Marine Mammal Monitoring on Navy Ranges (M3R) on the Southern California Anti-Submarine Warfare Range (SOAR) and the Pacific Missile Range Facility (PMRF) 2018

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14. ABSTRACT

Cuvier's beaked whale (Ziphius cavirostris) abundance estimates have been obtained at the U.S. Navy's Southern California Anti-Submarine Warfare Range (SOAR) for the period from August 2010 through November 2018. Data for December, 2018 through January, 2019 are currently being processed. The data were corrected for effort and spatial variation by applying correction factors as in DiMarzio et al [1].

Since 2010 the Cuvier's beaked whale abundance at SOAR appears to be stable or slightly increasing. Seasonally the mean Cuvier's beaked whale abundance peaks in January with a second peak in May, and it reaches its lowest point in September, with a smaller dip in March. The mean number of Cuvier's beaked whale dive starts per hour, mean group vocal period (GVP) length, and mean number of clicks detected per group were also examined, and they exhibited a similar seasonal pattern. The mean monthly number of Cuvier's beaked whale dive starts per hour at SOAR varies from 1.07 to 2.96; the mean monthly GVP varies from 36.27 min to 42.39 min; and the mean monthly number of foraging clicks detected per group varies from 2259 to 3549. Spatial distribution of Cuvier's beaked whales was also examined, and indicates most groups are detected in the western portion of the range, where there are deeper waters. This is consistent with Cuvier's beaked whale sighting data from MarEcoTel [2]. The effect of mid-frequency active sonar (MFAS) was also analyzed before, during, and after MFAS operations on range. GVP activity decreased in response to events involving high-power and mid-power sonar, with stronger decreases in GVPs during high-power sonar events.

An extended archive has been processed for the Pacific Missile Range Facility (PMRF) from February 2017 through April 2018. A disk containing archives from April, 2018 through January, 2019 is currently being processed. Data recordings prior to 2017 had been restricted to periods (days to weeks) around biannual tests.

Blainville's beaked whale (Mesoplodon densirostris) abundance estimates at PMRF have been derived from these data, and abundance values from 2015 to 2018 appear stable. Seasonally the abundance appears to peak in June and then in December, and is lowest in August and February, based on the data processed to date. The mean number of Blainville's beaked whale dive starts per hour, mean group vocal period (GVP) length, and mean number of clicks detected per group were also examined. The mean monthly number of Blainville's beaked whale dive starts per hour at PMRF varies from 0.78 to 2.0; the mean monthly GVP varies from 32.08 min to 37.75 min; and the mean monthly number of foraging clicks detected per group varies from 1288 to 1955. The effect of mid-frequency active sonar (MFAS) was also analyzed before, during, and after MFAS operations on range using the sonar detector output. In 13 of the 23 cases examined, the mean number of dive starts per hour was lower during the MFAS event than before or after; for the rest of the cases the mean number of dive starts during the three periods varied. Note, however, that this analysis did not verify the sonar detector output with manual review, and a daily time scale was used for detecting MFAS on range. Examining the presence of MFAS on a time scale of hours may provide better resolution on the effects of MFAS on the mean number of dive starts detected.

Passive acoustic monitoring support was provided to on-water teams who deployed tag and collected photo-IDs and biopsy samples at both SOAR and PMRF. The M3R system is monitored during field operations, and the on-water teams are directed to animals of interest. On SOAR the focus was on collecting photo-ID data and biopsy samples for Cuvier's beaked and fin whales. There were 35 sightings of about 88 Cuvier's beaked whales, with 23 individuals previously identified in SOCAL, and two biopsy samples collected. Nine biopsy samples were collected from fin whales, with 35 sightings of 53 whales. In addition, three Lander2 tags were deployed on Cuvier's beaked whales, and an MK10a tag was attached to a Baird's beaked whale and a Risso's dolphin [2].

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Acronyms

AUTEC	Atlantic Undersea Test and Evaluation Center
ASW	Anti-Submarine Warfare
BSURE	Barking Sands Underwater Range Expansion
CI	Confidence Interval
CREEM	Centre for Research into Ecological and Environmental Modelling
CS-SVM	Class-Specific Support Vector Machine classifier
CTP	Click Train Processor
CV	Coefficient of Variation
FFT	Fast Fourier Transform
FP	False Positive
ICI	Inter-Click Interval
kHz	kilohertz
LMR	Living Marine Resources
M3R	Marine Mammal Monitoring on Navy Ranges
MarEcoTel	Marine Ecology and Telemetry Research
PD	Probability of Detection
PMRF	Pacific Missile Range Facility
RL_{rms}	Received Level root mean squared
SOAR	Southern California Anti-Submarine Warfare Range
SWTR	Shallow Water Training Range

1.0 Executive Summary

Cuvier's beaked whale (*Ziphius cavirostris*) abundance estimates have been obtained at the U.S. Navy's Southern California Anti-Submarine Warfare Range (SOAR) for the period from August 2010 through November 2018. Data for December, 2018 through January, 2019 are currently being processed. The data were corrected for effort and spatial variation by applying correction factors as in DiMarzio et al [1].

Since 2010 the Cuvier's beaked whale abundance at SOAR appears to be stable or slightly increasing. Seasonally the mean Cuvier's beaked whale abundance peaks in January with a second peak in May, and it reaches its lowest point in September, with a smaller dip in March. The mean number of Cuvier's beaked whale dive starts per hour, mean group vocal period (GVP) length, and mean number of clicks detected per group were also examined, and they exhibited a similar seasonal pattern. The mean monthly number of Cuvier's beaked whale dive starts per hour at SOAR varies from 1.07 to 2.96; the mean monthly GVP varies from 36.27 min to 42.39 min; and the mean monthly number of foraging clicks detected per group varies from 2259 to 3549. Spatial distribution of Cuvier's beaked whales was also examined, and indicates most groups are detected in the western portion of the range, where there are deeper waters. This is consistent with Cuvier's beaked whale sighting data from MarEcoTel [2]. The effect of mid-frequency active sonar (MFAS) was also analyzed before, during, and after MFAS operations on range. GVP activity decreased in response to events involving high-power and mid-power sonar, with stronger decreases in GVPs during high-power sonar events.

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focus was on collecting photo-ID data and biopsy samples for Cuvier's beaked and fin whales. There were 35 sightings of about 88 Cuvier's beaked whales, with 23 individuals previously identified in SOCAL, and two biopsy samples collected. Nine biopsy samples were collected from fin whales, with 35 sightings of 53 whales. In addition, three Lander2 tags were deployed on Cuvier's beaked whales, and an MK10a tag was attached to a Baird's beaked whale and a Risso's dolphin [2].

2.0 SOAR Abundance & Distribution

2.1. SOAR Methods

2.1.1 SOAR Study Area

SOAR is located in the San Nicolas Basin west of San Clemente Island, CA. San Clemente Island is one of the Channel Islands in the southern California Bight. SOAR is an Anti-submarine Warfare (ASW) training range on which sound sources, including mid-frequency active sonar, are routinely used, and Cuvier's beaked whale are regularly detected acoustically and visually, displaying a high level of site fidelity to the area [3] [4] [5].

The SOAR range consists of an array of 178 bottom-mounted hydrophones covering an area of about 1800 km^2 (Figure 1).

The SOAR hydrophone baselines range from about 2.5 to 6.5 km, and are at average depths of 1600-1800 m. The original 88 hydrophones have a bandwidth of ~8 to 40 kHz, while the newer 89 hydrophones have a bandwidth of ~50 Hz to 48 kHz [6].

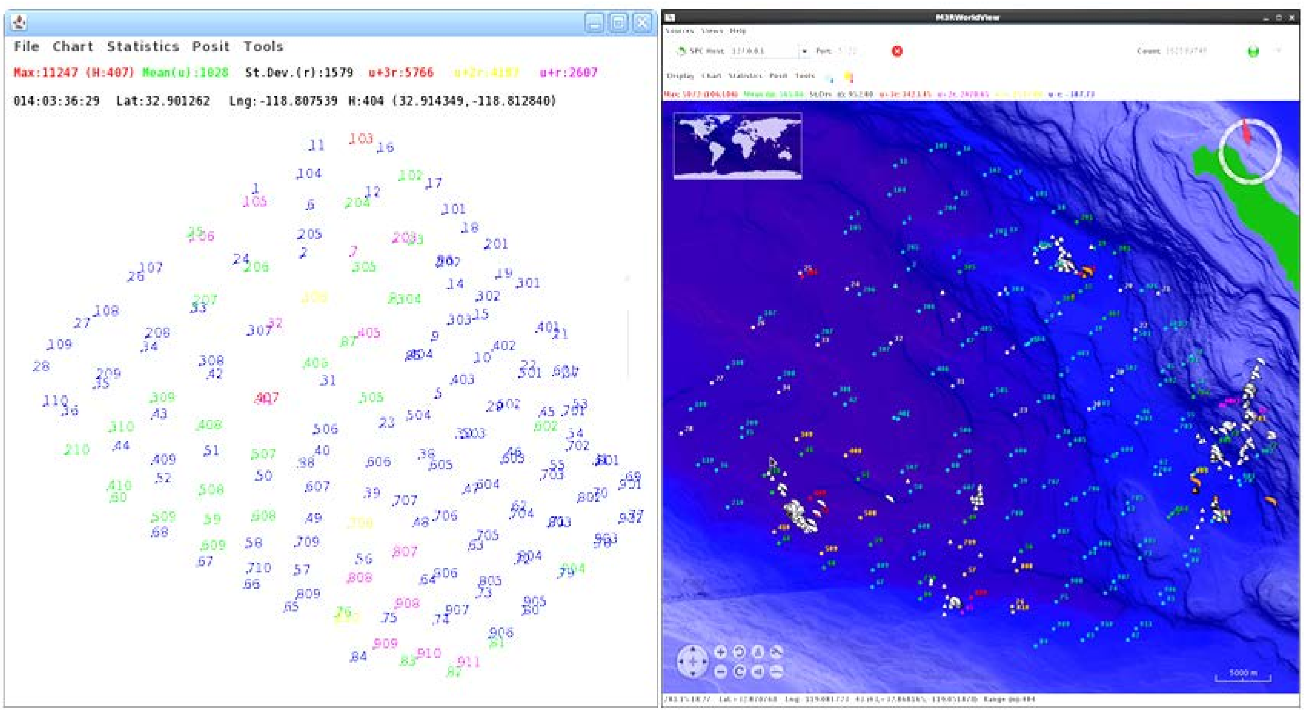

Figure 1. SOAR hydrophone range showing the M3R MMAMMAL display on the left and M3R World Wind display on right.

2.1.2 SOAR Data

In 2006 the Marine Mammal Monitoring on Navy Ranges (M3R) program installed a real-time passive acoustic system to automatically detect, classify and localize (DCL) marine mammals using the SOAR hydrophones. Unless the system is turned off for a particular operation, it continuously samples acoustic data from all range hydrophones simultaneously, runs DCL algorithms on the data, and archives the results. Binary archives of detection, classification, and localization data are usually collected continuously year-round, unless there is an operation with a classification that precludes it. At times the system was inadvertently not restarted or the hard disk was damaged, producing time periods without data. Raw acoustic recordings are collected periodically.

The system primarily uses two types of detectors: a Fast Fourier Transform (FFT)-based spectral energy detector (called 'Whdetect') and a class-specific support vector machine (CS-SVM) classifier.
FFT-based spectral energy detector- FFT-based detections (Whdetect) have been collected at SOAR since 2006. There are two versions of the FFT-based energy detector: full-bandwidth (0-48 kHz) and a low-frequency (0-3 kHz) version added in 2010. Each compares the bins of the FFT to the noise-varying background, sets each bin to '0' (below threshold) or '1' (above threshold), and outputs a detection report with a binary FFT.

The full-bandwidth FFT detector then separates the output into 'clicks' (if at least 10 bins are set to 1) or 'whistles' for further processing. Clicks are classified into types 1 through 5 by finding the frequency band with the most energy (Table 1).

Frequency Band (kHz)	Type	"Class"
45 - 48	1	high frequency
24 - 48	2	beaked whale
12 - 48	3	delphinid
1.5 - 18	4	sperm whale
0 - 1.5	5	low frequency

Table 1. Click types for the full-bandwidth FFT-based energy detector.

Class-specific support vector machine (CS-SVM) classifier- The CS-SVM classifier, installed in May 2010, provides robust real-time, automated detection and classification of clicks from several types of odontocetes [7] [8].

When initially installed at SOAR the CS-SVM had six classes, which included Blainville's beaked whale foraging clicks (*Mesoplodon densirostris)*, Cuvier's beaked whale foraging clicks (*Ziphius cavirostris*), pilot whale clicks (*Globicephala macrorhynchus)*, Risso's dolphin clicks (*Grampus griseus)*, sperm whale foraging clicks (*Physeter macrocephalus)*, and Pantropical spotted dolphin clicks (*Stenella attenuata)*.

Starting in May, 2014 the dolphin classes for pilot whale and Risso's dolphins were combined into a 'generalized dolphin' (GD) class (8); the Cuvier's beaked whale foraging buzz (52) class was added [8]; and Blainville's beaked whale and Pantropical spotted dolphin were removed, as they are not present on SOAR. Pilot whales and Risso's dolphins were combined into a 'generalized dolphin' category, as classification of delphinids to species level at SOAR was not considered sufficiently robust.

Therefore, CS-SVM at SOAR currently has four classes (Table 2). A detection report is generated for each CS-SVM detection. The Cuvier's beaked whale groups identified for the analysis in this report are generated from CS-SVM foraging click detections.

	Species/Family			
Class	**Class**	**Scientific Name**	**Common Name**	**Description**
2	*Zc*	*Ziphius cavirostris*	Cuvier's beaked whale	foraging click
52	*Zc*	*Ziphius cavirostris*	Cuvier's beaked whale	buzz click
5	*Pm*	*Physeter macrocephalus*	sperm whale	foraging click
8	GD	delphinidae	generalized dolphin	click

Table 2. CS-SVM classes at SOAR as of May 2014.

Table 3 shows the number of days per month on which archives with CS-SVM detections have been collected at SOAR between 2010 and 2018.

M3R SOAR Detection Archives												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2010					7			9	30	29	22	23
2011	22	27	8	3	13		6	28	30	31	22	31
2012	27	23	18	30	15	6	1	4		17	13	10
2013					17	30	24	31	30	6	2	12
2014	31	22	28	29	28	17	14	17	28	14	4	31
2015	31	28	24	25	31	15	22	21	15	30	15	11
2016	31	27	31	25	18	7	16	31	27		26	22
2017	15		13	17	2		11	31	24	17	29	27
2018	27	14	4	17	28	30	21	31	30	31	30	28+

Table 3. The number of days per month on which archives were collected at SOAR with the CS-SVM classifier.

The CS-SVM Cuvier's beaked whale foraging click classifier was installed in May, 2010 (blue) and the CS-SVM buzz click classifier was installed in July, 2014 (pink).

2.1.3 SOAR Cuvier's beaked whale Group Analysis

2.1.3.1 Formation of Cuvier's beaked whale groups

Software tools have been developed to automatically process the large amounts of M3R archive data and localize groups of diving Cuvier's beaked whales. Several steps are involved in automatically identifying these groups. Small groups of Cuvier's beaked whales appear to dive synchronously, typically vocalizing only below 400 m depth during deep foraging dives [9] [10]. The echolocation foraging clicks during deep foraging dives are first detected and classified as

Cuvier's beaked whale, then they are formed into click trains, and finally the clicks trains are associated into Cuvier's beaked whale groups.

For this analysis, only foraging clicks generated by the CS-SVM classifier were used. For each foraging click detection CS-SVM generates a detection report which includes a time stamp, the hydrophone, and a quality factor which indicates the strength of the classification.

A Java-based click train processor (CTP) program then forms the Cuvier's beaked whale click detections into click trains on a per hydrophone basis. A click train is initiated when a click is detected, and clicks are added to the click train until at least three minutes pass without detections. At this point if the click train has at least five clicks a click train report is generated; otherwise the click train is discarded. Click train reports include the hydrophone, the click train start and stop times, the total number of clicks in the click train, and the inter-click interval (ICI).

A Matlab-based Autogrouper (AG) program then uses a set of rules based on time and location of the click trains to associate the CTP click trains into individual groups of vocalizing Cuvier's beaked whales. Only click trains with ICI >= 0.35 sec and ICI <= 0.75 sec and with duration greater than 1 min and less than 60 min are used in the grouping process. Locations are based on the hydrophone locations, with the Cuvier's beaked whale group center being the hydrophone with the highest click density (number of clicks per min). To form a Cuvier's beaked whale group the click trains must be within 9.75 km of the group center and the duration of the Cuvier's beaked whale group vocal period must be less than one hour.

2.1.3.2 SOAR Autogrouper Detection Statistics

Detection statistics for the Autogrouper were derived by comparing the output to a manual review of a set of systematic random samples of the data. The Cuvier's beaked whale groups determined by manual review were considered "truth," and the probability of detection (PD), percent of false-negatives (FNs), and percent of false-positives (FPs) were calculated for the Autogrouper program, and applied to the data. Detection statistics were derived for both the case of all detected Cuvier's beaked whale groups, and for the case in which "edge-only" groups were removed (Table 4). The "edge-only" cases are those groups that only contain hydrophones on the edge of the range. These are removed as it is likely that the associated group occurs outside the range boundary. Details on the derivation can be found in [1].

AutoGrouper case	n	Probability of Detection (PD)	% False Negative (FN)	% False Positive (FP)
all groups	31	0.738	0.262	0.173
no edge only groups	31	0.759	0.241	0.185

Table 4. Autogrouper detection statistics for Cuvier's beaked whales on SOAR.

2.1.3.3 SOAR Autogrouper Correction Factors for Varying Spatial Coverage of the CS-SVM Detector

In the course of data analysis, it was found that CS-SVM, at different times, was not running on certain hydrophones. This could have occurred if the algorithm wasn't started, or if a hydrophone or computer node was not functioning properly. In addition, during some periods the CS-SVM was run solely on the newer hydrophones (100 through 900), while at other times it was run on both the newer hydrophones and the legacy hydrophones (< 100). In order to account for this, correction factors for both the missing hydrophones and for the additional legacy hydrophones were derived to apply to the data. The correction factors normalized the data to the baseline case, in which CS-SVM was running on all the newer hydrophones, but not on the legacy hydrophones [1].

2.1.4 SOAR Cuvier's beaked whale Abundance

Moretti, et al. in 2010 [11] described a passive acoustic method for determining Blainville's beaked whale density and abundance at the U.S. Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) using a dive counting method. This method uses the start of a deep foraging dive, as indicated by the first detected click, as the cue for determining density and abundance. As Blainville's and Cuvier's beaked whales have similar dive behavior, both consisting of small groups that conduct deep foraging dives synchronously, and producing echolocation clicks at depth [9], a modified version of this method has been applied to derive Cuvier's beaked whale abundance on the SOAR range.

The equation for animal abundance (N) presented by Moretti, et al. in 2010 [11] was:

Equation 1: $N = n_d\, s \,/\, r_d\, T$

where:

n_d = total number of dive starts
s = average group size
r_d = dive rate (dives/unit time)
T = time period over which the measurement was made

For the Moretti et al. estimate, data were obtained over a relatively short time period, approximately six days around a multi-ship sonar exercise, and the data were manually reviewed. It was therefore assumed that the probability of detection was 1, and that there were no false positives. However, at SOAR there is a much higher density of marine mammals, and in particular delphinids, than at AUTEC. Also, this analysis is conducted over long time periods (years) with automated tools, as opposed to the manual analysis carried out at AUTEC; thus the abundance equation is modified to account for both the probability of detection (PD) and the proportion of false positives (FP).

The equation used for abundance in this analysis is:

Equation 2: $N = n_d\, s\, (1 - c) \,/\, r_d\, T\, P_D$

where:

n_d = total number of dive starts
s = average group size
r_d = dive rate (dives/unit time)
T = time period over which the measurement was made
c = proportion of false positives
P_D = probability of detection

Cuvier's beaked whale abundance was calculated at SOAR between 2010 and 2018 with all groups except those detected only on edge hydrophones, and the abundance equation 2 above.

The following values were used: average group size (s) of 3.18 (Coefficient of Variation (CV)=0.62) (E. Falcone, pers. comm., December 06, 2017); dive rate (r_d) of 0.3 (CV=0.17), from Schorr et al. 2014 [5], proportion of false positives (c) of 0.185 (CV=0.32), probability of detection (P_D) of 0.76 (CV=0.05), and the total corrected number of dive starts (n_d) and total hours of effort (T) values.

2.2 SOAR Results

2.2.1 SOAR Overview

SOAR archives were analyzed from August 2010 through November 2018. A total of 43,962 hours of data were processed, with the number of hours per year varying from a low of 2402 hours in 2010 to a high of 6666 hours in 2018 (Table 5).

Total Number of Hours of Effort - SOAR								
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
2402	4983	3472	3565	5976	6010	6296	4591	6666

Table 5. Total number of hours of effort per year in which data was recorded at SOAR.

Figure 2 and Figure 3 show, for the years 2010 to 2013 and 2014 to 2018, respectively, the length of the dive start Group Vocal Periods (GVP) (in min) plotted on the y-axis against the time of the year. The GVP lengths are the total number of minutes that a group is vocally active during a deep foraging dive. Effort start and stop periods, determined by finding gaps in effort greater than 24 hours, are shown as green and red vertical lines, respectively.

The number of Cuvier's beaked whale dive starts per hour of effort, total number of Cuvier's beaked whale clicks detected per group per hour of effort, the length of the Cuvier's beaked whale group vocal periods (GVPs) (in min), and Cuvier's beaked whale abundance were analyzed after cases of 'edge-only' groups were removed. 'Edge-only' groups are those that are only detected on hydrophones on the edge of the range. They are removed on the assumption these are groups located off the range.

The GVP is the total length of time, in minutes, that a Cuvier's beaked whale group is vocally active during a deep foraging dive; thus it covers the time period from the first detected clicks from any group member to the final detected clicks from the group. The number of clicks per group and length of the GVPs were examined to investigate the vocal behavior of Cuvier's beaked whale groups on the range, as opposed to being used as proxies for abundance. The number of clicks detected per group and length of the GVPs could indicate group size and the variability of click rates if combined with visual sighting data of Cuvier's beaked whales at SOAR from MarEcoTel.

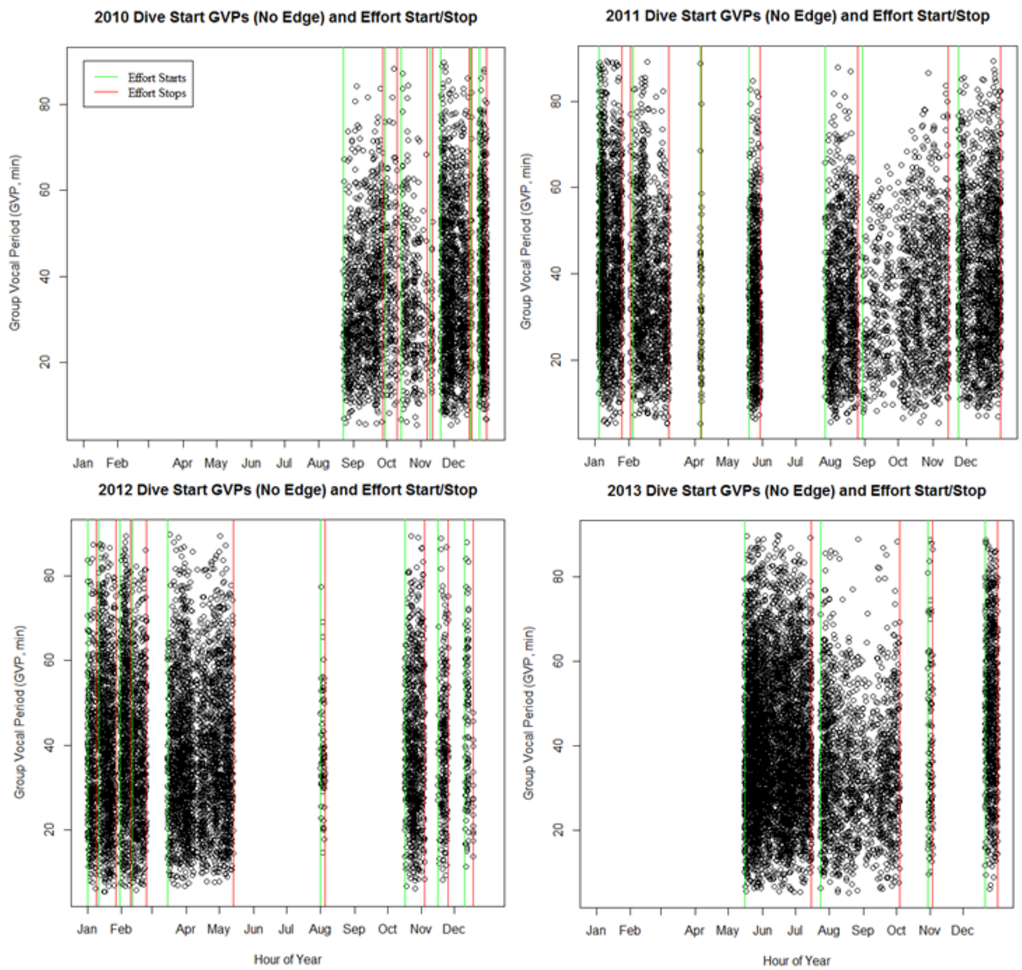

Figure 2. Dive start GVP lengths (in min) for the years 2010 to 2013, along with effort start (green) and effort stop (red) times indicated with vertical lines.

Effort start and stop times calculated by finding gaps in effort greater than 24 hours.

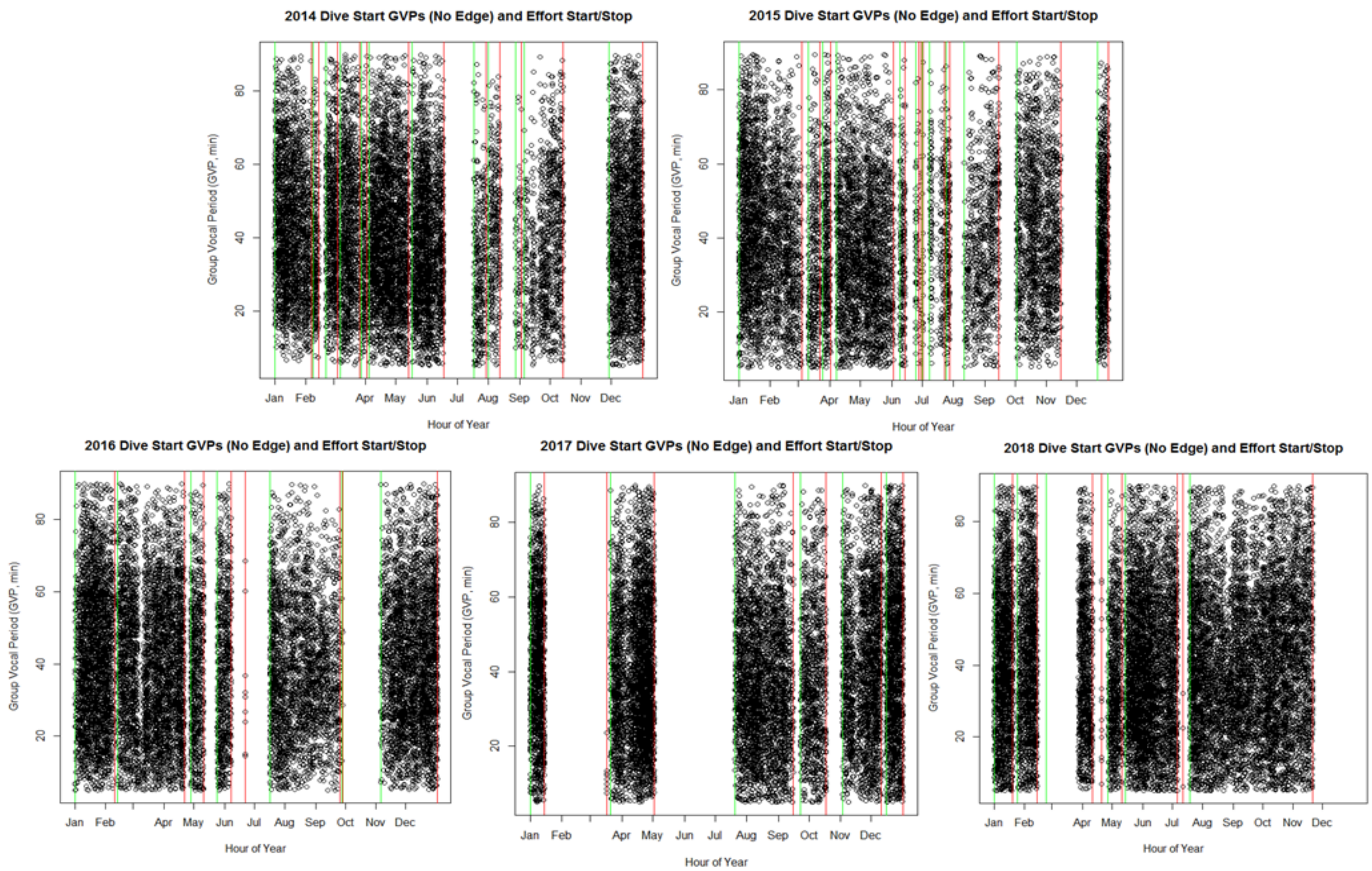

Figure 3. Dive start GVP lengths (in min) for the years 2014 to 2018, along with effort start (green) and effort stop (red) times indicated with vertical lines.

Effort start and stop times calculated by finding gaps in effort greater than 24 hours.

2.2.2 SOAR Cuvier's Beaked Whale Abundance

2.2.2.1 SOAR Cuvier's Beaked Whale Monthly Abundance

Table 6 shows the total number of Cuvier's beaked whale dive starts (n_d) detected per month at SOAR for the years 2010 to 2018, and Table 7 indicates the total measurement time period per month, or the total number of hours of effort per month (T), for the years 2010 to 2018. These values are used in the abundance equation 2 in section 2.4 to calculate Cuvier's beaked whale monthly abundance at SOAR. The NA's indicate periods in which data was not collected.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	229.2	760.2	505.0	975.7	1271.9
2011	1679.5	1148.4	361.4	75.8	782.9	0.0	167.2	1276.6	236.0	625.5	639.4	1441.1
2012	1734.3	1543.3	1376.4	1577.5	759.0	0.0	15.4	60.1	0.0	731.0	340.0	145.7
2013	NA	NA	NA	NA	1834.4	2193.0	1197.0	651.0	542.0	126.0	61.0	746.0
2014	1924.0	990.0	1593.0	1950.0	1894.0	1017.0	343.0	427.4	578.6	438.0	134.0	1951.0
2015	1813.0	1009.0	851.0	1165.0	1394.0	386.4	475.0	413.0	390.0	1171.0	570.5	916.9
2016	2425.6	1584.1	1561.0	1534.0	911.0	295.0	833.0	1101.0	661.0	0.0	1226.0	1844.4
2017	1131.2	0.0	598.8	2108.8	85.2	0.0	557.6	1445.0	809.8	555.9	1127.8	1974.7
2018	1852.4	938.0	294.4	796.3	1872.6	1795.0	1191.1	1239.2	1275.4	1473.7	820.8	NA

Table 6. Total number of dive starts (n_d) per month for 2010-2018 at SOAR.

NA's indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	N/A	N/A	N/A	N/A	N/A	N/A	N/A	210.9	629.3	623.2	473.3	465.3
2011	477.4	596.5	180.2	27.4	237.4	N/A	122.5	629.4	720.0	744.0	504.5	743.9
2012	589.9	517.8	433.5	720.0	283.2	N/A	23.8	67.3	N/A	390.3	254.8	191.6
2013	N/A	N/A	N/A	N/A	391.6	720.0	553.4	743.8	720.0	125.1	46.1	265.1
2014	743.3	482.0	615.3	665.8	643.2	395.9	295.1	375.7	647.5	318.1	50.0	743.9
2015	743.9	671.8	485.5	568.8	744.0	223.5	456.8	488.4	338.3	702.6	342.9	243.5
2016	721.6	622.6	744.0	567.1	409.9	141.8	392.1	744.0	586.1	0.0	626.6	740.7
2017	333.6	0.0	271.5	699.0	36.0	0.0	270.7	744.0	547.1	403.3	663.7	622.4
2018	622.5	446.5	744.0	350.5	650.1	720.0	446.2	744.0	720.0	744.0	478.0	N/A

Table 7. Total measurement time period per month, or total number of hours of effort per month (T), for years 2010-2018.

NAs indicate periods without data.

Abundance values were generated using numbers of dive starts corrected for varying spatial coverage of the CS-SVM detector (section 2.1.3.3). Confidence intervals, displayed in the following plots with dotted gray lines, were derived using the delta method as described in Moretti et al. (2010) [11].

The corrected mean monthly abundances of Cuvier's beaked whales at SOAR averaged from 2010 through 2018, along with confidence intervals (CIs) calculated using a CV of 0.71, are presented in Table 8 and shown in Figure 4. The CV of 0.71 was calculated using the delta method, which takes the square root of the sum of the squared CVs of: the average group size (CV=0.62), the proportion of false positives (c) (CV=0.32), the probability of detection (P_D) (0.05), and average dive rate (CV=0.17). The CVs of P_D and c were calculated using a bootstrap method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	59.18	42.67	39.68	50.04	56.03	46.55	32.30	25.94	21.28	26.69	34.08	49.55
mean abundance	34.45	24.84	23.10	29.13	32.61	27.10	18.80	15.10	12.39	15.54	19.84	28.85
lower CI	9.72	7.01	6.52	8.22	9.20	7.64	5.30	4.26	3.49	4.38	5.59	8.14

Table 8. Mean monthly Cuvier's beaked whale abundances at SOAR averaged 2010-2018.

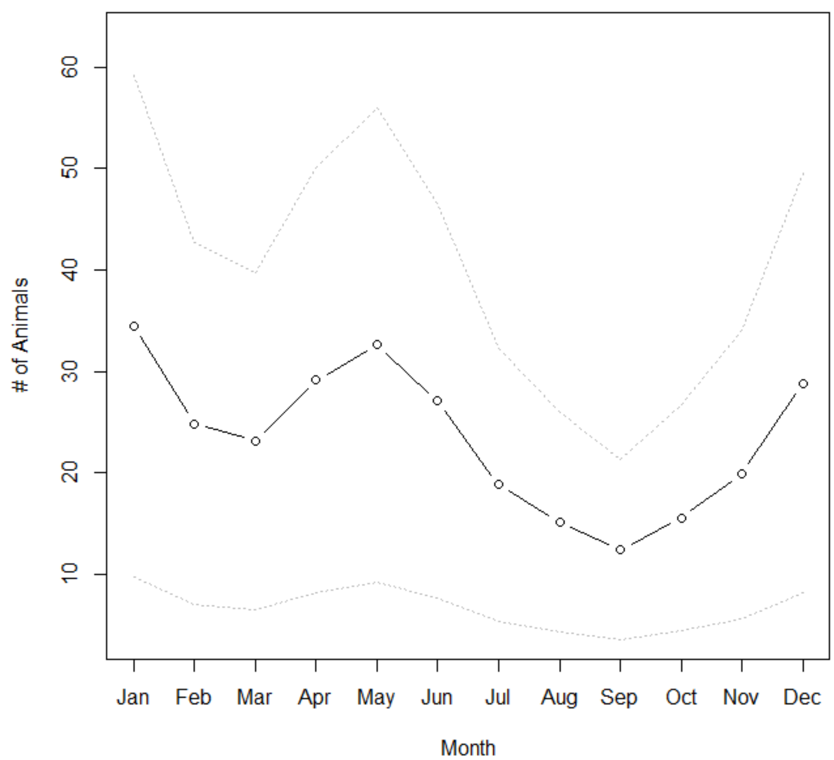

Figure 4. Mean monthly Cuvier's beaked whale abundance at SOAR averaged between 2010 and 2018.

The values are corrected for varying spatial coverage of the CS-SVM detector (section 2.1.3.3). Dashed lines indicate 95% confidence intervals.

The mean monthly Cuvier's beaked whale abundance for 2010 to 2018 peaks in January at 34.45 animals, followed by a peak in May of 32.61 animals. The abundance is lowest in September at 12.39 animals, with another smaller drop in abundance in March with 23.10.

The drop in abundance in September is consistent with observations first reported from off range Navy funded passive acoustic monitoring for beaked whales [Simone Bauman-Pickering (personal communication 2017), Rice et al. (2018) [12]].

The monthly Cuvier's beaked whale abundance values for each year from 2010 to 2018 are shown in Figure 5 and Table 9.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	12.35	13.74	9.21	23.44	31.08
2011	40.00	21.89	22.81	31.50	37.49	NA	15.51	23.06	3.73	9.56	14.41	22.02
2012	33.42	33.89	36.10	24.91	30.47	NA	7.34	10.16	NA	21.29	15.17	8.65
2013	NA	NA	NA	NA	53.26	34.63	24.59	9.95	8.56	11.45	15.04	32.00
2014	29.43	23.35	29.44	33.30	33.48	29.20	13.22	12.94	10.16	15.66	30.47	29.82
2015	27.71	17.08	19.93	23.29	21.30	19.65	11.82	9.61	13.11	18.95	18.92	42.81
2016	38.22	28.93	23.85	30.75	25.27	23.66	24.15	16.82	12.82	NA	22.25	28.31
2017	38.55	NA	25.07	34.30	26.89	NA	23.42	22.08	16.83	15.67	19.32	36.07
2018	33.83	23.88	4.50	25.83	32.75	28.35	30.35	18.94	20.14	22.52	19.52	NA

Table 9. Monthly SOAR Cuvier's beaked whale abundances 2010 - 2018.

NAs indicate periods without data.

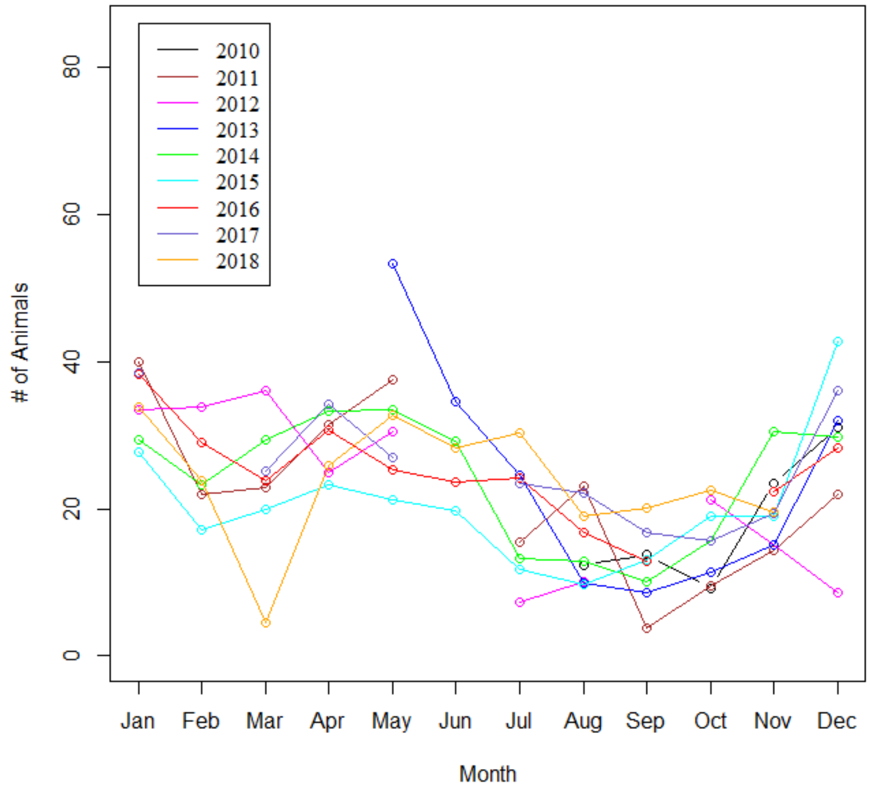

Figure 5. Corrected monthly Cuvier's beaked whale abundance at SOAR from 2010-2018.

2.2.2.2 SOAR Yearly Cuvier's Beaked Whale Abundance Trends

Because there is a seasonal change in Cuvier's beaked whale abundance, the yearly trends were investigated by looking at a given month in which there was comparable effort over the years being analyzed. Four months were examined: May, July, August and December (Table 10, Figure 6). Each of these months has data available for eight or nine of the nine years between 2010 and 2018.

In general, the overall trend in Cuvier's beaked whale abundance on SOAR appears to be stable or increasing slightly from 2010 to 2018.

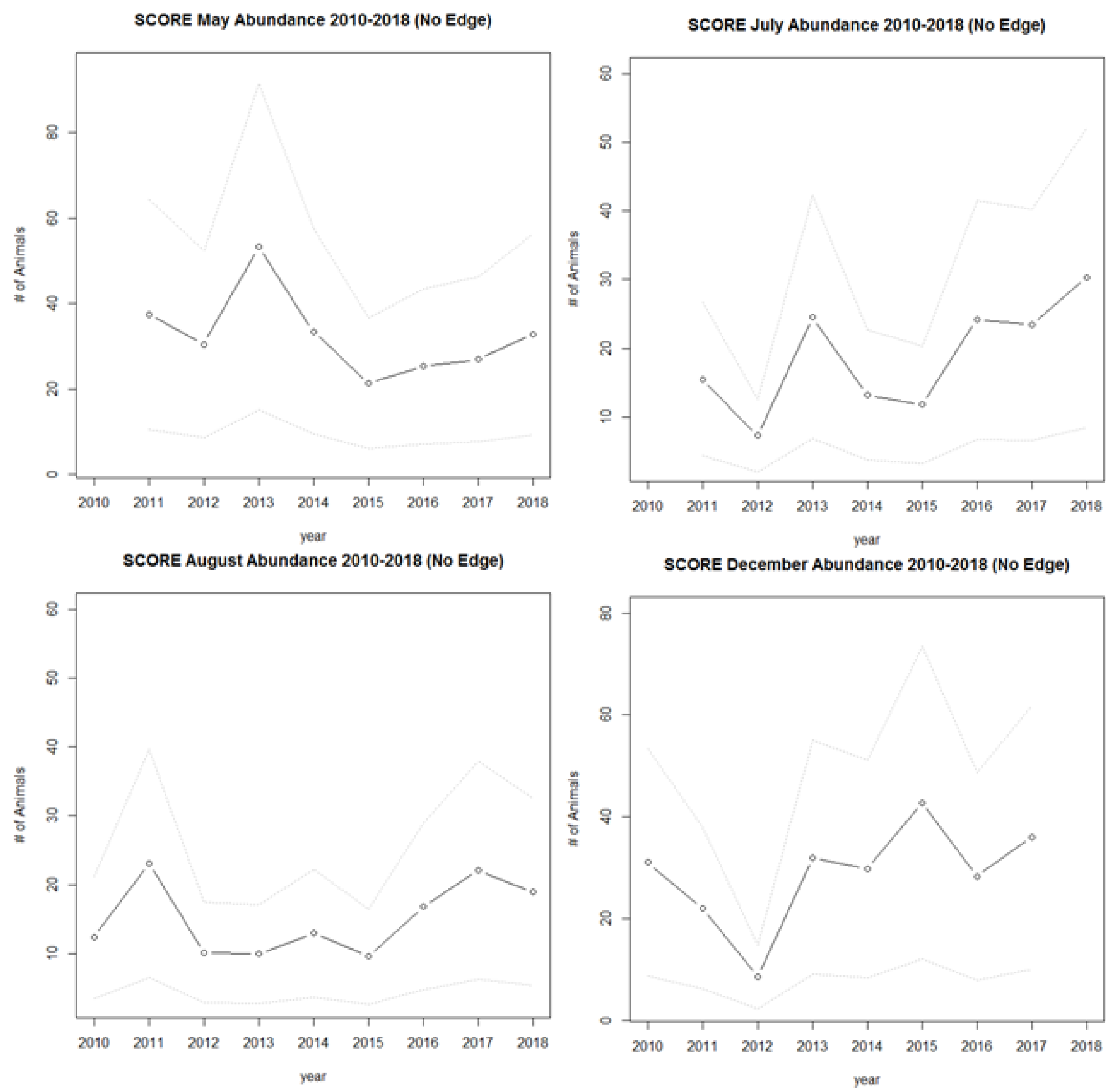

Figure 6. Mean Cuvier's beaked whale abundance for the months of May, July, August, and December from 2010 to 2018.

Dashed lines indicate 95% confidence intervals.

Abundance	Year								
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
MAY									
upper CI	NA	64.40	52.34	91.50	57.52	36.60	43.41	46.20	56.26
mean abundance	NA	37.49	30.47	53.26	33.48	21.30	25.27	26.89	32.75
lower CI	NA	10.57	8.59	15.02	9.44	6.01	7.13	7.59	9.24
JULY									
upper CI	NA	26.65	12.61	42.24	22.70	20.31	41.49	40.23	52.14
mean abundance	NA	15.51	7.34	24.59	13.22	11.82	24.15	23.42	30.35
lower CI	NA	4.38	2.07	6.94	3.73	3.34	6.81	6.60	8.56
AUGUST									
upper CI	21.22	39.61	17.45	17.09	22.22	16.52	28.90	37.93	32.53
mean abundance	12.35	23.06	10.16	9.95	12.94	9.61	16.82	22.08	18.94
lower CI	3.48	6.50	2.86	2.81	3.65	2.71	4.75	6.23	5.34
DECEMBER									
upper CI	53.39	37.84	14.85	54.97	51.22	73.55	48.63	61.97	NA
mean abundance	31.08	22.02	8.65	32.00	29.82	42.81	28.31	36.07	NA
lower CI	8.77	6.21	2.44	9.03	8.41	12.08	7.99	10.17	NA

Table 10. Cuvier's beaked whale mean abundance by indicated month 2010 through 2018.

NAs indicate periods without data.

2.2.3 SOAR Cuvier's Beaked Whale Dive Starts per Hour Effort

The mean number of Cuvier's beaked whale dive starts per hour effort for each month, averaged across the years 2010 through 2018, with the CVs used to calculate the confidence intervals, are shown in Table 11 and Figure 7.

Mean dive starts per hour varies from a high of 2.96 per hour effort across the range in January to a low of 1.07 in September.

The monthly mean number of dive starts per hour effort for each year is shown in Table 12 and Figure 8.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	5.18	4.12	3.90	4.54	4.84	4.40	3.58	2.81	2.38	2.90	3.45	4.63
mean # dive starts	2.96	2.16	1.90	2.55	2.80	2.58	1.86	1.39	1.07	1.39	1.71	2.56
lower CI	0.74	0.19	-0.09	0.56	0.77	0.77	0.14	-0.03	-0.24	-0.12	-0.03	0.48
dive start CVs	0.75	0.91	1.05	0.78	0.72	0.70	0.93	1.02	1.23	1.09	1.02	0.81

Table 11. Mean monthly number of SOAR Cuvier's beaked whale dive starts per hour effort, averaged across 2010 to 2018.

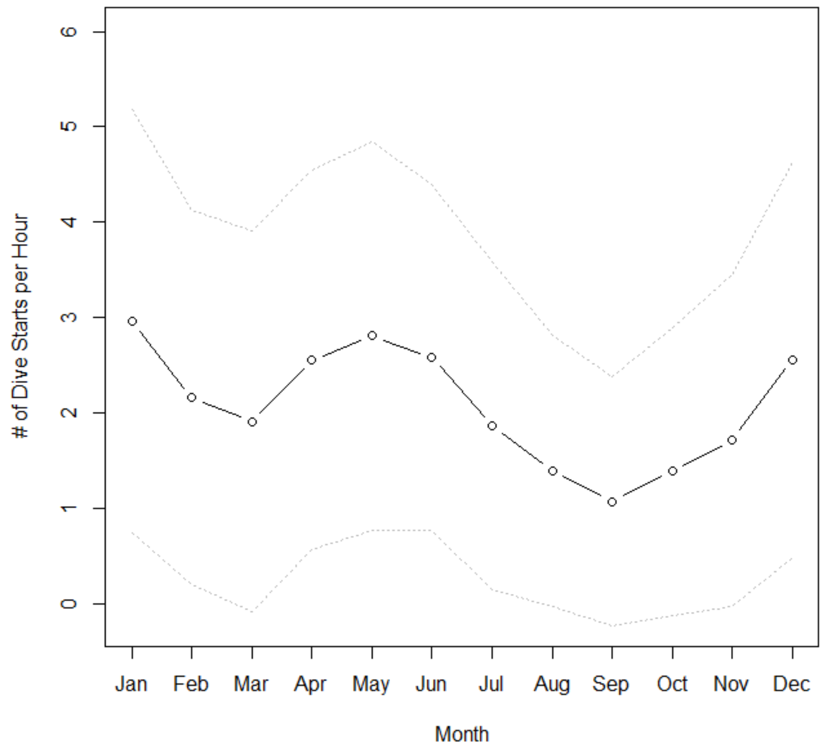

Figure 7. Mean monthly number of SOAR Cuvier's beaked whale dive starts per hour effort averaged across 2010 to 2018.

Dashed lines indicate 95% confidence intervals.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	1.08	1.19	0.80	2.05	2.69
2011	3.48	1.92	2.01	2.67	3.28	NA	1.35	1.63	0.33	0.84	1.26	1.94
2012	2.92	2.97	3.17	2.20	2.68	NA	0.64	0.86	NA	1.87	1.34	0.76
2013	NA	NA	NA	NA	4.66	3.05	2.16	0.88	0.75	1.01	1.38	2.80
2014	2.59	2.05	2.58	2.92	2.94	2.58	1.15	1.13	0.89	1.38	2.63	2.63
2015	2.44	1.50	1.74	2.04	1.88	1.69	1.03	0.84	1.15	1.66	1.67	3.75
2016	3.36	2.54	2.10	2.70	2.22	2.06	2.12	1.48	1.12	NA	1.95	2.49
2017	3.38	NA	2.16	3.00	2.42	NA	2.05	1.95	1.48	1.38	1.69	3.17
2018	2.97	2.10	0.40	2.27	2.88	2.50	2.66	1.67	1.77	1.99	1.72	NA

Table 12. SOAR corrected monthly mean number of Cuvier's beaked whale group dive starts 2010 to 2018. NAs indicate periods without data.

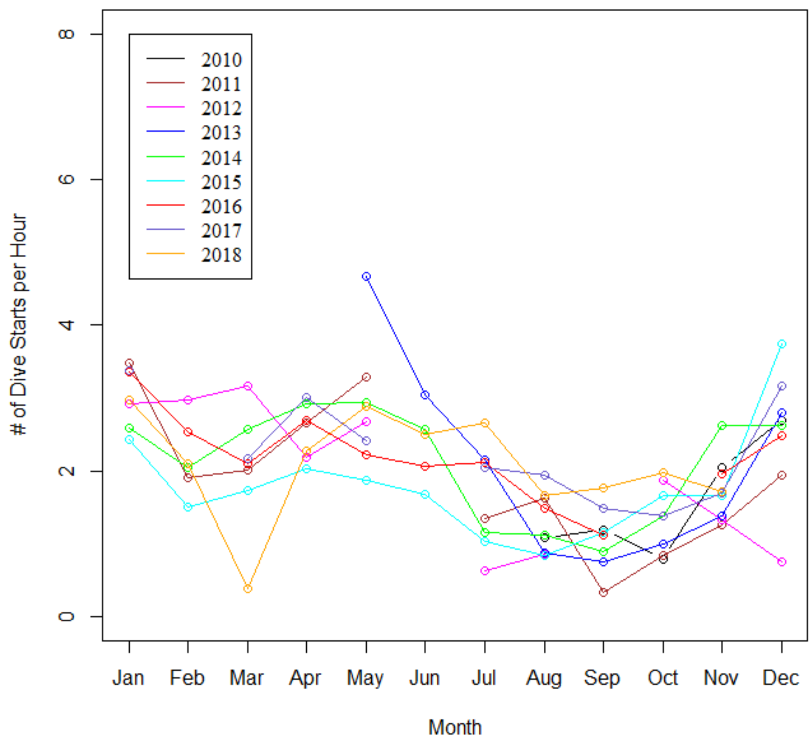

Figure 8. Mean monthly number of Cuvier's beaked whale dive starts per hour effort 2010 to 2018.

In order to view the number of dive starts per hour on a 24-hour cycle using data over the whole year, the data were first corrected for the fact that there is varying effort over the years and a variation in the number of dive starts over each year. The mean number of dive starts per hour of the year across the years 2010 to 2018 were first plotted, and a fit to these data was found (Figure 9). A 4th order fit to the mean values was then used to correct the dive start data by dividing each dive start data point by the corresponding fit value. The mean number of dive starts per hour was then generated for a 24-hour cycle (Figure 10).

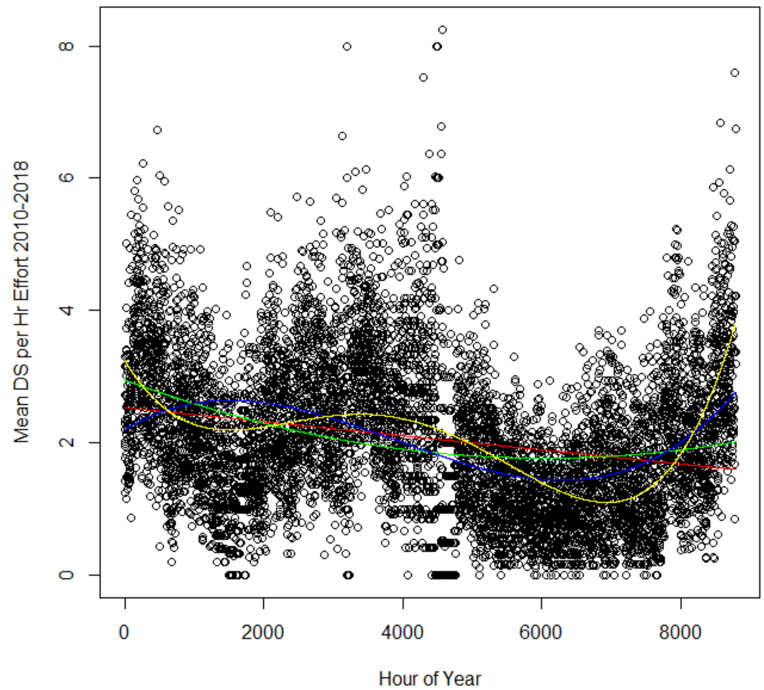

Figure 9. Number of Cuvier's beaked whale dive starts per hour averaged across 2010-2018 for every hour of the year, along with 1st to 4th order fits to the data. The 4th order fit used to correct the dive start data is shown in yellow.

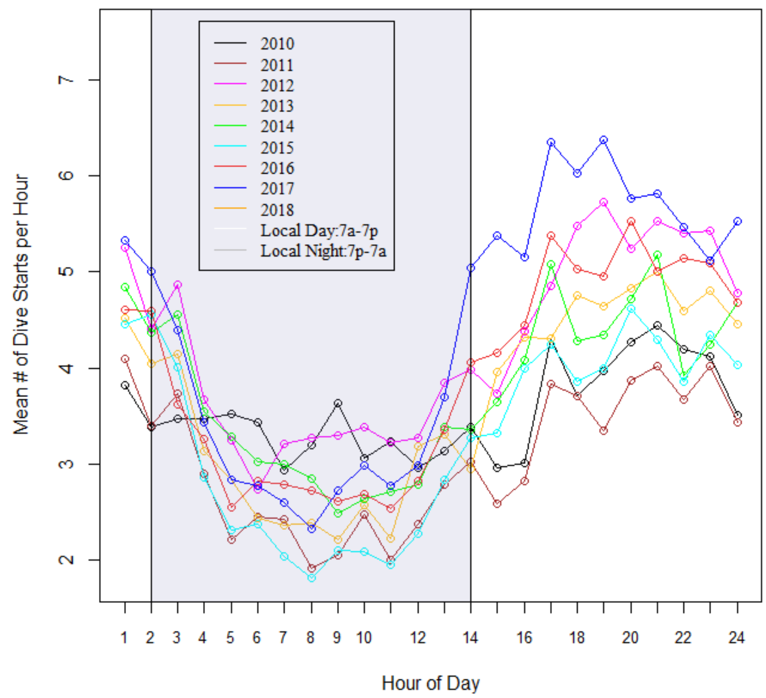

Figure 10. Mean number of Cuvier's beaked whale group dive starts per hour on a 24-hour cycle.

Note that the times are in UTC, and the gray shaded area indicates the approximate local night hours, if local day is considered 7a to 7p, and local night is considered 7p to 7a. There is a 7 or 8-hour difference between local time on San Clemente Island and UTC, depending on Daylight Savings Time.

The local San Clemente Island 'day'/'night' periods were roughly considered from 7a-7p and 7p-7a, respectively. The sunrise and sunset times were averaged for the June and December solstices from 2010 through 2017, resulting in average sunrise and sunset times of approximately 0645 and 1854. Note also that the local time on San Clemente Island is 7 to 8 hours earlier than UTC, depending on Daylight Savings Time. The times associated with these data are in UTC. Note that the apparent 'banding' in Figure 9 occurs either because there is only data available for one year during these time periods, or there is data for more than one year, but only one year has non-zero values. There is a drop in the number of dive starts per hour effort at night, with the lowest numbers at about midnight to 0100 local, and the peak at approximately 1300 to 1400 local time (Figure 10). The lowest mean number of dive starts per hour is 1.89 at 0800 UTC, 2015, and the highest is 6.78 at 1900 UTC, 2017.

Note that as the apparent drop in the number of Cuvier's beaked whale dive starts per hour and abundance during night-time hours does not appear to be consistent with satellite tag data on Cuvier's beaked whales at SOAR [5] [3], several factors should be examined that could explain the discrepancy: the probability of detection, false alarm rate, and dive rate over the 24-hour cycle, all of which are assumed to be constant; possible masking by delphinid vocalizations; the impacts of MFAS; and the possibility that some Cuvier's beaked whale groups move off-range at night.

2.2.4 SOAR Cuvier's Beaked Whale Group Vocal Period (GVP) lengths

The mean monthly Group Vocal Period (GVP) lengths (in min) of the Cuvier's beaked whale dives were calculated for 2010 through 2018 (Table 13). The mean Cuvier's beaked whale GVP lengths averaged across 2010 to 2018 for each month, along with the CIs and corresponding CVs are shown in Table 14. These values were calculated with the edge-only groups removed. The monthly mean across all years varies from a low of 36.27 min in August to a high of 42.39 min in January (Figure 11). The mean monthly GVP lengths for each year, 2010 through 2018, are shown in Figure 12.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	29.57	35.27	35.52	37.16	38.06
2011	41.94	37.20	32.90	33.05	33.47	NA	31.18	32.90	32.28	34.52	39.28	38.89
2012	38.96	40.52	39.30	38.54	39.41	NA	40.35	39.14	NA	39.70	39.79	42.91
2013	NA	NA	NA	NA	40.14	41.02	39.53	33.75	33.15	38.80	38.70	48.04
2014	43.71	40.72	42.52	41.63	40.06	37.52	32.38	40.88	34.53	43.50	43.93	41.76
2015	44.30	39.25	36.13	38.11	37.28	36.26	40.90	35.41	43.40	43.38	42.09	40.14
2016	43.69	42.83	38.25	40.28	38.44	42.09	38.80	39.15	38.50	NA	41.82	41.30
2017	42.60	NA	38.98	39.58	39.15	NA	39.93	37.18	36.84	37.75	39.94	43.81
2018	40.88	42.61	42.19	37.40	39.02	39.04	40.61	37.07	40.10	40.44	44.92	NA

Table 13. SOAR mean monthly Cuvier's beaked whale group vocal period (GVP) lengths (in min) for 2010 to 2018.

NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	61.17	59.11	57.93	57.96	56.95	57.71	57.43	53.63	54.61	58.42	59.66	60.64
mean GVP	42.39	40.73	39.24	39.55	38.68	39.49	39.12	36.27	37.37	39.77	40.89	41.69
lower CI	23.60	22.36	20.54	21.14	20.42	21.26	20.82	18.91	20.12	21.12	22.13	22.75
GVP CV	0.44	0.45	0.48	0.47	0.47	0.46	0.47	0.48	0.46	0.47	0.46	0.45

Table 14. Mean SOAR Cuvier's beaked whale GVP lengths (in min) per month averaged across 2010 to 2018, with upper and lower confidence intervals (CIs), and the corresponding Coefficients of Variation (CVs).

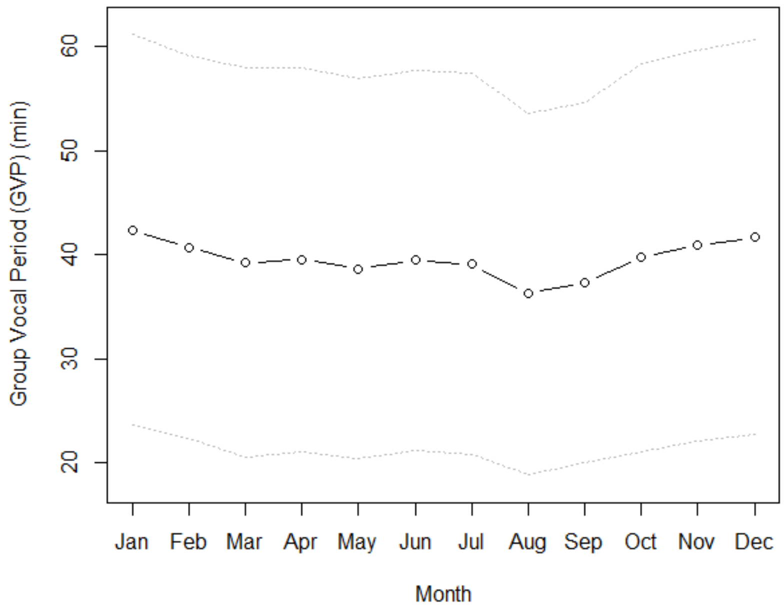

Figure 11. SOAR mean monthly Cuvier's beaked whale group vocal period (GVP) length (min), averaged across 2010-2018.

Dashed lines indicate 95% confidence intervals**.**

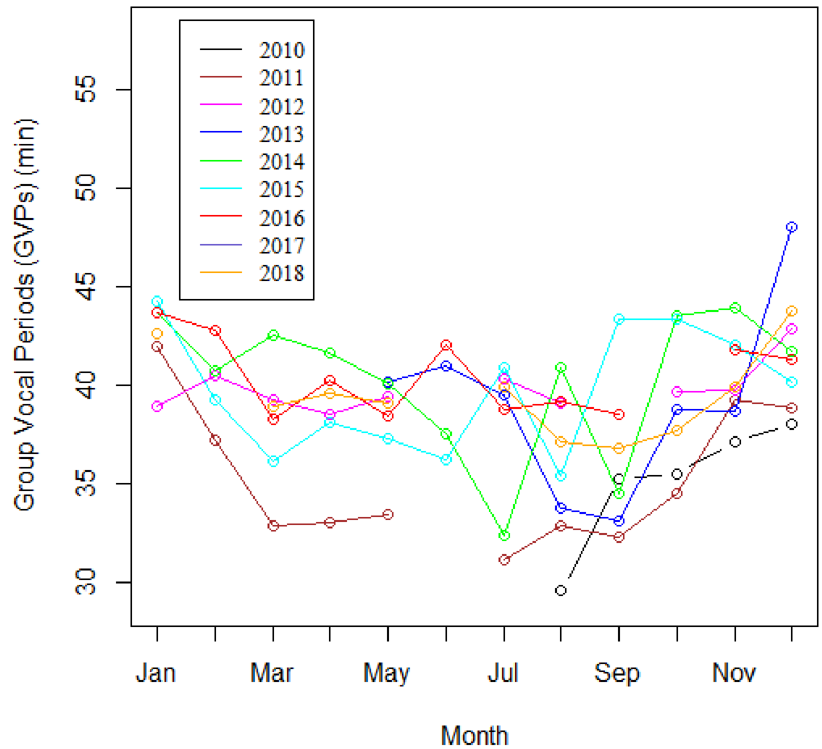

Figure 12. SOAR mean monthly Cuvier's beaked whale group vocal periods (GVP) lengths (in min) for 2010 through 2018.

2.2.5 SOAR Cuvier's Beaked Whale Mean Number of Foraging Clicks per Group

The mean monthly number of Cuvier's beaked whale foraging clicks detected per group for the years 2010 through 2018 are shown in Table 15. The mean number of Cuvier's beaked whale clicks detected per group, averaged across 2010 to 2018 for each month, along with the CIs and corresponding CVs are shown in Table 16. The monthly mean varies from 2259 clicks in September to 3549 in January. The monthly mean across years is shown in Figure 13, and the monthly means for each year in Figure 14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	951.5	1342.4	1484.7	2071.2	2415.1
2011	3137.6	2337.1	1729.8	1997.1	1561.3	NA	1426.9	1621.5	1018.6	1586.5	2281.7	2305.4
2012	2256.4	2408.0	2085.2	1873.6	1993.4	NA	2078.7	1615.3	NA	2233.4	1745.7	2056.2
2013	NA	NA	NA	NA	2103.0	2203.2	2106.6	1565.7	1841.9	2338.7	1961.5	3337.2
2014	2688.2	2331.3	3221.6	3343.1	2884.6	2466.9	2086.0	2655.4	2020.3	3391.7	4110.6	3760.4
2015	4437.7	3481.5	2945.5	2891.9	2583.1	3119.7	2775.2	1757.1	2911.0	3150.6	2653.0	2819.0
2016	3691.1	3344.4	2823.7	3269.9	3659.6	3936.7	2764.5	2588.8	2271.4	NA	2747.4	3346.7
2017	4201.9	NA	2785.0	3256.7	3243.7	NA	3029.9	2778.0	2799.2	2929.5	3182.8	4657.7
2018	4211.9	4692.5	3932.5	2964.2	3150.3	3469.6	3737.9	2798.6	2646.5	3219.3	3788.3	NA

Table 15. SOAR mean monthly number of Cuvier's beaked whale clicks per group for 2010 to 2018.

NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	7406.7	6730.9	5985.0	6377.5	5653.9	5927.0	5966.1	4988.6	4801.6	5919.0	6019.2	7249.4
mean click count	3548.8	3117.2	2830.0	3026.4	2678.2	2838.2	2823.1	2310.0	2258.9	2735.8	2821.7	3424.6
lower CI	-309.2	-496.5	-325.0	-324.7	-297.6	-250.5	-319.8	-368.6	-283.8	-447.3	-375.8	-400.3
click count CV	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.1	1.2	1.1	1.1

Table 16. Mean monthly number of Cuvier's beaked whale clicks per group averaged across 2010 to 2018 at SOAR, with upper and lower confidence intervals (CIs), and the corresponding Coefficients of Variation (CVs).

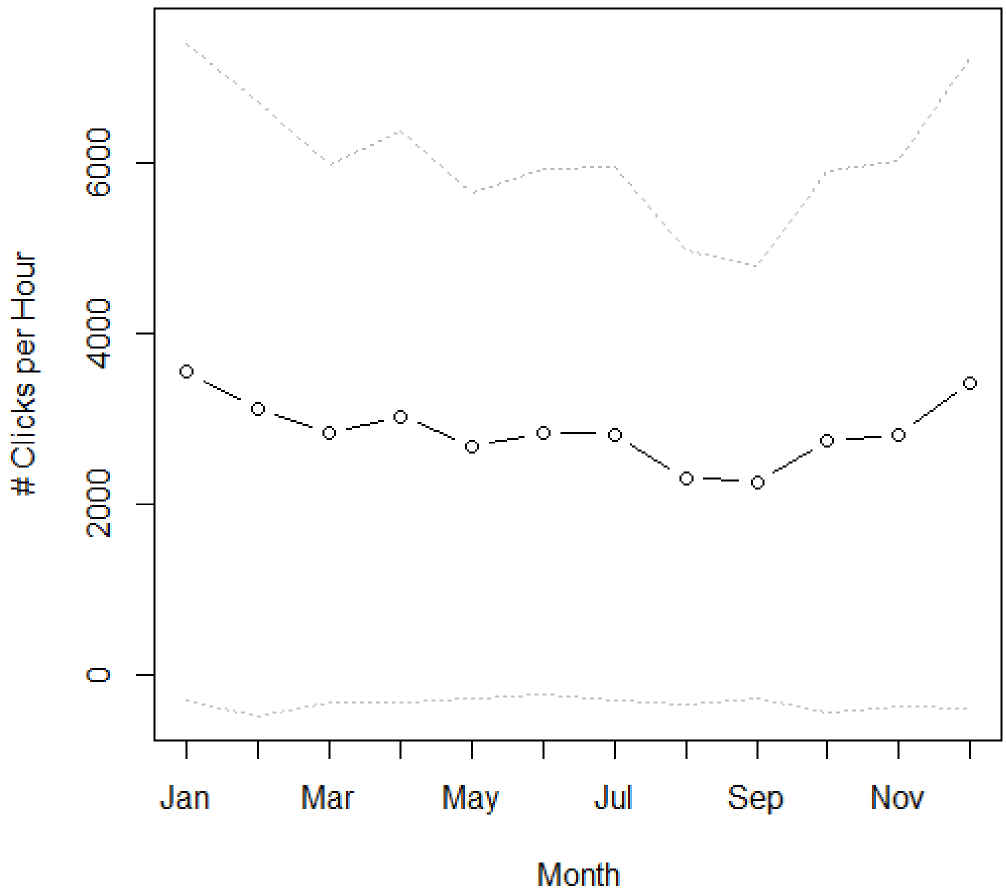

Figure 13. Mean monthly number of Cuvier's beaked whale clicks detected per group, averaged across 2010-2018.

Dashed lines indicate 95% confidence intervals**.**

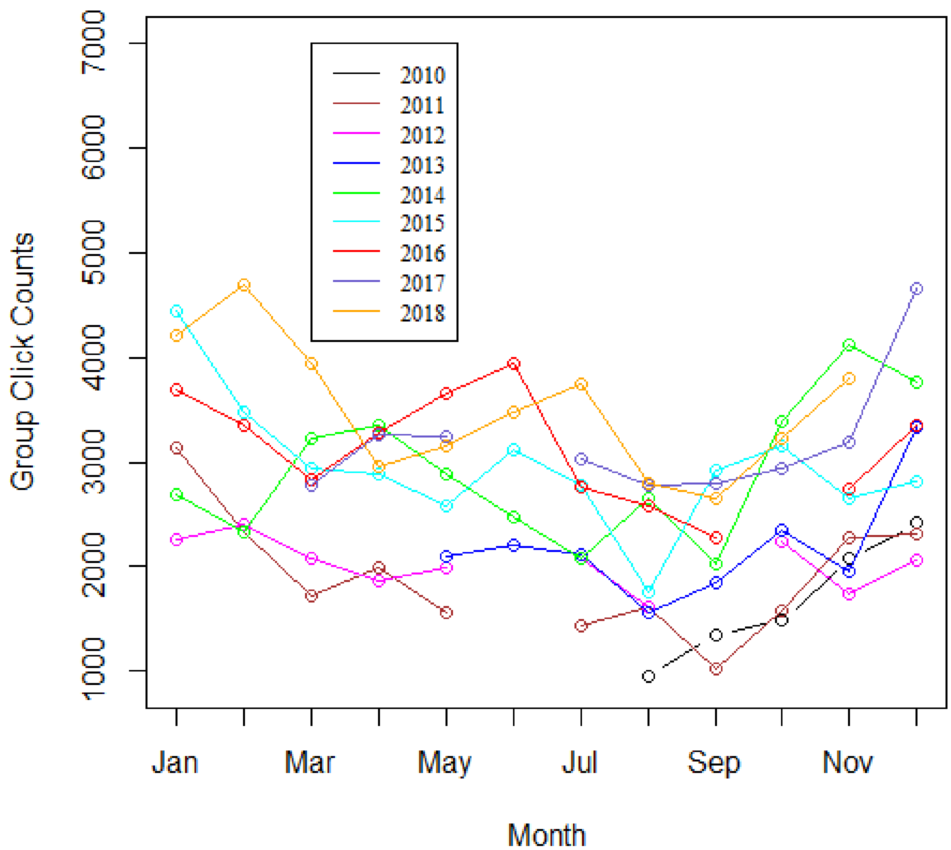

Figure 14. Mean monthly number of Cuvier's beaked whale clicks detected per group for the years 2010 through 2018.

2.2.6 SOAR Spatial Distribution – Number of Cuvier's Beaked Whale Groups per Year

The Cuvier's beaked whale spatial distribution on SOAR for years 2010 through 2018 is displayed in Figure 15 and Figure 16. Figure 15 shows all years on the same scale, with the scale, indicating the number of Cuvier's beaked whale groups detected per hydrophone per year, to the left of the plots. The years have different scales in Figure 16 to make the Cuvier's beaked whale distribution on the range more obvious. The data have not yet been corrected for some variation in spatial coverage, but they are consistent with the distribution of Cuvier's beaked whale sightings by MarEcoTel during field efforts on SOAR [2]. Cuvier's beaked whales are primarily found in the western portion of the range in deeper waters, as can be seen in Figure 17.

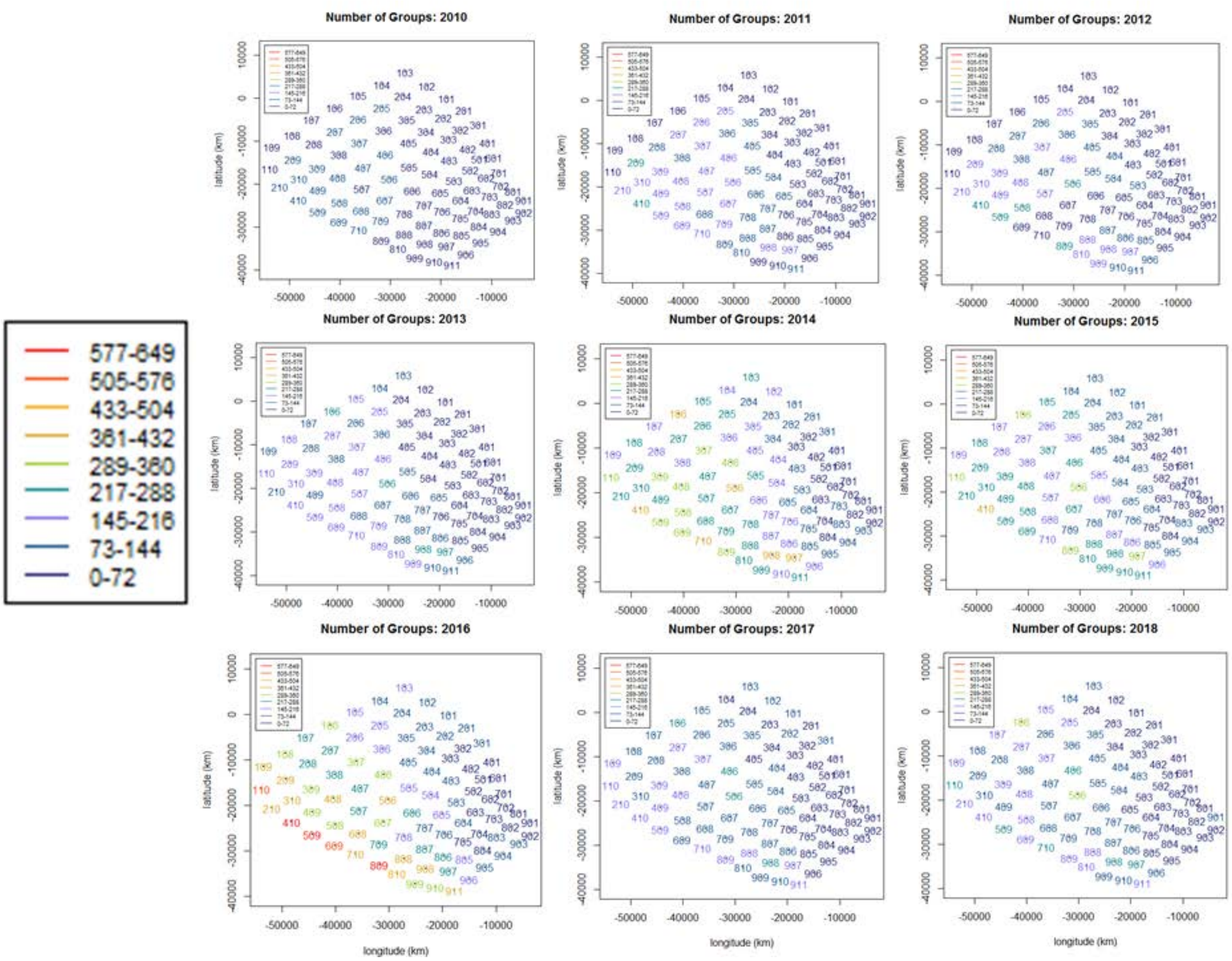

Figure 15. SOAR spatial distribution: Number of Cuvier's beaked whale groups detected per hydrophone per year. ***Top row, left to right:*** **2010-2012;** ***middle row, left to right:*** **2013-2015;** ***bottom row, left to right:*** **2016-2018. Note that all plots are on the same scale, displayed to the left of the plots. The data are not yet corrected for some variation in spatial coverage.**

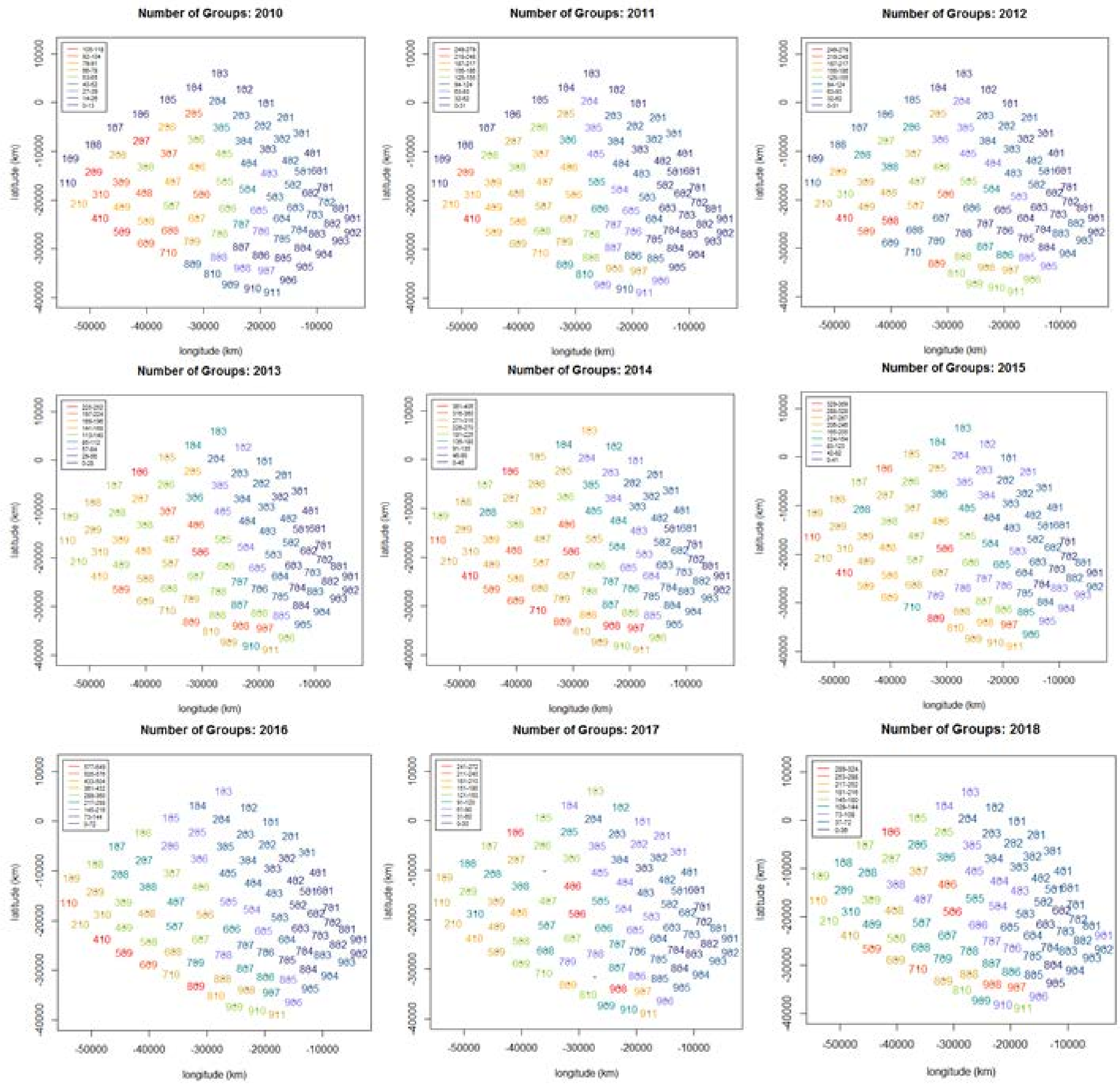

Figure 16. SOAR spatial distribution: Number of Cuvier's beaked whale groups detected per hydrophone per year. ***Top row, left to right*****: 2010-2012;** ***middle row, left to right:*** **2013-2015;** ***bottom row, left to right:*** **2016-2018. Note the years have different scales to better display the area of range use by Cuvier's beaked whales, and the data are not yet corrected for some variation in spatial coverage.**

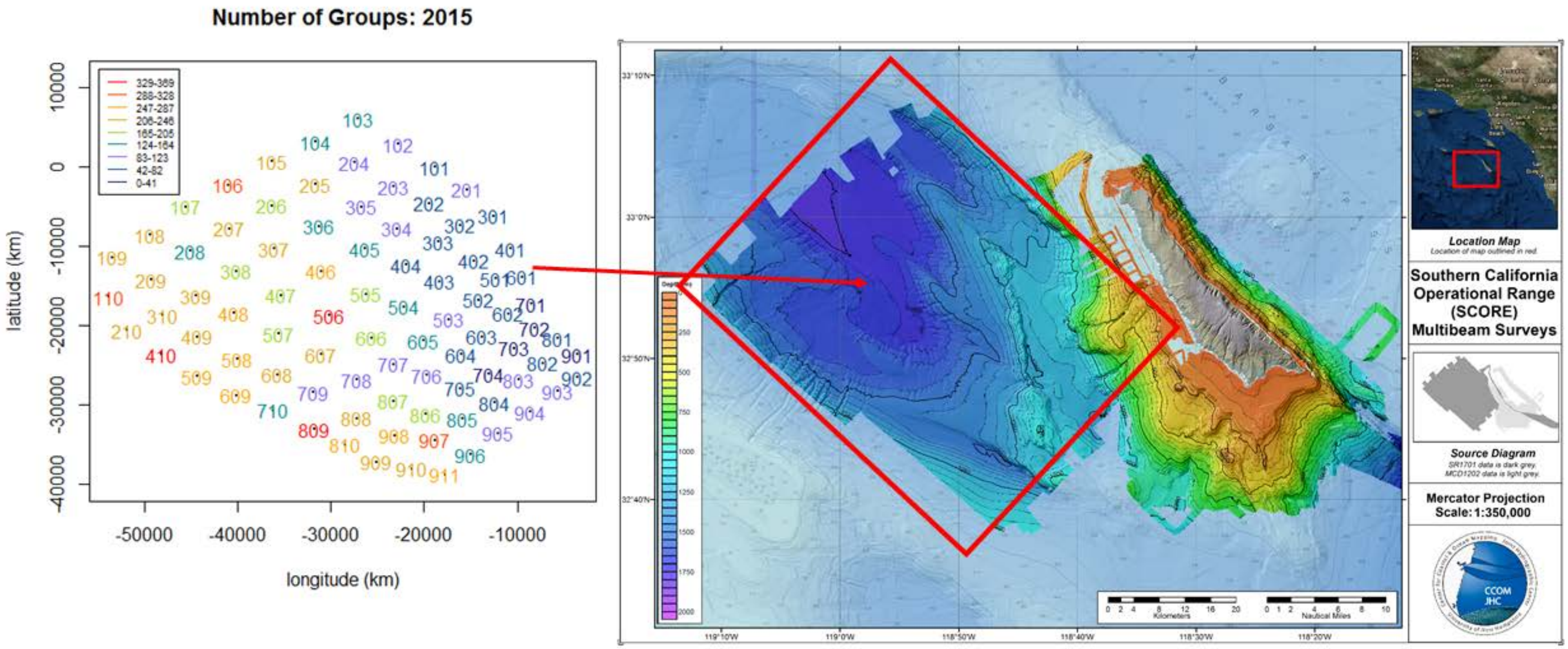

Figure 17. ***Right:*** **SCORE bathymetry collected by the University of New Hampshire during a survey in 2017;** ***Left:*** **An example of the SOAR hydrophone range with the number of Cuvier's beaked whale groups detected per hydrophone for the year 2015. The red arrow and box indicate the approximate location of the hydrophone range on the bathymetry map.**

3.0 SOAR: Beaked whale foraging behavior before, during, and after sonar exposure

Cuvier's beaked whales (*Ziphius cavirostris*) are a cryptic, deep-diving species that are known to respond to military sonar [13], [3] [14] [15]. DeRuiter et al. [14] reported that two tagged whales stopped echolocating and increased swimming speed and dive duration during playbacks of mid-frequency sonar signals. Falcone et al. 2017 [3] showed that deep dives, shallow dives, and surface intervals all became longer during mid-frequency sonar use, and the responses intensified with proximity to sonar, and were more pronounced during mid-power than high-power sonar. Beyond the responses of individual animals, McCarthy et al. [15] reported on the response of Blainville's beaked whales (*Mesoplodon densirostris*) to sonar during a military training exercise on the Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. They demonstrated a strong decline in echolocation periods during the training event, and an extended recovery period before the number of echolocation periods returned to pre-event levels. Similar results were seen by Manzano-Roth et al. (2016) [16] for Blainville's beaked whales at PMRF. Given the known response by individual Cuvier's beaked whales, and the general response trend seen in Blainville's beaked whales over a large area when exposed to sonar, the goal of this analysis was to repeat the McCarthy et al. [15] analysis for Cuvier's beaked whales on the SOAR range.

Data were collected from the M3R system on the SOAR range between April 2014 and November 2015. The SOAR event schedule was used to isolate testing and training events that coincided with sonar use. Events were broken into three types: (1) nine events that involved primarily hull-mounted surface ship sonar, (2) 11 events that primarily involved helicopter-deployed dipping sonar, and (3) three events that involved both types of sonar. Time was binned into two-hour time windows, and each time window was marked for the presence or absence of sonar at some point during the time window. Periods with sonar were compared to the SOAR event schedule to determine type of event. Before and after periods were then designated as five two-hour time windows (10 hours before and 10 hours after) without sonar surrounding time windows encompassing the event with sonar, while the during time windows were variable in duration depending on the length of each event (Figure 18). M3R detection archives were processed through a custom Java FFT-based energy detector in frequency bands of interest to determine the presence of sonar, as well as to calculate the maximum estimated received level within the mid-frequency sonar band at any hydrophone on the SOAR range within a given two-hour time window. Peak magnitude (volts) was converted to an estimated RL in dB rms re 1 µPa at the hydrophone.

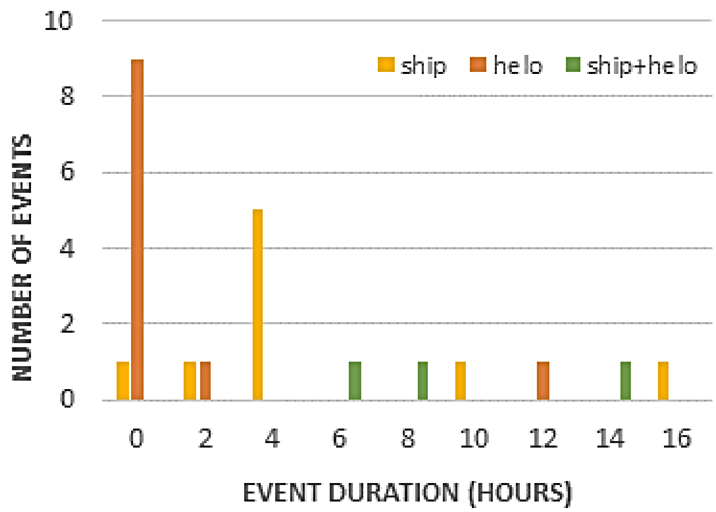

Figure 18. Event durations

M3R archives were processed through the custom CTP and Autogrouper programs to isolate the number of GVPs in each two-hour window (after edge-only groups were removed). A Generalized Linear Model was run to examine the effect of sonar presence and event type on the number of GVPs.

Overall, there was a trend of decreased GVPs on average during sonar events, regardless of type (Figure 19**)**. Statistical analysis showed a significant decline in the number of GVPs from before the event started to during the event for all events types (Table 17). The decline from before to during was significantly less for helicopter events than for ship events, but there was no difference in the magnitude of the decline between ship events and events with both ships and helicopters. Finally, there was no difference in the number of GVPs in the before and after periods, for all event types.

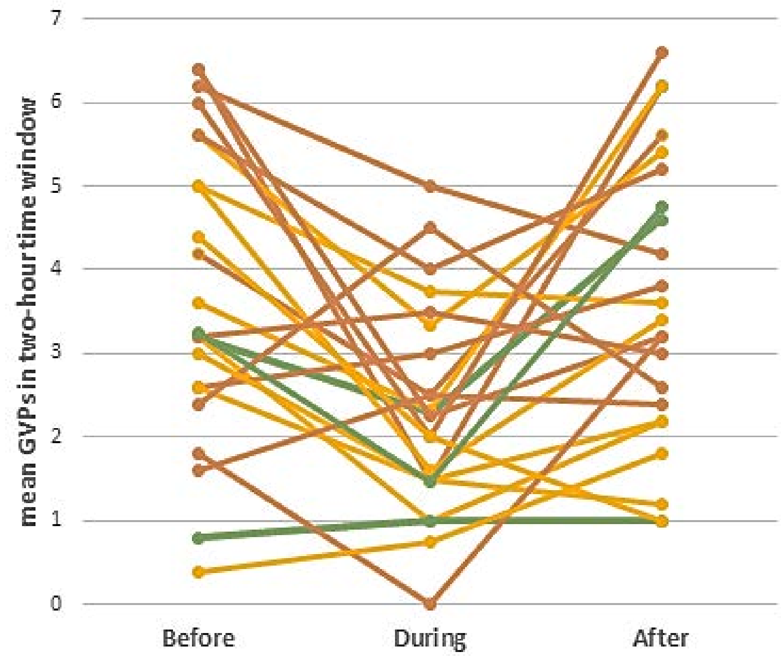

Figure 19. Mean GVPs per two hour time window before, during, and after a ship event (yellow), helo event (orange) or ship+helo event (green).

```
Call:
glm(formula = GVP ~ Period_BDA + Sonar.Type, family = poisson,
    data = subdat)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.9181  -0.9129  -0.1432   0.5042   4.3953

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.19451    0.06346  18.822  < 2e-16 ***
Period_BDA2 -0.36947    0.07884  -4.687 2.78e-06 ***
Period_BDA3 -0.01248    0.06761  -0.185  0.85361
Sonar.Type2  0.25421    0.06676   3.808  0.00014 ***
Sonar.Type3 -0.03233    0.08456  -0.382  0.70220
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

    Null deviance: 659.19  on 356  degrees of freedom
Residual deviance: 594.99  on 352  degrees of freedom
AIC: 1568.6

Number of Fisher Scoring iterations: 5
```

Table 17. GLM output comparing Sonar Type (1 = ship events, 2 = helo events, 3 = ship+ helo events) and Period (1 = before, 2 = during, 3 = after).

For each GVP, the maximum received level on the closest hydrophone (hydrophone with the most detected echolocation clicks) for that GVP was determined at any time during the GVP. The proportion of GVPs that fell into various receive level bins were compared for GVPs that started in the before, during, and after periods (Figure 20). GVP values that were assigned a receive level bin of 100 were "below threshold," where the threshold was a value set by the sonar detector algorithm to determine if sufficient energy was received within the frequency band of interest to record a detection. If no detection was received, it was because all sound energy on that hydrophone during the GVP duration fell below this threshold. Values ">135" are due to the hydrophones clipping at received levels above approximately 140 dB. The plots demonstrate that there are groups vocalizing even when received sounds levels are high during sonar events. Also, there are a quarter of the groups during each event type that were vocalizing when sonar was not active within the 2-hour window (indicated by the "during" bars under receive level of 100), which is due to either the GVP starting and ending before sonar started, or the GVP starting after sonar ended. GVPs last on average 20-40 minutes, and sonar is not usually continuous within the 2-hour "during" windows.

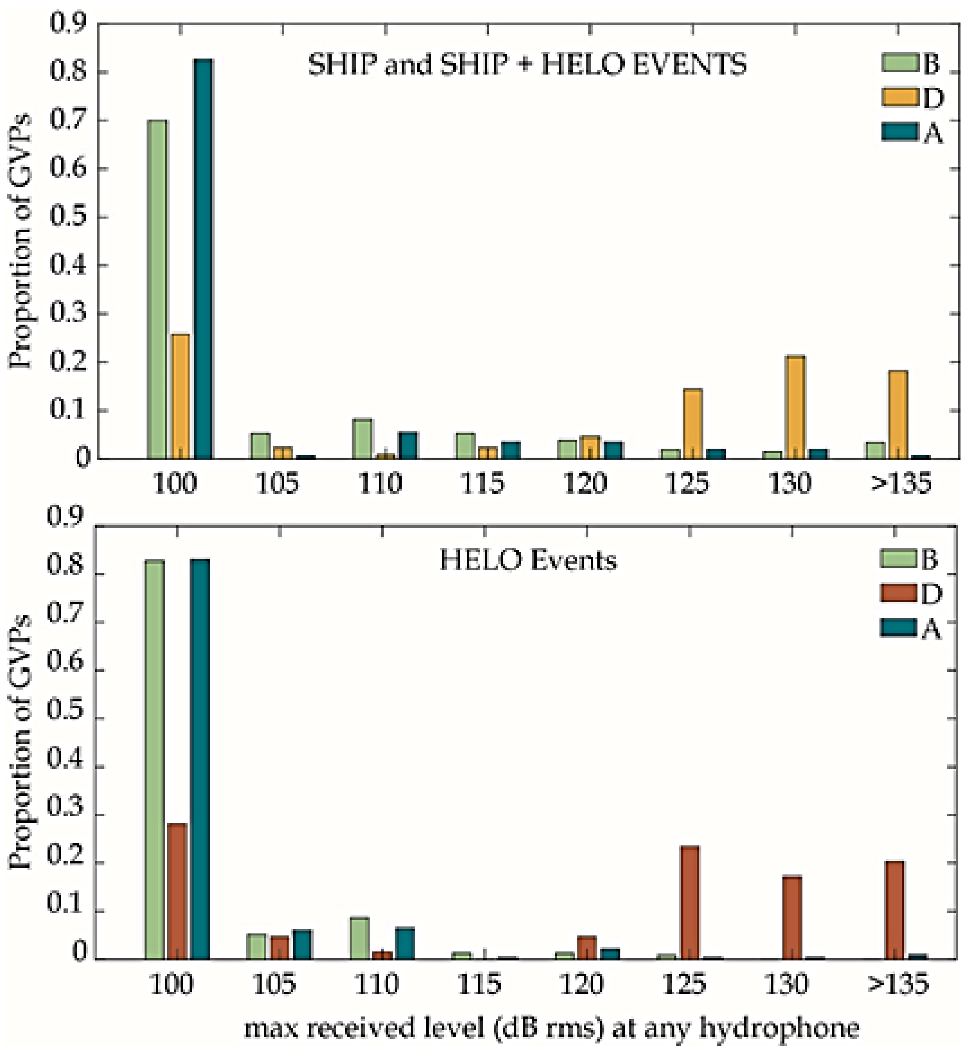

Figure 20. Maximum estimated received level during GVP duration on GVP center hydrophones for GVPs starting before, during, and after ship sonar events (top, yellow) and helo sonar events (bottom, orange).

The during period bars in Figure 20 are carried over to Figure 21**,** which compares the distribution of maximum received levels during GVPs to the distribution of the maximum received levels during all time windows during sonar events. The purple bars represent the distribution of maximum received levels on any hydrophone on range in the "during" periods, while the orange/red bars represent the maximum received levels only during the times a GVP is active. This is one way to compare the relative distributions of the maximum sound field and echolocating beaked whales. It is apparent that the distribution of GVPs is underrepresented in the highest sound levels (above 125 dB) for all three event types, as there are fewer active GVPs (red/orange) during the highest received levels (purple above 125 dB) Therefore, GVPs are not occurring within the highest regions of sound exposure as you might expect if they were randomly distributed across the range.

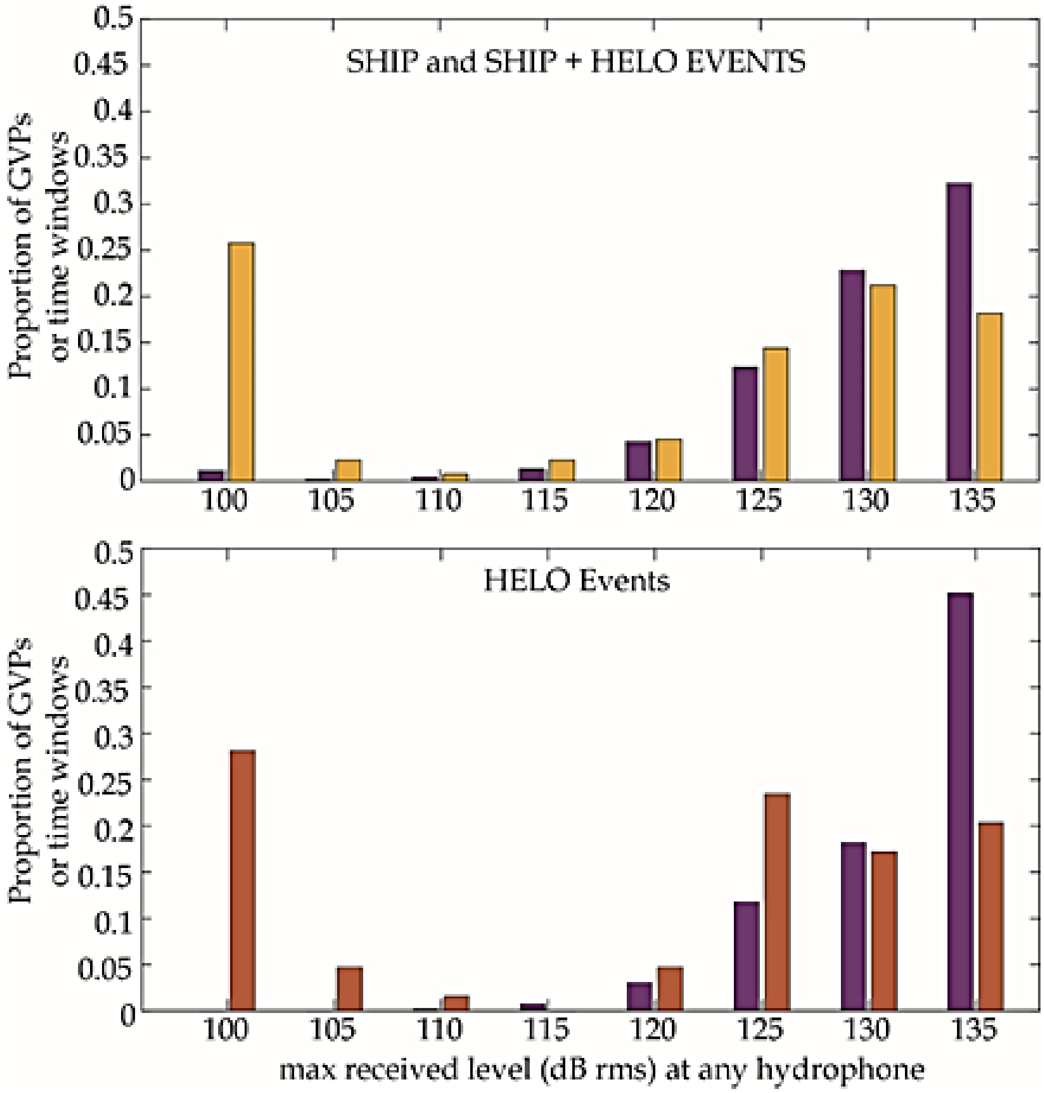

Figure 21. Maximum received level during GVP duration for ship events (top, yellow) and helo events (bottom, orange) and during all time windows during each sonar event type (purple).

The goal of this analysis was to look at the distributional change in GVPs in response to actual training events occurring on the SOAR range. Notably, there were some differences between the three types of events; namely, that events with only helicopter-deployed dipping sonar were generally shorter in duration than those with primarily hull-mounted sonar; helo-deployed dipping sonar has a lower source level than hull-mounted sonar; and from an animal perspective, helicopters may be a more unpredictable platform than surface ships.

Analyses indicated that there were significant declines in GVPs on SOAR when both hull-mounted ship sonar and helicopter-deployed dipping sonar were active. Declines were larger during hull-mounted ship sonar events than during helicopter-deployed dipping sonar events. This may be due to increased duration or source level of ship events compared to helicopter events. Recovery to levels of GVP before the events appeared to be on the order of the events themselves, as there were no differences in the number of GVPs in the before and after periods. This is faster than the extended recovery period seen in McCarthy et al. (2010), however, the event durations were much shorter on SOAR than the multi-day events analyzed at AUTEC.

These results indicate a stronger change in GVP distribution across the SOAR range during hull-mounted surface ship sonar events compared to events involving helicopter-deployed dipping sonar. These results do not necessarily contradict those seen by Falcone et al. (2017), which demonstrated that individual Cuvier's beaked whales had a stronger response to helicopter-deployed dipping sonar at shorter ranges. The source level of helicopter-deployed dipping sonar is lower than that of hull-mounted surface ship sonar, and therefore, the area over which beaked whales might respond to a sonar event is greater for ship events. Therefore, when looking at total GVP decline over an entire range, it is possible that the decline is greater for ship events because more groups of beaked whales are exposed (and therefore respond) over the larger area than would be exposed to a helicopter event. Thus, even if individual whales react more strongly to helicopter-deployed dipping sonar, the overall change in distribution of GVPs may still be more impacted from ship events than helicopter events. Additional analyses looking more finely at GVP response will be necessary to fully understand the relationship between these two analyses.

4.0 PMRF Abundance & Distribution

4.1 PMRF Methods

4.1.1 PMRF Study Area

The Pacific Missile Range Facility (PMRF) is located off the northwest coast of Kauai, HI. The range consists of the three distinct areas, known as the Barking Sands Tactical Underwater Tracking Range (BARSTUR), the Barking Sands Underwater Range Expansion (BSURE) and the Shallow Water Tracking Range (SWTR). For this analysis, hydrophones for BARSTUR at depths of approximately 1-2 km and BSURE with hydrophones at depths of 2-4 km were used (Figure 22).

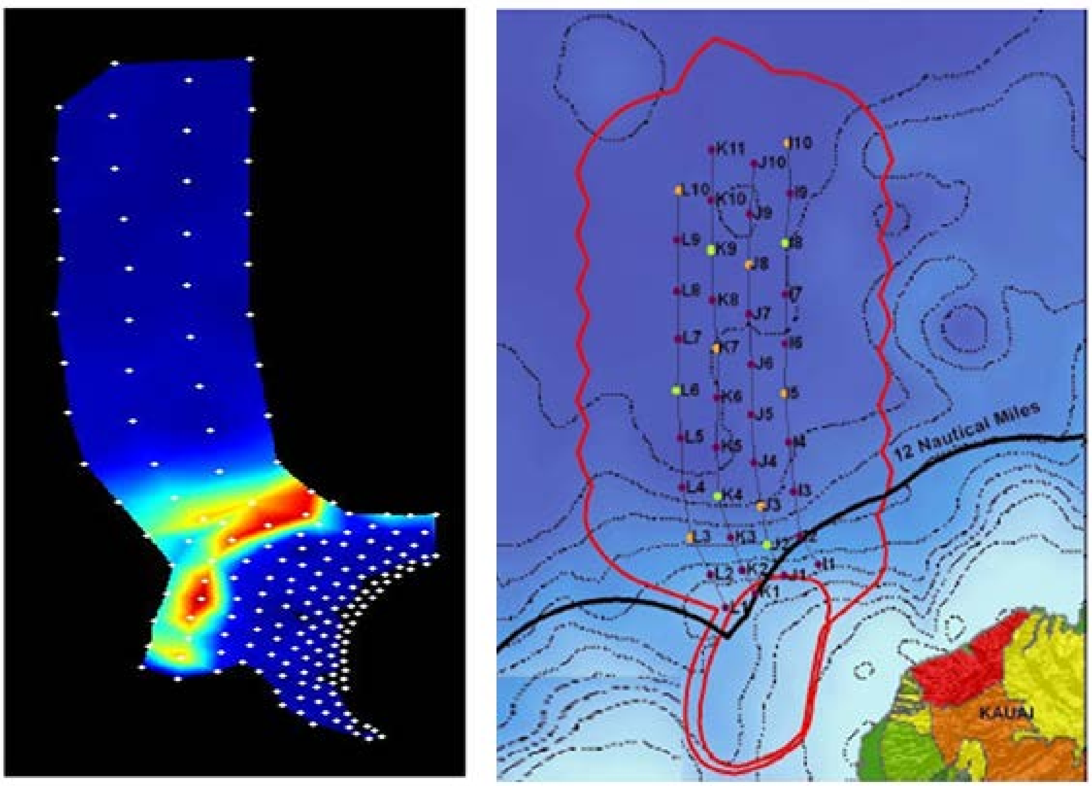

Figure 22. Outline of PMRF range on the right. PMRF range boundaries indicated by outer red line. BARSTUR range area indicated by the inner red line. while the BSURE range area extends north. Left plot shows distribution of Blainville's beaked whale click detections for the time period 11-Jun-2012 through 02-Aug-2012. Dots represent range hydrophones, including those in SWTR.

The BSURE hydrophones are identical to those described in section 2.1 for SOAR. BARSTUR consists of 42 hydrophones with a bandwidth of approximately 8-45 kHz, with six broadband hydrophones that cover a bandwidth of approximately 20 Hz to 45 kHz. BSURE has 41 newer hydrophones with a bandwidth of 50 Hz to 45 kHz, and the original 18 hydrophones with a bandwidth of 50 Hz to 18 kHz. Only the newer BSURE hydrophones were used, as Blainville's beaked whale vocalizations are above 18 kHz.

4.1.2 PMRF Data

PMRF archives were analyzed from 2015 through 2018. A total of 10,869.43 hours of data were processed, with the number of hours per year varying from a low of 109 hours in 2015 to a high of 7,854 hours in 2017 (Table 18). The number of days per month for the years 2015 through 2018 on which CS-SVM and FFT-based detection archives were collected at PMRF are shown in Table 19. The CS-SVM detections were used to determine the Blainville's beaked whale groups.

Total # Hours of Effort - PMRF

2015	2016	2017	2018
109.34	473.15	7854.04	2432.90

Table 18. Total number of hours of effort per year in which data was recorded at PMRF.

M3R PMRF Detection Archives												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015									5	1		
2016		11						11				
2017		27	31	30	31	30	18	29	30	30	30	31
2018	31	28	31	12+								

Table 19. Number of days per month for the years 2015-2018 on which archives were collected at PMRF with CS-SVM classifier.

Through 2016 data were only collected during tests at PMRF when M3R personnel were on range to start the M3R archiver, typically in advance of specific training events. Data were collected during the event and after as long as the system remained running. Typically, however, the system was rebooted within days of the completion of the event for a number of reasons, including classified operations, power outages, etc. As the M3R archiver did not automatically restart during these reboots, only a small amount of archive data was collected in 2015 and 2016.

The data presented here include the first extended archive, which runs from February 2017 through April 2018. The disk covering the period April 2018 through January 2019 is currently being processed.

4.1.3 PMRF Blainville's beaked whale Group Analysis

The derivation of the Blainville's beaked whale groups was conducted in the same manner as for Cuvier's beaked whale groups at SOAR (section 2.1.3.1), except that CS-SVM Blainville's beaked whale foraging click detections are used rather than CS-SVM Cuvier's beaked whale foraging click detections. In addition, the Autogrouper was set to filter for an inter-click interval (ICI) range of 0.23 to 0.4 sec.

The CS-SVM Cuvier's beaked whale foraging click detections are first associated into click trains on a per-hydrophone basis using a Java-based click train processor (CTP) program, and then a Matlab-based Autogrouper program is used to form the click trains into groups. Detection statistics are applied to the data for the abundance calculations.

4.1.4 PMRF Blainville's beaked whale Abundance

Blainville's beaked whale abundance at PMRF is calculated using equation 2 in section 2.1.4, but with different values for the input variables from those used for Cuvier's beaked whales at SOAR. The following values were used: average group size (s) of 3.6 [17]; dive rate (r_d) of 0.42 (average of mean day/night, [18]), proportion of false positives (c) of 0.17 [18], probability of detection (P_D) of 0.86 [18]. The average group size for Blainville's beaked whales in Hawai'i from Baird, 2006 [17] was used, and the average of the Blainville's beaked whale mean day and night dive rates from Baird, 2008 [18] was used as the dive rate. Since Autogrouper detection statistics have not yet been calculated for the PMRF range, the P_D and c values for Blainville's beaked whales on the AUTEC range were used [19]. While the absolute abundance numbers are likely to change once P_D and c are found for PMRF and applied to the data, the trends presented in the plots below will remain unchanged.

Figure 23 shows, for years 2015 through 2018, the periods for which M3R archives are available. Specifically, the plots show the lengths (in min) of the PMRF Blainville's beaked whale dive start group vocal periods (GVPs) plotted on the y-axis against the time of the year. The vertical green lines indicate the starts of periods of effort, and vertical red lines indicate the stops. The displayed gaps in effort (time between stop and start) are at least 24 hours in length.

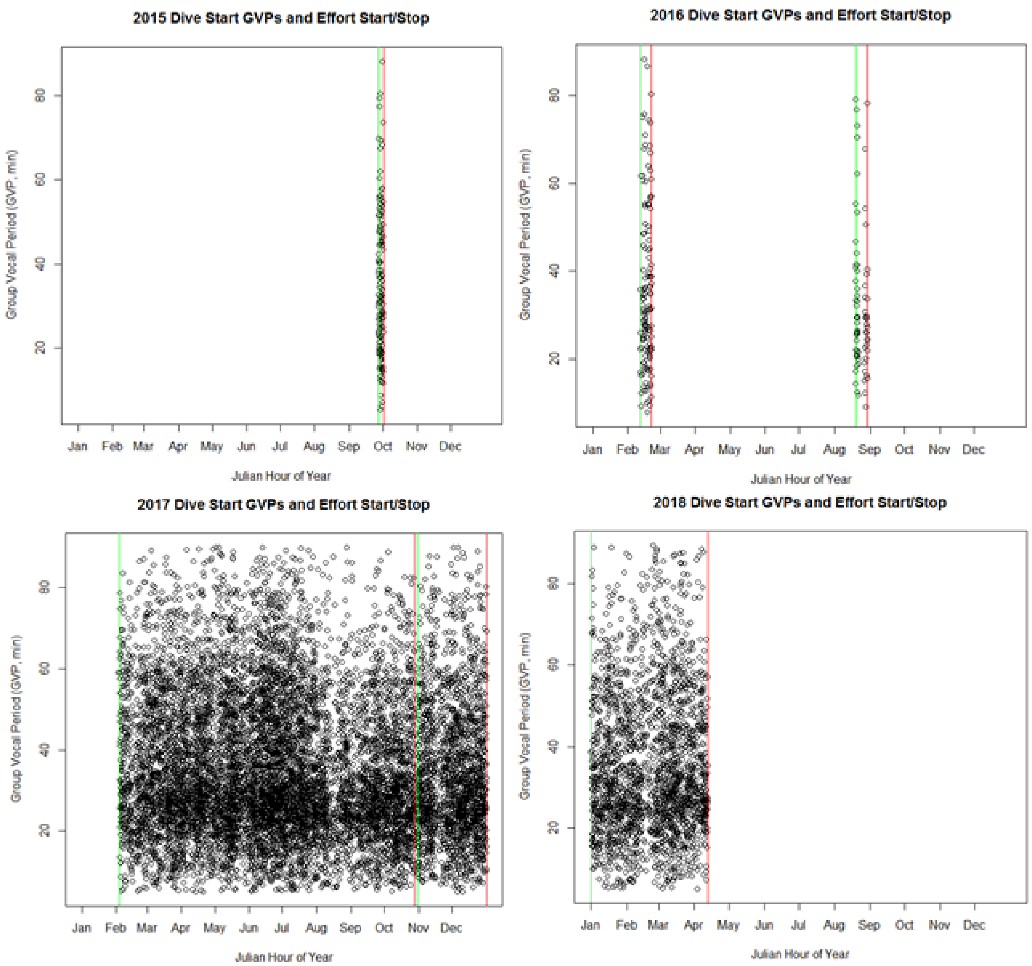

Figure 23. PMRF Blainville's beaked whale dive start GVP lengths (in min) along with effort start (green) and effort stop (red) times indicated with vertical lines for 2015 (upper left), 2016 (upper right), 2017 (lower left), and 2018 (lower right).

Effort start and stop times calculated by finding gaps in effort greater than 24 hours.

Blainville's beaked whale groups were found using the same procedure as for Cuvier's beaked whale groups in section 2.1.3.1, except that CS-SVM Blainville's beaked whale foraging click detections were used rather than Cuvier's beaked whale foraging click detections. The Autogrouper was also set to filter for an ICI between 0.23 and 0.4 sec, rather than between 0.35 and 0.75 sec, as was used for Cuvier's beaked whales at SOAR.

The number of Blainville's beaked whale dive starts per hour of effort, total number of Blainville's beaked whale clicks detected per group per hour of effort, the length of the Blainville's beaked whale GVPs (in min), and Blainville's beaked whale abundance were analyzed.

4.2 PMRF Results

4.2.1 PMRF Blainville's Beaked Whale Abundance

Blainville's beaked whale abundance was calculated at PMRF between 2015 and 2018 using all Blainville's beaked whale groups detected, and the abundance equation 2 in section 2.4. The following values were used: average group size (s) of 3.6 [17]; dive rate (r_d) of 0.42 (average of mean day/night, [18]), proportion of false positives (c) of 0.17, probability of detection (P_D) of 0.86 [19].

The mean PMRF Blainville's beaked whale abundance at any point of time on range within the given year is shown in Table 20 and Figure 24. It has varied from about four to twelve animals.

	2015	2016	2017	2018
upper CI	20.81	7.18	21.81	13.80
mean Blainville's beaked whale abundance	10.90	3.76	11.42	7.23
lower CI	0.98	0.34	1.03	0.65

Table 20. Mean Blainville's beaked whale abundance at PMRF, at any time within the given year, with CI values

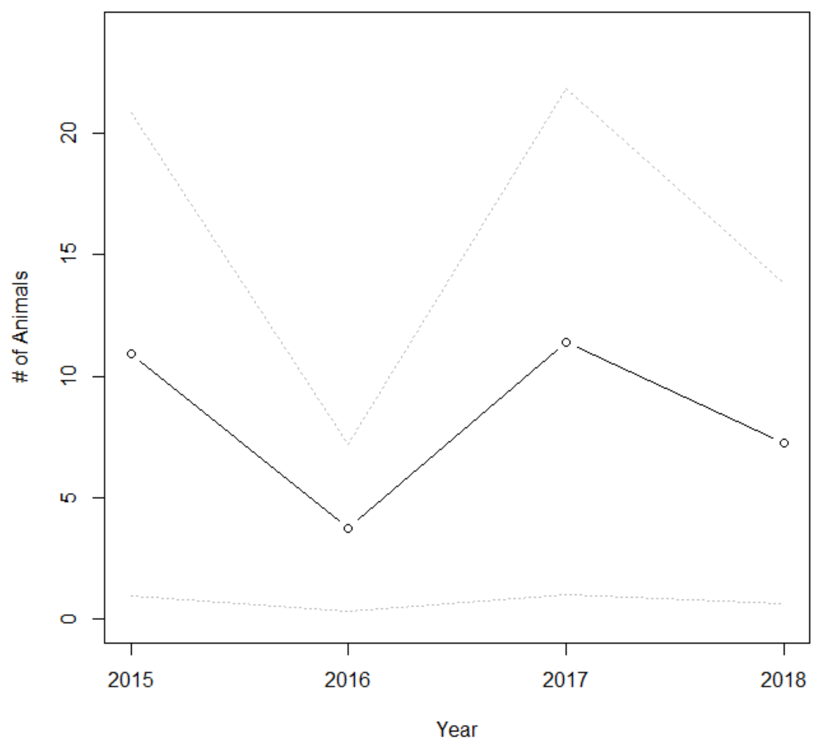

Figure 24. Mean PMRF Blainville's beaked whale abundance per year from 2015-2018.

Dashed lines indicate 95% confidence intervals**.**

Mean monthly Blainville's beaked whale abundances averaged across the years 2015 to 2018 is shown in Table 21 and Figure 25, and the mean Blainville's beaked whale monthly abundance for each year is in Table 22 and Figure 26. This refers to the mean Blainville's beaked whale abundance on range for any point of time within that particular month.

Monthly Blainville's beaked whale abundance appears to peak in June (Figure 25), with the highest value in June of 2017 at 16.56 animals, and then in December. The lowest values are in August and February, with the lowest abundance being 2.57 animals in August, 2016. This should be caveated that several months only have data from one year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	14.17	12.10	18.72	17.87	23.15	31.62	27.12	10.02	19.93	17.03	18.32	24.11
mean monthly Blainville's beaked whale abundance	7.42	6.33	9.80	9.36	12.12	16.56	14.20	5.24	10.44	8.92	9.59	12.62
lower CI	0.67	0.57	0.88	0.84	1.09	1.49	1.28	0.47	0.94	0.80	0.86	1.14

Table 21. Mean monthly Blainville's beaked whale abundances for PMRF averaged across 2015 to 2018.

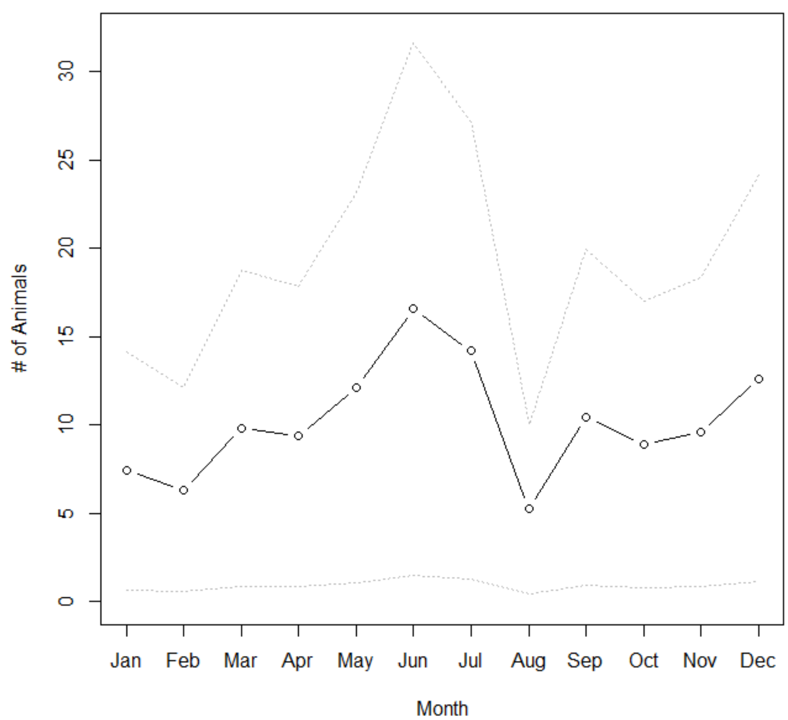

Figure 25. Mean monthly Blainville's beaked whale abundance averaged across years 2015-2018.

Dashed lines indicate 95% confidence intervals.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	11.38	6.66	NA	NA
2016	NA	5.07	NA	NA	NA	NA	NA	2.57	NA	NA	NA	NA
2017	NA	7.96	11.24	12.02	12.12	16.56	14.20	7.92	9.49	11.18	9.59	12.62
2018	7.42	5.97	8.36	6.69	NA	NA	NA	NA	NA	NA	NA	NA

Table 22. Mean monthly Blainville's beaked whale abundances for PMRF 2015-2018.

NA's indicate periods without data.

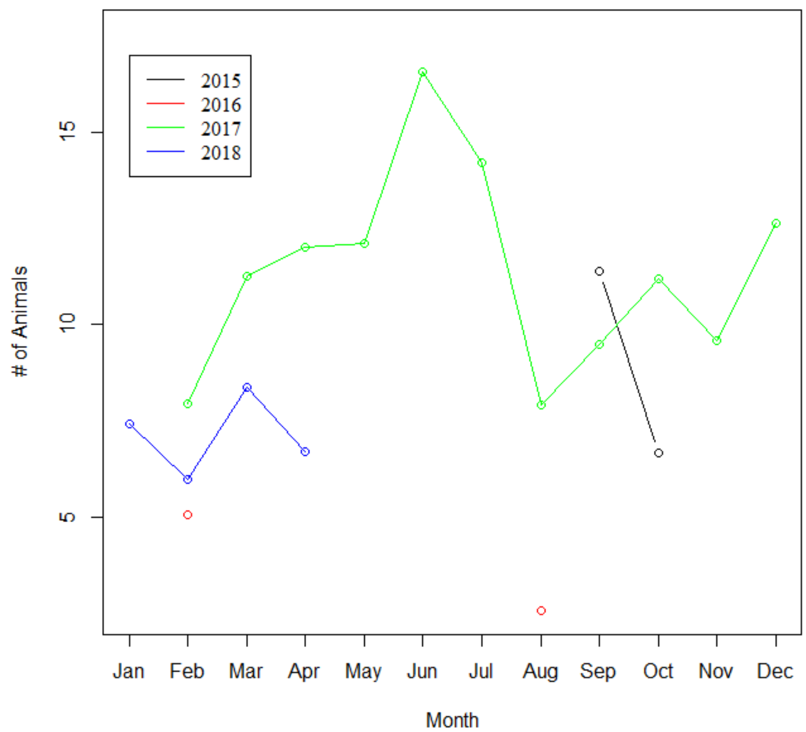

Figure 26. Mean monthly Blainville's beaked whale abundance for 2015-2018.

4.2.2 PMRF Blainville's Beaked Whale Dive Starts per Hour Effort

The mean number of dive starts per hour effort for each month, averaged across the years 2015 through 2018, with the CVs used to calculate the 95% confidence intervals, are shown in Table 23 and Figure 27.

The mean number of dive starts per hour varies from a high of 2.0 per hour of effort across the range in June to a low of 0.78 in August.

The monthly mean number of dive starts per hour of effort for each year is shown in Table 24 and Figure 28.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	1.81	1.75	2.27	2.39	2.68	3.37	2.98	1.77	2.24	2.47	2.27	2.72
mean # dive starts	0.90	0.80	1.18	1.27	1.47	2.00	1.71	0.78	1.17	1.33	1.16	1.53
lower CI	-0.01	-0.14	0.10	0.16	0.25	0.62	0.45	-0.21	0.10	0.19	0.05	0.33
dive start CVs	1.01	1.18	0.92	0.87	0.83	0.69	0.74	1.26	0.92	0.85	0.96	0.78

Table 23. Mean monthly number of PMRF Blainville's beaked whale dive starts per hour effort, averaged across 2015 to 2018.

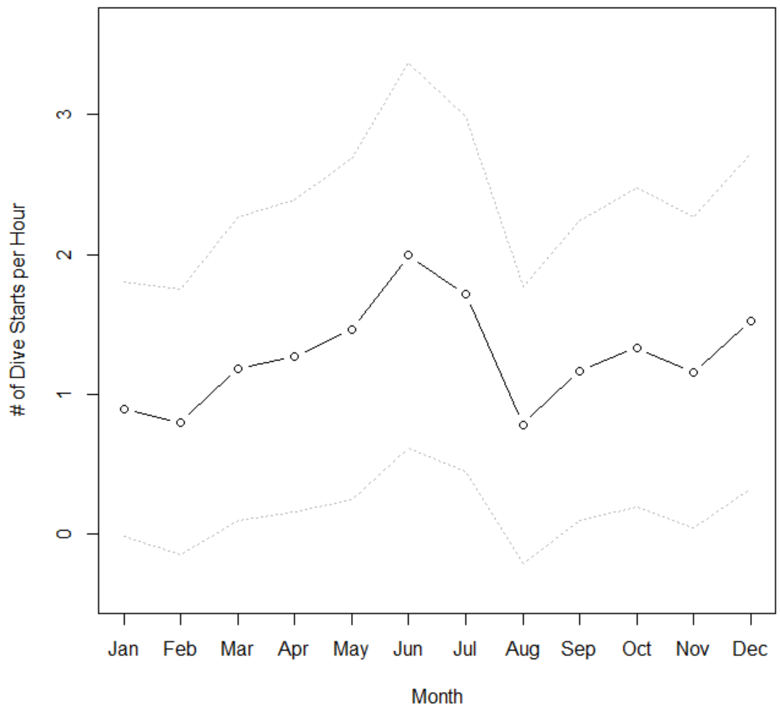

Figure 27. Mean monthly number of PMRF Blainville's beaked whale dive starts per hour effort averaged across 2015 to 2018.

Dashed lines indicate 95% confidence intervals.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	1.36	0.75	NA	NA
2016	NA	0.61	NA	NA	NA	NA	NA	0.31	NA	NA	NA	NA
2017	NA	0.96	1.36	1.45	1.47	2.00	1.71	0.95	1.14	1.34	1.16	1.53
2018	0.90	0.72	1.01	0.81	NA	NA	NA	NA	NA	NA	NA	NA

Table 24. PMRF monthly mean number of Blainville's beaked whale group dive starts for 2015 to 2018.

NA's indicate periods without data.

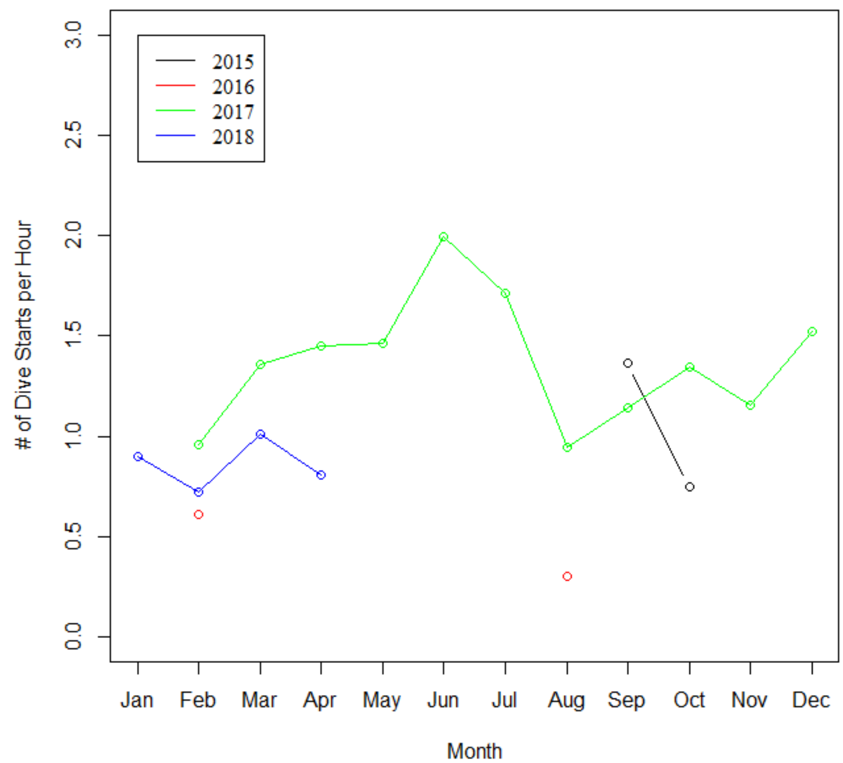

Figure 28. Mean monthly number of PMRF Blainville's beaked whale dive starts per hour effort for 2015 to 2018.

4.2.3 PMRF Blainville's Beaked Whale Group Vocal Period (GVP) lengths

The mean monthly Group Vocal Period (GVP) lengths (in min) of the PMRF Blainville's beaked whale group dives were calculated for 2015 through 2018 (Table 26). The mean Blainville's beaked whale GVP lengths (in min), averaged across 2015 to 2018 for each month, along with the 95% CIs and corresponding CVs are shown in Table 25.

The monthly mean GVP length across all years varies from a high of 37.75 min in June, dropping to a low of 32.08 min in August (Figure 29). The mean monthly GVP lengths (in min) for each year, 2015 through 2018, are shown in Figure 30.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	50.76	53.73	53.60	52.37	54.04	55.69	53.03	47.69	48.01	48.38	51.57	50.81
mean GVP	34.12	35.89	36.32	36.08	36.54	37.75	35.79	32.08	32.43	32.36	34.88	34.19
lower CI	17.48	18.05	19.03	19.79	19.03	19.80	18.56	16.46	16.85	16.33	18.19	17.56
GVP CV	0.49	0.50	0.48	0.45	0.48	0.48	0.48	0.49	0.48	0.50	0.48	0.49

Table 25. Mean PMRF Blainville's beaked whale GVP lengths (in min) per month averaged across 2015 to 2018, with upper and lower confidence intervals (CIs), and the corresponding Coefficients of Variation (CVs).

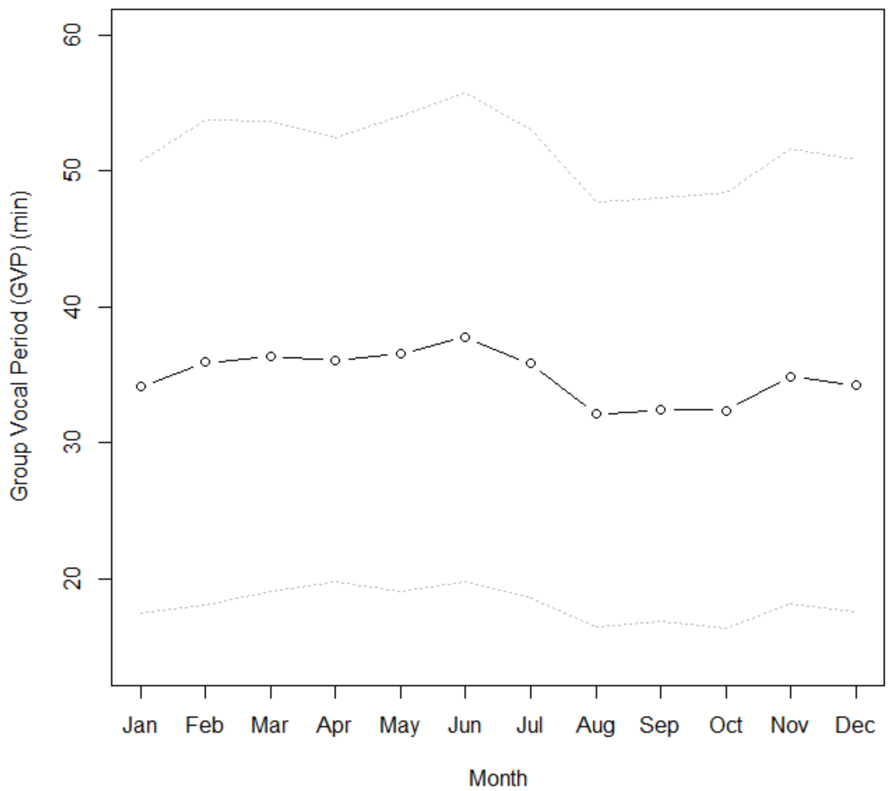

Figure 29. PMRF mean monthly Blainville's beaked whale group vocal period (GVP) lengths (in min), averaged across 2015-2018.

Dashed lines indicate 95% confidence intervals**.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	34.68	36.20	NA	NA
2016	NA	35.11	NA	NA	NA	NA	NA	32.23	NA	NA	NA	NA
2017	NA	35.79	36.44	36.36	36.54	37.75	35.79	32.06	32.05	32.32	34.88	34.19
2018	34.12	36.23	36.16	34.73	NA	NA	NA	NA	NA	NA	NA	NA

Table 26. PMRF mean monthly Blainville's beaked whale group vocal period (GVP) lengths (in min) for 2015 to 2018.

NA's indicate periods without data.

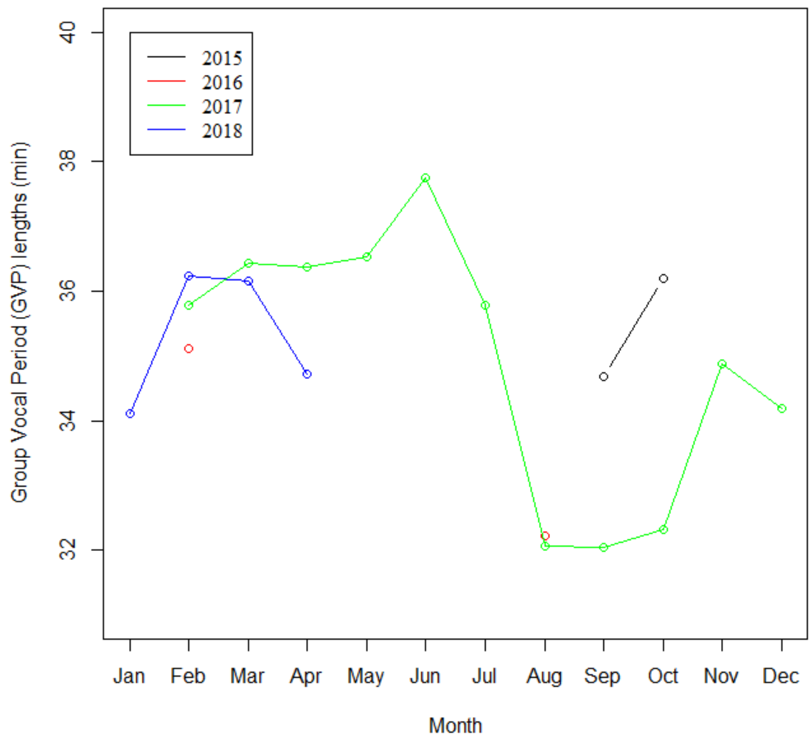

Figure 30. Mean monthly group vocal period (GVP) lengths (in min) for Blainville's beaked whales at PMRF for 2015 to 2018.

4.2.4 PMRF Blainville's Beaked Whale Mean Number of Foraging Clicks per Group

The mean number of Blainville's beaked whale foraging clicks detected per group per month for the years 2015 through 2018 are shown in Table 28. The number of Blainville's beaked whale foraging clicks detected per group, averaged across 2015 to 2018 for each month, along with the 95% confidence intervals CIs and corresponding CVs are shown in Table 27.

The monthly mean varies from 1288 clicks per group in January to 1955 in June. The monthly mean across years is shown in Figure 31, and the monthly means for each year in Figure 32.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	2576.6	3235.2	3793.6	3871.2	4372.2	4113.0	3863.7	2988.6	4114.4	3246.0	3591.0	3681.0
mean group click count	1287.9	1561.7	1710.1	1820.5	1895.6	1954.5	1793.9	1453.9	1801.5	1536.6	1558.2	1651.4
lower CI	-0.8	-111.8	-373.4	-230.1	-581.1	-204.0	-275.9	-80.8	-511.4	-172.9	-474.6	-378.3
group click count CV	1.0	1.1	1.2	1.1	1.3	1.1	1.2	1.1	1.3	1.1	1.3	1.2

Table 27. Mean PMRF Blainvlle's beaked whale number of clicks per group averaged across 2015 to 2018, with upper and lower confidence intervals (CIs), and the corresponding Coefficients of Variation (CVs).

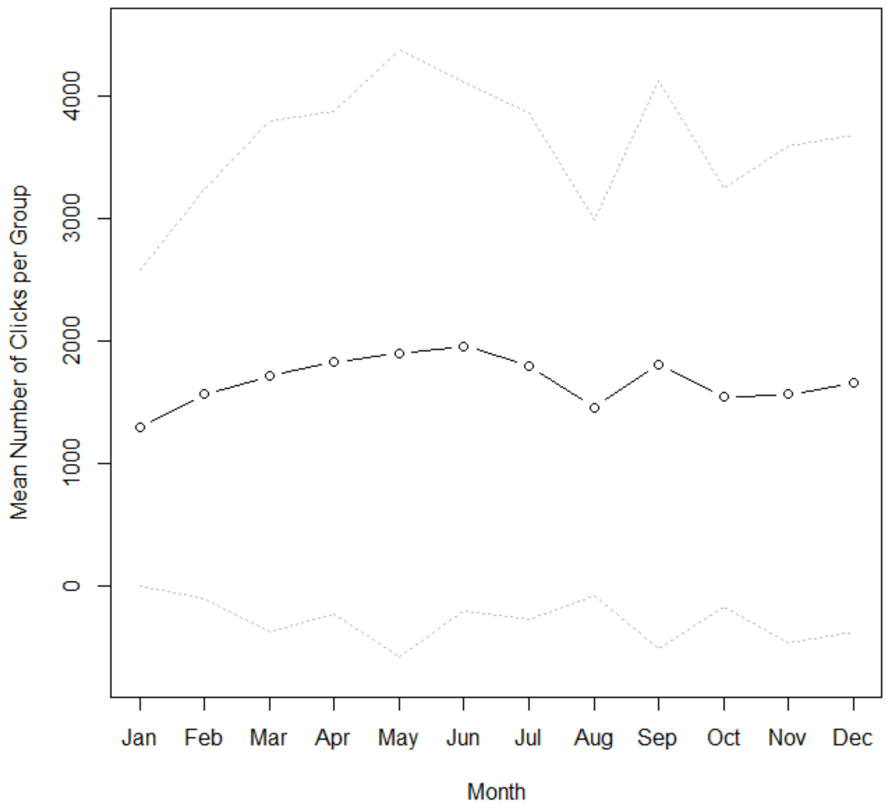

Figure 31. Mean monthly number of Blainville's beaked whale clicks detected per group at PMRF, averaged across 2015-2018.

Dashed lines indicate 95% confidence intervals.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	1442.2	1409.1	NA	NA
2016	NA	1706.0	NA	NA	NA	NA	NA	1118.3	NA	NA	NA	NA
2017	NA	1672.6	1937.1	1866.5	1895.6	1954.5	1793.9	1491.6	1861.9	1537.8	1558.2	1651.4
2018	1287.9	1383.5	1404.1	1603.0	NA	NA	NA	NA	NA	NA	NA	NA

Table 28. PMRF mean monthly number of Blainville's beaked whale clicks per group for 2015 to 2018.

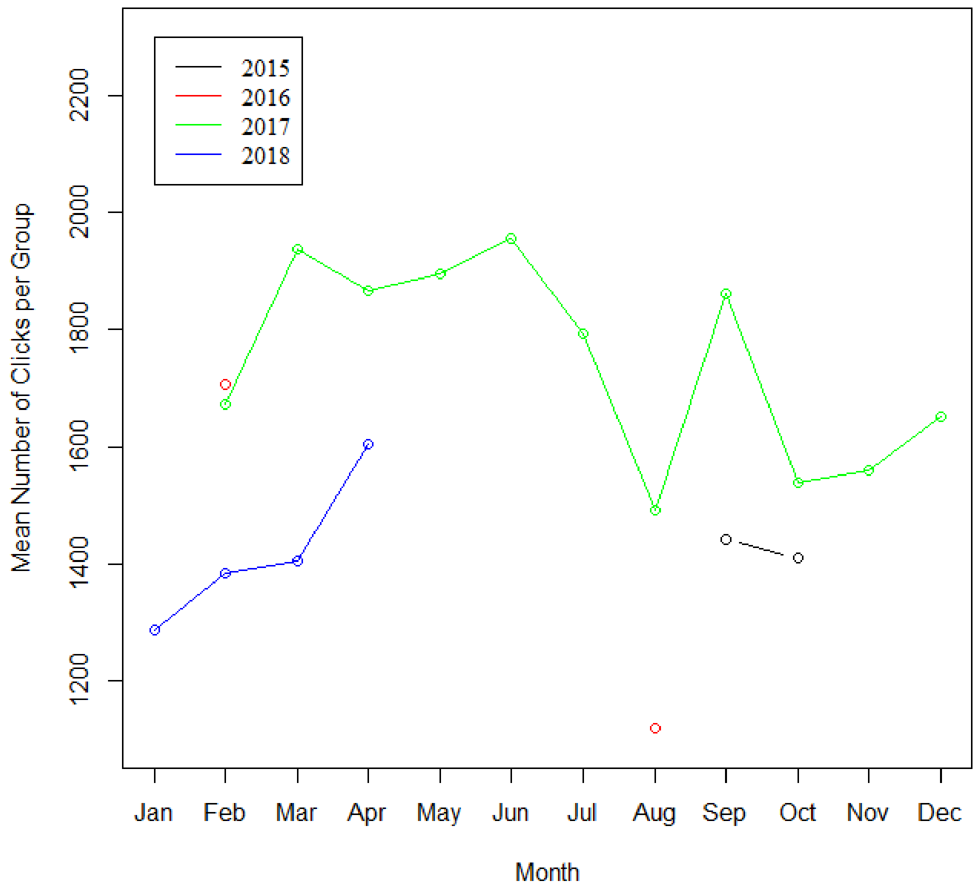

Figure 32. Mean monthly number of Blainville's beaked whale clicks detected per group at PMRF for the years 2015 through 2018.

5.0 PMRF: Beaked whale foraging behavior before, during, and after sonar exposure

An initial analysis was conducted to examine the mean number of Blainville's beaked whale dive starts per hour before, during, and after presumed mid-frequency active sonar (MFAS) events at PMRF in 2017 and 2018. Sixteen events were evaluated in 2017, and seven in 2018. Periods in which the sonar detector output met or exceeded the maximum level of the system were considered. The sonar detector is an energy detector for frequency bands consistent with MFAS; thus these detections indicate a high likelihood of MFAS being present on the range. It is possible that other sound sources triggered the detections; however, for this analysis these periods are considered as probable MFAS. These data need to be corroborated with range schedules and a manual review of the data.

The time periods of probable MFAS varied from one to six consecutive days. In most cases the mean number of dive starts were calculated for the period during MFAS, and an equivalent number of days before and after the MFAS event. Only periods in which there was at least one full day without MFAS prior to the 'before' period were considered, to allow for a potential recovery period of 24 hours after a previous MFAS event. In two cases, however (one in 2017 and one in 2018), MFAS occurred on numerous days with one to two or three days without MFAS in between, and these were combined as two larger events. Thus in 2017 the following sequence occurred: two days with MFAS, one day without MFAS, one day without data available on MFAS, one day without MFAS, and four days with MFAS. These nine days were combined, and eight days were examined before and after this period, as only eight were available without MFAS for the 'before' period. In Table 29 this entry is indicated as "6 (9)," with 6 being the number of days in the period with known MFAS, and 9 being the total number of days in the period. In 2018 this sequence occurred: two days with MFAS, one day without MFAS, and six days with MFAS. These nine days were combined as a single larger event, and seven days before and after the event were examined, as only seven days of data were available beforehand. The entry "8 (9)" in Table 30 references to the 8 days with MFAS out of the 9 day period.

Table 29 shows, for 2017, and Table 30 for 2018, the mean number of dive starts per hour before, during, and after each event, along with the number of days in each event. The bottom rows indicate the ratio of mean number of dive starts during MFAS to before MFAS, and the ratio of the mean dive starts after MFAS to during MFAS.

PMRF 2017	Mean Number of Dive Starts (DS) per Event															
Pre-MFAS # DS	1.07	1.15	1.17	0.88	1.71	1.79	1.42	1.92	1.79	1.35	1.17	1.21	1.75	1.83	1.58	1.25
MFAS # DS	0.32	0.96	1.04	0.75	1.10	1.08	1.10	1.63	1.04	0.63	1.00	1.33	1.29	1.21	1.22	1.42
Post-MFAS # DS	0.93	1.29	1.25	0.75	1.94	1.21	1.15	1.04	1.42	0.86	1.50	1.46	1.50	1.38	0.64	1.67
# Days/Event	3	3	1	1	2	1	2	1	1	6 (9)	1	1	1	1	3	1
MFAS / Pre	0.30	0.83	0.89	0.86	0.65	0.60	0.78	0.85	0.58	0.46	0.86	1.10	0.74	0.66	0.77	1.13
Post / MFAS	2.91	1.35	1.20	1.00	1.75	1.12	1.04	0.64	1.36	1.38	1.50	1.09	1.16	1.14	0.52	1.18

Table 29. Mean number of dive starts before, during, and after presumed MFAS events at PMRF in 2017. The number of days per MFAS event are indicated, along with the ratio of mean number of dive starts during/before, and after/during.

PMRF 2018	Mean Number of Dive Starts (DS) per Event						
Pre-MFAS # DS	0.80	0.44	0.63	0.96	1.11	0.96	0.88
MFAS # DS	0.89	0.35	0.67	1.16	1.04	0.92	1.00
Post-MFAS # DS	0.80	0.50	1.02	0.81	0.94	1.21	1.04
# Days	8 (9)	2	2	4	3	1	1
MFAS / Pre	1.11	0.81	1.07	1.21	0.94	0.96	1.14
Post / MFAS	0.91	1.41	1.53	0.70	0.91	1.32	1.04

Table 30. Mean number of dive starts before, during, and after presumed MFAS events at PMRF in 2018. The number of days per MFAS event are indicated, along with the ratio of mean number of dive starts during/before, and after/during.

Figure 33 and Figure 34 show, for 2017 and 2018, respectively, the mean number of dive starts before, during, and after each probable MFAS event. In eleven of the sixteen events in 2017 the mean number of dive starts per hour is lower during MFAS than before or after. In one case it decreases during the event and remains the same after, and there are two events each in which the mean number of dive starts either decreased or increased throughout.

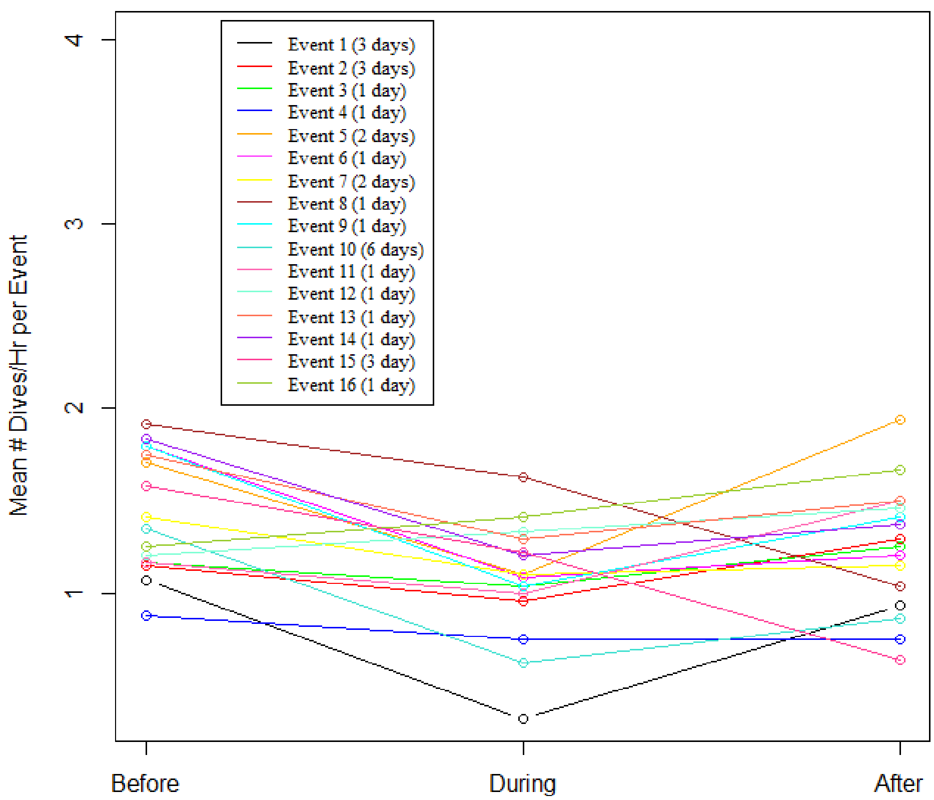

Figure 33. PMRF 2017 mean number of dive starts per hour before, during, and after sixteen presumed MFAS events.

In 2018 there is more variability in the results. Of the seven events, there are two in which there are fewer dive starts during MFAS than before or after, two with more dive starts during than before or after, two with the number of dive starts increasing through, and one with decreasing numbers throughout.

However, this is an initial analysis, with a number of caveats. The sonar detector data needs to be verified, as it is possible other loud sources in the frequency band could trigger the detections. In addition, a day is considered to have MFAS on range if the sonar detector output exceeds threshold at least once during the day. This could occur if a sonar was operating continuously for the time period, or if it only operated for a very short time. Thus a more fine-grained analysis should be carried out. Finally, the two larger events included days in which no MFAS was detected, and the 'during' time periods were compared to shorter 'before' and 'after' periods.

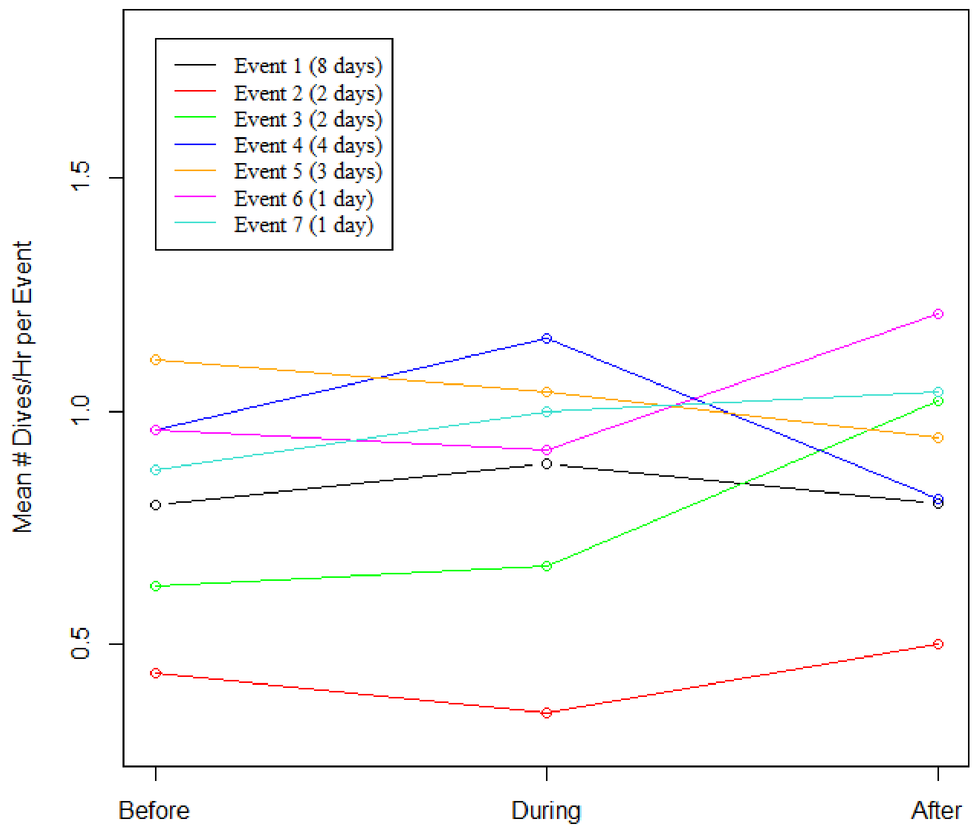

Figure 34. PMRF 2018 mean number of dive starts per hour before, during, and after seven presumed MFAS events.

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