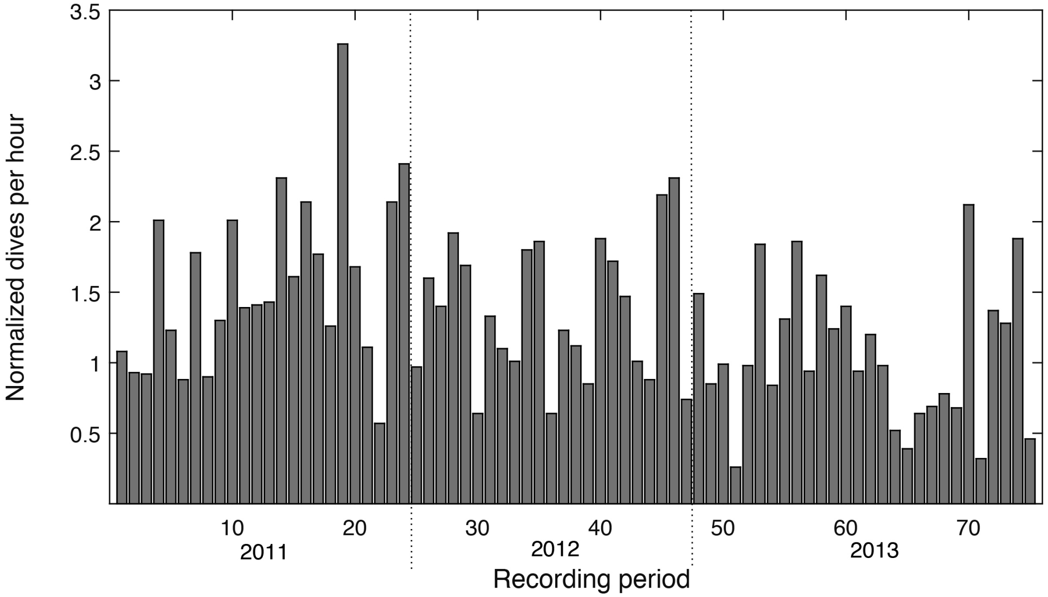

Figure 2. The number of Blainville's beaked whale (*Mesoplodon densirostris*) dives per recording period on 31 hydrophones, normalized by the recording effort per period

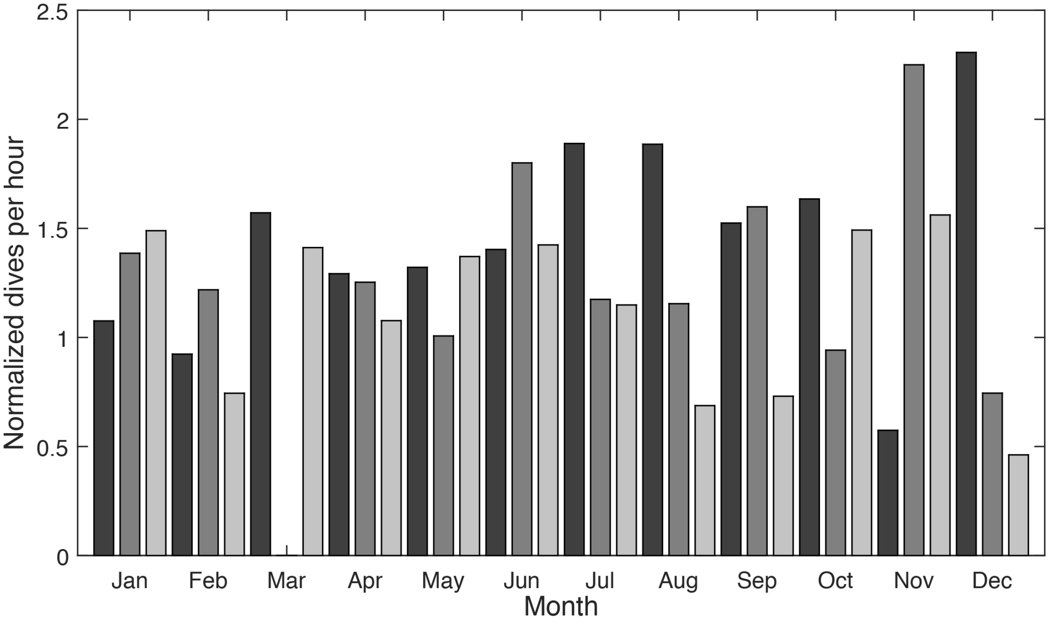

Figure 3. The number of Blainville's beaked whale dives at PMRF, normalized by recording effort to dives per hour per month in 2011 (dark grey), 2012 (medium grey), and 2013 (light grey) detected on 31 hydrophones

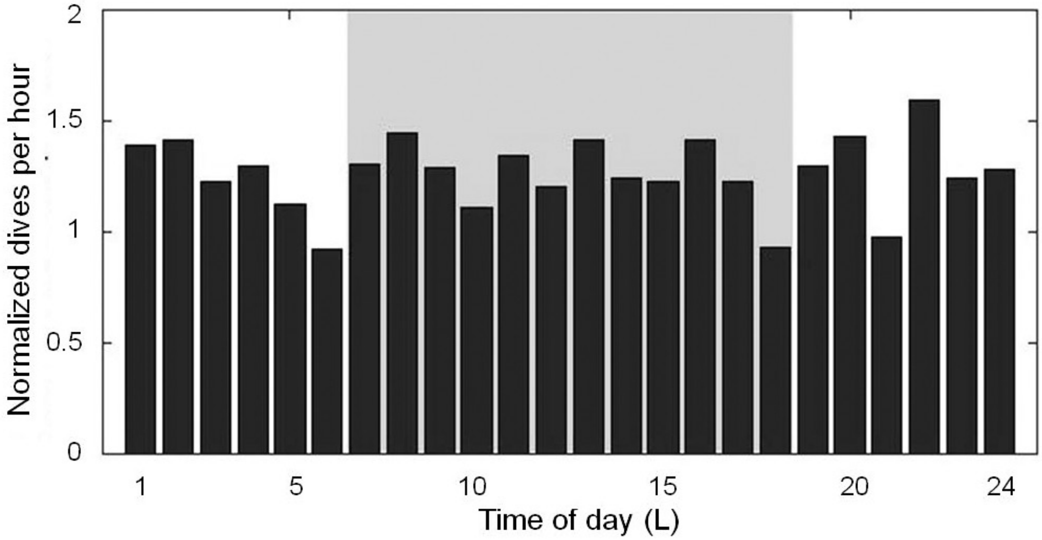

Figure 4. The number of Blainville's beaked whale dives per hour from 31 hydrophones recorded at PMRF, normalized by the number of hours recorded; the grey background indicates daylight hours.

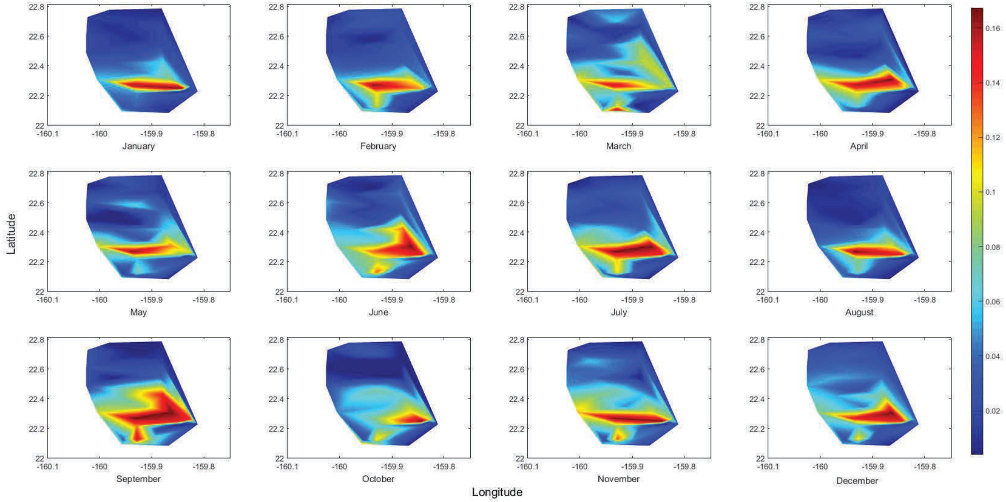

Figure 5. Map of Blainville's beaked whale dive locations across PMRF for each month, combined across all years and normalized by the monthly recording effort

also strongly negatively correlated (Rho = -0.58, $p < 0.001$).

Spatio-Temporal Habitat Model

GAMs were developed using a binomial distribution with a logit link. Temporal variables of Year, Month, and Start Hour, and spatial variables of Depth and Slope were included initially. Due to the strong interaction between Depth and Slope, these terms were included one at a time. This initial model included Start Hour and Depth (Figure 6a), smoothed using a cubic regression spline with

Table 2. Generalized Additive Model (GAM) results describing Blainville's beaked whale spatio-temporal habitat use; REML = restricted maximum likelihood.

Model	Predictor variables	*p* value	REML score	Explained deviance	Smoother SD
1	Start Hour	0.07	119.3	11%	0.16
	Depth	0.02			0.0001
2	Depth	0.02	106	25.3%	0.0001
	Lunar Cycle/Start Hour	0.03			30.26, 4.4

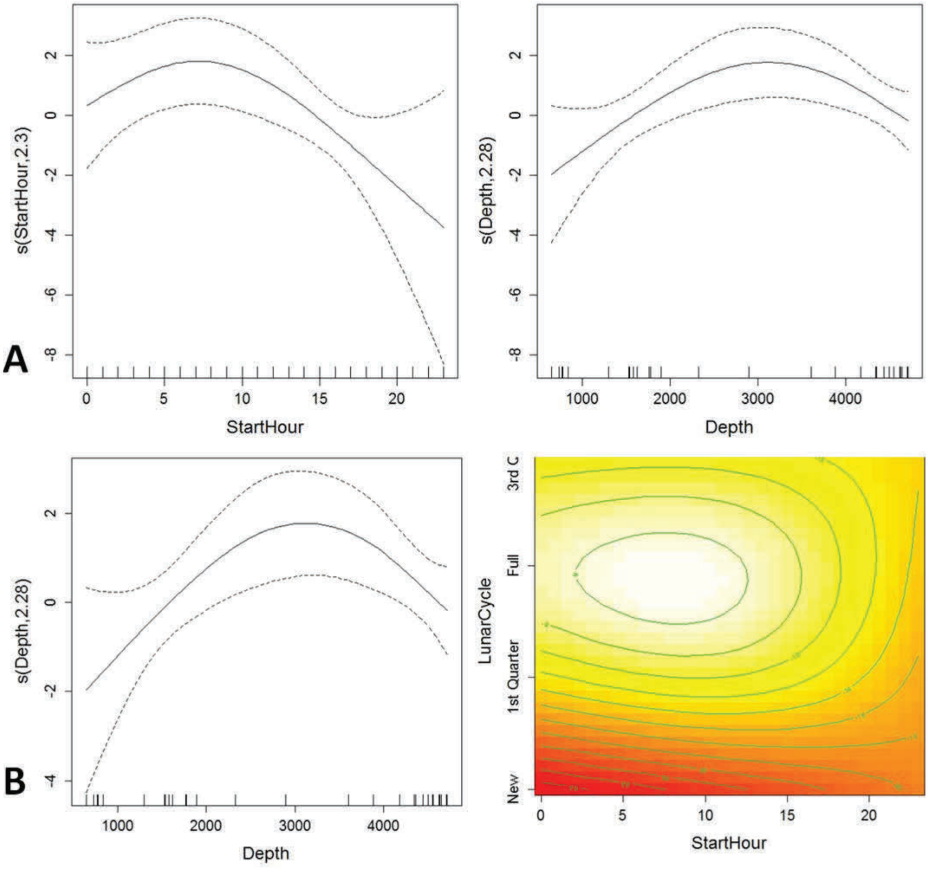

Figure 6. Predictor variables from the Generalized Additive Models (GAMs) of Blainville's beaked whale habitat use at PMRF, including (A) Start Hour and Depth and (B) Depth and an interaction between Start Hour and Lunar Cycle

shrinkage. The REML score was 119.3, and the deviance explained was only 11% (Table 2).

The diel pattern resulting from the model differs from that observed in the normalized GVP per hour data. In the model, GVPs occur most often in the first half of the day, peaking in the morning and then decreasing in the afternoon. The variance becomes very wide for the night-time GVPs, such that although the majority of GVPs continue to decrease, there is broad variability in that pattern. To explore this further, Lunar Cycle data were added to the model, both as a separate variable and as an interaction term with Start Hour using a tensor product smooth. In this case, the final

Table 3. Hours of training and testing activities at PMRF that could involve active sonar or explosive sounds for a portion of the activity from 2011 through 2013

Month	2011	2012	2013
January	36.5	69	43.5
February	217	167.5	194.5
March	116.5	35	45
April	82.5	48.5	26
May	27	38	40
June	44	47	87
July	38	99.5	51
August	180.5	227.5	207.4
September	37	54.5	43.5
October	62.5	98.5	70.5
November	58	63	90
December	20	24	51
Total	919.5	972	949.4

model that maximizes the REML score included Depth and the Start Hour/Lunar Cycle interaction term, with a decreased REML score but an increase in explained deviance to 25.3% (Table 2; Figure 6b).

Impact of Sonar Activity

The hours of training and testing activities that could involve active sonar or explosive sounds for some portion of the activity at PMRF were summed for each month (Table 3) and were plotted against the normalized number of GVPs per month (Figure 7). When a Spearman's rank test was used to determine if a correlation existed between the number of normalized GVPs and the hours of training activity on a monthly basis across each year, no correlation was found (Table 4). When data from all years combined were tested, there was still no significant correlation, although the months of February and August started to drive the signal (Figure 7).

This pattern held true when looking at any training activity in the week before an acoustic recording period (Table 4). In 2011 and 2012, there was still no correlation between the number of training hours normalized by the number of days of training and the number of GVPs per hour, even when a time lag factor was included to give increased weighting to training that may have occurred directly before a recording period. In 2013, the correlation becomes significant when the time lag was included, and this significance continued when all data were combined. However, this again was driven by the high number of training hours in February and August. When those were removed from the data, the correlation was no longer significant. This indicates that for most of the training conducted at PMRF that may include active sonar or explosive sounds, there was no subsequent decrease in Blainville's beaked whale foraging dives. Since the impact of those extended training events in February and August has already been examined in detail for Blainville's beaked whales (Manzano-Roth et al., 2016), it lies outside of the scope of this paper.

Discussion

Blainville's beaked whales were acoustically detected performing deep foraging dives year-round at PMRF, with a strong preference for steep slopes and depths from 2,000 to 3,000 m. While there was intra-annual variability in the number of GVPs detected per month, there was no clear seasonal trend, nor was there an inter-annual trend. Without knowledge of this inter-annual variability, some of the large differences in GVPs might mistakenly be attributed to Navy activity, highlighting the importance of understanding natural variation in habitat use when estimating noise impacts. Passive acoustic monitoring efforts have continued through to the present time. Ongoing analyses will help determine the longer-term trend in GVP rates of Blainville's beaked whales at PMRF.

The habitat use patterns observed for Blainville's beaked whales at PMRF are similar to those observed for populations of beaked whales in other

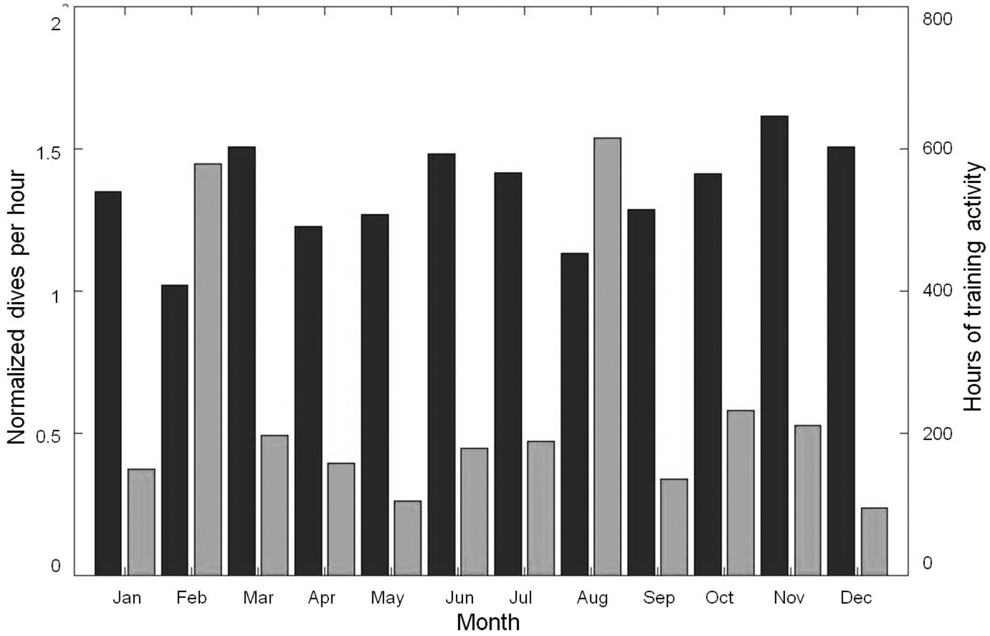

Figure 7. Dives per hour (in dark grey, on the left y-axis) plotted with the number of hours of training activity at PMRF that may involve active sonar or explosive sounds (in light grey, on the right y-axis)

locations, with most dives occurring at depth and slope values of 2,342 m and 15%, respectively. This population is found in deeper water than in the Bahamas where animals were always found in depths between 100 and 1,300 m, with a mean of around 500 m (MacLeod & Zuur, 2005; Claridge, 2006; Hazen et al., 2011). The PMRF population is also found in deeper waters than the population off the west coast of Hawaii Island, which was typically observed in waters between 250 and 2,000 m deep (Schorr et al., 2009; Abecassis et al., 2015). However, it should be noted that while the maximum water depths vary across these locations, the beaked whales are likely foraging at similar depths. Slope is also an important bathymetric feature for this species. All three populations, including the animals presented herein, were associated with slopes between 6 and 23% (MacLeod & Zuur, 2005; Claridge, 2006; Schorr et al., 2009).

Habitat modeling indicated that the region off Hawaii Island most regularly utilized by Blainville's beaked whales is characterized by upwelling and weak surface currents, where local circulation patterns would accumulate prey (Abecassis et al., 2015). Blainville's beaked whale distributions were also determined to overlap with the depth region of high micronekton density in the scattering layer (Dalebout et al., 2014). Hazen et al. (2011) also found Blainville's beaked whale foraging dives in the Tongue of the Ocean to occur in areas of the highest scattering layer densities. MacLeod et al. (2003) found cephalopod, demersal, and deepwater fish remains in the stomach contents of *Mesoplodon* whales, and a stranded beaked whale in Hawaii had equal parts fish and squid in its stomach (Abecassis et al., 2015). Primary and secondary production is often retained or enhanced at seamounts and regions of steep slopes due to physical processes, including currents, upwelling, and reduced sedimentation (Boehlert & Genin, 1987; Pitcher & Bulman, 2007). The entrained or increased producers attract predators, including demersal and mid-water fish, cephalopods, sharks, sea turtles, and marine mammals (Pitcher et al., 2008). No prey data or proxy data such as temperature or salinity were included in the models presented herein, limiting their efficacy in predicting Blainville's beaked whale foraging patterns. While temporal and spatial patterns are also important to the distribution of Blainville's beaked whales, they are likely responding directly to the behavior of their prey; therefore, without data on the prey themselves, any habitat model will be limited. Future efforts at incorporating oceanographic and prey metrics into a model are planned.

Although no prey data were included in the model, the lunar phase proved to be an important predictor variable, likely linked to the behavior of squid and other scattering layer organisms

Table 4. Correlation test results of the number of dives per month against the hours of training activity per month at PMRF, tested for each year and all data totaled, and of the training activity per hour in the week prior to a recording period against the number of Blainville's beaked whale dives per hour in that recording period, tested with and without a time lag for each year and tested with and without the months of February and August for all data. Significant *p* values are highlighted in bold.

Test	Statistic	2011	2012	2013	All years
Monthly	Rho	-0.2	0.01	0	
	p value	0.54	0.99	1	
All data by month (with Feb and Aug)	Rho				-0.5
	p value				0.1
All data by month (without Feb and Aug)	Rho				-0.15
	p value				0.68
Single recording (no time lag)	Rho	-0.15	-0.09	-0.34	
	p value	0.5	0.67	0.08	
Single recording (with time lag)	Rho	-0.13	-0.21	-47	
	p value	0.53	0.34	**0.01**	
Combined single recording data (with Feb and Aug)	Rho				-0.29
	p value				**0.01**
Combined single recording data (without Feb and Aug)	Rho				-0.14
	p value				0.27

remaining in deeper water during full moon periods (e.g., Gilly et al., 2006; Benoit-Bird et al., 2009). Blainville's beaked whales at PMRF, much like other *Mesoplodon* and *Ziphius* beaked whales, are likely utilizing the steep slope habitat to forage throughout the day and night, but may increase their night-time diving during the full moon when more prey is available at depth. Blainville's and Cuvier's beaked whales off the island of Hawaii (Baird et al., 2008) and Blainville's beaked whales in the Bahamas (Hazen et al., 2011) did not show any diel periodicity to their deep foraging dives, although lunar phase was not included in those studies. However, in a recent analysis of dive depths from Blainville's beaked whale tag data compared to the fraction of moonlight illumination, Baird (pers. comm., 2016) found a positive relationship ($r^2 = 0.37$) between the variables, indicating dives were deeper with increased moonlight. This provides further support to the hypothesis that Blainville's beaked whale prey may remain at depth during full moon phases, and Blainville's beaked whales may increase their night-time dives as a result. In addition, although there was no diel pattern in foraging dive behavior, Blainville's beaked whale dives did occur in slightly more shallow, nearshore waters at night than during the day off the island of Hawaii. This indicates they were likely tracking the mesopelagic boundary community found in the Hawaiian islands that migrates both horizontally and vertically (Benoit-Bird et al., 2001; Benoit-Bird & Au, 2004, 2006; Abecassis et al., 2015). Spinner dolphins (*Stenella longirostris*) have been shown to track this migration while foraging at night (Benoit-Bird & Au, 2003), and short-finned pilot whales (*Globicephala macrorhynchus*) appear to do so as well (Abecassis et al., 2015).

The training events that occur every February and August at PMRF have been shown to impact Blainville's beaked whale foraging behavior and spatial occurrence (Manzano-Roth et al., 2016).

Blainville's beaked whales at AUTEC in the Bahamas have also been shown to reduce their foraging dives during periods of active sonar. These whales may be leaving the ranges during active sonar periods and returning shortly thereafter as was demonstrated by one tagged whale during a sonar playback study (Tyack et al., 2011). This pattern can also be observed in the spatial distribution of GVPs across the range each month. In February and August, the GVPs are more clearly compressed to the southern portion of the range; while in almost every other month of the year, they occur more broadly across the range. While the majority of Blainville's beaked whale foraging dives occurred within 32 km of Kauai, there were GVPs detected throughout the range, even on the northernmost hydrophones in depths over 4,500 m.

This broad distribution of GVPs, coupled with a lack of correlation in GVP counts relative to smaller training events, seems to support the idea that the ongoing smaller scale events seem to have little to no impact on foraging dives, at least on the sampling scales analyzed herein. Cuvier's beaked whales in southern California have been photo-identified and tagged using both acoustic recording tags (e.g., DTAG) and satellite time-depth recording tags (e.g., SPLASH10 LIMPET tag) (Baird et al., 2004, 2006b; Schorr et al., 2014). Photo-identification work has demonstrated the potential for a resident population of Cuvier's beaked whales to inhabit San Nicholas Basin and adjacent waters (Falcone et al., 2009), similar to the resident populations of Blainville's beaked whales in the Bahamas on and near AUTEC (MacLeod & Zuur, 2005; Claridge, 2006). The San Nicholas Basin includes much of the Southern California Offshore Range (SCORE) and is also an area frequently used for U.S. Navy active sonar testing and training. While the tagged Cuvier's beaked whales moved throughout the Southern California Bight, they spent 36% of their time within the bounds of the range (Schorr et al., 2014). Some of the longest and deepest dives on record were recorded for Cuvier's beaked whales in this region. Although these dives could have occurred as a response to active sonar activity, the tags at the time were not acoustic, so no direct connection could be made (Schorr et al., 2014; Tyack et al., 2015). It may be that some populations of beaked whales habituate to active sonar and other acoustic activity, particularly those resident to range areas, and the beaked whales at PMRF could be one of those populations. Alternatively, Blainville's beaked whales off Kauai may be part of an open-ocean population (Baird et al., 2011; Baird, 2016) as suggested by the deeper depths that they are found at compared to the resident population off Hawaii Island (Abecassis et al., 2015), as well as their high variability in presence on the range (Figure 2).

The population of Cuvier's beaked whales in the Southern California Bight, along with a few Baird's beaked whales also in the area, have been the subject of an ongoing Behavioral Response Study (BRS) in which these and other cetacean species have been exposed to both simulated and real Navy active sonars after being tagged, with the goal of capturing individual behavioral responses (DeRuiter et al., 2013; Stimpert et al., 2014). Similar BRS efforts have been conducted on northern bottlenose whales in Norway (Miller et al., 2015) and on Blainville's beaked whales at AUTEC (McCarthy et al., 2011; Tyack et al., 2011). All of these studies have found beaked whales to respond to simulated and real Navy sonars at relatively low received levels (e.g., 95 to 142 dB re 1 μPa); however, in all cases, there were additional contextual factors that could have contributed to a behavioral response, including tagging the whale prior to exposure, the presence of multiple vessels, and the presence of the source within a few km of the animal. A few incidental exposures of more distant Navy sonar at similar received levels also occurred at SCORE, and no behavioral responses were detected during those exposures (DeRuiter et al., 2013; Southall, pers. comm., 2015). While beaked whales may perceive and respond to a sonar signal in a similar manner as they would a predator (Tyack et al., 2011; Curé et al., 2015), other cues such as distance to and movement of the sound source may play a role equal to or greater than the received level of the signal.

Monitoring marine mammals during real Navy training events creates opportunistic "real-world" behavioral response study, albeit without the control over many variables that can be maintained during a playback study. Nevertheless, monitoring efforts at PMRF, both during baseline periods as described herein as well as before, during, and after U.S. Navy training events (e.g., Manzano-Roth et al., 2016), are essential for understanding marine mammal responses to noise impacts and provide a low-cost, information-rich supplement to large-scale BRS efforts. By conducting this kind of opportunistic BRS, the responses of numerous individual calling animals or cohesive groups can be correlated with received levels from and distances to sound sources, and tagged animals could be tracked even when not vocalizing (e.g., Tyack et al., 2011; Baird et al., 2014). The behavior during training events can be compared against baseline behavior when no activities are occurring to better understand the observed responses; and over many years of monitoring, the long-term consequences of these repeated activities can be estimated.

In conclusion, Blainville's beaked whales regularly conduct foraging dives across the extent of the PMRF hydrophone range, with most GVPs occurring in depths between 2,000 and 3,000 km and along steep slopes. There is no annual or seasonal pattern to the GVPs, but there is a diel pattern, with more GVPs occurring at night during full moon phases. Other than the two major training events in February and August, the routine training that occurs on the range throughout the year that may include active sonar or explosive sounds did not appear to impact the number of foraging dives on the range. Continued monitoring and more detailed analyses of the smaller training events are needed to assess impacts on shorter (hours to days) and longer (years) time frames, and to look for any potential long-term or population-level consequences.

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