Marine Mammal Monitoring on Navy Ranges (M3R) for Beaked Whales on the Southern California Anti-Submarine Warfare Range (SOAR) and the Pacific Missile Range Facility (PMRF) 2019

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14. ABSTRACT
Beaked whale abundance and vocal behavior were examined at two different U. S. Navy training ranges: for Cuvier's beaked whale (Ziphius cavirostris) at the Southern California Anti-Submarine Warfare Range (SOAR) between August 2010 through October 2019, and for Blainville's beaked whales (Mesoplodon densirostris) at the Pacific Missile Range Facility (PMRF) between 2015 and 2018. The yearly and monthly abundance, mean number of group vocal periods (GVPs), mean duration of the GVPs in minutes, and the mean number of clicks detected per beaked whale group were calculated.

At SOAR, 49,691 hours of data were processed. The Cuvier's beaked whale abundance has increased significantly over the 10-year period from 2010 to 2019, as has the mean number of GVPs per hour on the range. Cuvier's beaked whale abundance peaks in January and reaches its lowest point in September, with another smaller dip in March. The Cuvier's beaked whale monthly mean number of GVPs per hour is highest in May and lowest in September. A total of 14,068 hours of data were processed at PMRF. At PMRF the Blainville's beaked whale abundance peaks in May and is lowest in February, while the mean number of GVPs per hour is highest in June and lowest in February. Aside from the lower abundance in 2016, the mean abundance per year between 2015 and 2018 has remained fairly constant. At both SOAR and PMRF the mean duration of the GVPs and the mean number of clicks per group follows a similar, but less pronounced, seasonal pattern as the abundance.

Cuvier's beaked whales forage primarily on the western and southwestern parts of the SOAR range. There are a significantly higher mean number of GVPs per hydrophone per year, averaged from 2010 to 2019, for the cool season (winter and spring) than for the warm season (summer and fall). This may be due to an increase in the availability of beaked whale prey from upwelling in the cool season.

At SOAR the number of days of Mid-Frequency Active Sonar (MFAS) and number of GVPs detected per effort month were calculated for 2019, for the year with the maximum number of days of MFAS, and for the mean from 2010 through 2019. There is weak evidence that the percentage of the effort month with sonar was significantly lower in 2019 than in the year with the maximum sonar, and that the number of GVPs per effort month was significantly higher.

The number of GVPs were examined before, during, and after a series of MFAS events at SOAR in 2018 and 2019. Most events were under ten hours in length, and the majority showed either a decrease in number during MFAS and increase after, or a decreasing number throughout the event and post-event period. For the 2018 data the Before-During and Before-After periods had a significantly different mean number of GVPs, whereas the During-After periods did not. There were no significant differences between time periods for the 2019 data. The time periods examined before and after the events were the same length as the events. Since these were mostly short periods, the recovery time examined afterwards may not have been sufficiently long in all cases to show a recovery to pre-event numbers of GVPs. This indicates that the recovery times are longer than on the order of several hours. A similar analysis was carried out at PMRF, with no significant differences found among the Before, During, and After periods. However, only eleven short events met the criteria laid out, and the low sample size may have been insufficient to show patterns between the time periods.

Field efforts are carried out at SOAR in conjunction with Marine Ecology and Telemetry Research (MarEcoTel) and at PMRF with the Cascadia Research Collective (CRC). Five field efforts were conducted in 2019 at SOAR, and though none occurred in 2019 at PMRF, there was one field test at PMRF in 2018. During these field efforts M3R personnel use the M3R monitoring tools to find animals on the range, and direct on-water researchers in RHIBs to these animals, where photo-IDs, behavioral data and/or biopsy data are collected, and satellite tags may be placed on animals. The methods used and typical species acoustically detected are presented.

15. SUBJECT TERMS
Acoustic monitoring, marine mammals, beaked whales, Southern California Anti-Submarine Warfare Range, Pacific Missile Range Facility, Hawaii Range Complex, Southern California Range Complex

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Acronyms

ASW	Anti-Submarine Warfare
AUTEC	Atlantic Undersea Test and Evaluation Center
BARSTUR	Barking Sands Tactical Underwater Range
BSURE	Barking Sands Underwater Range Expansion
CI	Confidence Interval
CRC	Cascadia Research Collective
CS-SVM	Class-Specific Support Vector Machine classifier
CTP	Click Train Processor
CV	Coefficient of Variation
DCL	Detection, Classification and Localization
FFT	Fast Fourier Transform
GVP	Group Vocal Period
FP	False Positive
ICI	Inter-Click Interval
IQR	Inter-Quartile Range
kHz	kilohertz
LIMPET	Low Impact Minimally Percutaneous Electronic Transmitter
LMR	Living Marine Resources
M3R	Marine Mammal Monitoring on Navy Ranges
MarEcoTel	Marine Ecology and Telemetry Research
MFAS	Mid-Frequency Active Sonar
Min	Minutes
MMAMMAL	Marine Mammal Monitoring And Localization
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
T	Time
Tukey's HSD	Tukey's Honest Significant Difference test
Whdetect	Whale Detection algorithm

1.0 Executive Summary

Beaked whale abundance and vocal behavior were examined at two different U. S. Navy training ranges: for Cuvier's beaked whale (*Ziphius cavirostris*) at the Southern California Anti-Submarine Warfare Range (SOAR) between August 2010 through October 2019, and for Blainville's beaked whales (*Mesoplodon densirostris*) at the Pacific Missile Range Facility (PMRF) between 2015 and 2018. The yearly and monthly abundance, mean number of group vocal periods (GVPs), mean duration of the GVPs in minutes, and the mean number of clicks detected per beaked whale group were calculated.

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Field efforts are carried out at SOAR in conjunction with Marine Ecology and Telemetry Research (MarEcoTel) and at PMRF with the Cascadia Research Collective (CRC). Five field efforts were conducted in 2019 at SOAR, and though none occurred in 2019 at PMRF, there was one field test at PMRF in 2018. During these field efforts M3R personnel use the M3R monitoring tools to find animals on the range, and direct on-water researchers in RHIBs to these animals, where photo-IDs, behavioral data and/or biopsy data are collected, and satellite tags may be placed on animals. The methods used and typical species acoustically detected are presented.

2.0 Southern California Anti-Submarine Warfare Range (SOAR)

SOAR is located in the San Nicolas Basin west of San Clemente Island, CA (Figure 1). 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 [1] [2] [3]. The SOAR range consists of an array of 178 bottom-mounted hydrophones covering an area of about 1800 km^2 (Table 1).

The SOAR hydrophone baselines range from about 2.5 to 6.5 km, and are at average depths of 1600-1800 m. The 89 original, or legacy, hydrophones have a bandwidth of ~8 to 40 kilohertz (kHz), while the newer refurbished 89 hydrophones have a bandwidth of ~50 Hz to 48 kHz [4].

Table 1. SOAR hydrophone numbers and approximate bandwidths.

Hydrophone #	Legacy/Refurbished	Bandwidth
1 to 89	Legacy	~8 to 40 kHz
101 to 110	Refurbished	~50 Hz to 48 kHz
201 to 210	Refurbished	~50 Hz to 48 kHz
301 to 310	Refurbished	~50 Hz to 48 kHz
401 to 410	Refurbished	~50 Hz to 48 kHz
501 to 509	Refurbished	~50 Hz to 48 kHz
601 to 609	Refurbished	~50 Hz to 48 kHz
701 to 710	Refurbished	~50 Hz to 48 kHz
801 to 810	Refurbished	~50 Hz to 48 kHz
901 to 911	Refurbished	~50 Hz to 48 kHz

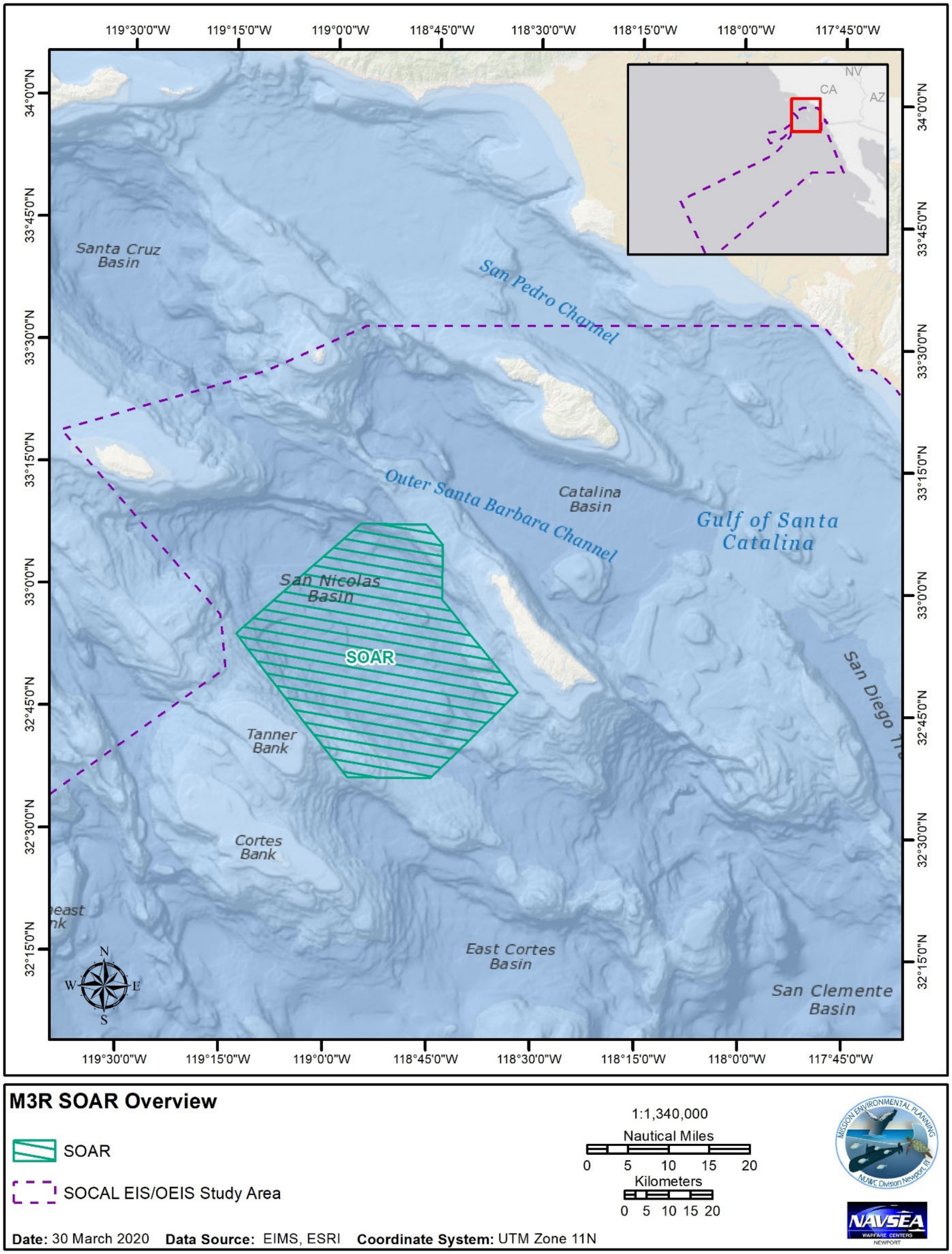

Figure 1. Location of SOAR hydrophone range, west of San Clemente Island off southern California.

2.1 SOAR Field Tests with Marine Ecology & Telemetry Research (MarEcoTel)

In 2019 M3R conducted five field tests in conjunction with Marine Ecology and Telemetry Research (MarEcoTel) in support of photo-ID and tagging of marine mammals. MarEcoTel personnel transit to San Clemente Island in their Rigid Hull Inflatable Boats (RHIBs) from the mainland during these field tests, and work from the island. They typically depart from San Clemente Island at sunrise to transit onto the SOAR range. During these tests M3R personnel use the M3R system to acoustically monitor animals on the range and direct MarEcoTel to their locations. Upon finding animals MarEcoTel will collect photo-ID and behavioral data and biopsy samples, and will potentially place Sound and Motion Recording Tags (SMRT tags) or Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite tags on individuals, depending on the focus of the particular effort. The focus for this effort has been Cuvier's beaked and fin whales, though data on other species has been collected.

M3R personnel work from a conference room at the Range Operations Center (ROC) at Naval Air Station North Island. The system is set up, and broken down and stored, at the beginning and end of each field test. They monitor the system, keeping track of species acoustically detected throughout the day, including baleen whales, but usually with a focus on tracking Cuvier's beaked whale group locations. These data and additional notes are recorded in a Logger program; raw acoustic data from the whole range or from selected hydrophones may be recorded; and all detections, localizations, and ancillary data are automatically saved to binary archive files ('spc archive' files) on a continuous basis.

M3R personnel use both a real-time review of binary spectrograms and output from the Class-Specific Support Vector Machine classifier (CS-SVM) classifier and Fast Fourier Transform (FFT) detector via a click train viewer display in order to identify relevant species (see Section 2.2.1.1 for more details). Both the MMAMMAL and WorldWind display show animal localizations ('posits'), with each having a different method of indicating the highest confidence posits. M3R personnel use these posits or dead-reckoning from the binary spectrograms to direct the on-water personnel to the locations of animals of interest. Communications are maintained throughout the day, via satellite texts, radio, and cell phone, to relay information such as animal locations and the start and stop times of vocalizing beaked whale groups. Table 2 lists the cetacean species acoustically identified using the M3R system during field tests between November 2018 and November 2019, along with summary information extracted from the associated SOAR field logs. More detailed information extracted from these field logs can be found in Appendix A.

A total of 651 acoustic sightings were logged, including 589 of Cuvier's beaked whales, 25 of fin whales, 15 of Risso's dolphins, eight of unidentified dolphin's, eight of unidentified baleen whales, and one each of sperm, blue, and gray whales. During these logged sightings, a total number of 77 acoustic sightings were directed, including 67 to Cuvier's beaked whales, seven to fin whales, one to Risso's dolphins, and two to unidentified baleen whales. Twenty-seven acoustic sightings were also visually verified. Ten satellite tags were placed on animals, including seven on Cuvier's beaked whales, one on a Risso's dolphins, and two on fin whales (Table 2).

Table 2. Species acoustically identified with the M3R system or visually sighted on SOAR Data are extracted from field test logs between November 2018 and November 2019.

Species (Abbreviation)	Species (Common Name)	Species (Scientific Name)	# Acoustic Sightings Logged	# Acoustic Sightings Directed	# Acoustic Sightings Visually Verified	# of Tags
Zc	Cuvier's beaked whale	*Ziphius cavirostris*	589	67	25	7
Gg	Risso's dolphin	*Grampus griseus*	15	1	1	1
Pm	Sperm whale	*Physeter macrocephalus*	1	0	0	0
Bp	Fin whale	*Balaenoptera physalus*	25	7	6	2
Mn	Humpback whale	*Megaptera novaeangliae*	3	0	1	0
Bm	Blue whale	*Balaenoptera musculus*	1	0	0	0
Er	Gray whale	*Eschrichtius robustus*	1	0	0	0
UD	unidentified dolphin	Delphinidae sp.	8	0	0	0
UM	unidentified baleen whale	Mysticeti sp.	8	2	0	0

Raven Pro Sound Analysis Software (Cornell University, Ithaca, NY) has been modified to stream M3R data and is available to view individual hydrophones on demand. Figure 2 shows examples of Cuvier's beaked whale clicks detected by M3R on the SOAR range in both Raven Pro and the M3R FFT spectrogram displays.

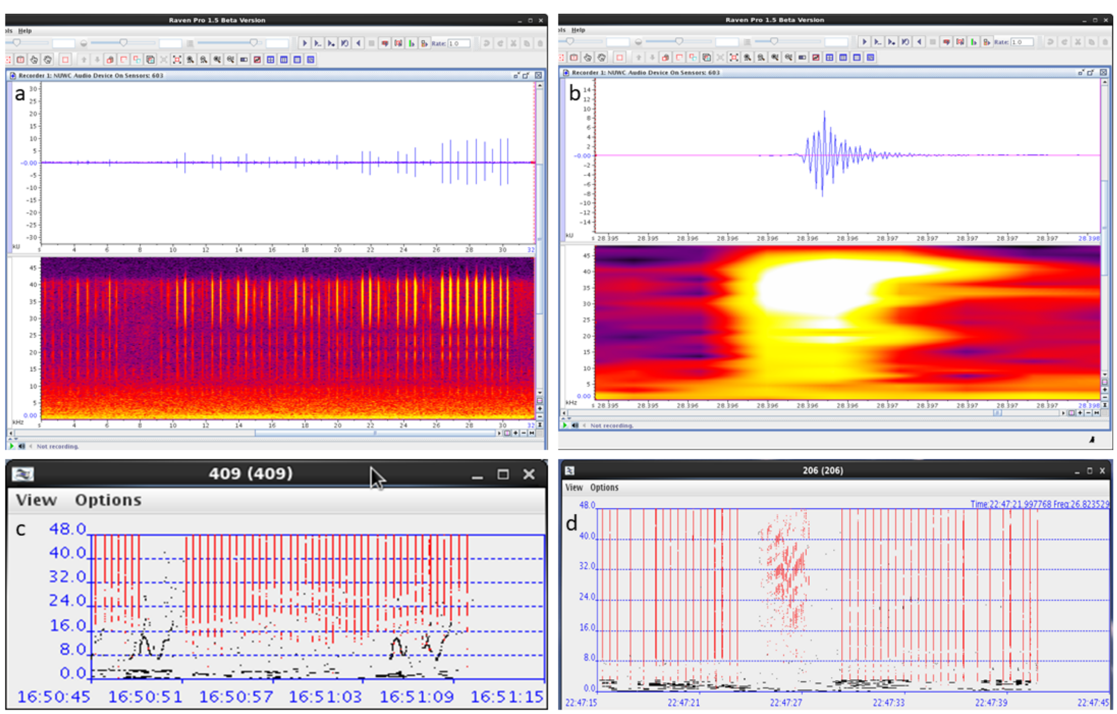

Figure 2. Examples of Cuvier's beaked whale clicks detected by M3R on the SOAR range.

a) Cuvier's beaked whale click train time series (top) and spectrogram (bottom) in Raven Pro; b) a single Cuvier's beaked whale click (top) and spectrogram (bottom) in Raven Pro; c) Cuvier's beaked whale click train time series and dolphin whistles in an M3R binary spectrogram display; and d) Cuvier's beaked whale click train time series with a buzz in an M3R binary spectrogram display.

Risso's dolphin (*Grampus griseus*) clicks, as they appear on the M3R binary spectrogram displays, are shown in Figure 3. At times Risso's dolphin click trains resemble Cuvier's beaked whale clicks and cause misidentifications over short time intervals.

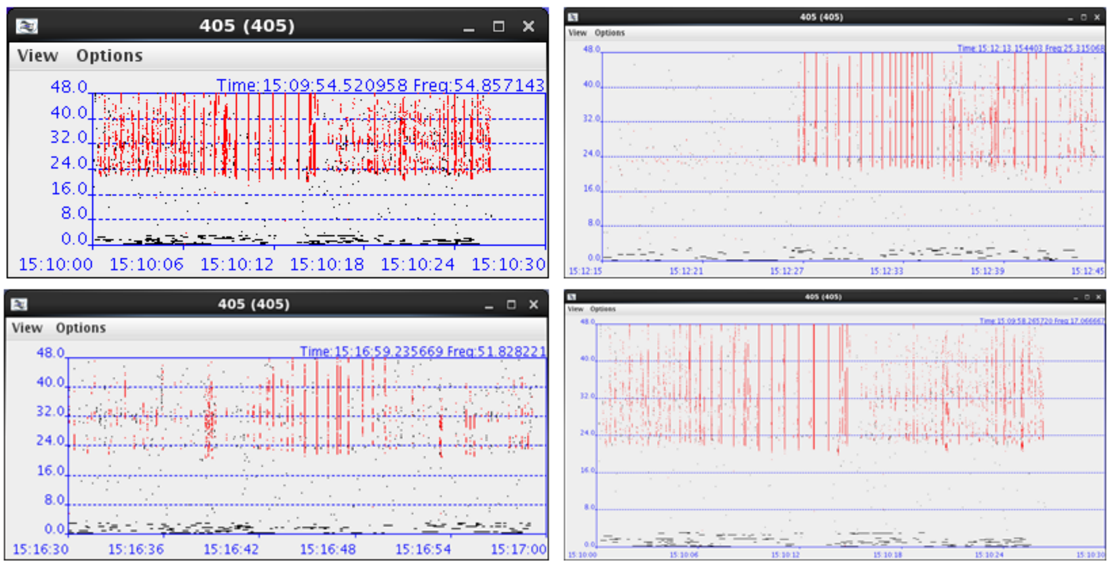

Figure 3. Examples of Risso's dolphin clicks on the M3R spectrogram displays. Risso's dolphin clicks can be misidentified as Cuvier's beaked whales over short time intervals.

Short-beaked common dolphin (*Delphinus delphis*) (Figure 4) are very frequently found on the range, more often on the eastern side.

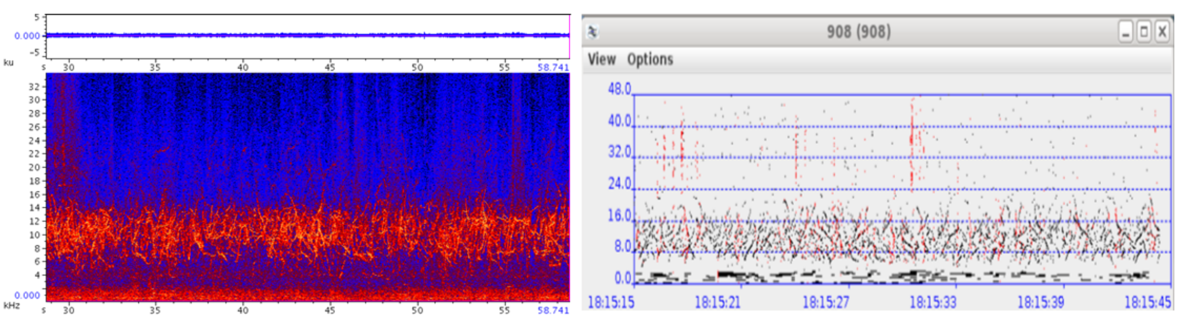

Figure 4. Short-beaked common dolphin whistles *(left)* in Raven Pro, and *(right)* on an M3R spectrogram display.

In 2019 the two primary species of interest were Cuvier's beaked whales and fin whales (*Balaenoptera physalus*). Fin whales are typically identified by their 20-30 Hz downsweep calls (Figure 5). Other baleen whales typically detected at SOAR include humpback whales (*Megaptera* *novaeangliae*) (Figure 6) and blue whales (*Balaenoptera musculus*) (Figure 7, Figure 8, and Figure 9). Baleen whales are detected with the low-frequency version of the FFT-based detector.

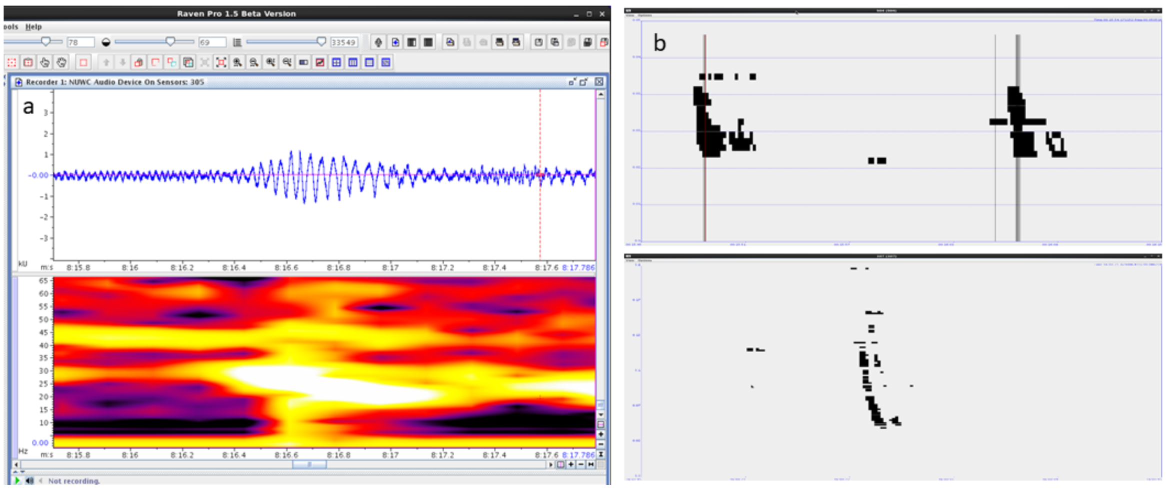

Figure 5. Fin whale 20-30 Hz downsweeps detected at SOAR.
a) single downsweep time series (top) and spectrogram (bottom) in Raven Pro; b) examples of downsweeps using the M3R binary spectrograms.

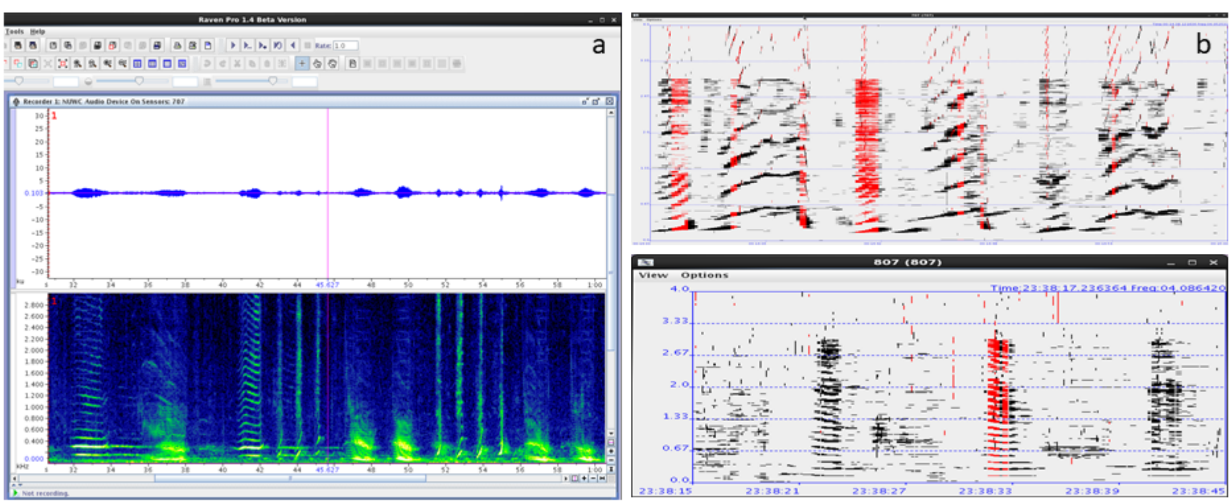

Figure 6. Humpback whales vocalizations detected at SOAR.
a) time series (top) and spectrogram (bottom) in Raven Pro; b) examples of humpback whale vocalizations using the M3R binary spectrograms.

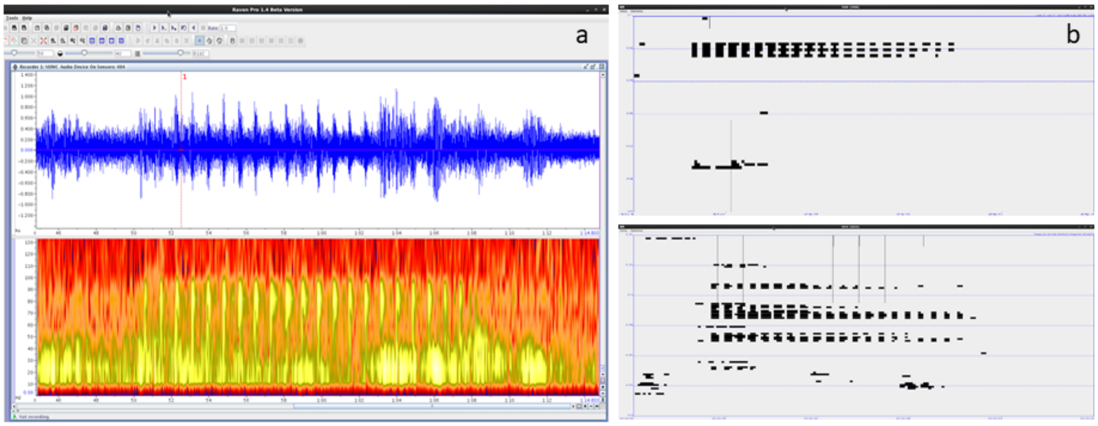

Figure 7. Blue whale A calls detected at SOAR.
a) time series (top) and spectrogram (bottom) in Raven Pro; b) examples of blue whale A calls using the M3R binary spectrograms.

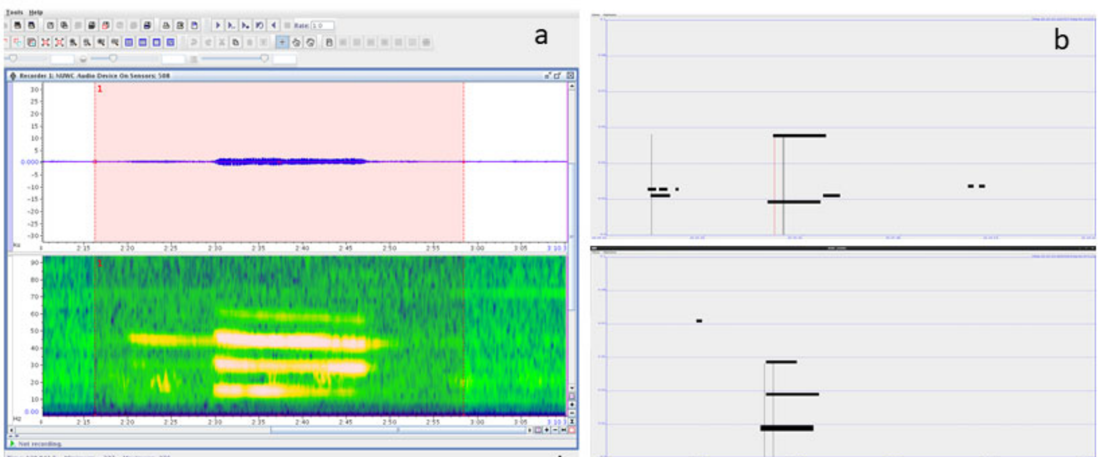

Figure 8. Blue whale B calls detected at SOAR.
a) time series (top) and spectrogram (bottom) in Raven Pro; b) examples of blue whale B calls using the M3R binary spectrograms.

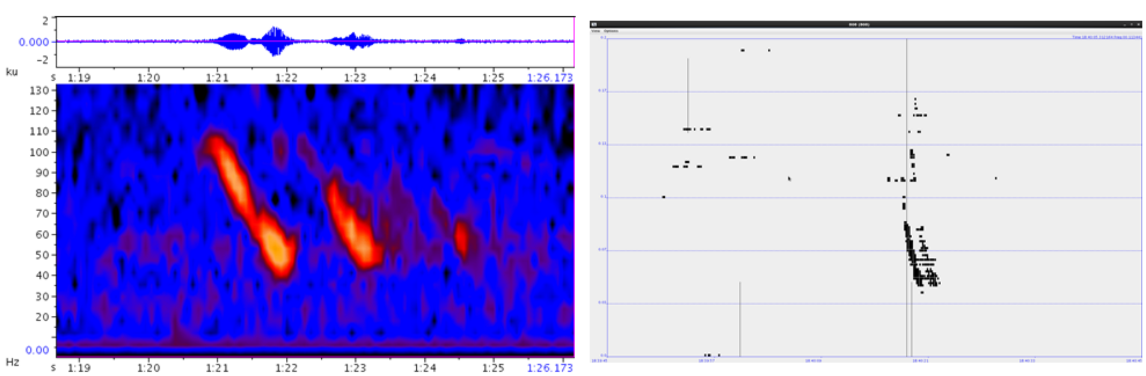

Figure 9. Blue whale D call detected at SOAR.

a) time series (top) and spectrogram (bottom) in Raven Pro; b) example of a blue whale downsweep call using the M3R binary spectrograms.

Killer whales (*Orcinus orca*) (Figure 10) and sperm whales (*Physeter macrocephalus*) (Figure 11) are occasionally detected on the SOAR range, among other species.

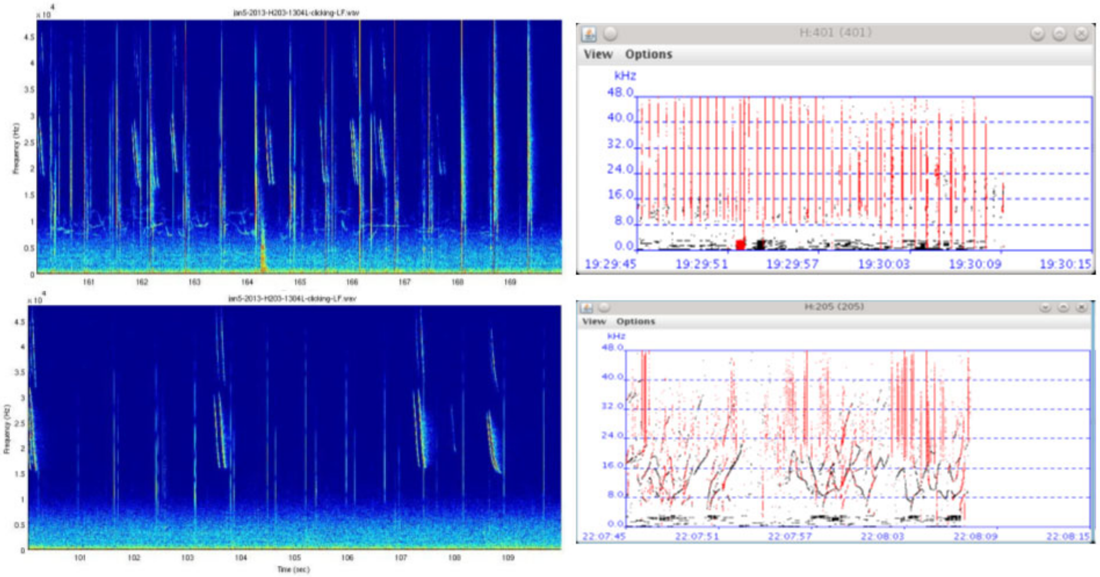

Figure 10. Killer whale calls (clicks and whistles) detected at SOAR.

a) spectrograms in Raven Pro; b) clicks and whistles using the M3R binary spectrograms.

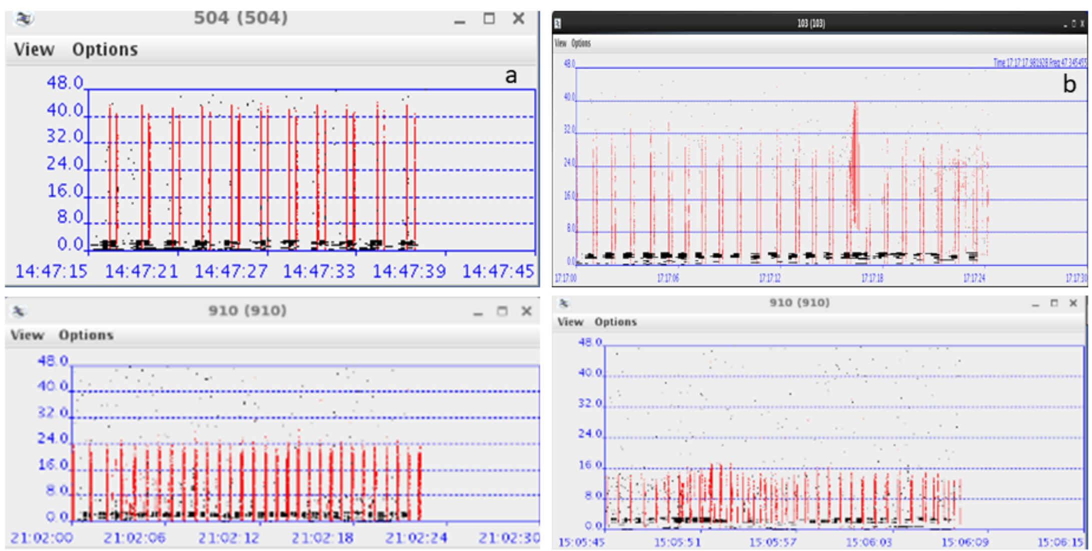

Figure 11. Sperm whale echolocation clicks detected at SOAR.
Examples of sperm whale echolocation clicks using the M3R binary spectrograms, with a possible creak in the upper right image. A sperm whale creak is a rapid series of clicks emitted just prior to a prey capture attempt.

2.2 Long-Term Monitoring of Cuvier's Beaked Whales at SOAR

2.2.1 SOAR Methods

2.2.1.1 SOAR Data

In 2006 the M3R program installed a real-time passive acoustic system to automatically detect, classify and localize (DCL) marine mammals using the SOAR hydrophones [4]. The system 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 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 FFT-based spectral energy detector (called 'Whdetect') and a CS-SVM classifier.

<u>FFT-based spectral energy detector</u>- 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 indicating the frequency band with the most energy (Table 3).

Table 3. Click types for the full-bandwidth FFT-based energy detector.

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

<u>Class-specific support vector machine (CS-SVM) classifier</u>- The CS-SVM classifier, installed in May 2010, provides robust real-time, automated detection and classification of clicks from several types of odontocetes [5] [6]. When initially installed at SOAR the CS-SVM classifier, adapted from another range installation, had six classes, which included the clicks of Blainville's beaked whales (*Mesoplodon densirostris)*, Cuvier's beaked whales, pilot whales (*Globicephala macrorhynchus*), Risso's dolphins, sperm whales (*Physeter macrocephalus*), and Pantropical spotted dolphins (*Stenella attenuata*). Starting in May, 2014 the dolphin classes for pilot whale and Risso's dolphins were combined into a 'generalized dolphin' (GD) class; the Cuvier's beaked whale foraging buzz (52) class was added; and Blainville's beaked whale and Pantropical spotted dolphin were removed, as they are not present on SOAR [6]. The 'generalized dolphin' category was created because classification of delphinids to species level at SOAR was not considered sufficiently robust at the time. Therefore, the CS-SVM classifier at SOAR currently has four classes (Table 4). A detection report is generated for each CS-SVM classifier detection. The Cuvier's beaked whale groups identified for the analysis in this report are generated from the CS-SVM classifier foraging click detections.

Table 4. CS-SVM classes at SOAR as of May 2014.

	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 5 shows the number of days per month on which archives with the CS-SVM classifier detections have been collected at SOAR between 2010 and 2019. Some archive files in August and September of 2019 have a timing error that needs to be corrected, and thus are not shown in this table.

Table 5. 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). Data collection is only indicated through part of October, 2019. The '4+' in October indicates that data is still being collected, but has not yet been processed.

M3R SOAR Detection Archives												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2010	NA	NA	NA	NA	7	NA	NA	9	30	29	22	23
2011	22	27	8	3	13	NA	6	28	30	31	22	31
2012	27	23	18	30	15	6	1	4	NA	17	13	10
2013	NA	NA	NA	NA	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	NA	26	22
2017	15	NA	13	17	2	NA	11	31	24	17	29	27
2018	27	14	4	17	28	30	21	31	30	31	30	22
2019	28	28	31	30	30	28	29	20	8	4+	NA	NA

2.2.1.2 SOAR Cuvier's Beaked Whale Group Analysis

2.2.1.2.1 SOAR 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. Small groups of Cuvier's beaked whales appear to dive synchronously, typically vocalizing only below 400 m depth during deep foraging dives [7] [8]. 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 the CS-SVM classifier 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 next 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 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 [9].

2.2.1.2.2 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 6). 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 [9].

Table 6. Autogrouper detection statistics for Cuvier's beaked whales on SOAR.

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

2.2.1.2.3 SOAR Autogrouper Correction Factors for Varying Spatial Coverage of the CS-SVM Classifier

In the course of data analysis, it was found that the CS-SVM classifier, at different times, was not running on certain hydrophones. This could have occurred if the algorithm was not started, or if a hydrophone or computer node was not functioning properly. In addition, during some periods the CS-SVM classifier 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 a baseline case in which the CS-SVM classifier was running on all the newer hydrophones, but not on the legacy hydrophones [9].

2.2.1.3 SOAR Cuvier's Beaked Whale Abundance

Moretti, et al. (2010) 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 [10]. 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 produce echolocation clicks at depth [7], 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. (2010) [10] 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. (2010) 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 2019 with all groups except those detected only on edge hydrophones. 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 [3], 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.

2.2.2 SOAR Results

2.2.2.1 SOAR Overview

SOAR archives were analyzed from August 2010 through October 2019. Data from partial hours of effort (effort per hour < 1.0) were removed from the following calculations in order to avoid the occasional instances with unrealistic numbers of GVPs per hour of effort. As there were only 290 out of a possible 87,840 hours with partial effort, this resulted in the removal of less than 0.5% of the data. A total of 49,691 hours of data were processed, with the number of hours per year varying from a low of 2376 hours in 2010 to a high of 7228 hours in 2018 (Table 7).

Table 7. Total number of hours of effort per year in which data were recorded at SOAR.

Total Number of Hours of Effort - SOAR									
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
2376	4962	3460	3557	5957	5985	6283	4581	7228	5302

Figure 12 and Figure 13 show, for the years 2010 to 2014 and 2015 to 2019, respectively, the duration of the Group Vocal Periods (GVP) (in min) plotted on the y-axis against the time of the year. The GVP durations 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.

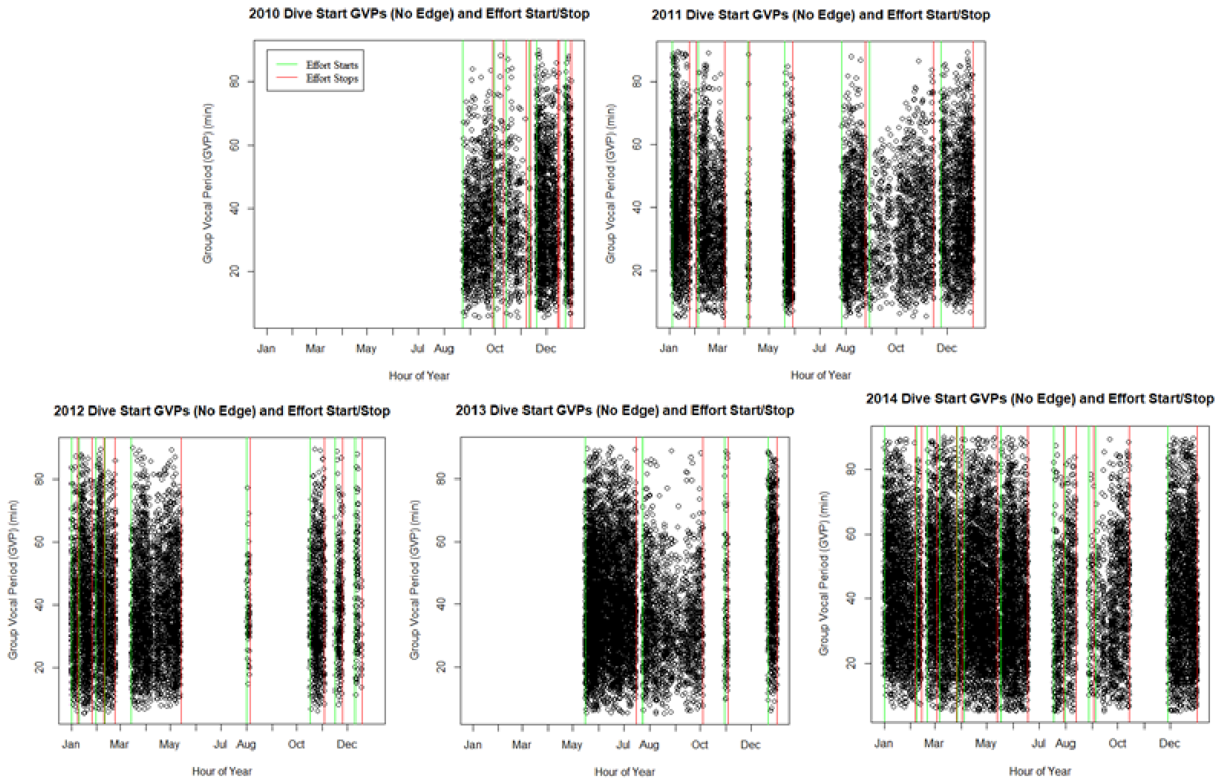

Figure 12. GVP duration of all groups except those located only on the edge of the range, for the years 2010 to 2014.
Effort start (green) and effort stop (red) times indicated with vertical lines.

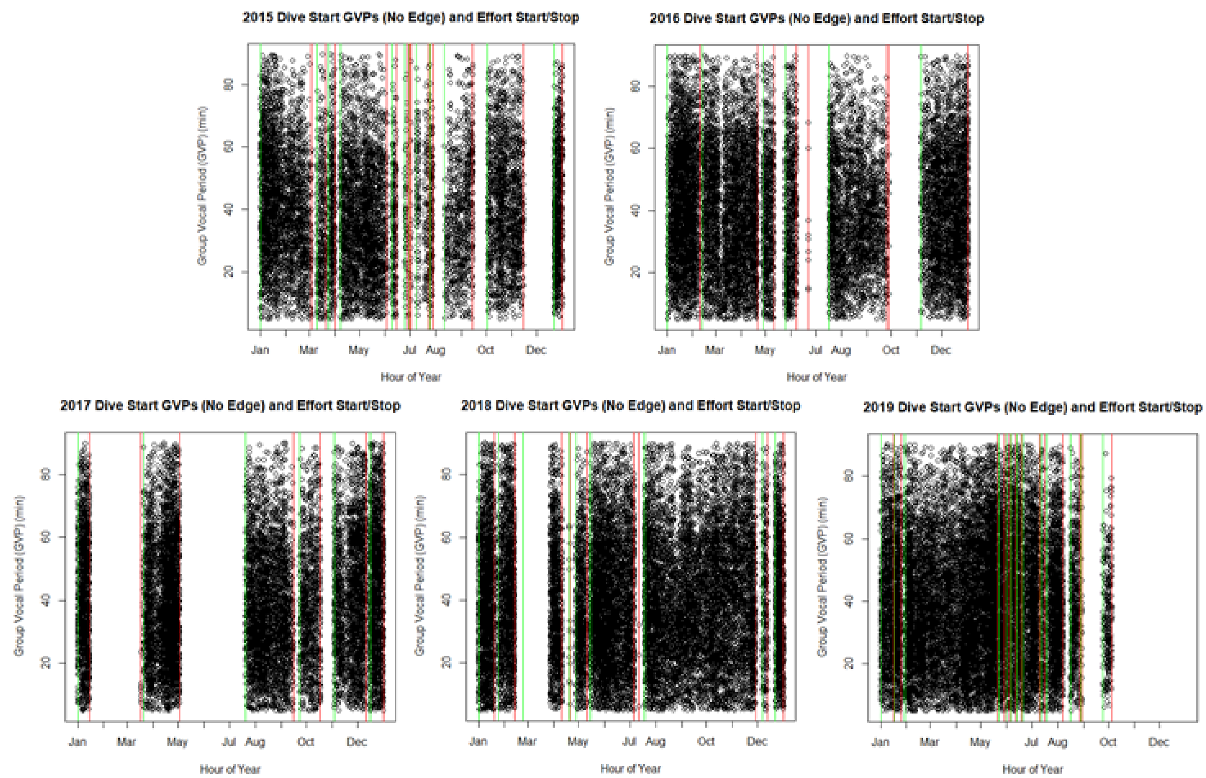

Figure 13. GVP duration of all groups except those located only on the edge of the range, for the years 2015 to 2019.
Effort start (green) and effort stop (red) times indicated with vertical lines.

The number of Cuvier's beaked whale group vocal periods (GVPs) per hour of effort, total number of Cuvier's beaked whale clicks detected per group per hour of effort, the duration of the Cuvier's beaked whale GVPs, and Cuvier's beaked whale abundance were analyzed after cases of 'edge-only' groups were removed. Note that in previous years the number of GVPs were referred to as the number of 'dive starts.'

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 click from any group member to the final detected click from the group. In addition to the abundance and the number of GVPs, 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. The number of clicks detected per group and duration 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.

2.2.2.2 SOAR Cuvier's Beaked Whale Abundance

2.2.2.2.1 SOAR Cuvier's Beaked Whale Monthly Abundance

The monthly Cuvier's beaked whale abundance was calculated using equation 2 in section 2.2.1.3, with the total number of GVPs (n_d from Equation 2) detected per month (Table 8), and the measurement time period, or total number of hours of effort per month (T from Equation 2) (Table 9).

Table 8. Total number of GVPs (n_d) per month for 2010-2019 at SOAR.
NA's indicate periods without data.

n_d	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	229.1	749.4	497.0	971.4	1254.3
2011	1639.2	1142.6	361.4	72.3	777.9	0.0	164.2	1271.6	236.0	624.5	639.4	1437.8
2012	1715.6	1540.9	1375.0	1577.5	759.0	0.0	15.4	60.1	0.0	729.0	338.0	145.7
2013	NA	NA	NA	NA	1820.1	2193.0	1190.0	651.0	542.0	123.0	61.0	743.0
2014	1913.0	988.0	1583.0	1947.0	1892.0	1017.0	343.0	420.8	577.6	438.0	134.0	1949.0
2015	1807.0	1009.0	841.0	1159.0	1394.0	378.8	471.8	412.0	390.0	1168.8	570.5	905.1
2016	2418.1	1577.8	1561.0	1532.0	906.0	290.0	833.0	1101.0	660.0	0.0	1224.0	1835.0
2017	1127.0	0.0	585.4	2094.5	85.2	0.0	553.4	1445.0	809.8	555.9	1124.4	1968.8
2018	1848.2	938.0	294.4	793.8	1865.9	1795.0	1187.7	1239.1	1275.4	1473.7	1274.6	1218.1
2019	1609.5	1648.3	1461.8	1892.9	2313.8	1815.3	1650.8	899.2	146.8	100.4	NA	NA

Table 9. Total number of hours of effort per month (T), for years 2010-2019.
NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	209	623	614	470	460
2011	469	593	180	26	236	NA	121	627	720	743	504	743
2012	585	517	433	720	283	NA	23	67	NA	390	253	189
2013	NA	NA	NA	NA	389	720	551	743	720	124	46	264
2014	740	480	612	665	642	395	291	374	647	318	50	743
2015	742	671	481	567	744	218	451	488	338	702	342	241
2016	719	620	744	566	409	140	392	744	585	NA	626	738
2017	332	NA	270	697	36	NA	270	744	546	403	662	621
2018	620	446	744	349	649	720	445	744	720	744	664	383
2019	606	671	744	720	624	606	649	427	167	88	NA	NA

The numbers of GVPs per month were corrected for varying spatial coverage of the CS-SVM classifier (section 2.2.1.2.3) prior to calculating the abundance. Confidence intervals on the mean monthly abundance values were generated using a CV of 0.71 (Table 10, Figure 14), which was calculated with the delta method. The delta method 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 procedure.

The mean monthly Cuvier's beaked whale abundance for 2010 to 2019 peaks in January at 33.88 animals, followed by a peak in May of 33.66 animals. The mean abundance is lowest in September at 12.12 animals, with another smaller drop in abundance in March to 23.0 animals (Table 10; Figure 14, left). 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) [11]].

Table 10. Mean monthly Cuvier's beaked whale abundances at SOAR averaged from 2010 to 2019.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	58.21	43.46	39.42	50.19	57.82	48.56	34.29	27.46	20.82	26.16	34.55	50.92
mean abundance	33.88	25.29	22.95	29.22	33.66	28.27	19.96	15.99	12.12	15.23	20.11	29.64
lower CI	9.56	7.13	6.47	8.24	9.49	7.97	5.63	4.51	3.42	4.30	5.67	8.36

Over the 10 year time-period the mean abundance in any month has varied from a high of 53 animals in May of 2013 to a low of 4 in September of 2011 (Table 11; Figure 14, right).

Table 11. Monthly SOAR Cuvier's beaked whale abundances 2010 - 2019.
NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	12.47	13.68	9.20	23.50	31.00
2011	39.74	21.91	22.83	31.61	37.48	NA	15.43	23.06	3.73	9.56	14.42	22.00
2012	33.34	33.89	36.10	24.91	30.49	NA	7.61	10.20	NA	21.25	15.19	8.77
2013	NA	NA	NA	NA	53.20	34.63	24.55	9.96	8.56	11.28	15.08	32.00
2014	29.39	23.40	29.41	33.29	33.51	29.27	13.40	12.79	10.15	15.66	30.47	29.82
2015	27.69	17.10	19.88	23.24	21.30	19.76	11.89	9.60	13.12	18.93	18.97	42.70
2016	38.24	28.93	23.85	30.77	25.19	23.55	24.16	16.82	12.83	NA	22.23	28.27
2017	38.59	NA	24.65	34.17	26.91	NA	23.30	22.08	16.86	15.68	19.31	36.05
2018	33.89	23.91	4.50	25.86	32.69	28.35	30.34	18.94	20.14	22.52	21.82	36.16
2019	30.20	27.93	22.34	29.89	42.16	34.06	28.92	23.94	9.99	12.97	NA	NA

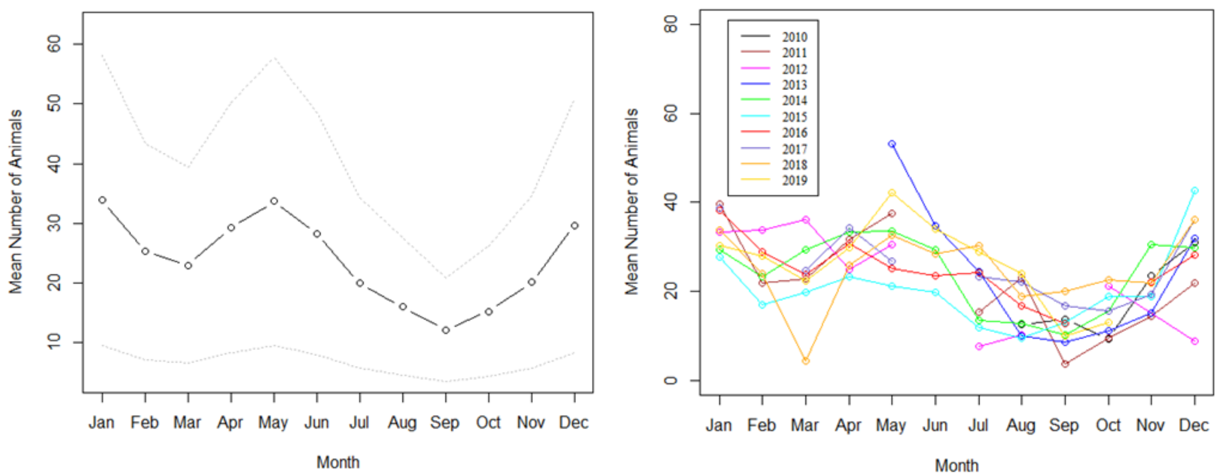

Figure 14. Mean monthly Cuvier's beaked whale abundance at SOAR
***Left:* averaged between 2010 and 2019, *Right:* for the years 2010 through 2019. Dashed lines indicate 95% confidence intervals.**

2.2.2.2.2 SOAR Yearly Cuvier's Beaked Whale Abundance Trends

The mean number of animals at any given time on SOAR per year has significantly increased over the ten year period from 2010 to 2019, with the mean rising from 17.74 animals to 29.08 animals ($p=0.04352$). There is a moderate linear correlation between the mean number of Cuvier's beaked whales on SOAR and year from 2010 to 2019 ($R^2 = 0.4176$) (Table 12, Figure 15).

Table 12. Mean yearly Cuvier's beaked whale abundances at SOAR from 2010 to 2019.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
upper CI	30.48	32.97	46.67	40.28	43.38	34.33	43.38	44.22	41.17	49.95
mean abundance	17.74	19.19	27.17	23.45	25.25	19.98	25.25	25.74	23.96	29.08
lower CI	5.00	5.41	7.66	6.61	7.12	5.64	7.12	7.26	6.76	8.20

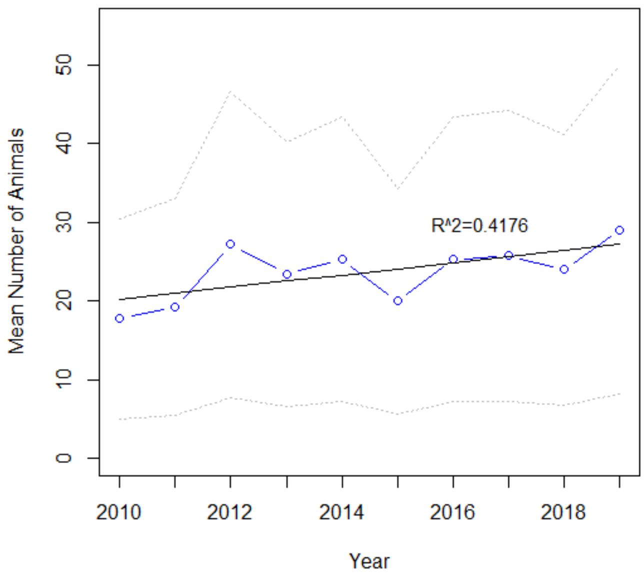

Figure 15. Mean number of Cuvier's beaked whales at any time per year at SOAR from 2010 to 2019.

The only significant monthly linear regression of the number of Cuvier's beaked whales per month against year was for July (p= 0.02295), which showed an increase from 15.43 in 2011 to 28.92 in 2019 (R^2= 0.546) (Figure 16, left). Therefore, the significant increase in abundance between 2010 and 2019 appears to be driven at least in part by the increase in the mean number of animals on the range in the month of July. The mean abundance for each month from the years 2010 to 2019 is shown on the right in Figure 16.

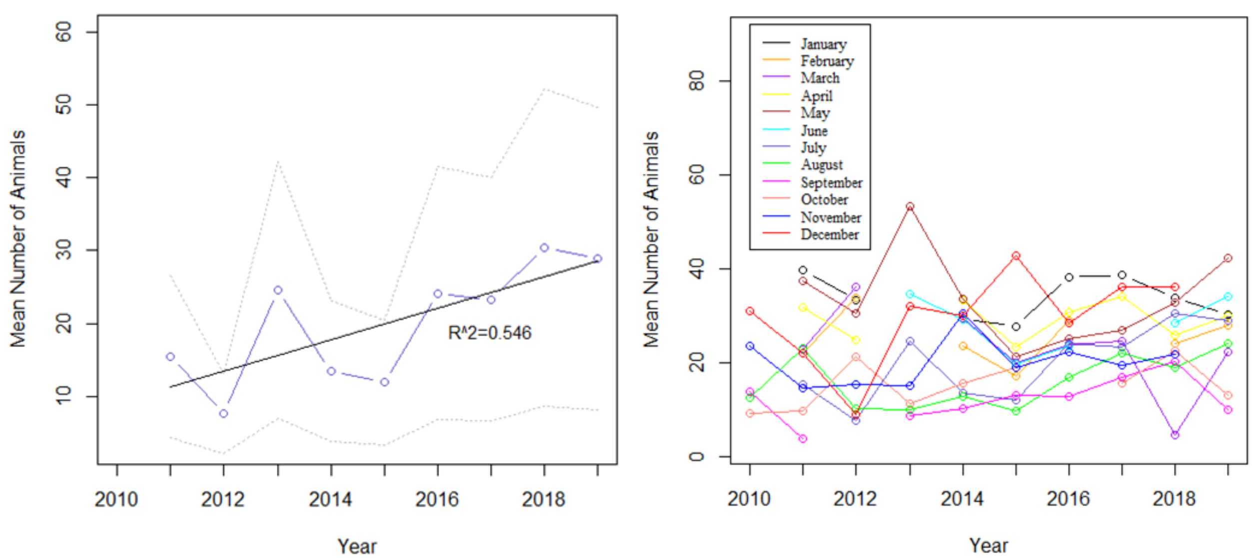

Figure 16. Montly Cuvier's beaked whale abundance
Left: **for the month of July,** ***Right:*** **for each month from 2010 to 2019.**

2.2.2.3 SOAR Number of Cuvier's Beaked Whale GVPs per Hour

2.2.2.3.1 SOAR Monthly Number of Cuvier's Beaked Whale GVPs per Hour

The monthly mean number of Cuvier's beaked whale GVPs per hour across the range varies from a high of 2.95 per hour in May to a low of 1.07 in September (Table 13; Figure 17, left). The seasonal pattern reflects that found for the Cuvier's beaked whale abundance.

Table 13. Monthly number of SOAR Cuvier's beaked whale GVPs per hour, averaged across 2010 to 2019.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	5.10	4.15	3.84	4.52	5.00	4.54	3.78	2.91	2.37	2.90	3.51	4.72
mean # GVPs	2.92	2.22	1.92	2.57	2.95	2.68	2.01	1.45	1.07	1.39	1.76	2.62
lower CI	0.75	0.28	0.00	0.63	0.90	0.83	0.24	0.00	-0.24	-0.12	0.00	0.51
GVP CVs	0.74	0.87	1.00	0.76	0.69	0.69	0.88	1.00	1.22	1.09	1.00	0.80

The highest monthly mean number of GVPs per hour on SOAR, 4.68, occurred in May, 2013, while the lowest was 0.33 in September of 2011 (Table 15; Figure 17, right).

Table 14. SOAR mean monthly number Cuvier's beaked whale group vocal period (GVP) per hour for 2010 to 2019. NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	1.10	1.20	0.81	2.07	2.74
2011	3.50	1.93	2.02	2.78	3.30	NA	1.36	1.63	0.33	0.84	1.27	1.94
2012	2.93	2.99	3.18	2.20	2.69	NA	0.67	0.90	NA	1.87	1.34	0.77
2013	NA	NA	NA	NA	4.68	3.05	2.16	0.88	0.75	1.00	1.41	2.81
2014	2.59	2.06	2.60	2.93	2.95	2.59	1.18	1.13	0.90	1.38	2.68	2.63
2015	2.44	1.50	1.76	2.05	1.88	1.75	1.05	0.84	1.16	1.67	1.67	3.76
2016	3.36	2.55	2.10	2.71	2.22	2.07	2.13	1.48	1.13	NA	1.96	2.49
2017	3.39	NA	2.17	3.01	2.48	NA	2.05	1.95	1.49	1.39	1.70	3.18
2018	2.98	2.11	0.40	2.29	2.88	2.50	2.67	1.67	1.77	1.99	1.93	3.18
2019	2.66	2.46	1.97	2.63	3.71	3.00	2.55	2.12	0.88	1.16	NA	NA

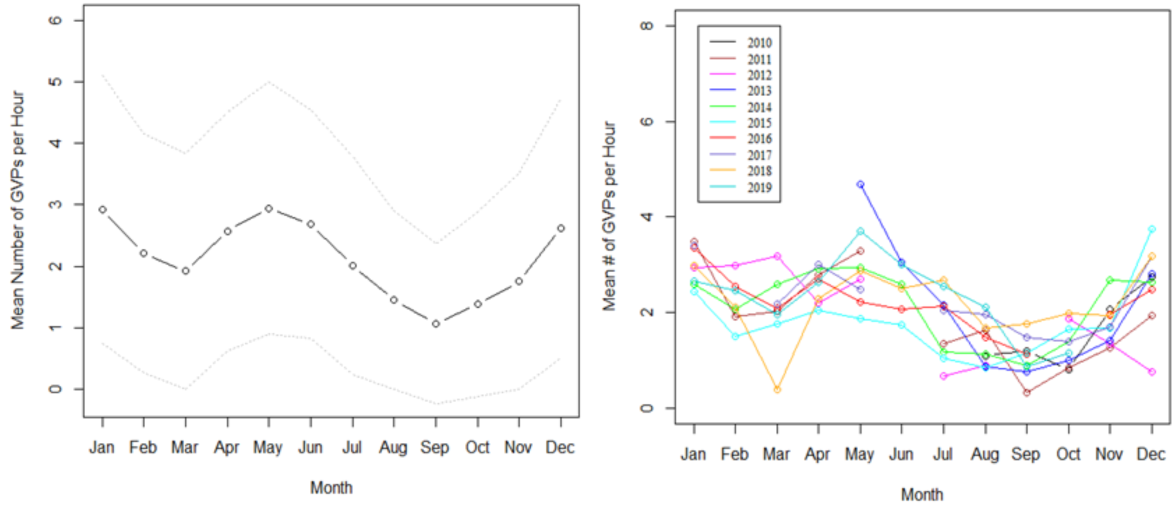

Figure 17. Number of SOAR Cuvier's beaked whale GVPs per hour averaged across 2010 to 2019. Dashed lines indicate 95% confidence intervals.

2.2.2.3.2 SOAR Yearly Trends in Number of Cuvier's Beaked Whale GVPs per Hour

The mean number of GVPs detected per hour across the SOAR range varies from 0 to 14, with the values strongly left-skewed (Figure 18). Mirroring the rise in abundance, the mean number of GVPs on SOAR in any given year has significantly increased over the ten year period from 2010 to 2019, going from 1.56 GVPs per hour to 2.56 GVPs per hour (p=0.04106). There is a somewhat strong linear correlation between the mean number of Cuvier's beaked whales on SOAR and year from 2010 to 2019 ($R^2 = 0.4251$) (Figure 19).

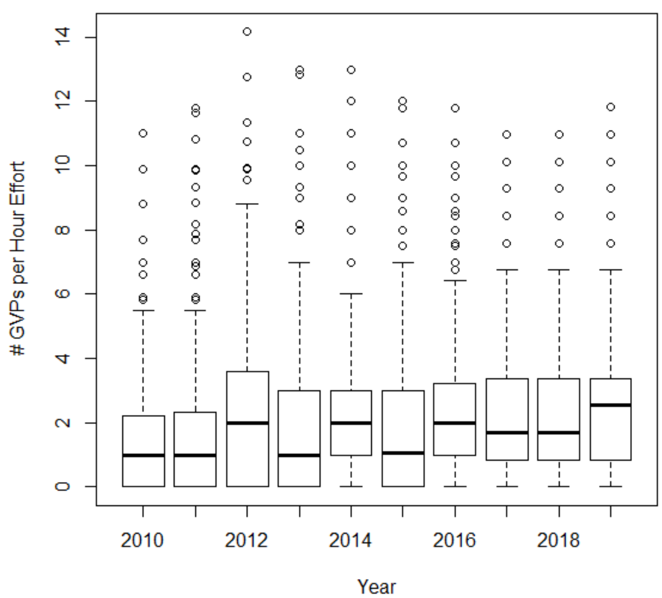

Figure 18. Mean number of GVPs per hour across the SOAR range from 2010 to 2019. The data are left-skewed, with many zeros, and the number detected per hour ranges from 0 to 14.

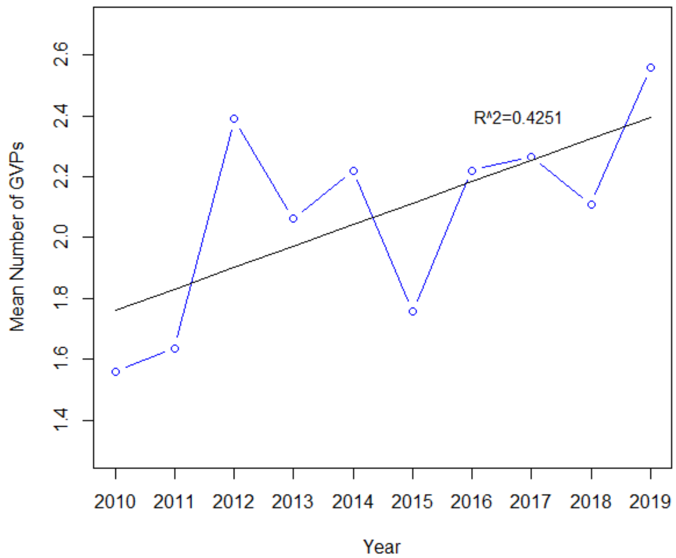

Figure 19. Mean number of GVPs per hour for each year at SOAR from 2010 to 2019.

2.2.2.4 SOAR Duration of Cuvier's Beaked Whale GVPs

The mean monthly Cuvier's beaked whale GVP duration over the years 2010 to 2019 varies from a low of 36.7 min in August to a high of 42.1 min in January (Table 15; Figure 20, left).

Table 15. Mean SOAR Cuvier's beaked whale GVP duration (in min) per month averaged across 2010 to 2019. Upper and lower confidence intervals (CIs) and the corresponding Coefficients of Variation (CVs) are given.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	61.0	58.5	57.9	58.0	57.9	58.9	57.6	54.2	54.5	58.4	59.6	60.5
mean GVP	42.1	40.1	39.3	39.4	39.3	40.0	39.2	36.7	37.3	39.7	40.8	41.5
lower CI	23.2	21.7	20.6	20.7	20.8	21.1	20.8	19.2	20.1	21.1	22.0	22.5
GVP CV	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Between 2010 and 2019 the shortest mean GVPs duration of 29.57 min occurred in August of 2010, and the longest GVP, 48.07 min, happened in December of 2013 (Table 16; Figure 20, right).

Table 16. SOAR mean monthly Cuvier's beaked GVP duration for 2010 to 2019. NAs indicate periods without data.

	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	42.06	37.27	32.90	33.20	33.48	NA	31.09	32.93	32.28	34.53	39.30	38.90
2012	38.90	40.51	39.30	38.54	39.41	NA	40.35	39.14	NA	39.71	39.84	42.91
2013	NA	NA	NA	NA	40.15	41.02	39.52	33.75	33.15	38.64	38.70	48.07
2014	43.76	40.73	42.55	41.64	40.07	37.52	32.38	40.80	34.47	43.50	43.93	41.78
2015	44.33	39.25	36.21	38.11	37.28	36.23	40.95	35.44	43.40	43.35	42.09	40.16
2016	43.70	42.81	38.25	40.30	38.50	42.12	38.80	39.15	38.54	NA	41.84	41.33

2017	42.64	NA	NA	39.57	39.15	NA	39.92	37.18	36.84	37.75	39.96	43.83
2018	40.89	42.61	42.19	37.42	39.00	39.04	40.64	37.07	40.10	40.44	43.00	40.09
2019	40.09	37.84	39.06	38.62	41.57	41.43	39.30	39.65	34.08	38.36	NA	NA

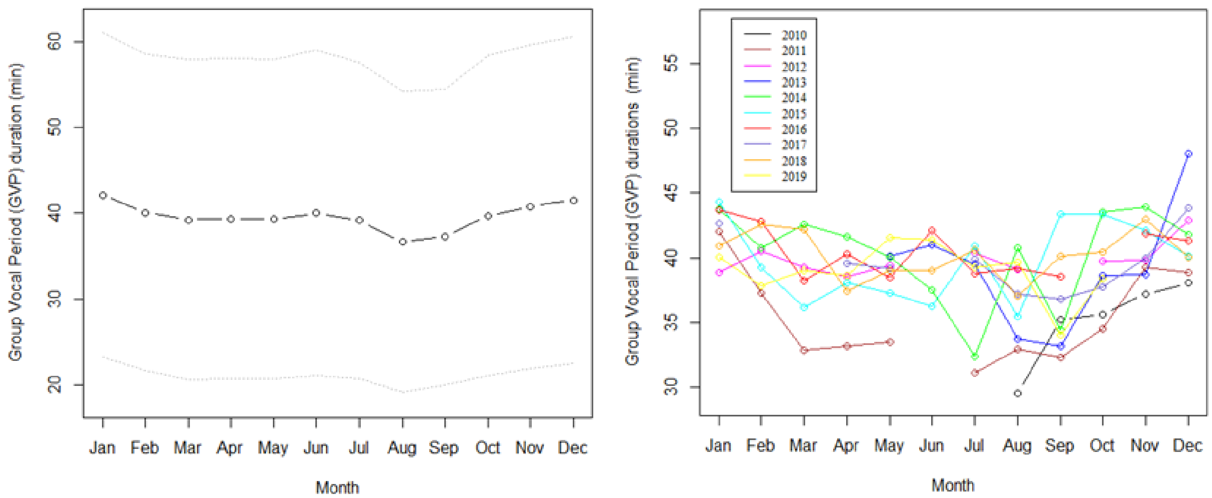

Figure 20. SOAR mean monthly Cuvier's beaked whale GVP duration
Left: **averaged across 2010-2019,** ***Right:*** **for 2010 through 2019. Dashed lines indicate 95% confidence intervals.**

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

The monthly mean number of Cuvier's beaked whale clicks detected per group, averaged across 2010 to 2019, varies from 2,267 clicks in September to 3,602 in January (Table 17; Figure 21, left).

Table 17. Mean monthly number of Cuvier's beaked whale clicks per group averaged across 2010 to 2019 at SOAR, with upper and lower confidence intervals (CIs), and the corresponding Coefficients of Variation (CVs).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	7568.8	6975.6	6305.1	6548.7	6139.8	6900.3	6535.1	5261.0	4812.5	5893.5	6111.3	7218.5
mean click count	3602.2	3199.0	2938.2	3074.1	2887.7	3228.2	3043.9	2429.9	2266.9	2727.4	2861.4	3413.2
lower CI	-364.4	-577.5	-428.6	-400.5	-364.5	-443.9	-447.2	-401.3	-278.8	-438.6	-388.5	-392.1
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

The lowest mean number of Cuvier's beaked whale clicks per group, 951.5, occurred in August of 2010, while the highest number of clicks per group, 4,692.5, happened in February of 2018 (Table 18; Figure 21, right).

Table 18. SOAR mean monthly number of Cuvier's beaked whale clicks detected per group for 2010 to 2019. NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	NA	NA	NA	NA	NA	NA	NA	951.5	1344.1	1489.6	2074.4	2412.6
2011	3145.5	2342.2	1729.8	1992.1	1562.6	NA	1433.8	1623.8	1018.6	1587.4	2284.4	2306.9
2012	2248.0	2407.8	2085.8	1873.6	1993.4	NA	2078.7	1615.3	NA	2234.6	1745.7	2056.2
2013	NA	NA	NA	NA	2093.2	2203.2	2103.5	1565.7	1841.9	2326.0	1961.5	3341.6
2014	2690.3	2333.7	3217.2	3345.6	2883.7	2466.9	2086.0	2655.4	2008.1	3391.7	4110.6	3763.7
2015	4441.5	3481.5	2952.9	2888.9	2583.1	3089.2	2789.6	1759.9	2911.0	3148.8	2653.0	2805.7
2016	3691.3	3341.0	2823.7	3271.6	3654.8	3960.0	2764.5	2588.8	2273.6	NA	2749.7	3355.2
2017	4210.2	NA	NA	3246.2	3243.7	NA	3022.3	2778.0	2799.2	2929.5	3185.8	4654.3
2018	4214.7	4692.5	3932.5	2971.2	3146.2	3469.6	3739.1	2798.6	2646.5	3219.3	3607.7	3314.5
2019	3921.4	3483.4	3332.5	3277.8	3627.4	4318.2	3611.2	3247.9	2489.2	2217.7	NA	NA

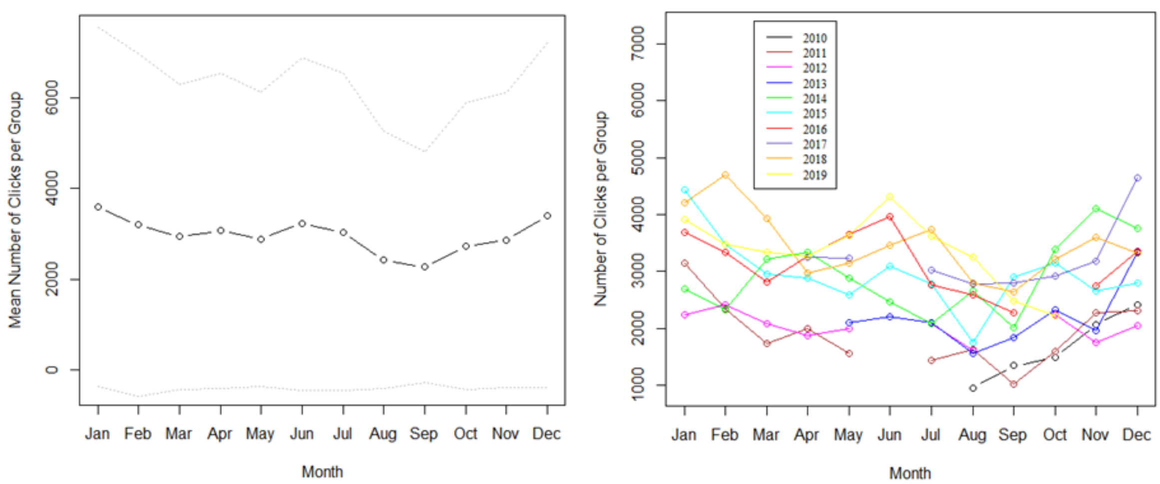

Figure 21. Mean monthly number of Cuvier's beaked whale clicks detected per group
Left: **averaged across 2010-2019,** ***Right:*** **for the years 2010 through 2019. Dashed lines indicate 95% confidence intervals.**

2.3 Spatial Distribution of GVPs

Cuvier's beaked whales primarily forage in the west and southwestern part of the SOAR range. Figure 23 shows the mean from 2010 through 2019 of the total number of GVPs detected per hydrophone per year. Hydrophone 410, which has the highest mean number of GVPs, 289.2, is located on the far western edge of the range, slightly to the south. The spatial distribution was generated using all GVPs, rather than only those with 'edge-only' groups removed. Note that hydrophone 410 is an 'edge phone,' which is a hydrophone located on the edge of the range. Some analyses are conducted with 'edge-only' groups removed, which are groups that only contain hydrophones located on the edge of the range. In these cases it is assumed that the group is located off-range. However, when 'edge-only' groups are removed the total number of GVPs detected is reduced by about 15% (Table 22).

Table 19. All GVPs detected on the SOAR range per year versus the number detected when 'edge-only' groups (groups only containing hydrophones located on the edge of the range) are removed.
There are approximately 15% fewer GVPs detected when 'edge-only' groups are removed.

Number of GVPs	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
All Detected GVPs	3835	8532	7796	8851	16380	13700	18755	13771	19560	17512	12869.2
Edge-only GVPs Removed	3511	7741	6724	7271	13225	10337	13874	12346	18093	16136	10925.8

The 10-year mean number of GVPs per hydrophone differs between the cool and warm seasons on SOAR. The cool water season, winter and spring, was considered to be between December 21st and June 20th, while the warm water season, summer and fall, was taken as June 21st through December 20th. The mean for 2010 to 2019 of the total number of GVPs per hydrophone was calculated for the cool (Figure 24) and warm (Figure 25) seasons. There are a significantly higher mean number of GVPs per hydrophone per year, averaged from 2010 to 2019, for the cool season than for the warm season (Welch two sample t-test, p=2.009e-08) (Figure 22), and the foraging appears to expand farther to the east in the cool season. This could be due to several reasons. There is more upwelling in cooler waters, potentially increasing the availability of beaked whale prey during the cool season. The mean number of days per year with sonar in the warm season (57.7) is somewhat higher than the mean in the cool season (50.9). Though the number of days of sonar per season is not significantly different (Welch two sample t-test), there could conceivably be some impact on reducing the mean number of GVPs per year in the warm season.

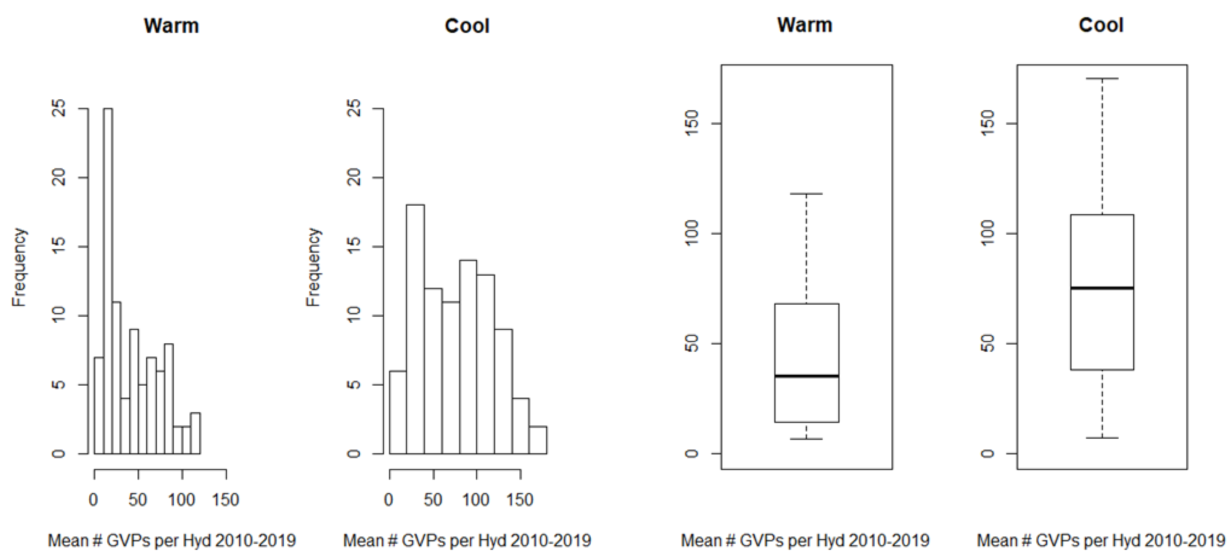

Figure 22. Mean number of GVPs per hydrophone per year, averaged from 2010 to 2019, in the warm season and cool season
***Left:* Histogram and *Right:* Boxplot. The mean number of GVPs per hydrophone per year is significantly higher in the cool season.**

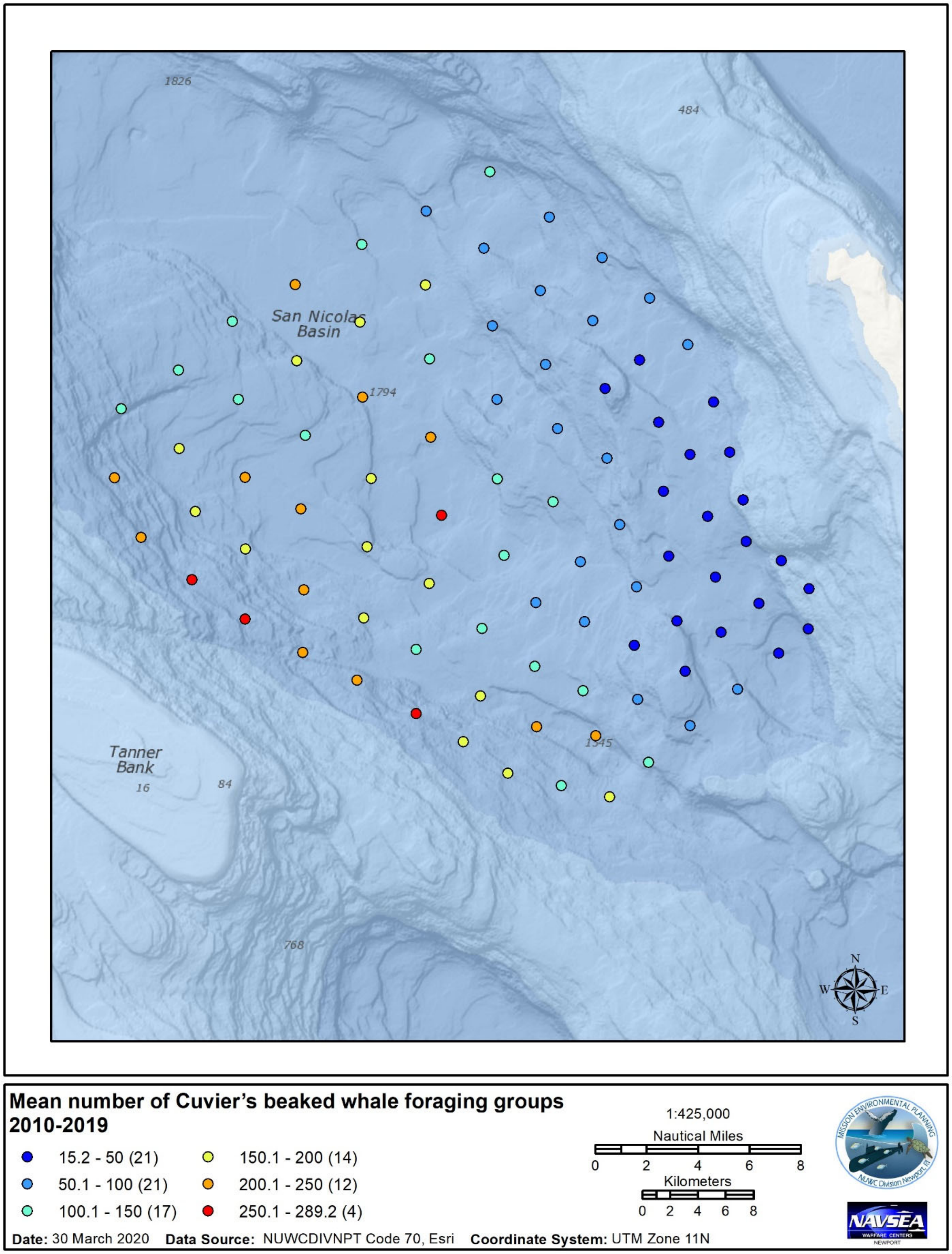

Figure 23. Mean annual total number of GVPs per hydrophone on the SOAR range from 2010-2019. The numbers in parenthesis indicate the number of hydrophones in the given category.

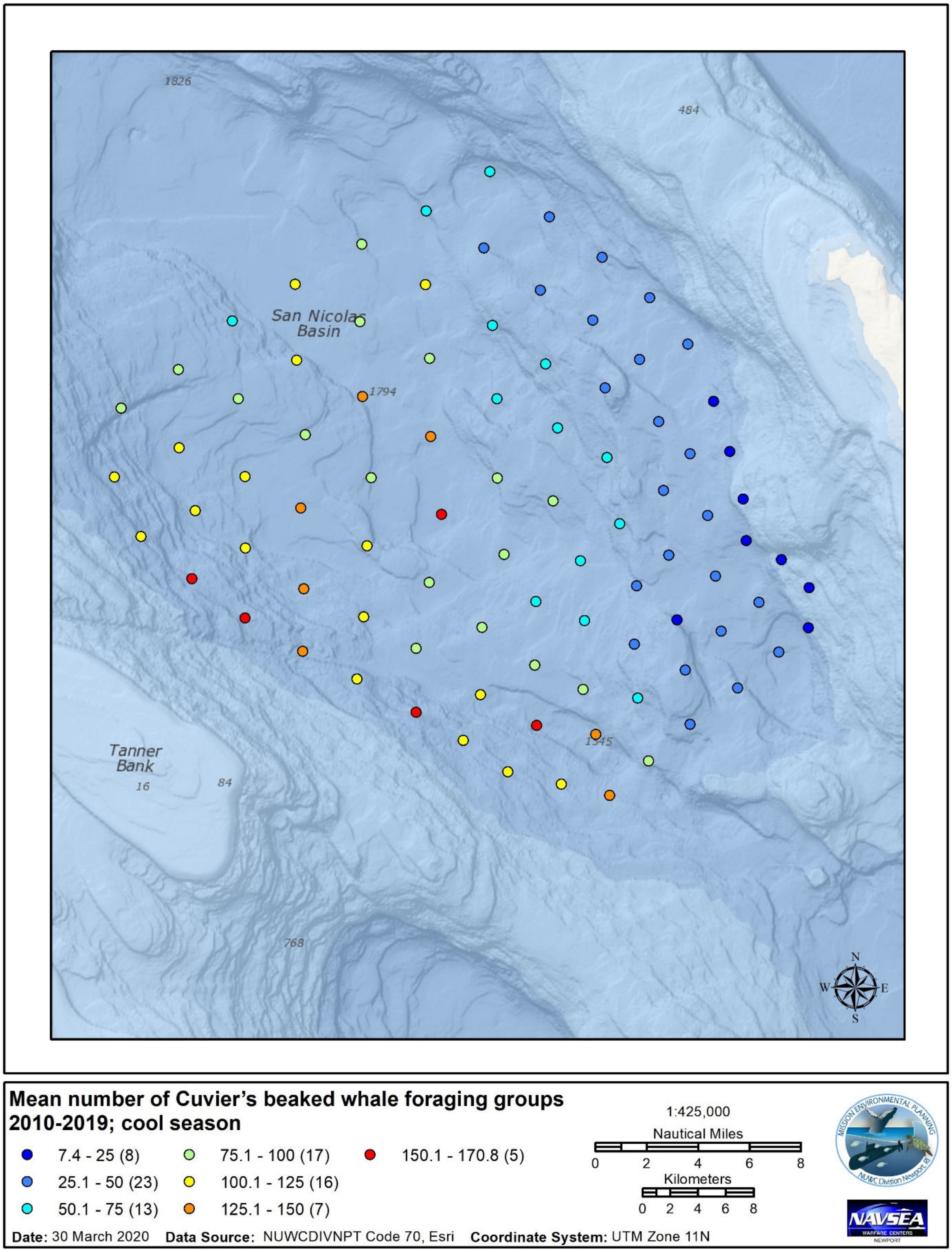

Figure 24. Mean total SOAR cool water season GVPs per hydrophone from 2010-2019.
The numbers in parenthesis indicate the number of hydrophones in the given category. The cool season was considered to be between December 21st and June 20th.

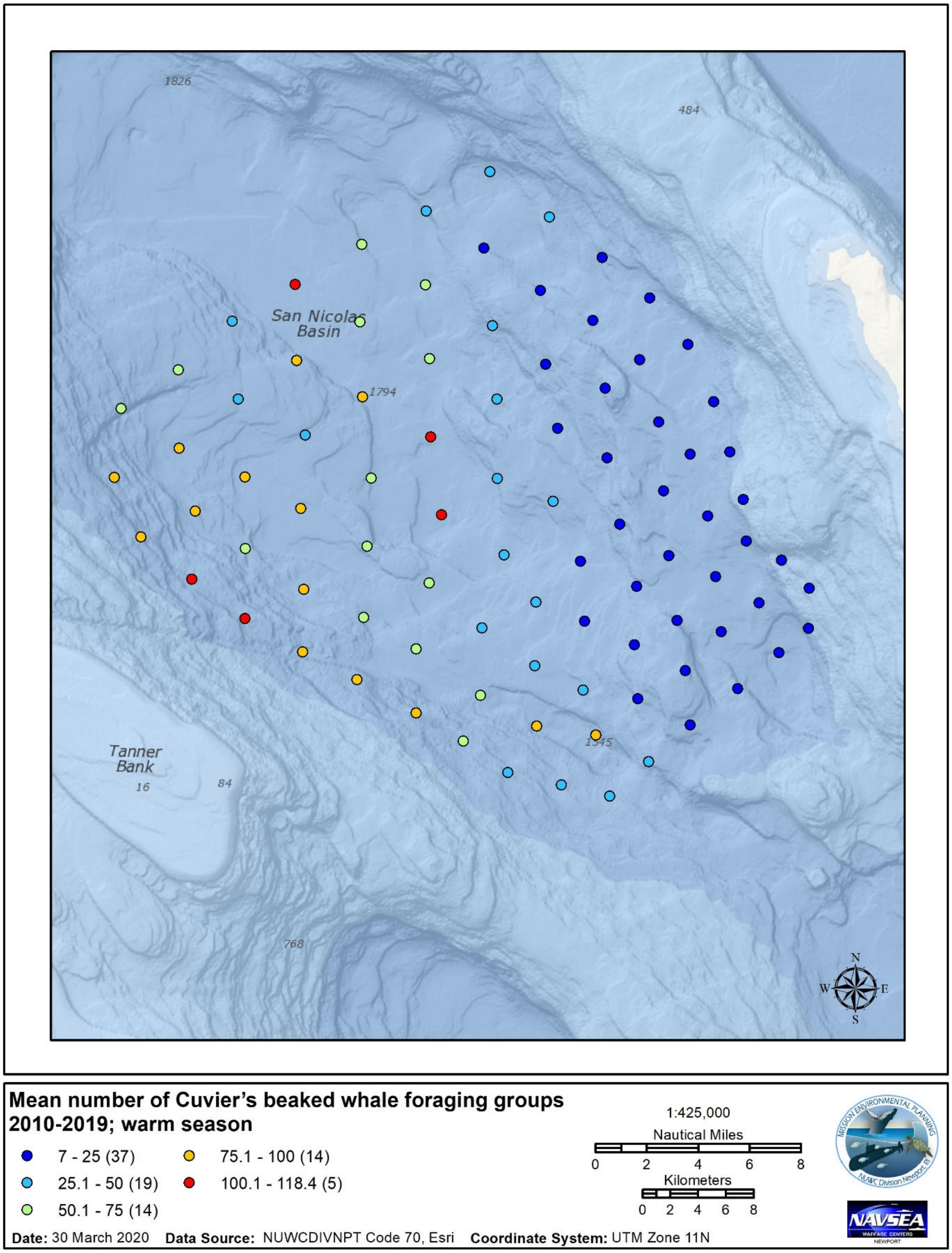

Figure 25. Mean total SOAR warm water season GVPs per hydrophone from 2010-2019.
The numbers in parenthesis indicate the number of hydrophones in the given category. The warm season was considered to be between June 21st and December 20th.

2.4 Monthly Distribution of MFAS, GVPs, and Effort

The number of days of sonar detected per month has varied each year at SOAR, as has the effort per month and the number of GVPs detected per month. There appears to be something of an inverse pattern between the mean number of GVPs per month and the mean number of days of sonar detected per month, but as the pattern does not always hold (for instance in April and August), other factors must be affecting the number of GVPs besides sonar (Figure 26).

Though the last 2.5 months of data from 2019 have not yet been processed, once completed 2019 will have the highest record of effort to date. The mean percentage of the effort month with sonar, from sonar detector output, is lower in 2019 (42%, Figure 28) than in the highest year (58%, Figure 27), and the mean number of GVPs per effort month is higher in 2019 (1359.19) than in the year with the maximum sonar (879.54).

There is weak evidence that the percentage of the effort month with sonar was significantly lower in 2019 than in the highest year (Tukey's honest significant difference (HSD) test, p= 0.1013405), but the percentage of the effort month with sonar is not significantly different between 2019 and the mean, or between the maximum year and the mean. There is also weak evidence that the number of GVPs per effort month in 2019 is significantly higher than in the year with the maximum sonar (Tukey's HSD test, p= 0.1046713), but differences in number of GVPs per month between the mean year and 2019 and between the mean year and year with maximum sonar are not significant.

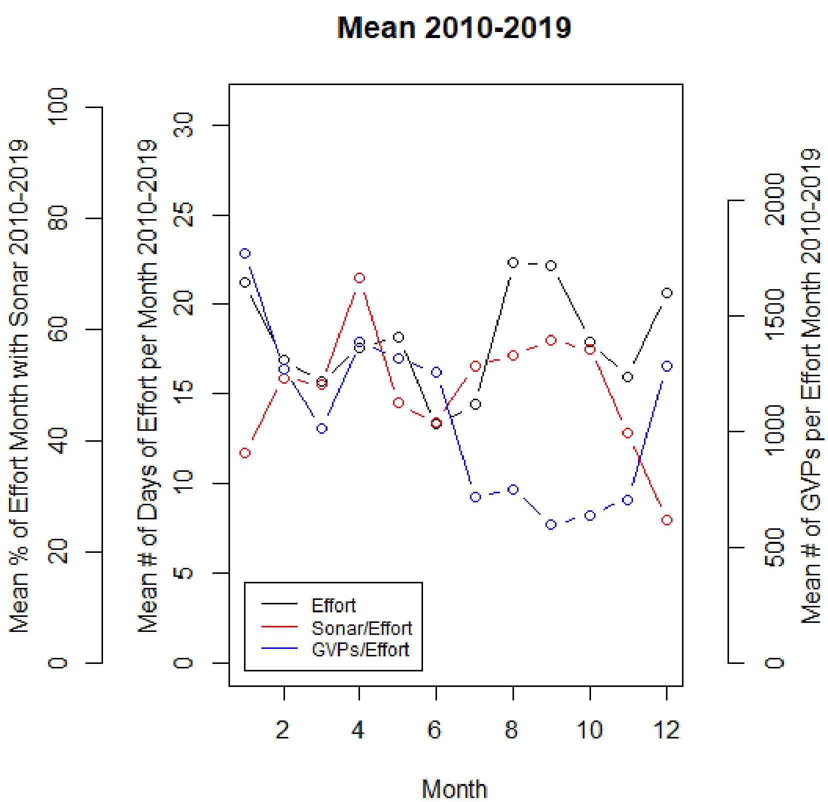

Figure 26. Mean number of days of effort per month (black), mean of the percentage of the effort month with sonar (red), and the mean number GVPs per effort month (blue) from 2010-2019.

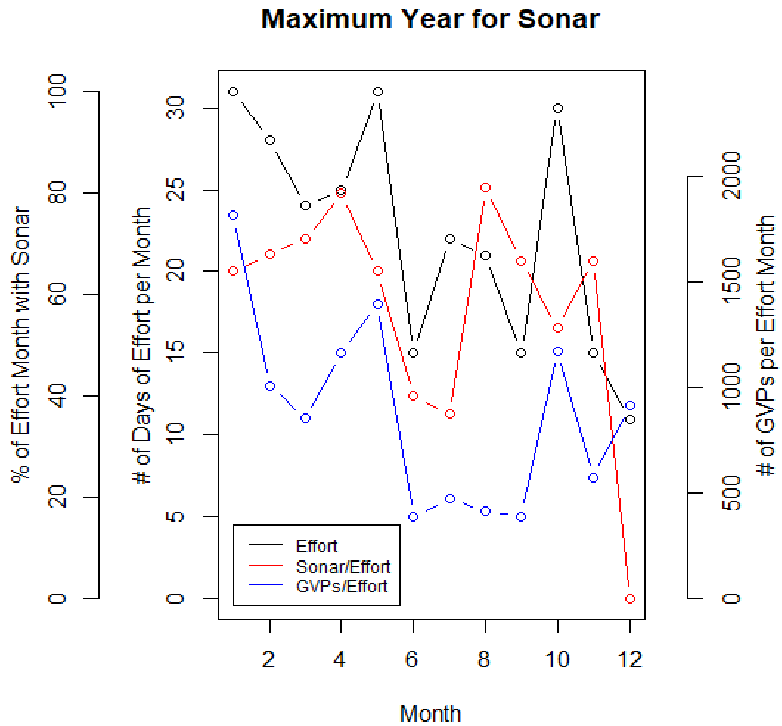

Figure 27. Number of days of effort per month (black), the percentage of the effort month with sonar (red), and the number of GVPs per effort month (blue) for a maximum sonar year.

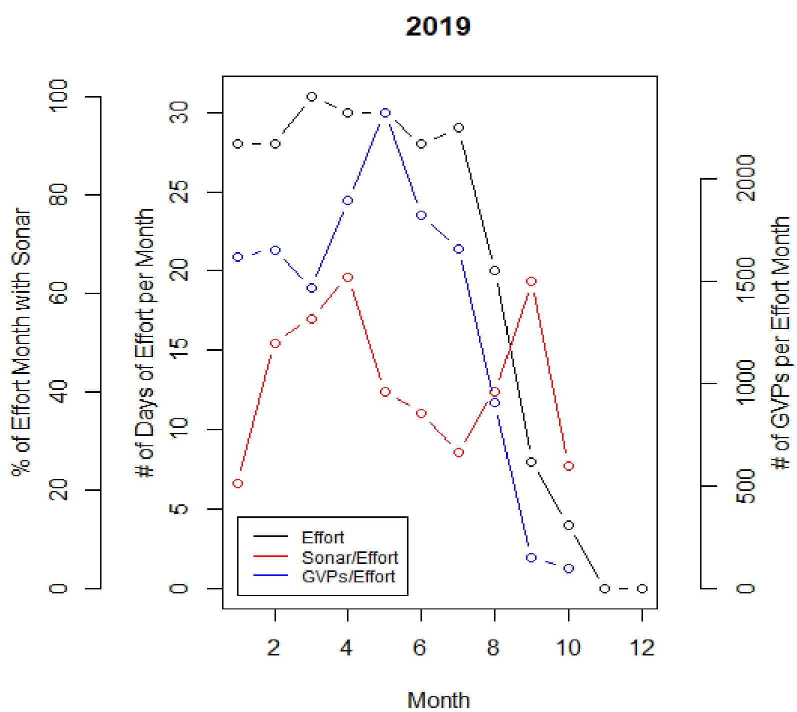

Figure 28. Number of days of effort per month (black), the percentage of the effort month with sonar (red), and the number of GVPs per effort month (blue) for Jan-Oct 2019.

2.5 The Effect of Mid-Frequency Active Sonar (MFAS) on Cuvier's beaked whale Distribution at SOAR

2.5.1 SOAR Methods

Thirty-six periods in 2018 and nineteen periods in 2019 were examined before, during, and after presumed mid-frequency active sonar (MFAS) events at SOAR, and the mean number of Cuvier's beaked whale GVPs per hour were calculated. These periods of presumed MFAS were obtained by filtering the output of a sonar detector program to only retain periods above a threshold level that met or exceeded the maximum level of the system. 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 were considered as likely to be MFAS. All of the 2019 events were checked against the range schedule, and did overlap with exercises that typically use MFAS.

Events were only considered if the threshold was exceeded for every hour in the event, and if at least the same number of hours before and after each event did not exceed the threshold level. In addition, only events with a minimum of three consecutive hours of MFAS were used, to minimize the likelihood of events that may be false alarms. Most events were ten hours or under in duration, though one in 2018 was twenty-two hours and one in 2019 was 17 hours long (Figure 29).The mean number of GVPs per hour was calculated for the duration of each event, and for an equivalent number of hours before and after each event.

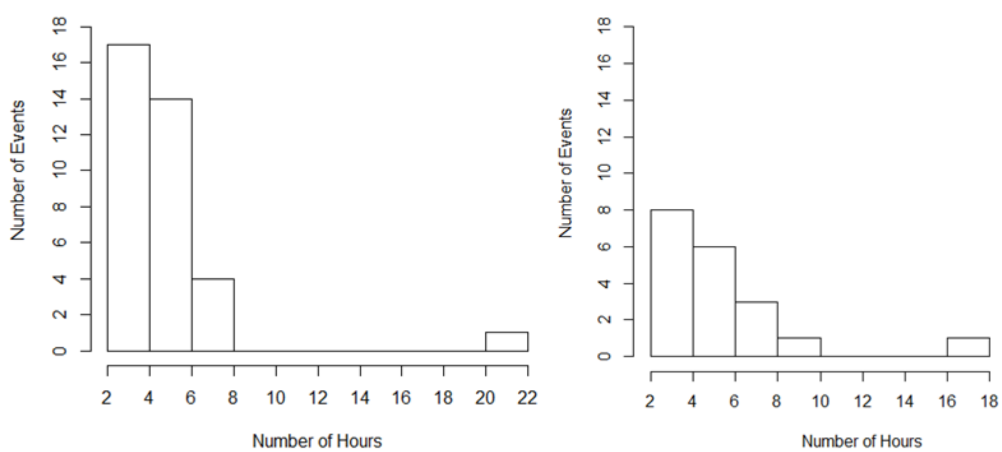

Figure 29. The number of sonar detector events of various durations (in hours).
***Left:* 2018 and *Right:* 2019. These are events for which the sonar detector exceed threshold for every hour of the event, and for which there were an equal number of hours under threshold both before and after the event.**

2.5.2 SOAR Results

2.5.2.1 SOAR 2018

The distribution of number of GVPs per hour varied among the Before, During, and After periods, with a higher mean number of GVPs per hour Before than During and After (Figure 30). The Before-During (Tukey's HSD, p=0.0009812) and Before-After (Tukey's HSD, p=0.0008243) periods had a significantly different mean number of GVPs, whereas the During-After (Tukey's HSD, p=0.9986054) periods did not.

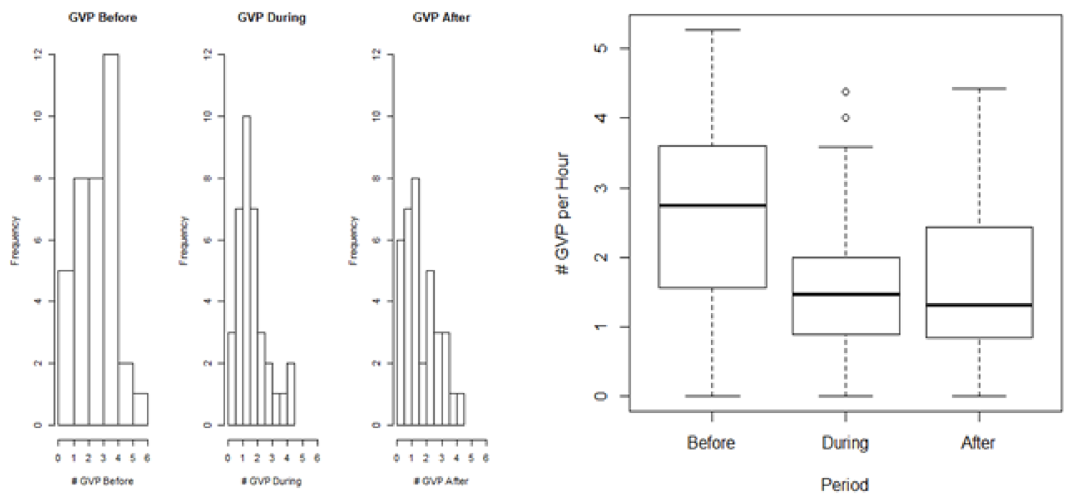

Figure 30. Number of GVPs per hour for the 2018 periods Before, During, and After MFAS.
Left: **Histogram and** ***Right:*** **boxplot of the number of GVPs per hour.**

Of the thirty-six events in 2018, fifteen (42%) had the mean number of GVPs per hour decrease during MFAS, and increase after; twelve had the mean number decrease throughout (33%); and in two cases the mean number of GVPs remained the same during MFAS and then decreased after. In addition, there were three cases in which the mean number of GVPs per hour increased throughout; three in which it increased during MFAS and then decreased; and one in which it stayed the same throughout. Thus in 75% of these shorter sonar events the number of GVPs during the event was lower than the number before the event (Figure 31).

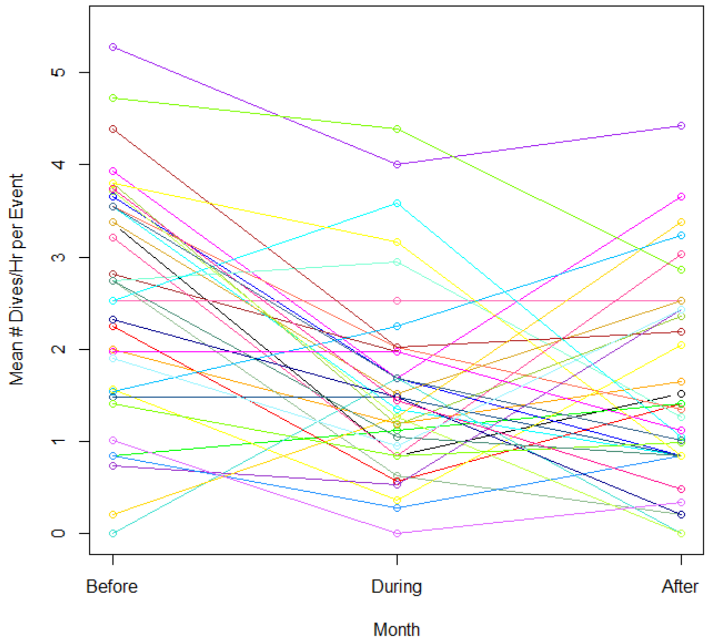

Figure 31. SOAR 2018 mean number of dive starts per hour before, during, and after thirty-six presumed MFAS events. All events except one were under 10 hours in length.

2.5.2.2 SOAR 2019

Nineteen events under 20 hours in length were examined in 2019. No significant differences in number of GVPs were found between any of the three periods (Before, During, and After) for these data (Figure 32). It is possible that the sample size was too small to detect any significant differences.

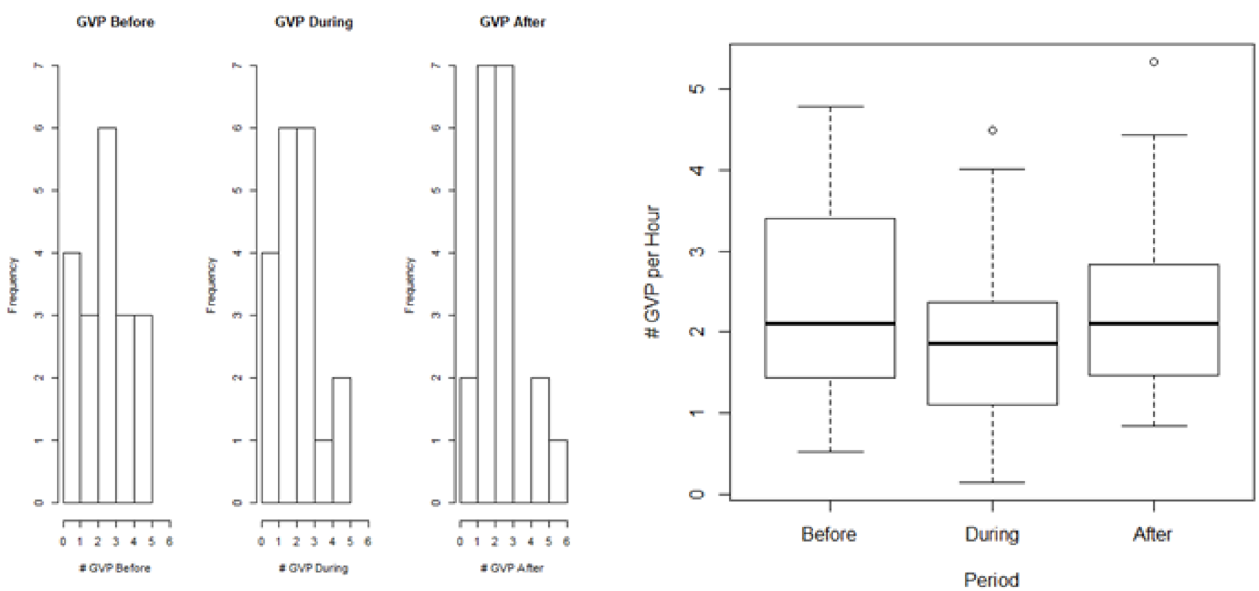

Figure 32. Number of GVPs per hour for the 2019 periods Before, During, and After MFAS. *Left*: Histogram and *Right*: boxplot of the number of GVPs per hour.

In the 2019 cases examined, ten (53%) had the mean number of GVPs per hour decrease during MFAS, and increase after; one had the mean number decrease throughout (5%); and one case had the mean number decrease during sonar and then remain the same (5%). Therefore in 63% of the 2019 cases the number of GVPs during sonar were lower than the period before. There were five cases (26%) in which the number of GVPs increased during sonar and then decreased, one in which it initially increased and then remained the same, and one in which it increased after (Figure 33).

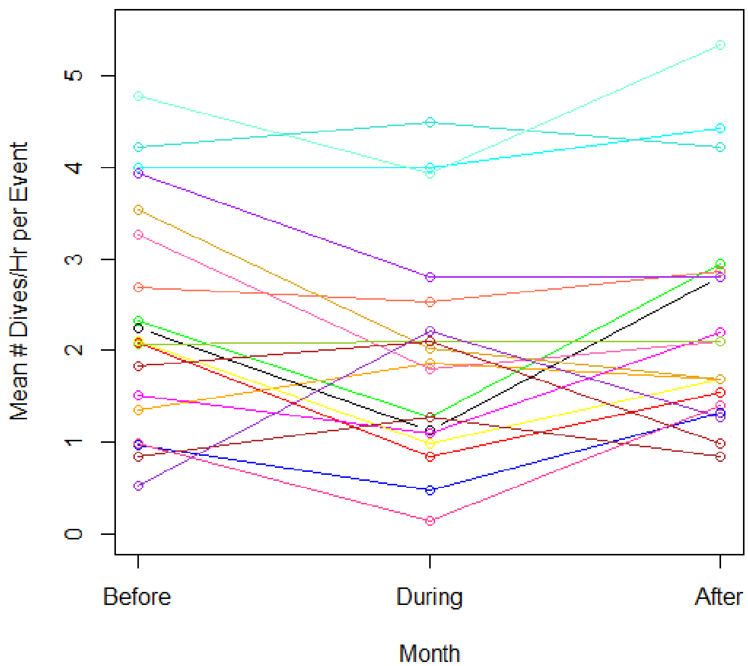

Figure 33. SOAR 2019 mean number of GVPs per hour before, during, and after nineteen presumed MFAS events. All events except one were up to 10 hours in length.

3.0 Pacific Missile Range Facility (PMRF)

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 34).

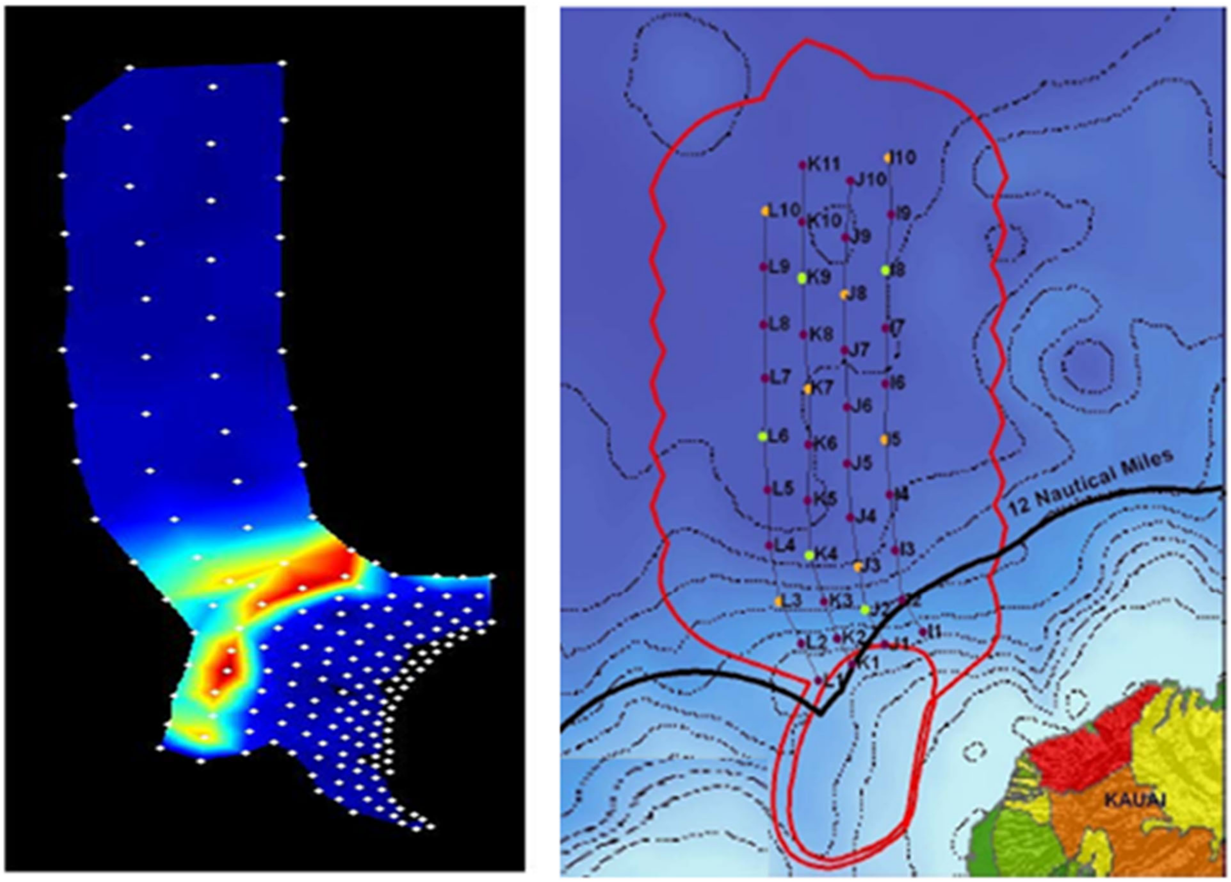

Figure 34. Outline of PMRF range on the right. PMRF range boundaries indicated by outer red line. BARSTUR range area indicated by the inner red line, while the BSURE range area extends north. Left plot shows distribution of Blainville's beaked whale click detections for the time period 11-Jun-2012 through 02-Aug-2012. Dots represent range hydrophones, including those in SWTR.

The BSURE hydrophones are identical to those described in section 2.0 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.

3.1 PMRF Field Tests with Cascadia Research Collective

From January 2018 to December 2019 M3R conducted one field test in conjunction with the Cascadia Research Collective (CRC). CRC personnel typically transit from Kikiaola Harbor at sunrise to the PMRF range. During these tests NUWC personnel use the M3R system to acoustically monitor animals on the range and direct CRC to their locations. Upon finding animals, CRC personnel will collect photo-ID, behavioral data, biopsy samples, and potentially place tags on the animals, with the tag type varying depending on the focus of the particular effort. Typical species of interest in this area are Blainville's beaked whales (*Mesoplodon densirostris*) (Figure 35), short-finned pilot whales (*Globicephala macrorhynchus*) (Figure 36), and false killer whales (*Pseudorca crassidens*) (Figure 37).

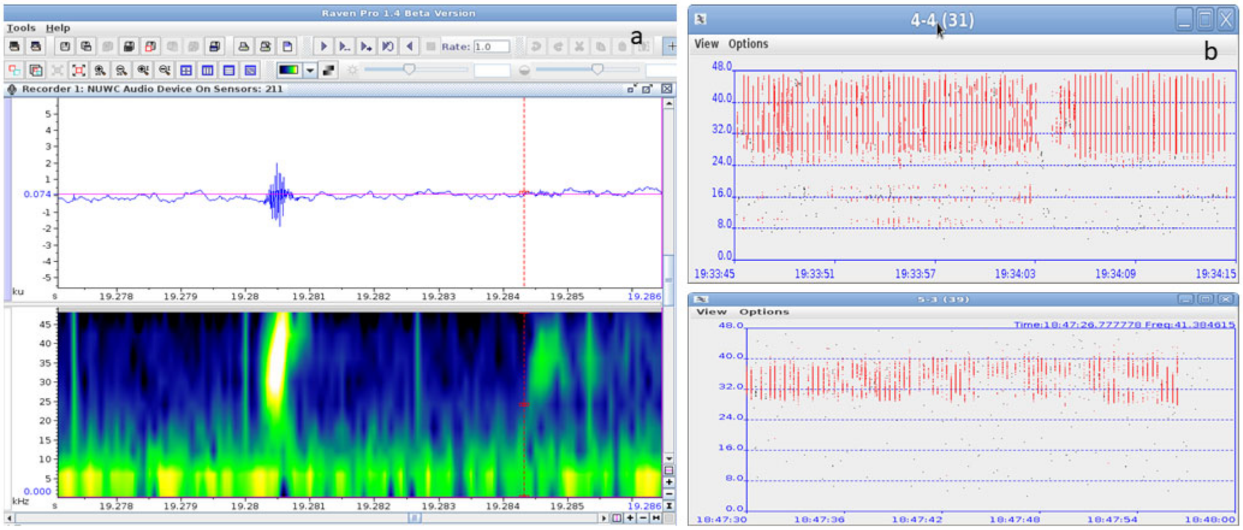

Figure 35. Blainville's beaked whale (*Mesoplodon densirostris*) echolocation clicks detected at PMRF.
a) time series (top) and spectrogram (bottom) of a single click in Raven Pro; b) series of clicks using the M3R binary spectrograms.

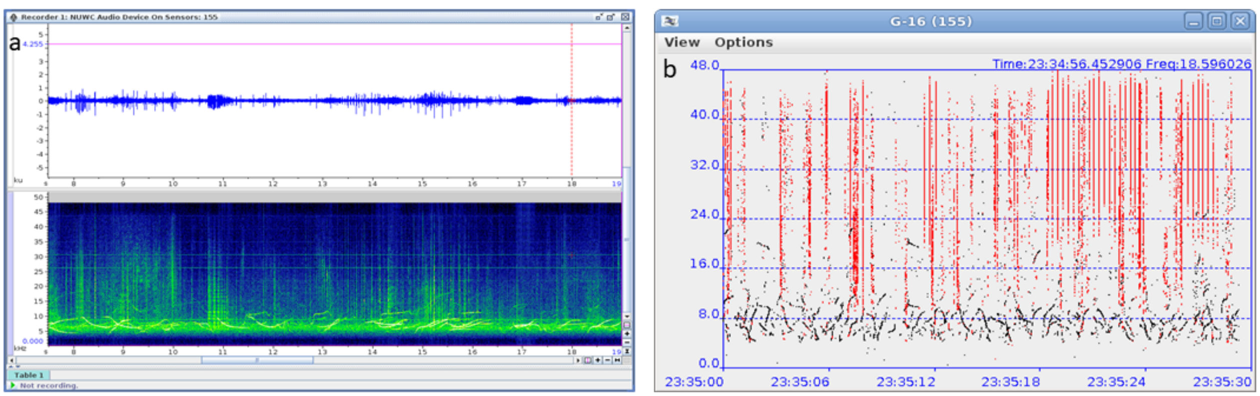

Figure 36. Short-finned pilot whale (*Globicephala macrorhynchus*) calls detected at PMRF.
a) time series (top) and spectrogram (bottom) of pilot whale calls in Raven Pro; b) clicks and whistles using the M3R binary spectrograms.

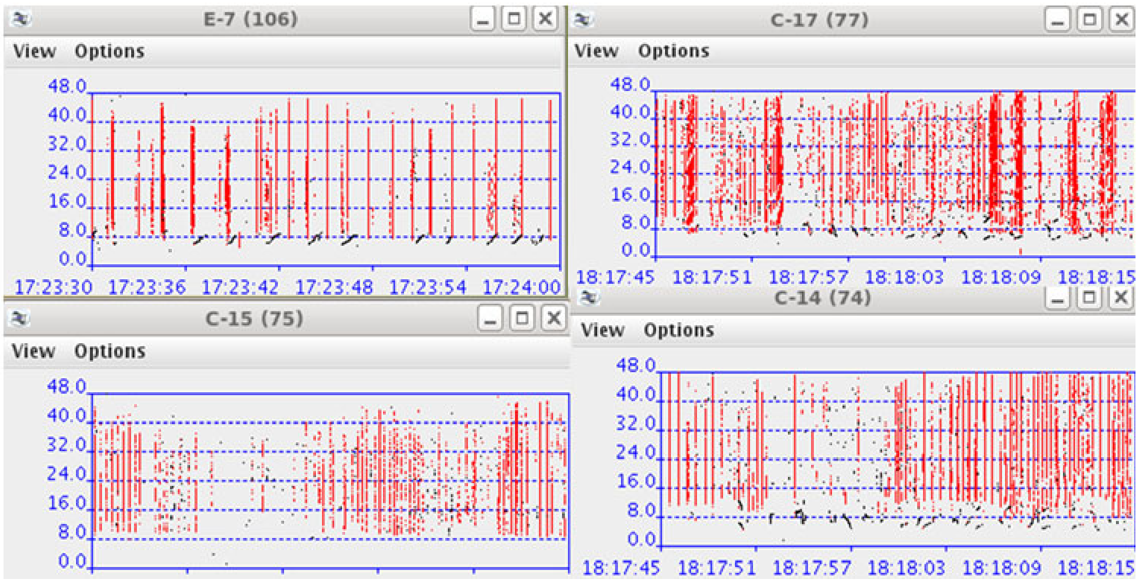

Figure 37. False killer whale (*Pseudorca crassidens*) calls detected at PMRF.
Examples of false killer whale clicks and whistles using the M3R binary spectrograms.

M3R personnel use the M3R system at PMRF as they do at SOAR to direct the on-water personnel to the locations of animals of interest. Communications are maintained via radio and cell phone. The cetacean species acoustically identified by M3R system during the August 2018 field test at PMRF, along with summary information extracted from the associated field logs, is shown in Table 20. More detailed information extracted from these field logs can be found in Appendix B.

A total number of 119 'acoustic sightings' were logged, including 48 of Blainville's beaked whales, eleven of rough-toothed dolphins, six of sperm whales, and 47 of unidentified dolphins. Of the acoustic sightings, ten were directed, and three were visually verified. Two satellite tags were also placed on short-finned pilot whales (Table 20).

Table 20. Species acoustically identified with the M3R system or visually sighted at PMRF
Data are extracted from the August 2018 field effort logs.

Species (Abbreviation)	Species (Common Name)	Species (Scientific Name)	# Acoustic Sightings Logged	# Acoustic Sightings Directed	# Acoustic Sightings Visually Verified	# of Tags
Md	Blainville's beaked whale	*Mesoplodon densirostris*	48	1	0	0
Pm	Sperm whale	*Physeter macrocephalus*	6	2	1	0
Gm	Short-finned pilot whale	*Globicephala macrorhynchus*	2	1	1	2
Sb	Rough-toothed dolphin	*Steno bredanensis*	11	0	1	0
Pc	False killer whale	*Pseudorca crassidens*	1	0	0	0
Tt	Bottlenose dolphin	*Tursiops truncatus*	1	0	0	0
UD	Unidentified dolphin	Delphinidae sp.	47	6	0	0
UM	Unidentified baleen whale	Mysticeti sp.	3	0	0	0

3.2 Long-Term Monitoring of Blainville's beaked whales at PMRF

3.2.1 PMRF Methods

3.2.1.1 PMRF Data

PMRF archives were analyzed starting from the install of the CS-SVM classifier install in September 2015 through 2018. The number of days per month for the years 2015 through 2018 on which CS-SVM detection archives were collected at PMRF are shown in Table 21. The CS-SVM detections were used to determine the Blainville's beaked whale groups.

Table 21. Number of days per month for the years 2015-2018 on which archives were collected at PMRF with CS-SVM classifier.

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	7	13	31	22	11	31	25	

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 an extended archive which runs from February 2017 through November 2018. Data collected in 2019 were received too late to complete analysis and will be included in the following year's report.

3.2.1.2 PMRF Blainville's beaked whale Group Analysis

3.2.1.2.1 PMRF Formation of Blainville's beaked whale groups

Blainville's beaked whale groups were found using the same procedure as for Cuvier's beaked whale groups in section 2.2.1.2.1, 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 CS-SVM Blainville'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.

3.2.1.3 PMRF Blainville's beaked whale Abundance

Blainville's beaked whale abundance at PMRF is calculated using equation 2 in section 2.2.1.3, 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 [12]; dive rate (r_d) of 0.42 (average of mean day/night, [13]), proportion of false positives (c) of 0.17 [14], probability of detection (P_D) of 0.86 [14]. The average group size for Blainville's beaked whales in Hawai'i from Baird, 2006 [12] was used, and the average of the Blainville's beaked whale mean day and night dive rates from Baird, 2008 [13] 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 [14]. 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. PMRF detection statistics will be calculated this year.

3.2.2 PMRF Results

3.2.2.1 PMRF Overview

PMRF archives were analyzed from 2015 through 2018. Data from partial hours of effort (effort per hour < 1.0) were removed from the following calculations in order to avoid the occasional instances with unrealistic numbers of GVPs per hour of effort. As there were only 53 hours of partial effort out of 14,121 effort hours, this resulted in the removal of less than 0.5% of the data. A total of 14,068 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 7,837 hours in 2017 (Table 22). 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 23. The CS-SVM detections were used to determine the Blainville's beaked whale groups.

Table 22. Total hours of effort per year in which data were recorded at PMRF, with partial hours of effort removed.

2015	2016	2017	2018
109	471	7837	5651

Table 23. The number of days per month on which archives were collected at PMRF with the CS-SVM classifier.
Data collection is only indicated through part of November, 2018. The '25+' in November indicates that data are still being collected, but have not yet been processed.

M3R PMRF Detection Archives												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	5	1	NA	NA
2016	NA	11	NA	NA	NA	NA	NA	11	NA	NA	NA	NA
2017	NA	27	31	30	31	30	18	29	30	30	30	31
2018	31	28	31	12	7	13	31	22	11	31	25+	NA

Figure 38 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 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.

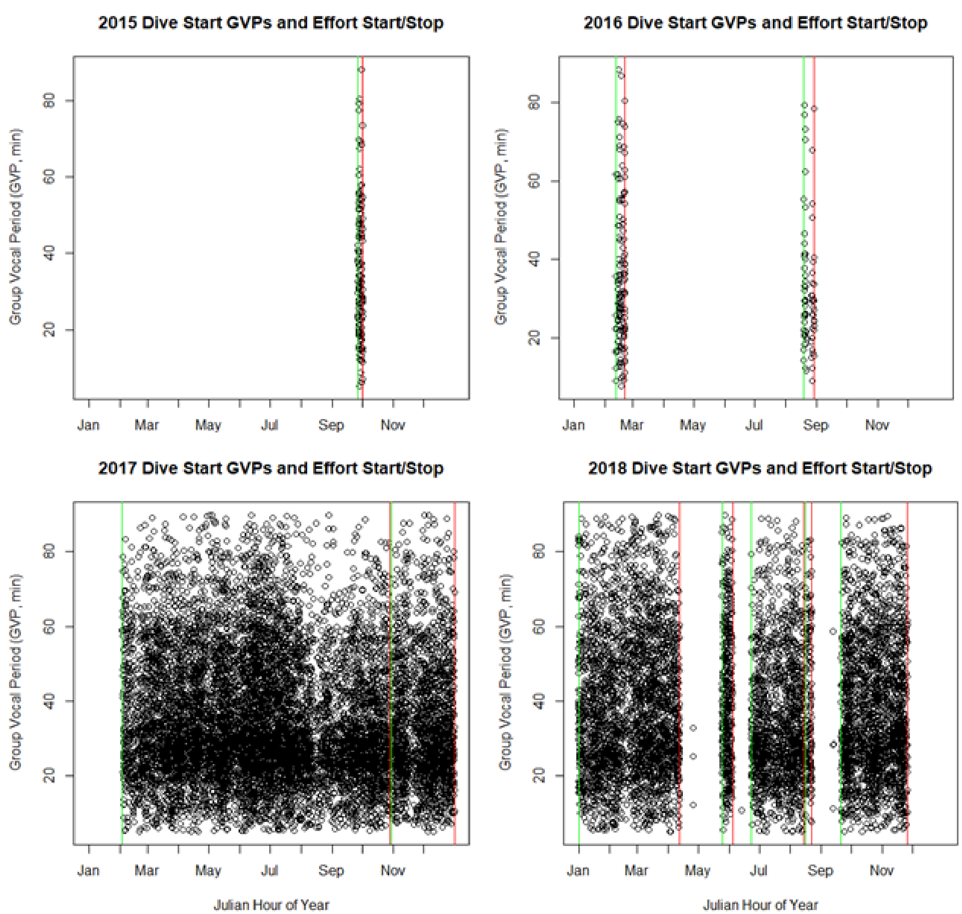

Figure 38. PMRF Blainville's beaked whale dive start GVP duration.
Effort start (green) and effort stop (red) times indicated with vertical lines for 2015 (upper left), 2016 (upper right), 2017 (lower left), and 2018 (lower right).

3.2.2.2 PMRF Blainville's Beaked Whale Abundance

3.2.2.2.1 PMRF Blainville's Beaked Whale Monthly Abundance

Table 24 shows the total number of GVPs (n_d) detected per month at PMRF for years 2015 to 2018, and Table 25 indicates the total hours of effort (T) per month. These values are used in the abundance equation 2 in section 2.2.1.3 to calculate the Blainville's beaked whale monthly abundance at PMRF. Time periods where no data were collected are indicated by the label "NA".

Table 24. Total number of GVPs (n_d) per month for 2015-2018 at PMRF

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	135	9	NA	NA
2016	NA	138	NA	NA	NA	NA	NA	77	NA	NA	NA	NA
2017	NA	598	1011	1046	1090	1434	1276	685	803	927	834	1135
2018	859	680	1022	322	335	336	747	626	395	922	819	NA

Table 25. Total hours effort per month (T), for years 2015-2018 at PMRF.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	98	11	NA	NA
2016	NA	224	NA	NA	NA	NA	NA	247	NA	NA	NA	NA
2017	NA	619	744	720	744	714	743	708	699	684	719	743
2018	744	669	744	274	167	271	744	453	244	744	597	NA

Mean monthly Blainville's beaked whale abundances averaged across the years 2015 to 2018 are shown in Table 26 and Figure 39 (left). The mean monthly abundance refers to the average number of Blainville's beaked whales on range at any given point within the respective month. The number of animals is highest in May, at 14.36, and lowest in February, at 7.17 animals. This is be caveated by the fact that several months only have data from one year.

Over the time-period from 2015 to 2018 the abundance peaked in June of 2017 at 16.61 animals. The lowest abundance occurred in August 2016 with a value of 2.58 animals (Table 27; Figure 39, right).

Table 26. Mean monthly Blainville's beaked whale abundances for PMRF averaged across 2015 to 2018.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	18.24	13.69	21.59	20.76	27.42	25.66	21.50	14.02	21.83	17.97	20.00	24.14
mean abundance	9.55	7.17	11.30	10.87	14.36	13.44	11.26	7.34	11.43	9.41	10.47	12.64
lower CI	0.86	0.64	1.02	0.98	1.29	1.21	1.01	0.66	1.03	0.85	0.94	1.14

Table 27. Mean monthly Blainville's beaked whale abundances for PMRF 2015-2018.
NA's indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	11.40	6.77	NA	NA
2016	NA	5.10	NA	NA	NA	NA	NA	2.58	NA	NA	NA	NA
2017	NA	7.99	11.24	12.02	12.12	16.61	14.21	8.00	9.50	11.21	9.60	12.64
2018	9.55	8.41	11.36	9.72	16.59	10.26	8.31	11.43	13.39	10.25	11.35	NA

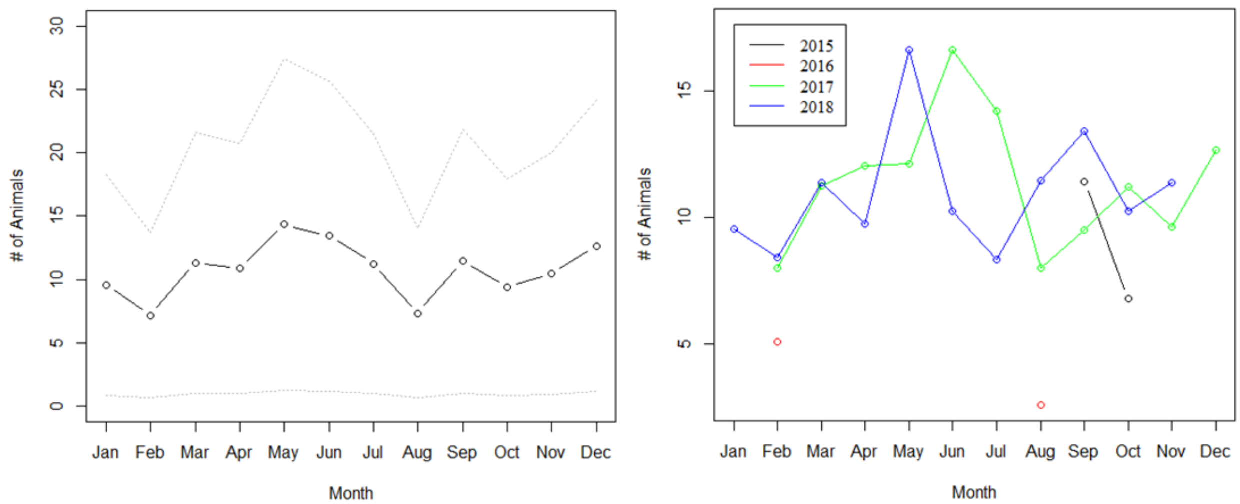

Figure 39. Mean monthly Blainville's beaked whale abundance at PMRF
Left: **averaged between 2015 and 2018,** ***Right:*** **for the years 2015 through 2018. Dashed lines indicate 95% confidence intervals.**

3.2.2.2.2 PMRF Yearly Blainville's Beaked Whale Abundance Trends

Blainville's beaked whale abundance was calculated at PMRF between 2015 and 2018 using the abundance equation 2 in section 2.2.1.3. The mean PMRF Blainville's beaked whale abundance at any point of time on range within the given year has varied from about four to eleven animals (Table 28, Figure 40). Aside from the low number in 2016, the abundance has remained consistent. Note, however, that there are far fewer hours of data available in 2015 and 2016 than in 2017 and 2018.

Table 28. Mean Blainville's beaked whale abundance at PMRF, at any time within the given year, with CI values.

	2015	2016	2017	2018
upper CI	20.87	7.11	21.80	19.69
mean *Md* abundance	10.93	3.72	11.41	10.31
lower CI	0.98	0.34	1.03	0.93

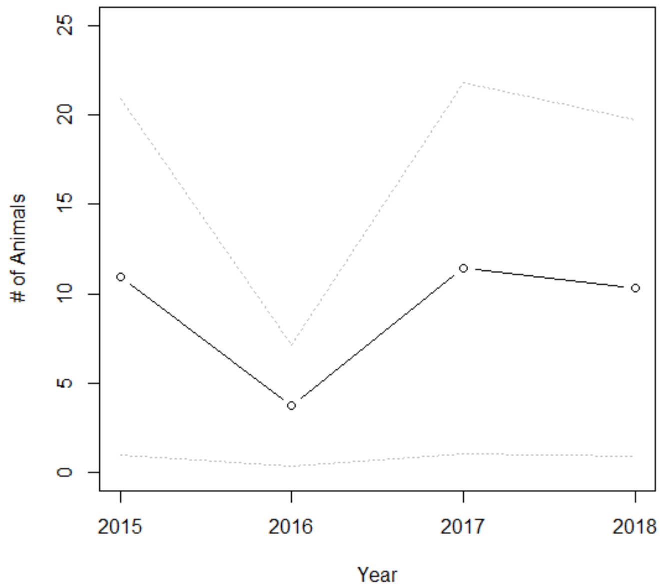

Figure 40. Mean PMRF Blainville's beaked whale abundance per year from 2015-2018. Dashed lines indicate 95% confidence intervals.

3.2.2.3 PMRF Blainville's Beaked Whale GVPs per Hour Effort

The mean number of GVPs 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 29.

Table 29. Mean monthly number of PMRF Blainville's beaked whale GVPs per hour effort, averaged across 2015 to 2018.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	2.19	1.96	2.53	2.50	2.83	3.12	2.53	2.08	2.40	2.41	2.37	2.72
mean # GVPs	1.15	0.93	1.37	1.37	1.56	1.79	1.36	0.97	1.27	1.29	1.26	1.53
lower CI	0.12	-0.09	0.20	0.25	0.30	0.46	0.19	-0.14	0.14	0.17	0.15	0.33
GVP CVs	0.89	1.10	0.85	0.82	0.81	0.74	0.86	1.14	0.89	0.87	0.88	0.78

The mean number of GVPs per hour varies from a high of 1.8 GVPs per hour of effort across the range in June to a low of 0.93 in February (Table 29; Figure 41, left). The monthly mean number of GVPs per hour of effort peaked at 2.0 in June of 2017, while the lowest, 0.3, occurred in August of 2016 (Table 30; Figure 41, right).

Table 30. PMRF monthly mean number of Blainville's beaked whale group GVPs per hour for 2015 to 2018. NA's indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	NA	NA	NA	NA	NA	NA	NA	NA	1.38	0.82	NA	NA
2016	NA	0.61	NA	NA	NA	NA	NA	0.30	NA	NA	NA	NA
2017	NA	0.96	1.36	1.45	1.47	2.00	1.72	0.95	1.15	1.35	1.16	1.53
2018	1.15	1.01	1.37	1.16	2.01	1.23	1.00	1.37	1.59	1.24	1.37	NA

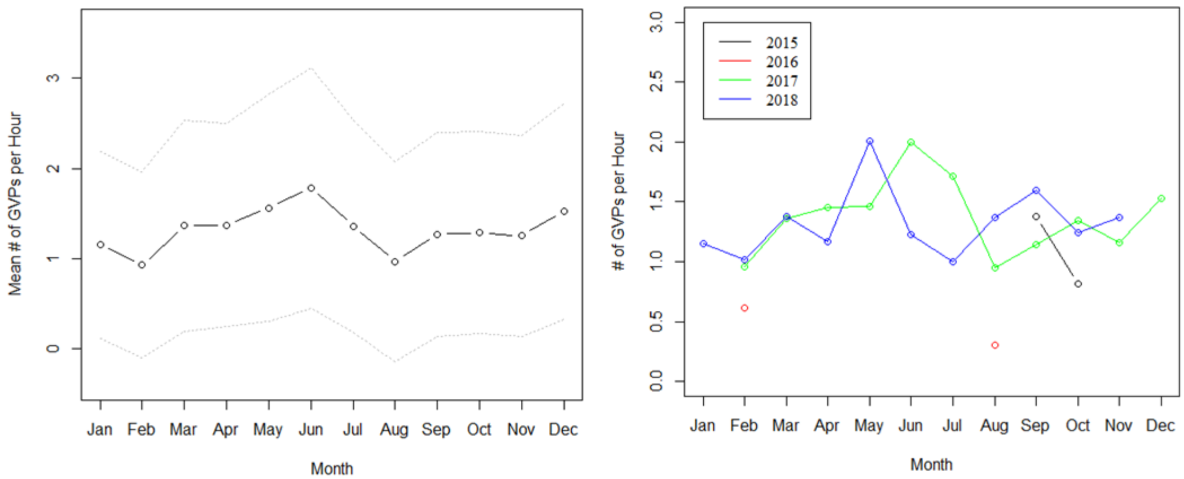

Figure 41. Mean monthly Blainville's beaked whale number of GVPs per hour of effort at PMRF *Left:* averaged between 2015 and 2018, *Right:* for the years 2015 through 2018. Dashed lines indicate 95% confidence intervals.

3.2.2.4 PMRF Blainville's Beaked Whale Group Vocal Period (GVP) Duration

The mean monthly GVP duration in minutes of the PMRF Blainville's beaked whale group dives were calculated for 2015 through 2018. Mean GVP durations, averaged across 2015 to 2018 for each month, were generated, with the 95% CIs and corresponding CVs (Table 31). The monthly mean GVP duration across all years varies from a high of 38.2 minutes in March to a low of 33.8 min in September (Table 31; Figure 42, left). The mean monthly GVP duration peaks at 41.6 min in May of 2018, and is lowest at 32.05 min in September, 2017 (Table 32; Figure 42, right).

Table 31. 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).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	56.35	57.02	56.24	53.39	55.64	55.18	53.24	50.31	50.23	52.69	54.56	50.81
mean GVP	37.83	38.17	38.19	36.75	37.73	37.43	35.81	33.82	33.79	35.38	36.76	34.19
lower CI	19.30	19.31	20.15	20.10	19.81	19.67	18.39	17.32	17.36	18.07	18.96	17.56
GVP CV	0.49	0.49	0.47	0.45	0.47	0.47	0.49	0.49	0.49	0.49	0.48	0.49

Table 32. PMRF mean monthly Blainville's beaked whale GVP lengths (in min) for 2015 to 2018. NA's indicate periods without data.

	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	37.83	40.88	39.93	37.99	41.60	36.05	35.84	35.94	37.04	38.45	38.67	NA

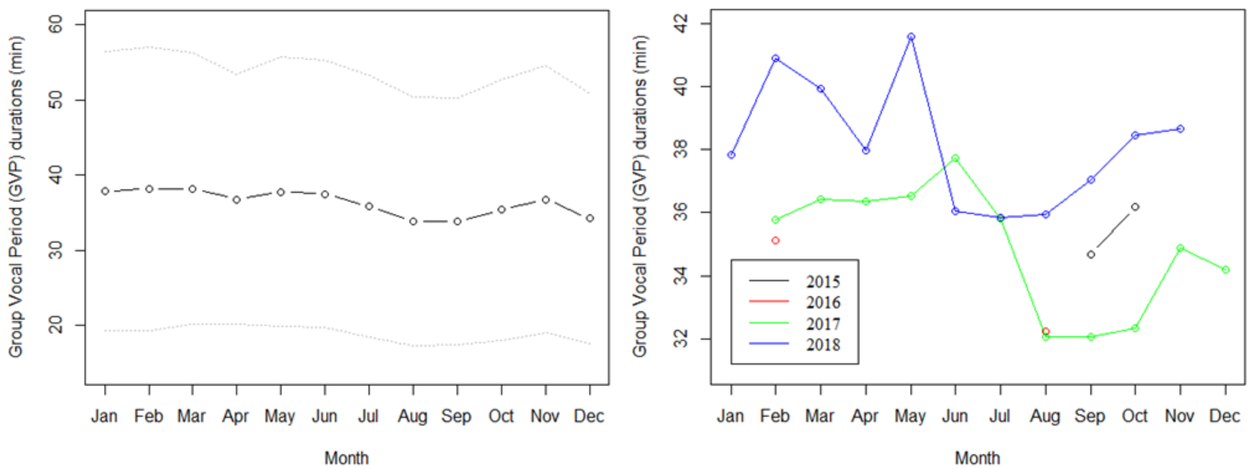

Figure 42. Mean monthly Blainville's beaked whale GVP lengths (in min) at PMRF - *Left:* averaged between 2015 and 2018, *Right:* for the years 2015 through 2018. Dashed lines indicate 95% confidence intervals.

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

The mean number of Blainville's beaked whale foraging clicks detected per group were calculated for each month for the years 2015 through 2018 (Table 34). The click count data were strongly left-skewed, so values greater the 20 times the interquartile range (IQR) were considered outliers and removed. The monthly foraging clicks detected per group, averaged between 2015 to 2018, were also generated, with 95% confidence intervals CIs and corresponding CVs (Table 33).

The monthly mean varies from 1455 clicks per group in August to 1929 in September (Table 33; Figure 43, left). The mean monthly number of clicks per group peaks at 2232 in September, 2018 and is lowest in August, 2016 at 1118 clicks (Table 34; Figure 43, right).

Table 33. Mean PMRF Blainville'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).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	3337.3	3318.9	4210.8	4010.0	4352.4	3977.0	3607.7	2982.5	4378.9	3652.4	3503.9	3681.0
mean group click count	1558.2	1606.4	1876.1	1887.8	1918.2	1891.5	1678.4	1455.0	1929.0	1708.9	1613.8	1651.4
lower CI	-220.9	-106.0	-458.6	-234.4	-515.9	-193.9	-251.0	-72.6	-520.8	-234.6	-276.2	-378.3
group click count CV	1.1	1.1	1.2	1.1	1.3	1.1	1.1	1.0	1.3	1.1	1.2	1.2

Table 34. PMRF mean monthly number of Blainville's beaked whale clicks per group for 2015 to 2018.

	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	1558.2	1528.1	1815.6	1957.5	1991.9	1621.4	1481.0	1456.3	2231.8	1884.2	1670.5	NA

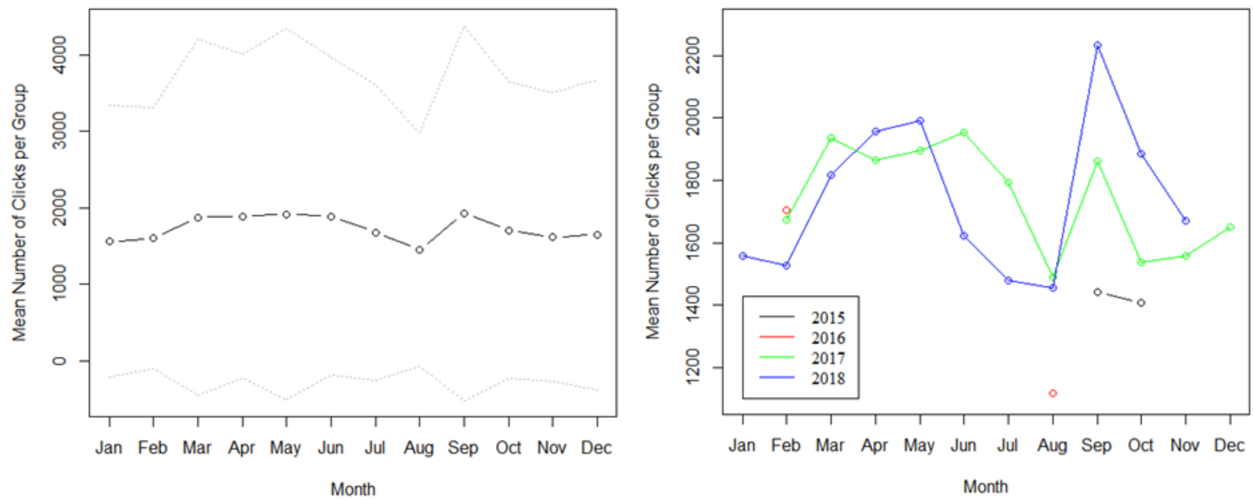

Figure 43. Mean monthly Blainville's beaked whale number of clicks per group at PMRF - *Left:* averaged between 2015 and 2018, *Right:* for the years 2015 through 2018. Dashed lines indicate 95% confidence intervals.

3.3 The Effect of Mid-Frequency Active Sonar (MFAS) on Blainville's beaked whale Distribution at PMRF

3.3.1 PMRF Methods

Five short periods in 2017 and six in 2018 were combined to examine the mean number of Blainville's beaked whale GVPs before, during, and after presumed mid-frequency active sonar (MFAS) events. These periods of presumed MFAS were obtained by filtering the output of a sonar detector program to only retain periods above a threshold level that met or exceeded the maximum level of the system, as was done for SOAR. Periods exceeding the threshold were considered as likely MFAS events, though they have not been corroborated against the range schedule.

The events durations varied, and were up to 11 hours (Figure 44). Events were only considered if the threshold was exceeded for every hour in the event, and if at least the same number of hours before and after each event did not exceed the threshold level. In addition, only events with a minimum of three consecutive hours of MFAS were used, to minimize the likelihood of events that may be false alarms. The mean number of GVPs per hour was calculated for the duration of each event, and for an equivalent number of hours before and after each event.

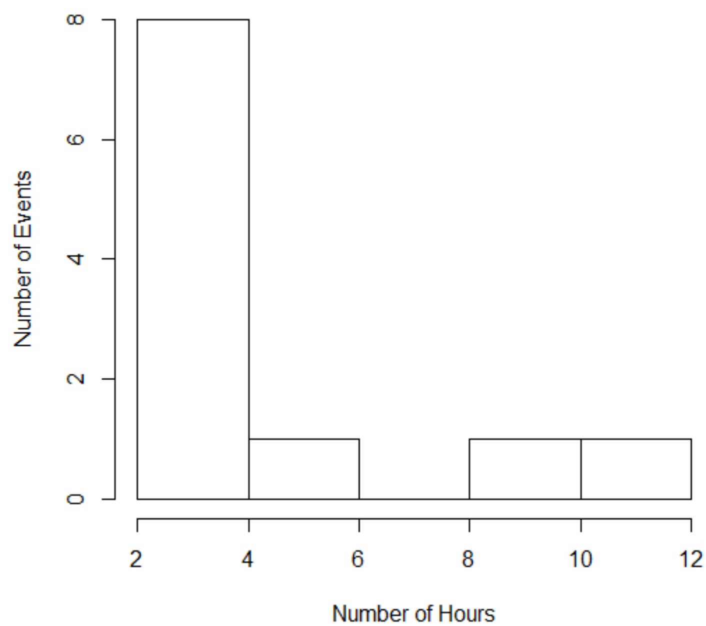

Figure 44. The number of PMRF sonar detector events of various durations (in hours) in 2017 and 2018. These are events in which the sonar detector exceed threshold for every hour of the event, and for which there were an equal number of hours under threshold both before and after the event.

3.3.2 PMRF Results

Eleven events up to 11 hours in length were examined from 2017 and 2018. The distribution of number of GVPs per hour varied among the Before, During, and After periods. However, no significant differences in number of GVPs were found between any of the three periods (Before, During, and After) for these data (Figure 45). It is possible that the sample size was too small to detect any significant differences.

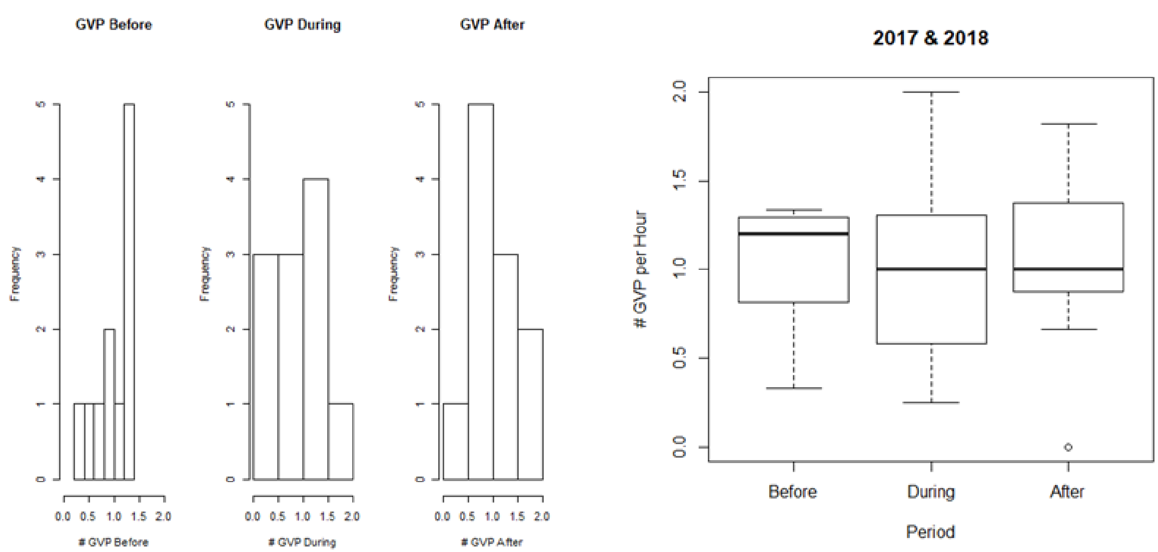

Figure 45. Number of GVPs per hour for the PMRF 2017 and 2018 periods Before, During, and After MFAS. *Left:* Histogram and *Right:* boxplot of the number of GVPs per hour.

Appendix A SOAR Field Work Logs

Table 35 shows excerpts from the M3R log files from five field efforts with MarEcoTel in 2019 and one at the end of 2018 on SOAR. The excerpts show the species acoustically identified and the number of such sightings, along with the number of sightings to which the RHIB was directed, the number of species sightings verified, and the number of tags deployed. Note the sightings do not necessarily indicate the number of groups present, as the same group may be resighted over the course of the day. In addition, these log excerpts indicate minimum numbers present on the range, as not all activity is logged. There are a variety of reasons for this, such as: particular species or parts of the range may be the focus on a particular day; personnel may have different levels of experience; and certain ever-present groups of animals such as dolphins are not usually logged.

Table 35. Excerpts of M3R log files from five field efforts on the SOAR range in 2019 and the last field test in 2018.
These excerpts indicate the species and number of 'acoustic sightings', the number of these sightings directed, visually verified, and the number of tags deployed. Note that these logs indicate minimum numbers, as not all sightings may be logged for a variety of reasons (such as focus on particular species or areas of the range, or experience of the personnel), and the numbers directed and verified are not always recorded.

Test Dates	# Hours Monitored	Species	# Acoustic Sightings Logged	# Acoustic Sightings Directed	# Acoustic Sightings Visually Verified	Tagged?	Notes
11/13/2018	9.5	*Zc*	19	0	0	No	
		UD	1	0	0	No	
		Bp	1	0	0	No	
11/14/2018	3.5	*Zc*	12	0	0	No	
11/15/2018	9	*Zc*	14	2	1	No	
		UD	1	0	0	No	
11/16/2018	3.7	*Zc*	29	4	0	No	
		Bp	1	0	1	No	pair of fin whales
11/17/2018	9	*Zc*	24	2	1	No	
11/18/2018	8	*Zc*	35	1	0	No	
11/19/2018	8.5	*Zc*	20	3	2	Yes, 1	Tag detached after deployment for unknown reasons.
11/20/2018	9.5	*Zc*	32	0	0	No	
		Gg	1	0	0	Yes, 1	
1/3/2019	5.45	*Zc*	14	2	0	No	One group possibly of Risso's dolphins.
		Er	1	0	0	No	possible gray whale (*Er*)
1/4/2019	7.83	*Zc*	9	3	1	No	

		UM	1	0	0	No	probable fin whale
		UM	1	0	0	No	probable gray whale
		Bp	1	1	1	Yes, 1	SPOT tag attached
1/5/2019	0.03	*Bp*	1	1	0	No	
1/7/2019	1.47	UM	1		0	No	off-range
		Zc	2	0	0	No	
		Bp	1	0	0	No	1 fin - faint, off-range
		Bp	1	0	0	No	multiple fin posits, moving to W-NW
1/8/2019	10.25	*Zc*	12	2	1	No	
		Bp	2	1	1	Yes, 1	Group of 4 fin whales
		Gg	1	0	0	No	
		UD	1	0	0	No	
1/9/2019	4.12	*Zc*	4	0	0	No	
1/10/2019	3.75	*Zc*	3	0	0	No	
1/11/2019	6.6	*Zc*	13	2	2	Yes, 1	
		UM	1	0	0	No	Humpback moving north off south SOAR
1/12/2019	1.23	*Zc*	3	0	0	No	
1/13/2019	9.38	*Zc*	17	1	1	Yes, 1	
3/1/2019	9.6	*Zc*	28	6	1	No	
		Gg	3	0	0	No	
		UD	1	0	0	No	
		Mn	1	0	0	No	
		Bp	3	0	0	No	
3/2/2019	0.7	Bp	1	0	0	No	off range
3/3/2019	1.5	*Zc*	2	0	0	No	
		Mn	1	0	0	No	
		UD	3	0	0	No	
		Bp	1	0	0	No	
3/5/2019	8	*Zc*	8	1	0	No	
		Gg	2	0	0	No	
		Bp	1	0	0	No	
3/7/2019	4.4	Gg	2	0	1	No	
		Mn	1	0	1	No	
3/10/2019	9.7	Zc	1	0	1	No	
		Gg	3	0	0	No	

		Bp	1	0	1	No	
7/22/2019	10	*Zc*	21	2	1	No	
		Bp	1	0	0	No	
7/23/2019	5.2	*Zc*	6	1	0	No	
		UM	2	1	0	No	
		Pm	1	0	0	No	
10/5/2019	9.3	*Zc*	13	1	1	No	
		Bp	1	0	0	No	
10/6/2019	9.1	*Zc*	18	2	2	No	
		Gg	2	1	0	No	
		Bp	1	0	1	No	
10/7/2019	5	*Zc*	8	0	0	No	
		UM	2	1	0	No	
		Bp	1	1	1	No	3 fin whales
10/10/2019	9.3	*Zc*	18	4	0	No	
		Bp	2	1	0	No	at least 5 fin whales in area
		UD	1	0	0	No	
10/11/2019	3	*Zc*	19	2	1	No	
10/12/2019	7.5	*Zc*	83	2	2	Yes, 2	
10/13/2019	8	*Zc*	6	1	0		
11/10/2019	7.9	*Zc*	15	4	0	No	
		Bp	1	1	0	No	
		Bm	1	0	0	No	
11/11/2019	6.3	*Zc*	23	6	1	Yes, 1	
		Bp	1	1	0	No	
11/12/2019	7.5	*Zc*	20	6	3	No	
		Bp	1	0	0	No	
11/16/2019	6.2	*Zc*	24	3	1	No	
		Bp	1	0	0	No	
11/17/2019	5.1	*Zc*	14	4	2	Yes, 1	
		Gg	1	0	0	No	

Appendix B PMRF Field Work Logs

Excerpts from the M3R log files from the field effort conducted with CRC at PMRF in August 2018 are shown in Table 36. The excerpts show the species acoustically identified and the number of such sightings, along with the number of sightings to which the RHIB was directed, the number of species sightings verified, and the number of tags deployed. Note the sightings do not necessarily indicate the number of groups present, as the same group may be resighted over the course of the day. In addition, these log excerpts indicate minimum numbers present on the range, as not all activity is logged.

Table 36. Excerpts from the M3R logs from the field test conducted at PMRF in August, 2018 with Cascadia Research.
These excerpts indicate the species and number of 'acoustic sightings', the number of these sightings directed, visually verified, and the number of tags deployed. Note that these logs indicate minimum numbers, as not all sightings may be logged for a variety of reasons (such as focus on particular species or areas of the range, or experience of the personnel), and the numbers directed and verified are not always recorded.

Test Dates	# Hours Monitored	Species	# Acoustic Sightings Logged	# Acoustic Sightings Directed	# Acoustic Sightings Verified	Tagged?	Notes
8/7/2018	3.9	*Md*	7	0	0	No	
		UM	1	0	0	No	
		UD	6	1	0	No	Possible *Tt*
8/8/2018	1	*Md*	1	0	0	No	
		UD	4	0	0	No	
		Pm	1	1	0	No	
		UM	1	0	0	No	
8/9/2018	0.8	*Md*	2	0	0	No	
		Sb	1	0	0	No	
		UD	3	0	0	No	
		UM	1	0	0	No	
8/10/2018	5	*Md*	3	0	0	No	
		UD	7	0	0	No	
8/11/2018	1.6	*Md*	1	0	0	No	
		UD	5	0	0	No	
8/12/2018	0.9	UD	2	0	0	No	possible *Sb*
		Gm	1	0	0	No	
8/13/2018	0.1	*Md*	1	0	0	No	
		UD	3	0	0	No	
8/15/2018	5	*Md*	7	0	0	No	
		Sb	1	0	0	No	
		Tt	1	0	0	No	
8/16/2016	6.6	*Pm*	1	1	1	No	
		Md	4	0	0	No	
		Sb	4	0	0	No	

		UD	3	0	0	No	
8/17/2018	6.8	*Pm*	2	0	0	No	
		Md	4	0	0	No	
		Sb	1	0	0	No	
		UD	6	0	0	No	
8/18/2018	6	*Md*	10	0	0	No	
		UD	2	1	0	No	
		Sb	1	0	0	No	
8/19/2018	7	*Md*	2	1	0	No	
		Sb	1	0	1	No	
		UD	5	4	0	No	
		Pm	1	0	0	No	
		Gm	1	1	1	Yes, 2	
8/20/2018	2.9	*Md*	6	0	0	No	
		Pm	1	0	0	No	
		Sb	2	0	0	No	
		Pc	1	0	0	No	
		UD	1	0	0	No	

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