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FINAL

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), 2022

Marine Mammal Monitoring on Navy Ranges (M3R) Program
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Naval Undersea Warfare Center
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14. ABSTRACT
In the Pacific the Marine Mammal Monitoring on Navy Ranges (M3R) program maintains systems that continuously run algorithms to detect, classify and localize marine mammals year-round on the U.S. Navy's deep-water Southern California Antisubmarine Warfare Range (SOAR) in Southern California and Pacific Missile Range Facility (PMRF) off Kauai, Hawai'i. Long-term archive data collected on these ranges allows for numerous types of studies on species inhabiting the ranges, including the monitoring of abundance and distribution, behavioral responses to naval activities, and habitat usage. They also provide the opportunity to study ambient noise and soundscapes.
In FY22 the M3R program had three areas of focus for SOAR and PMRF:
1. Support of on-site field surveys at SOAR and PMRF with real-time monitoring using the M3R system. In FY22, M3R conducted four field surveys at SOAR (November 2021 and January, March, and June 2022) in collaboration with Marine Ecology and Telemetry Research (MarEcoTel), and one field survey at PMRF (in August 2022) with Robin Baird of the Cascadia Research Collective (CRC). During these field surveys, M3R team members use acoustic detections data from the M3R system to direct on-water researchers to the locations of vocalizing animals derived from the acoustic detections, where they collect photos for photo-ID catalogs, behavioral data, biopsy data, and potentially place satellite tags on animals. The focus at SOAR was on Cuvier's beaked whales and fin whales, and during the four field surveys both species were acoustically detected, along with sei, blue, humpback, sperm, short-finned pilot, gray, and killer

whales, common and Risso's dolphins, and unidentified dolphins, pinnipeds, beaked and baleen whales. The Cuvier's beaked whales, fin whales, and short-finned pilot whale acoustic detections were all visually verified. Three species were successfully tagged, 8 tags in total, including Cuvier's beaked whales, fin whales, and short-finned pilot whales. At PMRF the following species were acoustically detected: Blainville's and Cuvier's beaked whales, melon-headed whales, short-finned pilot whales, false killer whales, bottlenose dolphins, rough-toothed dolphins, striped dolphins, and unidentified dolphins. The Blainville's beaked, melon-headed, and short-finned pilot whales, as well as bottlenose, rough-toothed and striped dolphins were visually verified. A total of 7 satellite tags were placed on four different species, including Blainville's beaked whales, melon headed whales, short-finned pilot whales, and bottlenose dolphins. M3R archive data and broadband recordings were also collected during the field surveys.

2. Long-term data collection and the evaluation of the distribution and abundance of Cuvier's beaked whales at SOAR and Blainville's and Cuvier's beaked whales at PMRF. Data from 2010-2022 was evaluated at SOAR and data from 2011-2022 at PMRF. Distribution was analyzed using beaked whale Group Vocal Periods (GVPs) detected on range, and the GVPs were converted to number of animals to estimate abundance. The Cuvier's beaked whales at SOAR exhibit a clear seasonal pattern, with the highest numbers in May, followed by the December/January timeframe. The numbers are lowest in September, followed by a less pronounced drop in March. A trend analysis shows that the sample mean number of GVPs per hour and sample mean abundance per hour has significantly dropped ($p < 2.2e-16$) between the periods of 2011-2013 ($\mu GVP = 4.33$, $\mu Abund=45.8$) and 2019-2021 ($\mu GVP = 3.73$, $\mu Abund = 35.4$), though the mean # GVPs ($\mu GVP = 1.72$) and mean abundance ($\mu Abund = 19.5$) for across the whole data set are lower than the periods used for analysis. This could be due to lower populations estimates from 2014-2018). At PMRF, the seasonal distribution of Blainville's beaked whales peaks in January and May through July, while it is lowest in April, with another dip in September. Cuvier's beaked whales, however, peak in March, during one of the low points for Blainville's beaked whales, and then the numbers drop through to September, when they are lowest. They then start to increase until reaching the March peak. Though both species reach peaks at different times, their numbers are both low in September. The trend analysis for Blainville's beaked whales at PMRF shows that the sample mean number of GVPs per hour and sample mean abundance per hour has significantly increased ($p < 2.2e-16$) between the periods of 2012-2014 ($\mu GVP = 0.83$, $\mu Abund = 6.04$) and 2019-2021 ($\mu GVP = 0.2.18$, $\mu Abund = 18.24$). Similarly, the sample mean number of Cuvier's beaked whale GVPs per hour has significantly increased ($p < 2.2e-16$) between the periods of 2012-2014 ($\mu GVP = 0.02$, $\mu Abund = 6.07$) and 2019-2021 ($\mu GVP = 0.37$, $\mu Abund = 18.15$).

3. Accuracy analysis of the M3R low-frequency detector algorithm at SOAR in coordination with the Naval Information Warfare Center (NIWC). In FY20 and in FY21 we conducted a first assessment of the accuracy of localizations of low-frequency (LF) calls automatically generated by the Marine Mammal Monitoring on Navy Ranges (M3R) system installed at the So-Cal ASW Range (SOAR). This was done by comparing LF localizations extracted from M3R archive files to fin whale detections and localizations generated by researchers at NIWC, San Diego, through their post-processing of whole range acoustic recordings (M3R packet recorder data) for select days. During this assessment we discovered that M3R appeared to be localizing only a fraction of the many LF calls it was receiving and that the tracks generated from M3R automatically generated posits exhibited greater scatter than the NIWC post-processed tracks. The cause for the discrepancy in the number of localizations was found to be excessive processing load on the computer nodes that associate times of call arrival among neighboring hydrophones. The increased scatter in M3R LF localization relative to the NIWC post-processed tracts was assumed to be related to the coarser time resolution (170.67 ms) of M3R's LF Fast Fourier Transform (FFT) detector relative to the NIWC detector. This year we implemented a fix to our call association programs to reduce the processing load. We also modified our LF FFT detector to increase its time resolution by a factor of eight.

15. SUBJECT TERMS

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Executive Summary

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In FY22 the M3R program had three areas of focus for SOAR and PMRF:

1. *Support of on-site field surveys at SOAR and PMRF with real-time monitoring using the M3R system.* In FY22, M3R conducted four field surveys at SOAR (November 2021 and January, March, and June 2022) in collaboration with Marine Ecology and Telemetry Research (MarEcoTel), and one field survey at PMRF (in August 2022) with Robin Baird of the Cascadia Research Collective (CRC). During these field surveys, M3R team members use acoustic detections data from the M3R system to direct on-water researchers to the locations of vocalizing animals derived from the acoustic detections, where they collect photos for photo-ID catalogs, behavioral data, biopsy data, and potentially place satellite tags on animals. The focus at SOAR was on Cuvier's beaked whales and fin whales, and during the four field surveys both species were acoustically detected, along with sei, blue, humpback, sperm, short-finned pilot, gray, and killer whales, common and Risso's dolphins, and unidentified dolphins, pinnipeds, beaked and baleen whales. The Cuvier's beaked whales, fin whales, and short-finned pilot whale acoustic detections were all visually verified. Three species were successfully tagged, 8 tags in total, including Cuvier's beaked whales, fin whales, and short-finned pilot whales. At PMRF the following species were acoustically detected: Blainville's and Cuvier's beaked whales, melon-headed whales, short-finned pilot whales, false killer whales, bottlenose dolphins, rough-toothed dolphins, striped dolphins, and unidentified dolphins. The Blainville's beaked, melon-headed, and short-finned pilot whales, as well as bottlenose, rough-toothed and striped dolphins were visually verified. A total of 7 satellite tags were placed on four different species, including Blainville's beaked whales, melon headed whales, short-finned pilot whales, and bottlenose dolphins. M3R archive data and broadband recordings were also collected during the field surveys.
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Abbreviations and Acronyms

Acronym	Definition
AIST	Advanced Instrumentation Systems Technology
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
FY	Fiscal Year
GVP	Group Vocal Period
FP	False Positive
HARP	High Frequency Recording Package
Hrs	Hours
ICI	Inter-Click Interval
IQR	Inter-Quartile Range
kHz	kilohertz
LF	Low-frequency
LIMPET	Low Impact Minimally Percutaneous Electronic Transmitter
LMR	Living Marine Resources
M3R	Marine Mammal Monitoring on Navy Ranges
MarEcoTel	Marine Ecology and Telemetry Research
METEOR	Marine Mammal Effects of Test and Evaluation on Ocean Ranges
MFAS	Mid-Frequency Active Sonar
Min	Minutes
MMAMMAL	Marine Mammal Monitoring And Localization
NIWC	Naval Information Warfare Center
NVT	Noise Variable Threshold
PD	Probability of Detection
PMRF	Pacific Missile Range Facility
RHIB	Rigid Hull Inflatable Boat
RL_{rms}	Received Level root mean squared
RMS	Root mean squared
SCORE	Southern California Offshore Range
SES	Shore Electronics System
SOAR	Southern California Anti-Submarine Warfare Range
SWTR	Shallow Water Training Range
T	Time
TDOA	Time difference of arrival
USWTR	Undersea Warfare Training Range
V_{rms}	Volts root mean squared
Whdetect	Whale Detection algorithm

1 Introduction

1.1 Background

The Marine Mammal Monitoring on Navy Ranges (M3R) program utilizes the U.S. Navy's instrumented hydrophone ranges for passive acoustic detection of marine species (Jarvis et al. 2014). This important resource allows for long-term monitoring of certain populations of interest, and provides data for answering key questions regarding basic biology, habitat usage, and behavioral responses to Navy training and testing activities. This report presents the results of annual baseline monitoring on two ranges managed by Commander, U.S. Pacific Fleet; the Southern California Anti-Submarine Warfare Range (SOAR) located off San Clemente Island, California, and the Pacific Missile Range Facility (PMRF), located off Kauai, Hawai'i.

1.2 Study Goals

The goals of the FY21 monitoring effort included the following:

1. Support real-time monitoring of on-water tagging operations at SOAR and PMRF.
2. Collect M3R archives at both SOAR and PMRF to inform long-term distribution and abundance estimates for Cuvier's beaked whales (*Ziphius cavirostris, Zc*) and Blainville's beaked whales (*Mesoplodon densirostris, Md*).
3. Analyze the accuracy of the installed LF detector algorithm at SOAR in coordination with the Naval Information Warfare Center (NIWC).

1.3 Study Sites

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 beaked whales are regularly detected acoustically and visually, displaying a high level of site fidelity to the area (Falcone et al. 2009, Schorr et al. 2014, Schorr et al. 2020). The SOAR range consists of an array of 177 bottom-mounted hydrophones covering an area of about 2200 square kilometers (km^2). The SOAR hydrophone separation ranges from about 2.5 to 6.5 kilometers (km), and hydrophones are at average depths of 1600-1800 meters (m). The 88 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].

PMRF is located off the northwest coast of Kauai, Hawai'i (Figure 2). 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 Training Range (SWTR). 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 (BSURE refurb) with a bandwidth of 50 Hz to 45 kHz, and the original 18 hydrophones with a bandwidth of 50 Hz to 18 kHz. This analysis used all hydrophones from the BARSTUR and BSURE portions of the range, aside from the original 18 in BSURE, due to restricted frequency range. Note that over this period of time the hydrophone configuration has changed as a result of certain hydrophones becoming nonfunctional, and this variation in spatial effort has not yet been accounted for in the analysis.

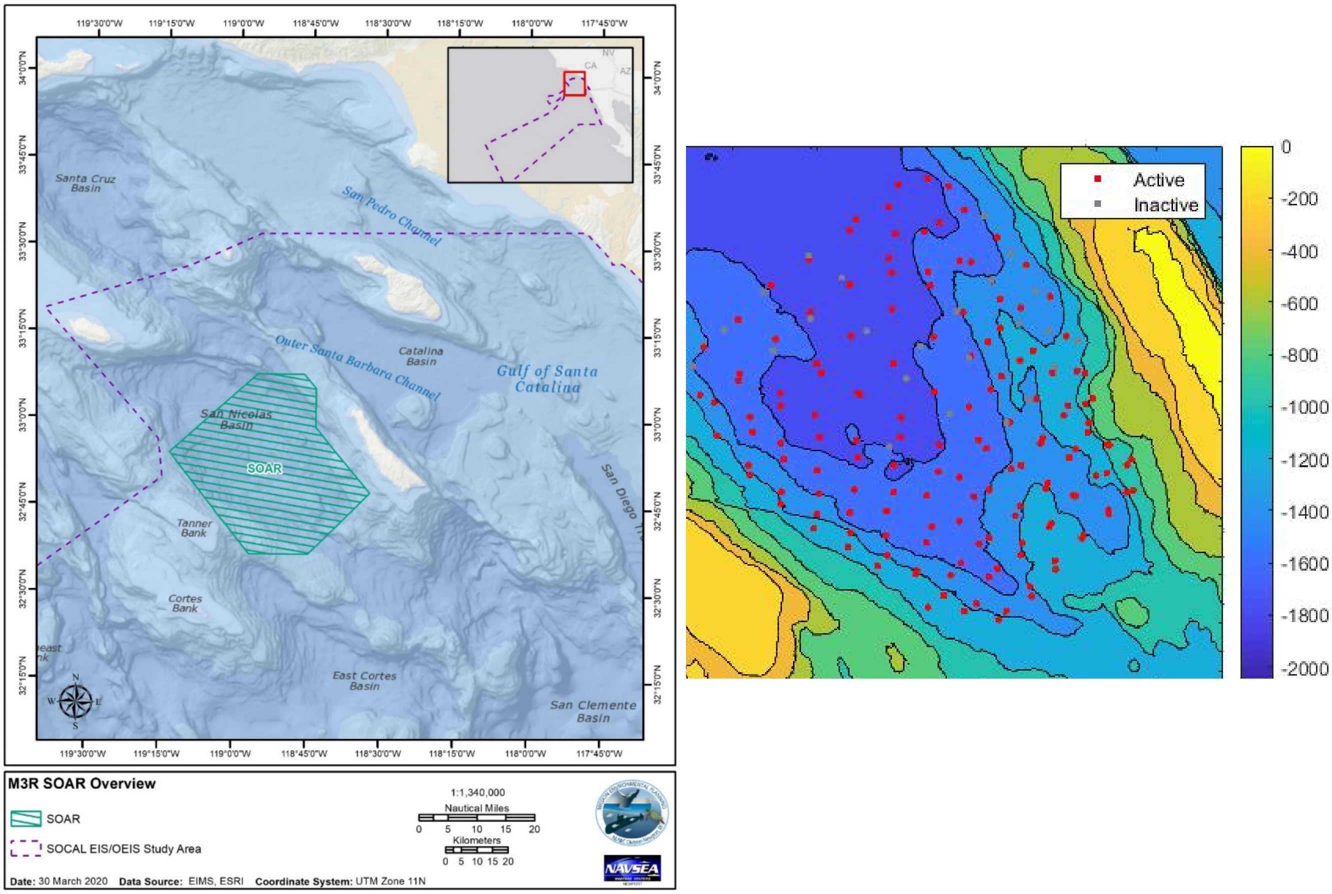


Figure 1. Location of SOAR hydrophone range, west of San Clemente Island off southern California (left). Hydrophone layout and bathymetry (right).

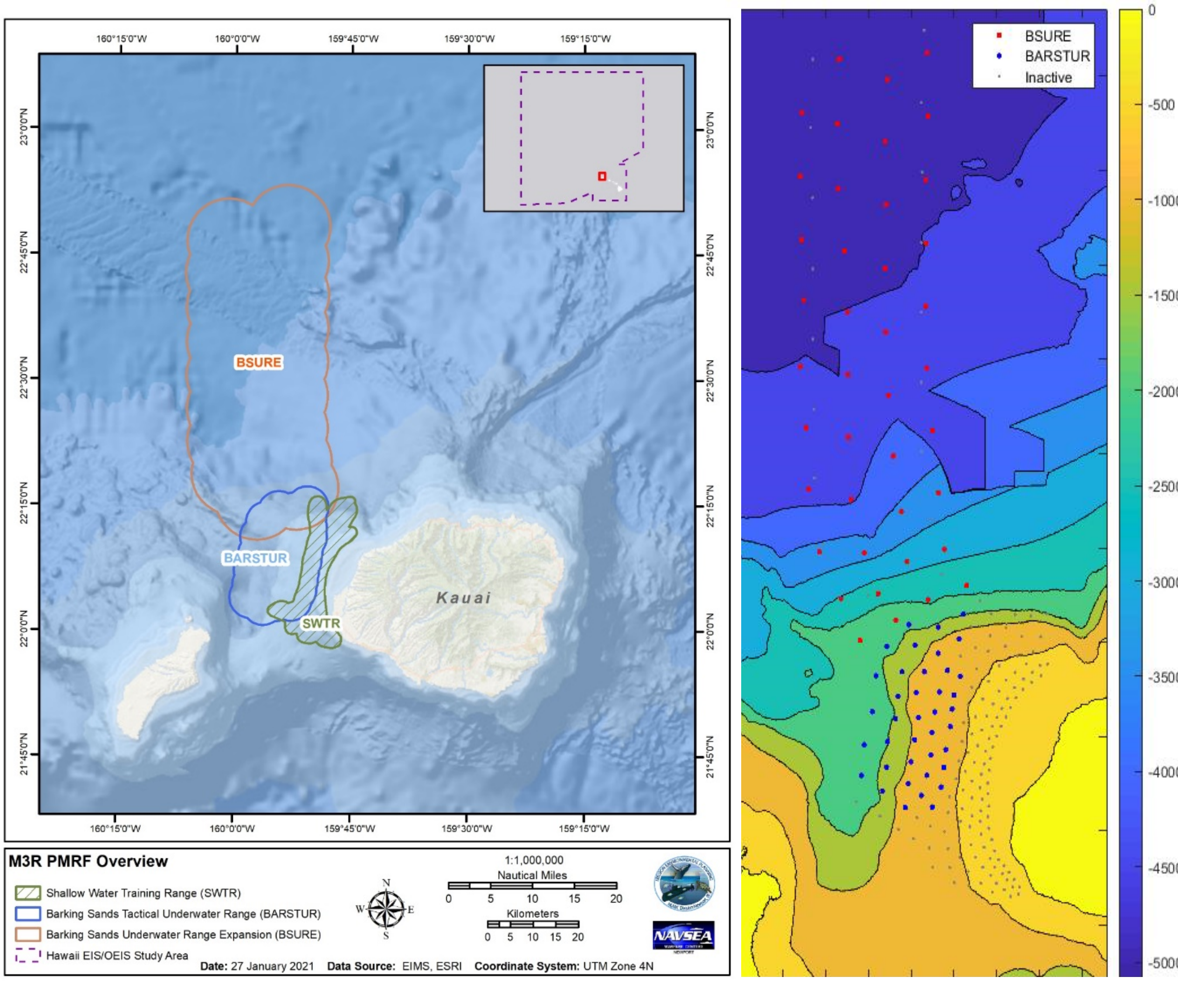


Figure 2. Location of PMRF hydrophone range, west of Kauai, Hawai'i (left). Hydrophone layout with bathymetry right).

1.4 Data Collection

The M3R system runs nearly continuously year-round from all range hydrophones simultaneously, provided there are no range activities that would preclude its operation. During these times detection, classification, and localization (DCL) algorithms are run in near-real time, and the reports from these algorithms are archived to binary files for later playback and analysis.

The M3R system employs three detector/classifiers: a full bandwidth Fast Fourier Transform (FFT)-based detector, a LF FFT (Section 3), and a Class-Specific Support Vector Machine (CS-SVM) detector/classifier (Jarvis et al. 2008). The full bandwidth FFT detector is formed using a 2048 point FFT with a rectangular window and 50% overlap, resulting in a frequency resolution of 46.875 Hz and a time step of 10.67 ms. FFTs are compared against a time varying threshold producing a binary output for each time-frequency bin which can be viewed in a binary spectrogram. The CS-SVM classifier currently has four classes at SOAR: Cuvier's beaked whale foraging and buzz clicks, sperm whale clicks, and 'generalized dolphin' clicks. At PMRF there are six CS-SVM classes: Blainville's beaked whale foraging and buzz clicks, Cuvier's beaked whale foraging and buzz clicks, sperm whale clicks, and 'generalized dolphin' clicks. The generalized dolphin class of the CS-SVM detector was formed to reduce false positive beaked whale detection. This class was trained on echolocation clicks from four delphinid species: pantropical spotted dolphin (*Stenella attenuata*), Risso's dolphin (*Grampus griseus*), short-fin pilot whale (*Globicephala macrorhynchus*), and common dolphins (*Delphinus delphis*). (Jarvis et al. 2008, Jarvis et al. 2014)

Archives which included FFT-based detections were first collected at SOAR in 2006, when the system was first installed (Table 1). The CS-SVM detector was implemented in May 2010, and the analyses of Cuvier's beaked whale distribution and abundance use the CS-SVM output; thus, they cover the time period from May 2010 through January 2022. The plus (+) sign in January indicates additional data are being collected. In this case there was a hardware issue, where the network switch was underperforming causing sporadic loss of data. Data from Jan-April 2022 will need to go through rigorous quality checks before being included in any future analysis.

Table 1. Number of days per month for which M3R detection archives have been collected at SOAR. CS-SVM archives were first collected in May, 2010 (indicated in blue).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006							6	11	0	0	0	0
2007	0	0	0	12	0	0	0	0	0	9	0	0
2008	0	0	0	0	0	0	4	19	7	16	12	0
2009	0	0	30	15	0	1	22	30	22	0	12	0
2010	3	0	0	0	**7**	0	0	9	30	29	22	23
2011	22	27	8	3	13	0	6	28	30	31	22	31
2012	27	23	18	30	15	6	1	4	0	17	13	10
2013	0	0	0	0	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	0	26	22
2017	15	0	13	17	2	0	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	26	29	31
2020	28	19	0	4	0	0	0	0	0	27	22	0
2021	7	9	31	30	9	20	16	28	30	27	8	0
2022	13+											

Archives that included FFT-based detections were first collected at PMRF in January 2011 when the system was installed, but the CS-SVM detector was incorporated in in May of 2011 (Table 2). Distribution and abundance of Blainville's and Cuvier's beaked whales at PMRF were analyzed using the CS-SVM detections, which covers the period from May 2011 through August 2022. The plus (+) sign in August 2022 indicates that data are still being collected, but have not yet been retrieved from the range. These results were for the BSURE and BARSTUR PMRF range hydrophones, excluding strings A, B, which have an upper frequency limit of 20 kHz. The shallow water SWTR hydrophones were also excluded.

Table 2. Number of days per month for which M3R detection archives have been collected at PMRF. CS-SVM archives were first collected in May, 2011 (indicated in blue).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	11	27	15	0	**1**	2	13	1	0	0	0	0
2012	12	0	0	0	0	18	2	0	0	0	0	0
2013	0	9	0	0	0	0	7	19	0	0	0	0
2014	1	27	15	0	5	30	31	20	0	11	0	0
2015	0	22	31	17	0	0	0	0	26	1	0	0
2016	0	11	0	0	0	0	0	11	0	0	0	0
2017	0	27	31	30	31	30	31	30	30	30	30	31
2018	31	28	31	12	7	13	31	22	11	31	25	0
2019	3	16	31	30	31	30	22	0	0	0	29	24
2020	26	29	31	30	31	30	23	29	30	31	30	16
2021	21	28	31	30	7	0	3	17	30	31	30	25
2022	31	28	31	30	31	30	13	9+				

2 Distribution & Abundance of Cuvier's and Blainville's beaked whales

2.1 Introduction

The long-term detection archives recorded at SOAR and PMRF allow for analysis of trends in detections over time. Changes in relative detections could indicate changes in foraging behavior, changes in prey quality or density, or changes in animal abundance. Passive acoustic methods of calculating abundance allow for the relatively low-cost collection of archive data to provide insights on populations of species on Navy ranges. But, by the nature of these methods they only account for vocalizing individuals.

2.2 Methods

2.2.1 Overview

The distribution and abundance of Cuvier's beaked whales at SOAR and for Blainville's and Cuvier's beaked whales at PMRF are assessed. In order to examine the temporal distribution of beaked whale foraging groups, their Group Vocal Periods (GVPs) are evaluated. A beaked whale group will typically ensonify at least one, and often several hydrophones in a given location while echolocating during deep foraging dives. The clicks detected on these hydrophones are referred to as a GVP, and are considered to represent a group of foraging beaked whales. The duration of the GVP is the time between the first and last detected click from the group. Temporal distribution is presented in terms of the number of GVPs detected on range, while the abundance, or number of animals detected, is derived from the GVPs and is reviewed separately.

The GVPs are automatically generated through several software processing steps. Cuvier's or Blainville's beaked whale foraging clicks detected with the CS-SVM classifier are each first combined into click trains on a per-hydrophone basis, then click trains are used to form groups, and the resulting group data are filtered and post-processed in R.

Cuvier's and Blainville's beaked whale clicks are detected and classified using a CS-SVM algorithm (Jarvis 2012). A Java-based click train processor (CTP) program next forms the click detections for a particular class 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. A MATLAB-based Auto-grouper program then uses a set of rules based on time and location of the click trains to associate the CTP click trains into GVPs. For Cuvier's beaked whales only click trains with an inter-click interval (ICI) greater than or equal to 0.35 sec and an ICI less than or equal to 0.75 sec, and with duration greater than 1 min and less than 60 min, are used in the grouping process. Blainville's beaked whale click trains with an ICI between 0.23 and 0.4 sec are used. Locations are based on the hydrophone locations, with the beaked whale group center being the hydrophone with the highest click density (number of clicks per min). To form a GVP the click trains must be within 9.75 km[1] of the group center. Post-processing in R generates summary data for each group after filtering the GVPs based on duration

[1] Group radius is based on observed spread of detections during real-time monitoring and manual review of the archives

and total number of clicks. For Cuvier's beaked whales GVPs with fewer than 300 clicks or more than 43,400 clicks are removed, and for Blainville's beaked whales the GVPs must contain between 360 and 64,800 clicks. For Cuvier's beaked whales the filtering on the number of clicks is based on a minimum of one animal clicking for 2.5 min and a maximum of six animals clicking for 60 min, at a click rate of two clicks per sec. For Blainville's beaked whales the click rate is three clicks per sec, the minimum is one animal clicking for 2 min, and the maximum is six animals clicking for 60 min. GVPs less than 5 min or greater than 90 min are also removed.

2.2.2 Beaked Whale Distribution

2.2.2.1 GVP Data Processing

GVPs are generated by processing click train output through the Autogrouper program. The Autogrouper output lists each click train associated with a group, and can contain either very short or very long duration GVPs, potentially triggered by dolphin clicks misclassified as beaked whales on some hydrophones in the group; thus further filtering is conducted in R. After combining all the data for a year, and filtering and summarizing the Autogrouper GVP output in R, the data consists of the following fields (Figure 3):

GpID – Identifier for the group

grp_clkcnt – sum of all clicks detected on all hydrophones associated with a group

maxhyd – the hydrophone in the group with the most clicks

maxclk – the number of clicks detected on maxhyd

nhyds – the number of hydrophones associated with the group

grp_start – start date and time of the GVP

grp_end – end date and time of the GVP

as.numeric.gvp – GVP duration in minutes

MON.start – month start of the GVP

DAY.start – day start of the GVP

YYYY.start – year start of the GVP

HR.start – hour start of the GVP

MM.start – minute start of the GVP

SS.start – second start of the GVP

MON.end – month end of the GVP

DAY.end – day end of the GVP

YYYY.end – year end of the GVP

HR.end – hour end of the GVP

MM.end – minute end of the GVP

SS.end – second end of the GVP

edge_only – indicates if the group consists solely of hydrophones located on the edge of the range (0/1)

JD_start – Julian day start of the GVP

JD_end – Julian day end of the GVP

Dec_hr_start – Decimal hour start of the GVP

Dec_hr_end – Decimal hour end of the GVP

Julian_hr_start – Hour of the year start of the GVP

Julian_hr_end – Hour of the year end of the GVP

```
> head(filtered_groups_2015_ne)
   GpID grp_clkcnt maxhyd maxclk nhyds            grp_strt             grp_end as.numeric.gvp.
7     3       1030    908    727     4 2015-01-01 00:04:27 2015-01-01 00:38:05        33.63333
9     5        874    509    867     2 2015-01-01 00:09:41 2015-01-01 00:44:01        34.33333
18   12        578    208    578     1 2015-01-01 00:40:35 2015-01-01 00:52:16        11.68333
19   13       4068    906   3978     2 2015-01-01 00:55:27 2015-01-01 01:30:27        35.00000
22   14       4481    205   4409     3 2015-01-01 00:58:40 2015-01-01 01:55:43        57.05000
28   16       5172    705   3518     4 2015-01-01 01:47:48 2015-01-01 02:23:50        36.03333
   MON.start. DAY.start. YYYY.start. HR.start. MM.start. SS.start. MON.end. DAY.end. YYYY.end. HR.end.
7           1          1        2015         0         4        27        1        1      2015       0
9           1          1        2015         0         9        41        1        1      2015       0
18          1          1        2015         0        40        35        1        1      2015       0
19          1          1        2015         0        55        27        1        1      2015       1
22          1          1        2015         0        58        40        1        1      2015       1
28          1          1        2015         1        47        48        1        1      2015       2
   MM.end. SS.end. edge_only JD_strt JD_end Dec_hr_strt Dec_hr_end Julian_hr_strt Julian_hr_end
7       38       5         0       0      0  0.07416667  0.6347222     0.07416667     0.6347222
9       44       1         0       0      0  0.16138889  0.7336111     0.16138889     0.7336111
18      52      16         0       0      0  0.67638889  0.8711111     0.67638889     0.8711111
19      30      27         0       0      0  0.92416667  1.5075000     0.92416667     1.5075000
22      55      43         0       0      0  0.97777778  1.9286111     0.97777778     1.9286111
28      23      50         0       0      0  1.79666667  2.3972222     1.79666667     2.3972222
```

Figure 3. Example of filtered Autogrouper output at SOAR for 2015.

For each year matrices are then created for both effort (with each entry either 1 or NA) and number of GVPs per hydrophone and hour of the year (matrix sizes 178 x 8784 for SOAR and 83x8784 for PMRF). For the effort, hours with partial effort are set to NA. For the GVP matrix, the "center hydrophone", or hydrophone in the group with the most clicks (maxhyd) is used to represent the GVP. Therefore, the entry in this matrix is the total number of times maxhyd is detected in a given hour and on a given hydrophone. Typically this number is zero or possibly one. The highest number per hydrophone and hour at SOAR has been four, which occurred in 2011. Finally a matrix of number of GVPs per hydrophone and hour of effort is generated by dividing the GVP matrix by the effort matrix.

The percent effort per hour for each year (array size 1x8784) is calculated by adding the effort over all hydrophones in each hour and dividing by the number of hydrophones being evaluated (178 for SOAR and 83 for PMRF). Similarly the number of GVPs per hour for each year is obtained by summing over the hydrophones for each hour, and the number of GVPs per hour effort for each year is generated by dividing the GVP arrays by the percent effort arrays.

Effort per day (array sizes 1x365/366) come from adding the effort from all hydrophones and hours in a day. Dividing the effort per day by the number of hydrophones multiplied by the number of hours in a day (178x24=4272 for SOAR) produces the percent effort per day. In the statistical model the log of the number of hours of effort per day (and not the log of the percent) is used as an offset. The number of GVPs per day, which is used in the model, is the total number of GVPs over all hydrophones and hours in a day.

2.2.2.2 Statistical Modelling

A Generalized Additive Model (GAM) was used to model the number of GVPs per day on range (GVP) (mcgv 1.8-31 package built under R version 3.5.3). The response of GVP's is not normally distributed, a Tweedie distribution was determined to be the best fit for Cuvier's at SOAR and a Negative Binomial distribution was determined to be the best fit for Blainville's and Cuvier's at PMRF. For each year a matrix is generated, using only the center hydrophone to represent a GVP, of the number of GVPs detected per hydrophone and per hour of the year. The number of GVPs per day used in the model is derived by adding all the GVPs in this matrix over all the hydrophones and hours in a day. The log of the effort per day is used as an offset in the model. Here the effort per day is the sum of effort over all hours and hydrophones in a day, where each hour-hydrophone entry is either a 1 or NA.

To examine the long-term trend, the sequential years over the analysis time period (Year: 2010-2022 for SOAR, 2011-2022 for PMRF) was used as a predictor. Cyclic days (JDay: 1-365/366) was used as a predictor for seasonal variation, and the log of the effort was used as an offset to account for the spatial variation in effort (i.e. the fact that at times data were not obtained from particular hydrophones):

(1) *SOAR:* GVP_JDay_Yr_corrected_mcgv_tw.gam = gam(GVP_corrected ~ s(JDay,bs="cc") + s(Year) + offset(log_effort_2010_2022), family=tw(),data=GVP_JDay_Yr_corrected, method="REML")

(2) *PMRF:* MdGVP_JDay_Yr_corrected_negbin_mcgv.gam = gam(Md_GVP_corrected+0.000001 ~ s(JDay, bs="cc") + s(Year) + offset(log_effort_2011_2022), family=negbin(1),data=MdGVP_JDay_Yr_corrected)

(3) *PMRF:* ZcGVP_JDay_Yr_corrected_negbin_mcgv.gam = gam(Zc_GVP_corrected+0.000001 ~ s(JDay,bs="cc") + s(Year) + offset(log_effort_2011_2022), family=negbin(2),data=ZcGVP_JDay_Yr_corrected)

2.2.3 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. 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, a modified version of this method has been applied to derive beaked whale abundance on the SOAR and PMRF ranges. The equation for animal abundance (N) presented by Moretti, et al. (2010) was:

(4) $N = \frac{n_d\, s}{r_d\, T}$

where n_d is the total number of dive starts (or GVPs), s is the average group size, r_d is the dive rate (dives/unit time), and T is the 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 the AUTEC in the Bahamas. 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 and the proportion of false positives. The equation used for abundance in this analysis is:

$$(5)\quad N = \frac{n_d\, s\, (1-c)}{r_d\, T\, PD}$$

where n_d is the total number of dive starts (or GVPs), s is the average group size, r_d is the dive rate (dives/unit time), T is the time period over which the measurement was made, c is the proportion of false positive detections, and PD is the probability of detection. Values used in the calculations are given in Table 3. Note that detection statistics have not yet been calculated for Cuvier's beaked whales at PMRF, so for this analysis the detection statistics for PMRF's Blainville's beaked whales were used for its Cuvier's beaked whales. Efforts are underway to calculate these values for Cuvier's at PMRF for the FY23 report.

Table 3. Variables used in abundance calculations

	SOAR		***PMRF***	
Variable	***Value (CV)***	***Reference***	***Value***	***Reference***
s	3.18 (0.62)	E. Falcone, pers. comm., December 06, 2017	3.6 (*Md*) / 2.6 (*Zc*)	Baird et al. 2006
r_d	0.3 (0.17)	Schorr et al. 2014	0.42 (*Md*) / 0.40 (*Zc*)	Baird et al. 2008
C	0.185 (0.32)	Calculated[2]	0.188 (*Md*)	Calculated[3]
PD	0.76 (0.05)	Calculated[2]	0.283 (*Md*)	Calculated[3]

[2] Values calculated using methods in DiMarzio and Jarvis (2016). Efforts are underway to finalize and document these values.

[3] Values updated from those in DiMarzio et.al. (2021). Efforts are underway to finalize and document these values.

2.3 Results

2.3.1 SOAR

2.3.1.1 SOAR: Cuvier's beaked whale temporal distribution

2.3.1.1.1 GVP data for Cuvier's beaked whales at SOAR

Cuvier's beaked whale temporal distribution was analyzed using SOAR archives from May 2010 through January 2022. After removing partial hours of effort (setting them to NA) and scaling by the number of hydrophones per hour on which data were collected, a total of 50,625 hours of data were processed, with the number of hours per year varying from a low of 215 hours in 2022 to a high of 6172 hours in 2018 (Table 4). The low in 2022 is due to issues with hardware issues with the network switch. Additional data was collected in 2022, but needs to be further quality checked before inclusion in the analysis.

Table 4. SOAR: Total number of hours of effort per year analyzed for 2010-2021.

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1109	2361	1382	1770	2946	2885	3163	3912	6172	6160	2215	4335	215

GVPs were calculated on an hourly basis, since this time scale is approximately the same as the deep foraging dive mean duration of 67.4 min (Schorr, et al., 2014). After accounting for effort, the average number of GVPs on any hydrophone in any hour varies from 0.02 to 0.03, and the maximum number of GVPs is of 4 in 2011 (Table 5).

Table 5. SOAR: Statistics on the number of *Zc* GVPs per hydrophone-hour effort from 2010-2022.

Year	Hours of effort	Zc GVPs per hydrophone per hour of effort				
		min	max	mean	median	stdev
2010	1109	0	2	0.02	0	0.1
2011	2361	0	4	0.02	0	0.1
2012	1382	0	2	0.03	0	0.2
2013	1770	0	3	0.02	0	0.2
2014	2946	0	3	0.03	0	0.2
2015	2885	0	3	0.02	0	0.1
2016	3163	0	2	0.02	0	0.2
2017	3912	0	3	0.02	0	0.1
2018	6172	0	3	0.02	0	0.1
2019	6160	0	3	0.02	0	0.1
2020	2215	0	3	0.03	0	0.2
2021	4335	0	3	0.02	0	0.1
2022	215	0	2	0.02	0	0.2

The average number of GVPs in any hour across the whole range varies from 2.93 to 4.98, with a maximum of almost 30 GVPs per hour in 2012 (Table 6; Figure 4, top).

Table 6. Statistics on the number of *Zc* GVPs per hour effort across SOAR from 2010 to 2022.

Year	Hours of effort	Zc GVPs per hour of effort				
		min	max	mean	median	stdev
2010	1109	0.00	22.82	3.19	2.00	3.78
2011	2361	0.00	24.00	3.30	2.00	3.86
2012	1382	0.00	29.67	4.98	4.00	4.69
2013	1770	0.00	26.00	4.11	2.00	4.30
2014	2946	0.00	26.00	4.45	4.00	3.94
2015	2885	0.00	24.78	3.57	2.25	3.50
2016	3163	0.00	24.78	4.44	4.00	3.69
2017	3912	0.00	15.22	3.14	2.34	2.57
2018	6172	0.00	15.22	2.93	2.34	2.58
2019	6160	0.00	16.39	3.17	2.34	2.68
2020	2215	0.00	23.42	4.81	4.68	3.57
2021	4335	0.00	14.50	3.26	2.64	2.35
2022	215	0.00	11.78	4.16	3.93	2.60

A trend analysis was conducted for Cuvier's beaked whales at SOAR and both Blainville's and Cuvier's beaked whales at PMRF by comparing the mean number of GVPs detected in three of the earlier years in the series (2011-2013 for SOAR, 2012-2014 for PMRF) with three of the later years (2019-2021 for SOAR and PMRF). Note, however, that the CS-SVM classes were updated in 2014, and any effects from the updates are not accounted for here, but are assumed to be minimal.

In order to determine if there is a significant long-term trend in the number of Cuvier's beaked whale GVPs detected per hour of effort at SOAR, the following procedure was used:

1. Discounting the years at the ends of the series, as the whole year was not present (2010, 2022) datasets of the number of GVPs per hour effort were created for the first three (2011-2013) and last three years (2019-2021) of the series.
2. 1000 bootstrap sample means were generated for the earlier (2011-2013) and later (2019-2021) data series by randomly drawing samples (of 1000 data points each) with replacement from each series, and calculating the means.
3. Statistics were generated for the earlier and later bootstrap mean samples, and a Welch two sample t-test was used to determine if there was a significant difference in the means (Table 7; Figure 4, bottom).

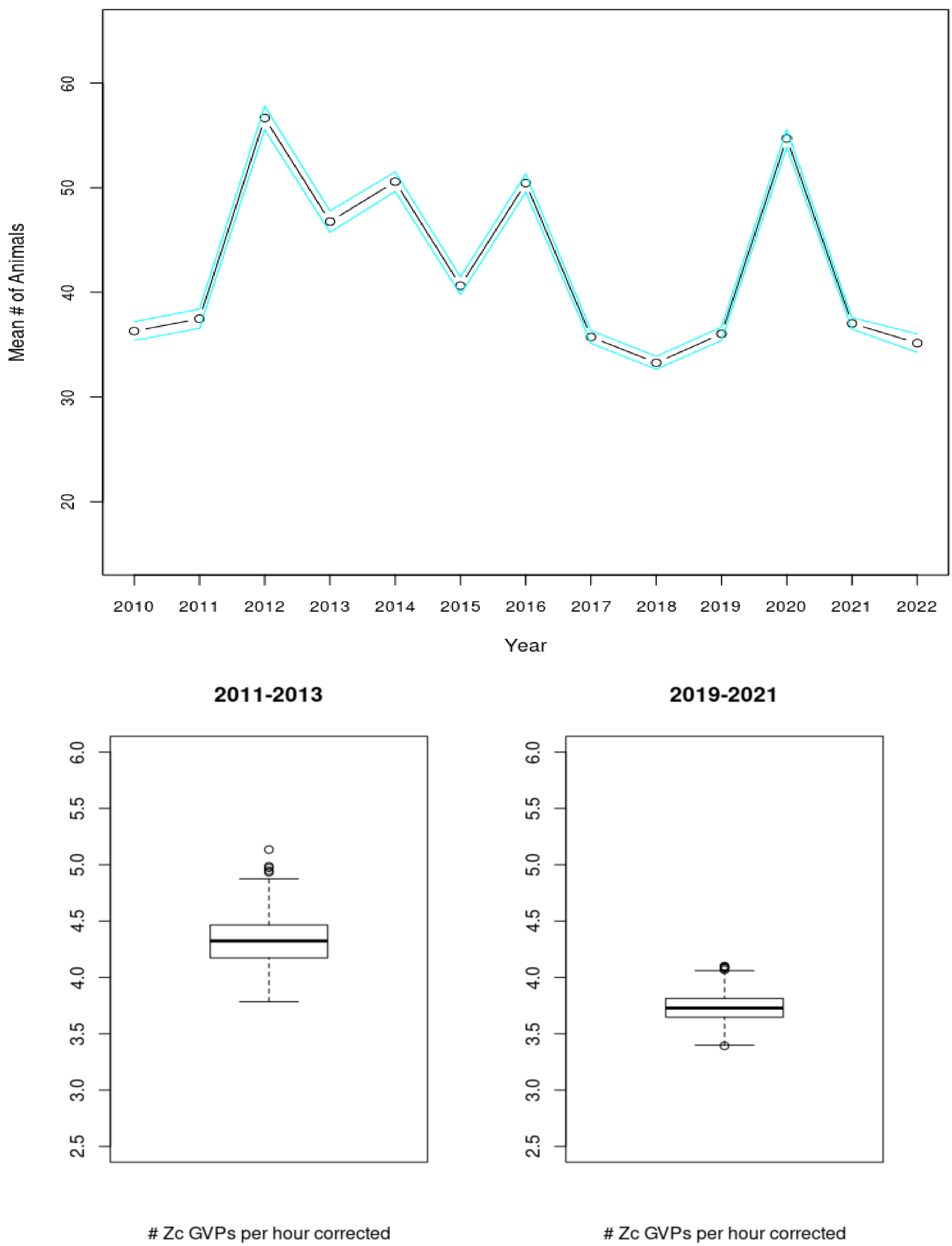


Figure 4. Mean number of *Zc* GVPs per hour of effort at SOAR.
Top: **For each year from 2010-2022; cyan lines indicate 95% confidence intervals. *Bottom:* Sample means from 1000 bootstrap samples for the periods 2011-2013 and 2019-2021.**

Table 7. SOAR: Statistics for *Zc* bootstrap sample mean GVPs per hour.

Series	Min	Max	Mean	Median	StdDev
2011-2013	3.78	5.13	4.33	4.32	0.22
2019-2021	3.39	4.10	3.73	3.73	0.12

The Welch two sample t-test found a significant difference (p < 2.2e-16) in the bootstrap sample means generated from the years 2011-2013 (μ=4.32) and the years 2019-2021 (μ=3.73), a drop of about 1 GVP per hour effort on range.

2.3.1.1.2 Statistical Model for Cuvier's beaked whales at SOAR

For the statistical modelling the mean number of GVPs per day after accounting for effort (per effort-day) were used. The number of GVPs per effort-day across the range between 2010 and 2022 varies from 0 to 229 (μ=56.5, median=54.7) (

Figure 5, left).

Figure 5, right shows the variation from year to year in the number of GVPs detected per effort-day across the SOAR range.

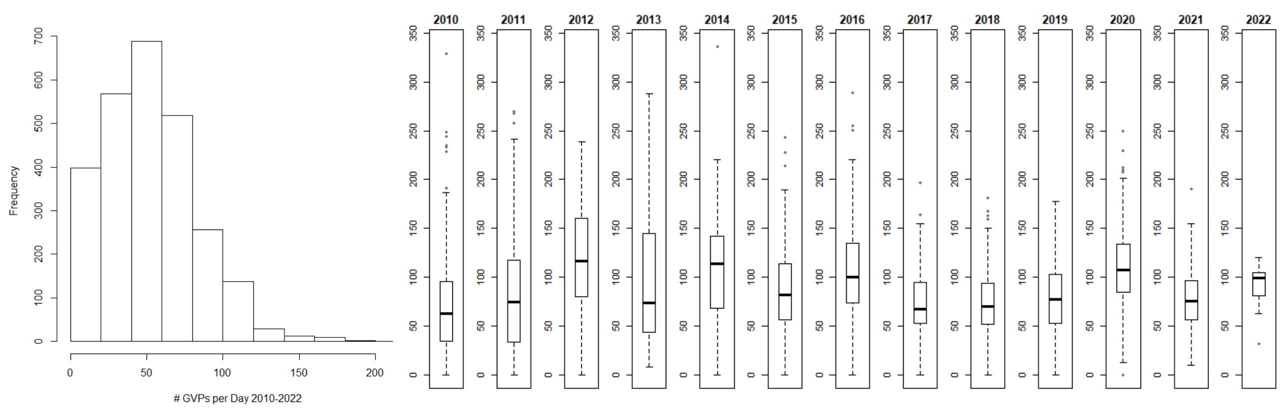


Figure 5. Number of *Zc* GVPs per day of effort on the SOAR range.
***Left:* Histogram of *Zc* GVPs for 2010 to 2022; *Right:* Boxplots for each year 2010 to 2022**

Both the JDay and Year predictors were very significant (p<2e-16) for determining the number of GVPs per day on the range (Table 8). The model had an R-squared value of 0.408 and only explained 28.0% of the deviance, indicating that other factors besides time are important in determining the number of Cuvier's beaked whale GVPs detected on range.

Table 8. Results of the GAM in equation 1.

Parametric coefficients:				
	Estimate	Std Error	z value	Pr(>|z|)
(Intercept)	-3.854020	0.009599	-401.5	<2e-16 ***
Approximate significance of smooth terms:				
	edf	Ref df	Chi sq	p-value
s(JDay)	7.591	8.000	99.39	<2e-16 ***
s(Year)	8.541	8.941	25.20	<2e-16 ***
Signif codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
R-sq (adj) = 0.408 Deviance explained = 28.0%				
-REML = 11947 Scale est = 5.3358 n = 2622				

The smooths for each predictor, both without and with the residuals, are shown in Figure 6. They indicate the contribution of the predictor to the response, but are shown on the scale of the predictor, and not the response. The mean of the response is related to the linear combination of predictors through a link function. The response is represented by a Tweedie distribution, and the link function is the log; so whereas the relationship between the response and predictors is nonlinear, the relationship the link scale is linear, where the log of the mean response is equal to the linear combination of predictors (Wood, 2006; Qian, 2017; Mackenzie & Cox, 2010).

There is a visible seasonal pattern to the Cuvier's beaked whale distribution on range, with the number of GVPs per day peaking in May and then again in December and January. The number of GVPs reach a low point in mid-September, with a smaller dip in numbers in March (Figure **6**, top left).

Over the past 13 years the number of GVPs per day has fluctuated, with peaks in 2013, 2015, and 2021 and a low point in 2019 (Figure 6, bottom right). A trend analysis on the number of GVPs per hour effort was conducted earlier, in section 2.3.1.1.2 showing a general decrease in the number of GVPs over the past decade.

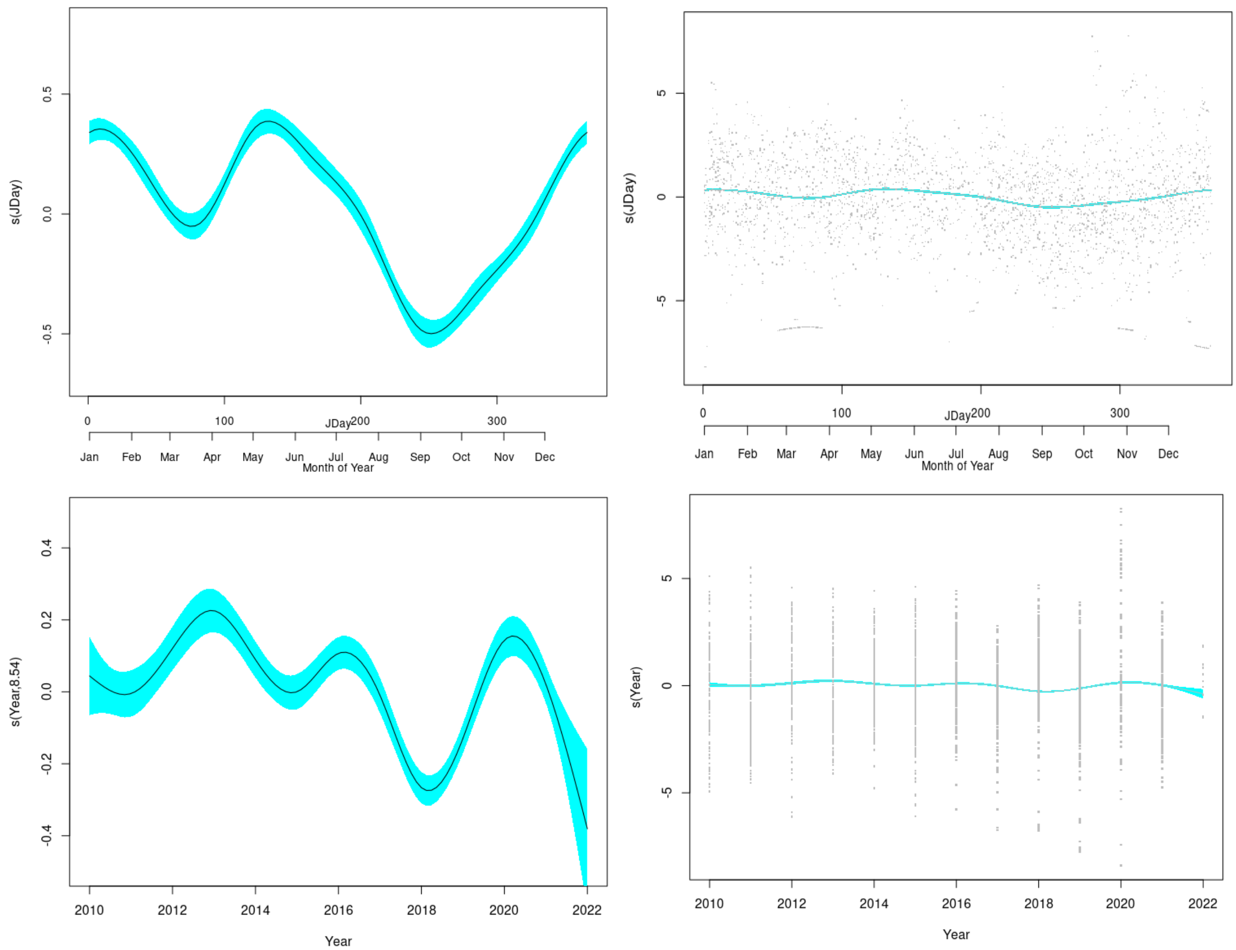


Figure 6. Smooths of the predictors for the number of Zc GVPs per day at SOAR for 2010-2022. ***Top:*** **Seasonal distribution – smooth of JDay on left, smooth of JDay with residuals on right;** ***Bottom:*** **Long-term trend – smooth of Year on left, smooth of Year with residuals on right**

2.3.1.2 SOAR: Cuvier's beaked whale abundance

The monthly Cuvier's beaked whale abundance was calculated using equation 5 in section 2.2.1.2. The mean monthly Cuvier's beaked whale abundance per hour for 2010 to 2022 peaks in January at 58.79 animals, followed by a peak in May of 58.15 animals. The mean abundance is lowest in September at 23.74 animals (Table 9; Figure 7, left). The drop in abundance in September is consistent with observations first reported from off range Navy funded passive acoustic monitoring for beaked whales [Baumann-Pickering, et al. 2014; Rice et al., 2018].

Table 9. Mean monthly Cuvier's beaked whale abundances at SOAR averaged from 2010 to 2022.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	83.97	69.20	64.34	69.45	81.26	65.12	55.84	44.14	38.00	47.24	57.89	74.20
mean abundance	58.79	47.33	42.78	49.16	58.15	46.12	38.27	29.15	23.74	29.32	37.37	50.14
lower CI	33.62	25.47	21.22	28.86	35.04	27.12	20.70	14.16	9.48	11.39	16.85	26.07

Over the 13-year time period the mean abundance per hour in any month has varied from a high of 105 animals in May of 2013 to a low of 6 in March of 2018 (Table 10; Figure 7, right).

Table 10. Monthly SOAR Cuvier's beaked whale abundances 2010 - 2022.
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	25.35	27.80	17.99	48.63	64.64
2011	78.51	42.34	44.40	61.09	76.21	NA	31.38	38.03	7.64	19.43	29.62	45.68
2012	69.82	72.25	75.64	52.33	64.12	NA	15.79	20.55	NA	42.50	30.56	16.94
2013	NA	NA	NA	NA	105.12	69.39	49.19	19.98	17.12	22.74	32.13	64.00
2014	58.78	47.33	59.04	66.58	67.01	58.83	26.80	26.45	20.64	31.46	60.94	59.86
2015	55.38	34.35	39.95	46.56	42.67	41.43	24.99	19.20	26.30	39.78	39.92	89.71
2016	80.34	60.05	47.77	61.59	50.43	47.10	48.32	33.71	25.69	NA	44.46	50.68
2017	53.58	NA	34.22	47.51	39.20	NA	32.35	30.76	23.51	21.87	26.81	50.13
2018	47.05	33.60	6.25	36.17	45.46	39.46	42.16	26.36	28.00	31.33	30.42	50.20
2019	41.92	38.91	31.07	41.53	58.55	47.32	40.25	33.39	13.87	16.19	26.45	27.51
2020	40.50	53.38	NA	48.82	NA	NA	NA	NA	NA	58.25	66.98	41.77
2021	65.26	49.81	50.43	43.21	36.70	33.61	37.58	32.05	32.53	23.39	24.56	NA
2022	35.14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

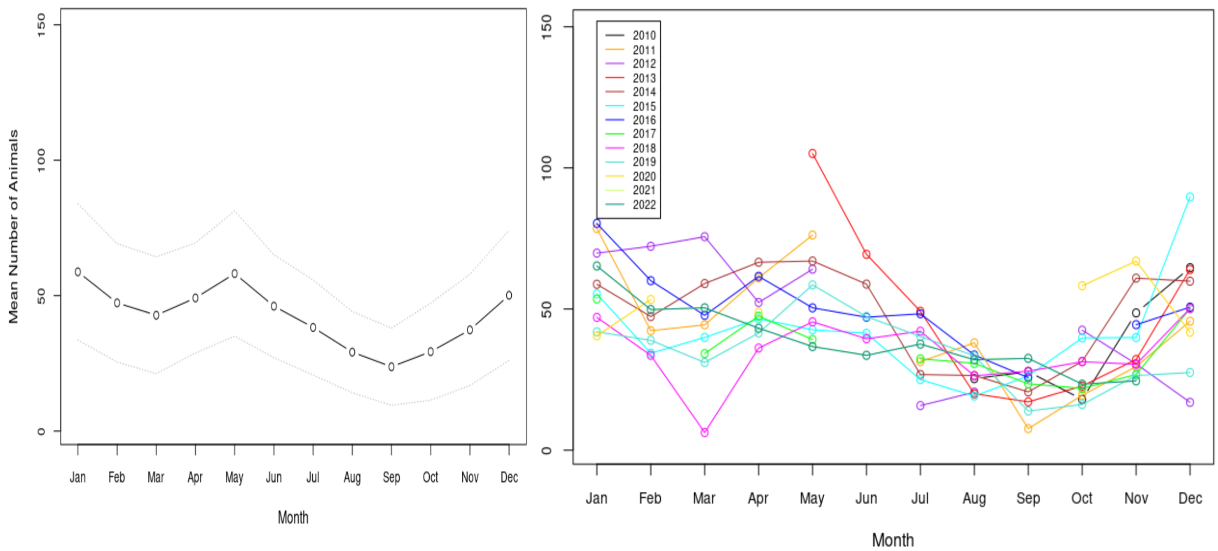


Figure 7. Mean monthly Cuvier's beaked whale abundance at SOAR.
Left: **mean of all years; dashed lines indicate 95% confidence intervals,** ***Right:*** **yearly means 2010 through 2022.**

Figure 8 indicates the mean number of *Zc* GVPs per hour of effort calculated for each year from 2011-2021. The trend in the Cuvier's beaked whale abundance per hour at SOAR was determined in the same manner as described for Cuvier's beaked whales GVPs in section 2.2.3. Since abundance is proportional to the number of GVPs, similar trends are expected.

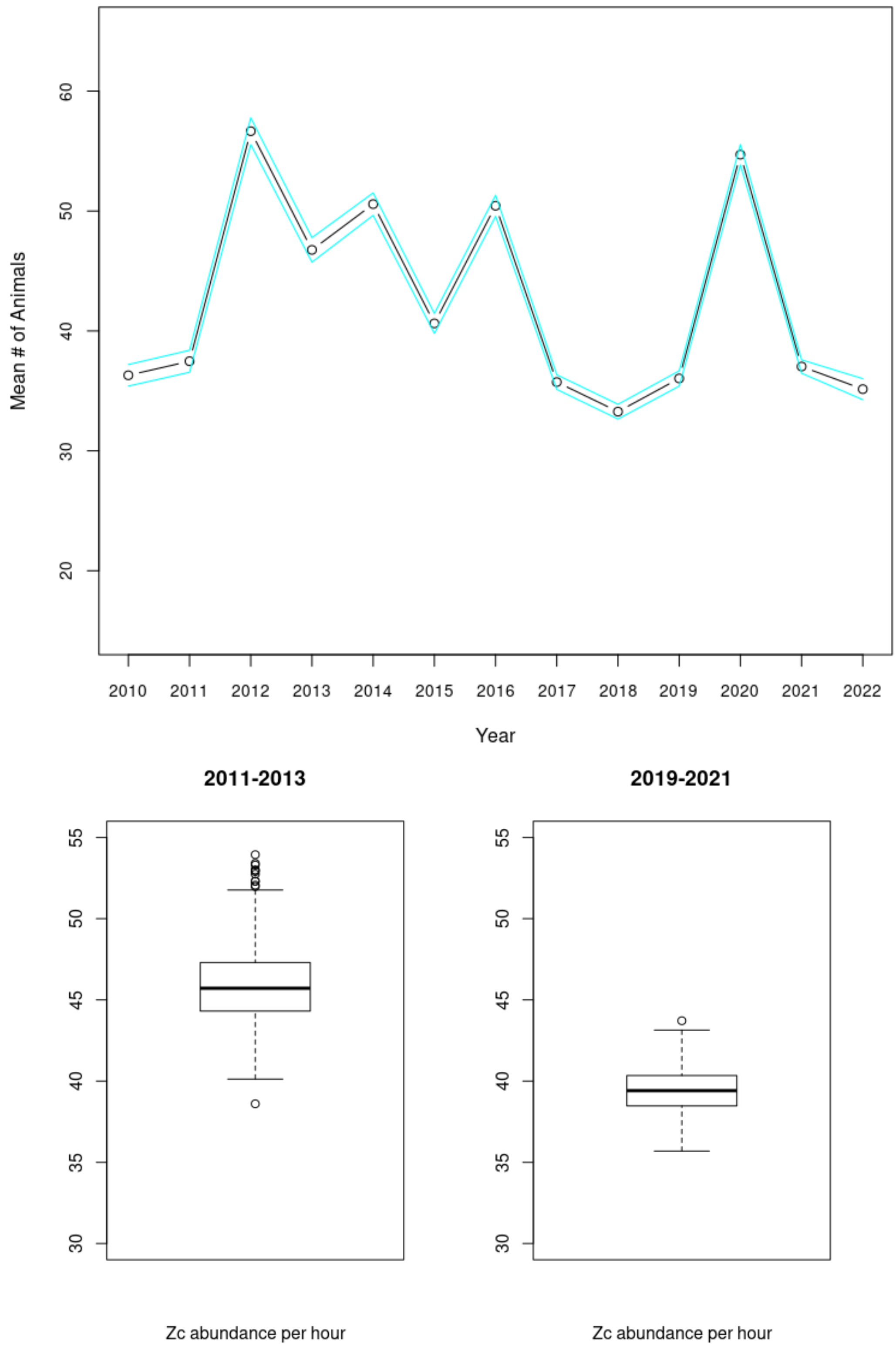


Figure 8. Mean abundance of *Zc* per hour of effort at SOAR.
Top: **For each year from 2010-2022; cyan lines indicate 95% confidence intervals.** ***Bottom:*** **Sample means from 1000 bootstrap samples for the periods 2011-2013 and 2019-2021.**

Table 11. SOAR: Statistics for *Zc* bootstrap sample mean abundance per hour.

Series	Min	Max	Mean	Median	StdDev
2011-2013	39.22	53.14	45.75	45.75	2.25
2019-2021	31.81	40.07	35.41	35.44	1.19

The Welch two sample t-test found a significant difference ($p < 2.2e\text{-}16$) in the bootstrap sample means generated from the years 2011-2013 (μ= 45.84) and the years 2019-2021 (μ= 39.42), a drop of about 6 animals per hour effort on range.

2.3.2 PMRF

Blainville's and Cuvier's beaked whale distribution and abundance were analyzed using PMRF CS-SVM archives from 2011 through 2022. After removing partial hours of effort and scaling by the number of hydrophones per hour on which data were collected, a total of 41,130 hours of data were processed, with the number of hours per year varying from a low of 267 hours in 2012 to a high of 7829 hours in 2017 (Table 12).

Table 12. PMRF: Total number of hours of effort per year of processed data.

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
267	685	743	2945	2140	454	7829	5650	4941	6753	3870	3804

2.3.2.1 PMRF: Blainville's beaked whale temporal distribution

2.3.2.1.1 GVP Data for Blainville's beaked whale at PMRF

GVPs were calculated on the same hourly basis as was used for Cuvier's beaked whales at SOAR. After accounting for effort, the average number of GVPs on any hydrophone in any hour varies from 0.01 to 0.02 with a maximum of 4 in 2020 and 2021 (Table 13).

Table 13. PMRF: Statistics on the number of *Md* GVPs per hydrophone-hour effort from 2011-2022.

Year	Hours of Effort	Md GVP per hydrophone per hour effort				
		min	max	mean	median	stdev
2011	267	0.00	2.00	0.02	0.00	0.13
2012	685	0.00	2.00	0.02	0.00	0.12
2013	743	0.00	2.00	0.01	0.00	0.11
2014	2945	0.00	2.00	0.01	0.00	0.10
2015	2140	0.00	3.00	0.01	0.00	0.09
2016	454	0.00	2.00	0.01	0.00	0.07
2017	7829	0.00	2.00	0.02	0.00	0.13
2018	5650	0.00	3.00	0.01	0.00	0.10
2019	4941	0.00	2.00	0.01	0.00	0.10
2020	6753	0.00	4.00	0.01	0.00	0.09
2021	3870	0.00	4.00	0.02	0.00	0.16
2022	3804	0.00	3.00	0.00	0.00	0.07

The average number of GVPs in any hour across the whole range varies from 0.98 to 3.45, with a maximum of almost 31 GVPs per hour in 2021 (Table 14; Figure 9, left).

Table 14. Statistics on the number of *Md* GVPs per hour effort at PMRF from 2011 to 2022.

Year	Hours of Effort	Md GVP per hour effort				
		min	max	mean	median	stdev
2011	267	0.00	11.74	2.98	2.35	2.69
2012	685	0.00	21.14	2.79	2.35	2.54
2013	743	0.00	14.27	2.10	2.38	2.35
2014	2945	0.00	14.65	1.87	0.00	2.32
2015	2140	0.00	13.74	1.65	2.29	2.03
2016	454	0.00	11.60	0.98	0.00	1.82
2017	7829	0.00	15.65	2.93	2.24	2.61
2018	5650	0.00	13.41	1.89	2.24	2.20
2019	4941	0.00	15.65	1.86	2.24	2.13
2020	6753	0.00	13.74	1.30	0.00	2.06
2021	3870	0.00	30.92	3.45	0.00	4.47
2022	3804	0.00	20.29	3.08	2.81	3.22

The trend in the number of Blainville's beaked whale GVPs per hour at PMRF was calculated in the same manner as described for Cuvier's beaked whales at SOAR in section 2.2.2.2, except that the period of earlier years was 2012-2014 rather than 2011-2013. Note the same caveat applies to PMRF, in that the CS-SVM classifiers were updated circa 2014, and any potential effects of the update has not yet been accounted for.

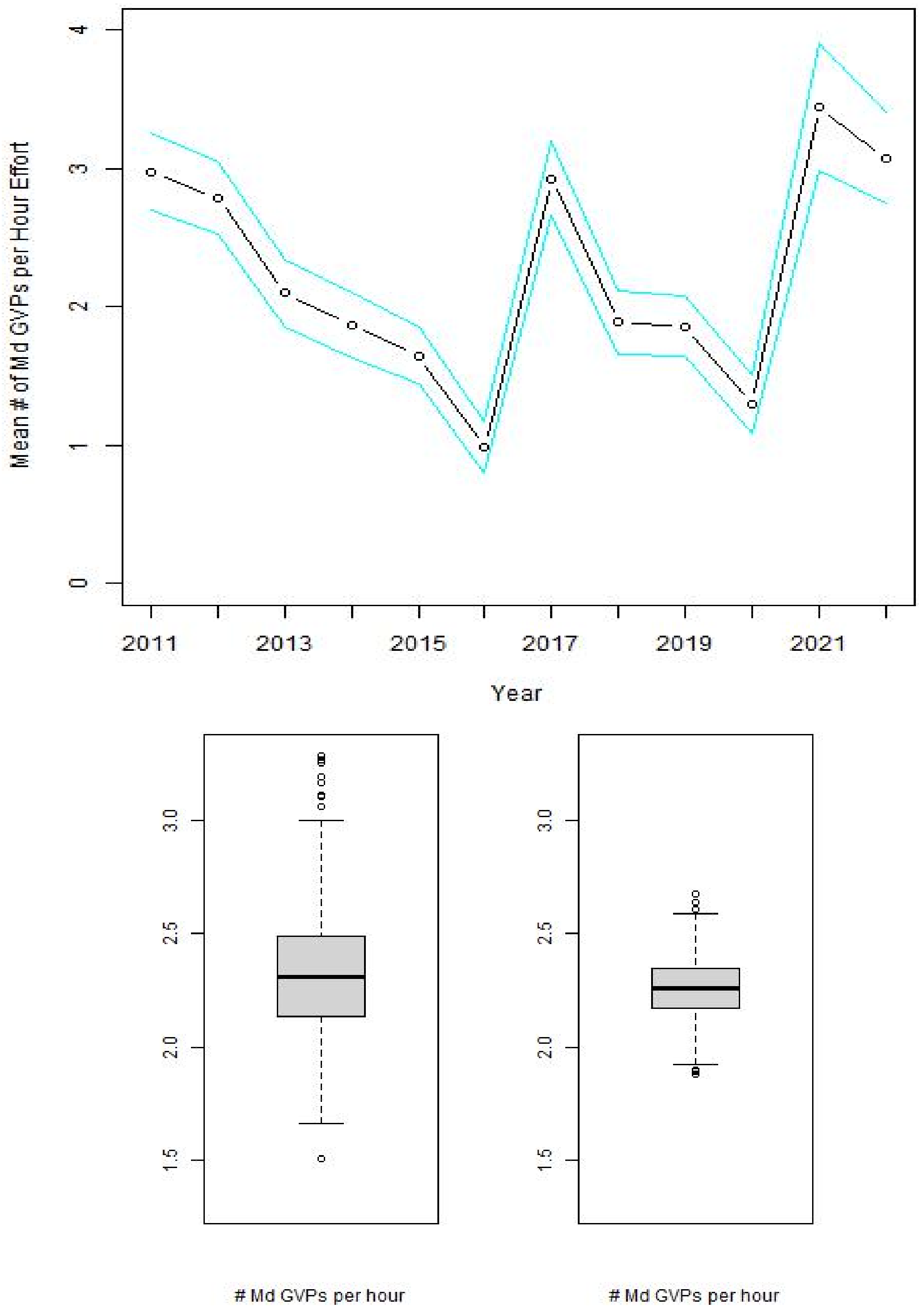


Figure 9. Mean number of *Md* GVPs per hour of effort at PMRF.
Left: **For each year from 2011-2022; cyan lines indicate 95% confidence intervals.** ***Right:*** **Sample means from 1000 bootstrap samples for the periods 2012-2014 and 2019-2021.**

Table 15. PMRF: Statistics for *Md* bootstrap sample mean GVPs per hour.

Series	Min	Max	Mean	Median	StdDev
2012-2014	1.50	3.28	2.31	2.31	0.26
2019-2021	1.88	2.67	2.26	2.26	0.13

The Welch two sample t-test found there was no significant difference in the bootstrap sample means generated from the years 2012-2014 (μ= 2.31) and the years 2019-2021 (μ= 2.26). Suggesting there was not an increase or decrease in Md GVPs over the past decade.

2.3.2.1.2 Statistical Model for Blainville's beaked whale at PMRF

For the statistical modelling, the mean number of GVPs per day after accounting for effort (per effort-day) were used. The number of *Md* GVPs per effort-day across the PMRF range between 2011 and 2022 varies from 0 to 270 (μ=50.6, median=48) (Figure 10, left). Figure 10 (right) shows the variation from year to year in the number of *Md* GVPs detected per effort-day across the PMRF range.

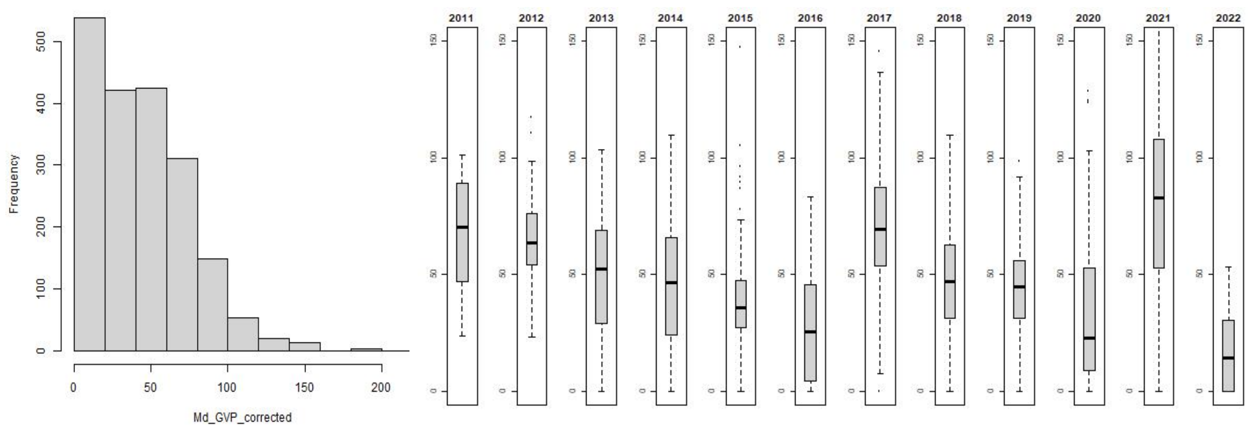


Figure 10. Number of *Md* GVPs per day of effort on the PMRF range.
***Left:* Histogram of *Md* GVPs for 2011 to 2021; *Right:* Boxplots for each year 2011 to 2021**

Both the Julian day (JDay) and Year predictors were very significant ($p<2e^{-16}$) for determining the number of GVPs per day on the range (Table 16). The model had an R-squared value of 0.358 and explained 16.4% of the deviance, indicating that other factors besides time are important in determining the number of Blainville's beaked whale GVPs detected on range. The smooths for each predictor are shown in

Figure 11.

Table 16. Results of the PMRF *Md* GAM in equation 2.

Parametric coefficients:				
	Estimate	Std Error	z value	Pr(>|z|)
(Intercept)	-3.7657	0.0231	-163	<2e-16 ***
Approximate significance of smooth terms:				
	edf	Ref df	Chi sq	p-value
s(JDay)	7.050	8.000	73.73	<2e-16 ***
s(Year)	8893	8.995	318.88	<2e-16 ***
Signif codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
R-sq (adj) = 0.358 Deviance explained = 16.4%				
UBRE = -0.049849 Scale est = 1 n = 1936				

The seasonal distribution of Blainville's beaked whales peaks in January and May through July, while it is lowest in March, with another dip in September (Figure 11, top). The long-term trend appears to have fluctuated, with highs around 2014 and 2017, and a low point in 2015-2016, and a less pronounced drop around 2012 (Figure 11, bottom). A trend analysis on the number of *Md* GVPs per hour effort was conducted earlier, in section 2.2.2.2.

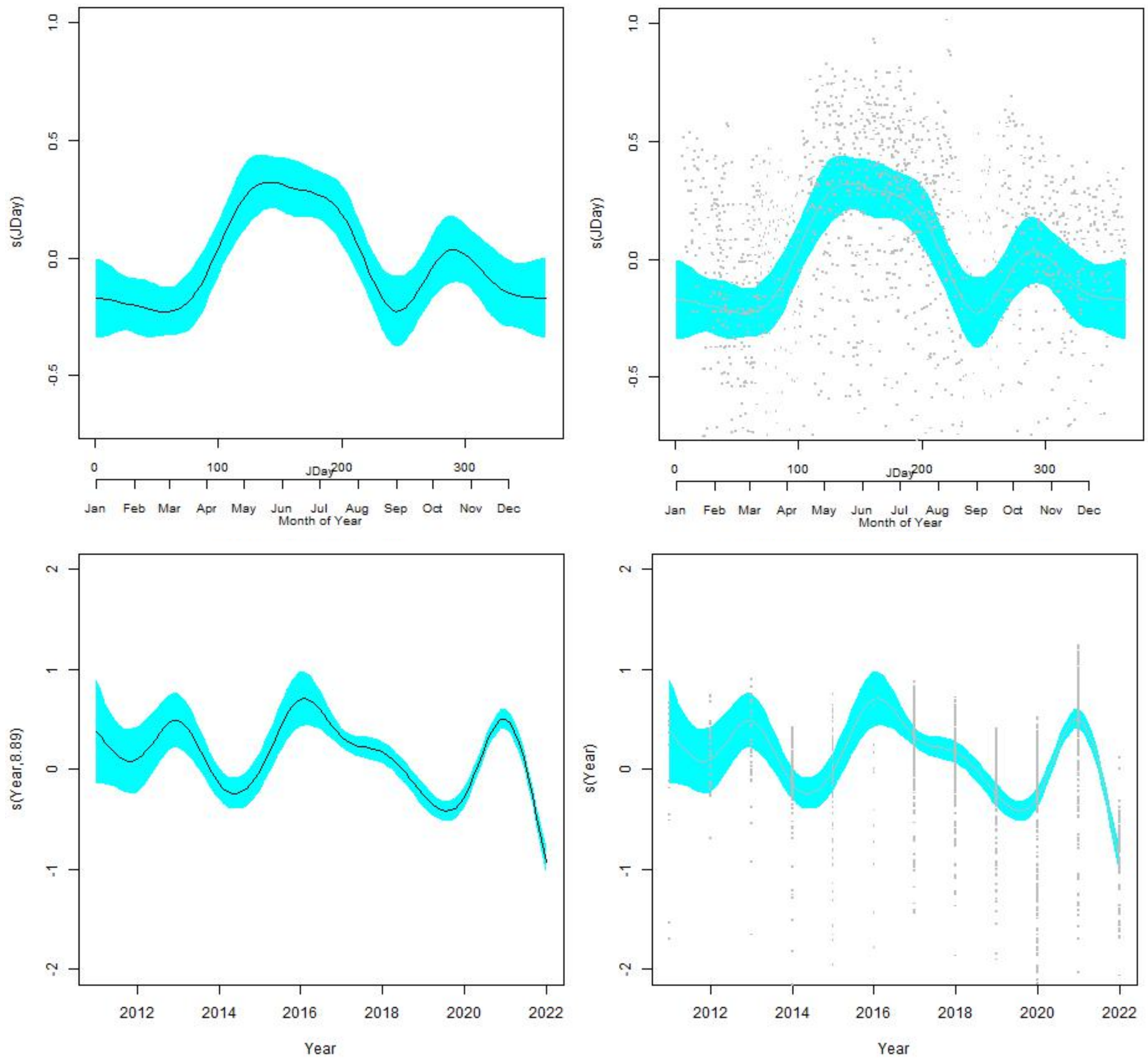


Figure 11. Smooths of the predictors for the number of *Md* GVPs per day at PMRF.
***Top:* Seasonal distribution – smooth of JDay on left, smooth of JDay with residuals on right; *Bottom:* Long-term trend – smooth of Year on left, smooth of Year with residuals on right**

2.3.2.2 PMRF: Blainville's beaked whale abundance

The mean hourly Blainville's beaked whale abundance was calculated using equation 5 in section 2.2.3. The mean hourly abundance for any month, averaged from 2011 to 2022, peaks at 26 animals in September and October and is lowest in February at 17 animals (Table 17; Figure 12, left).

Table 17. Mean hourly Blainville's beaked whale abundances at PMRF averaged monthly from 2011-2022.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	30.54	36.48	39.10	45.45	53.21	52.62	48.75	42.53	47.84	46.25	38.64	44.22
mean abundance	14.42	20.74	23.84	28.47	32.72	31.84	29.05	23.65	26.23	27.67	22.86	27.31
lower CI	-1.70	5.01	8.57	11.49	12.23	11.05	9.35	4.76	4.63	9.09	7.08	10.39

Over the twelve-year time period the mean hourly abundance in any month was highest at 66 animals in Aug of 2022, and lowest at 0 during several time periods (Table 18; Figure 12, right).

Table 18. Mean hourly abundance of PMRF Blainville's beaked whale abundances per month from 2011 - 2022. NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	NA	NA	NA	NA	NA	22.19	33.14	32.36	NA	NA	NA	NA
2012	32.34	NA	NA	NA	NA	30.06	28.09	NA	NA	NA	NA	NA
2013	NA	34.46	NA	NA	NA	NA	28.18	16.71	NA	NA	NA	NA
2014	NA	18.55	8.86	NA	23.48	23.40	20.55	22.98	NA	28.55	NA	NA
2015	NA	12.76	16.97	15.22	NA	NA	NA	NA	25.76	18.36	NA	NA
2016	NA	14.84	NA	NA	NA	NA	NA	7.14	NA	NA	NA	NA
2017	NA	22.33	31.40	33.82	34.31	46.80	40.13	22.14	26.79	32.39	27.14	35.82
2018	0	15.11	23.35	18.62	36.60	26.01	23.91	28.99	31.11	22.72	26.71	NA
2019	14.58	23.13	24.84	22.83	24.38	13.68	24.94	NA	NA	NA	15.33	15.05
2020	28.44	27.05	18.15	32.61	27.36	23.94	4.65	3.18	3.34	5.36	6.28	6.21
2021	18.26	17.37	25.45	25.10	35.78	43.22	46.85	44.74	47.36	50.42	39.06	43.09
2022	9.08	29.47	33.48	39.99	42.20	40.70	35.24	65.97	NA	NA	NA	NA

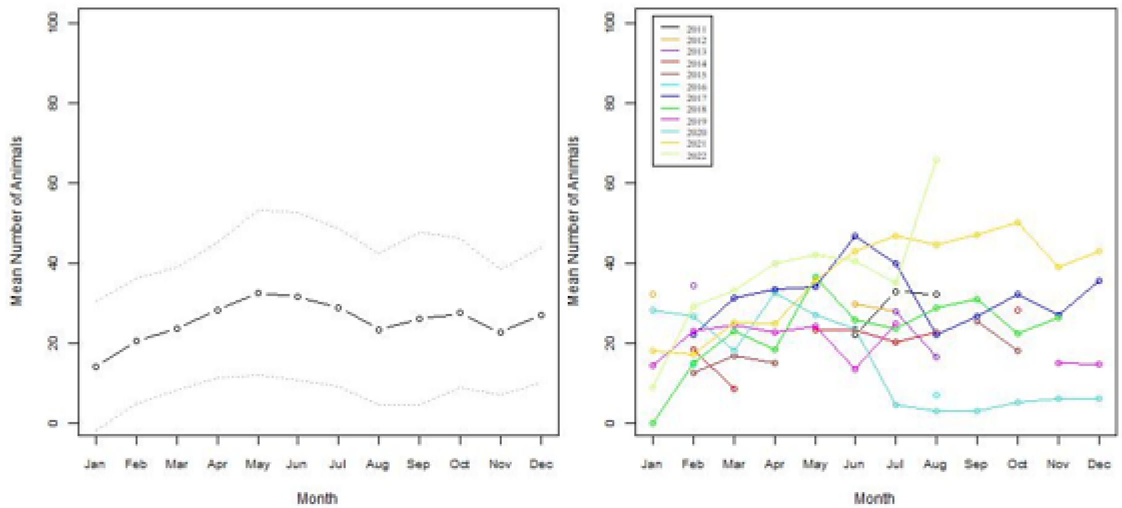


Figure 12. Mean monthly Blainville's beaked whale abundance at PMRF. **Left:** ***mean of all years; dashed lines indicate 95% confidence intervals,*** **Right:** ***yearly means 2011 through 2022.***

The trend in the Blainville's 's beaked whale abundance per hour at PMRF was calculated in the same manner as described for Blainville's beaked whales GVPs in (Table 19; Figure 13, right). Since abundance is proportional to the number of GVPs, similar trends are expected.

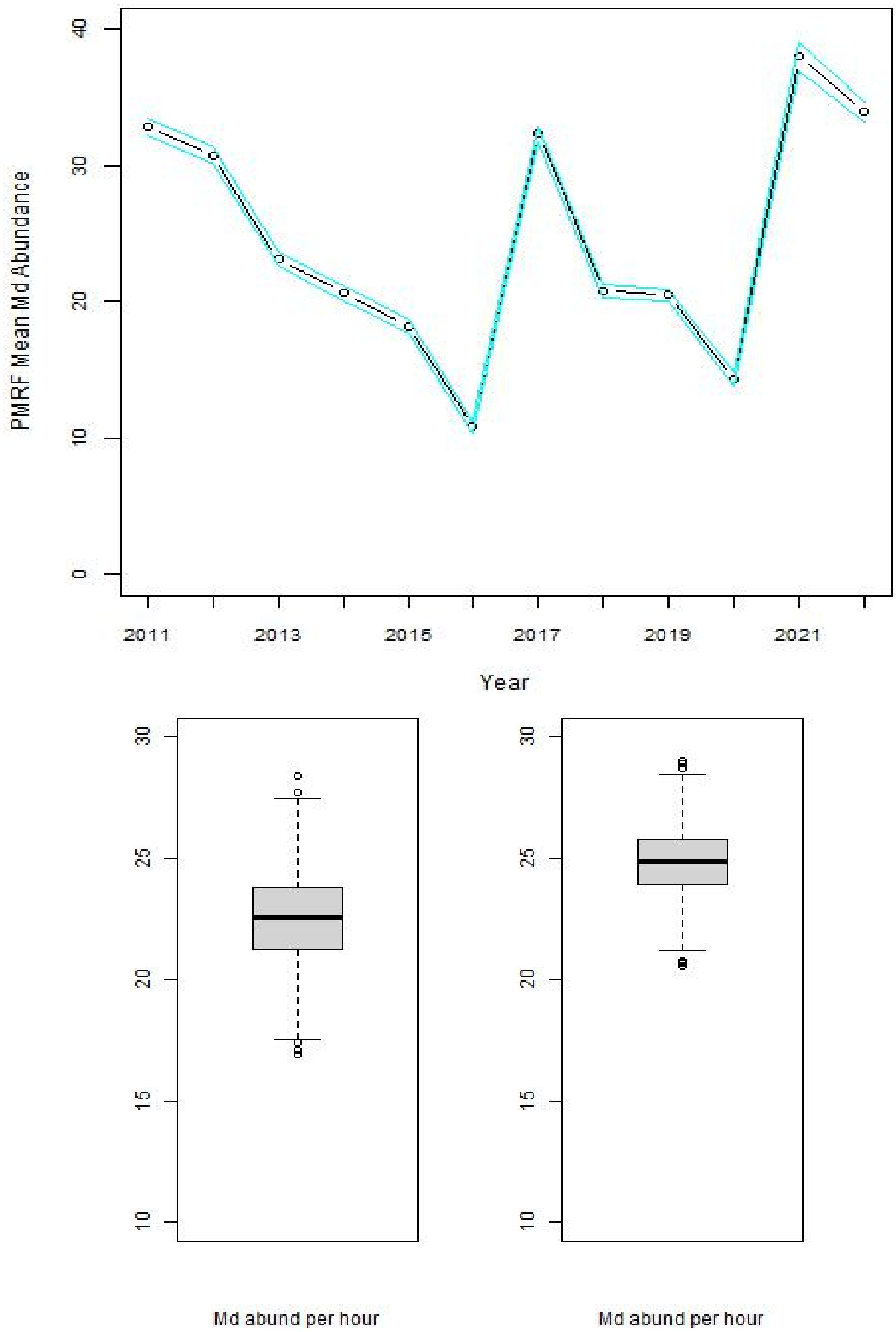


Figure 13. Mean abundance of *Md* per hour of effort at PMRF.
Left: **For each year from 2011-2022; cyan lines indicate 95% confidence intervals.** ***Right:*** **Sample means from 1000 bootstrap samples for the periods 2012-2014 and 2019-2021.**

Table 19. PMRF: Statistics for *Md* bootstrap sample mean abundance per hour.

Series	Min	Max	Mean	Median	StdDev
2012-2014	16.93	28.44	22.53	22.55	1.92
2019-2021	20.55	29.01	24.87	24.85	1.39

The Welch two sample t-test found no significant difference in the bootstrap sample means generated from the years 2012-2014 ($\mu = 22.60$) and the years 2019-2021 ($\mu = 24.91$), showing the number of Md on range hourly has not changed significantly in the past decade.

2.3.2.3 PMRF: Cuvier's beaked whale temporal distribution

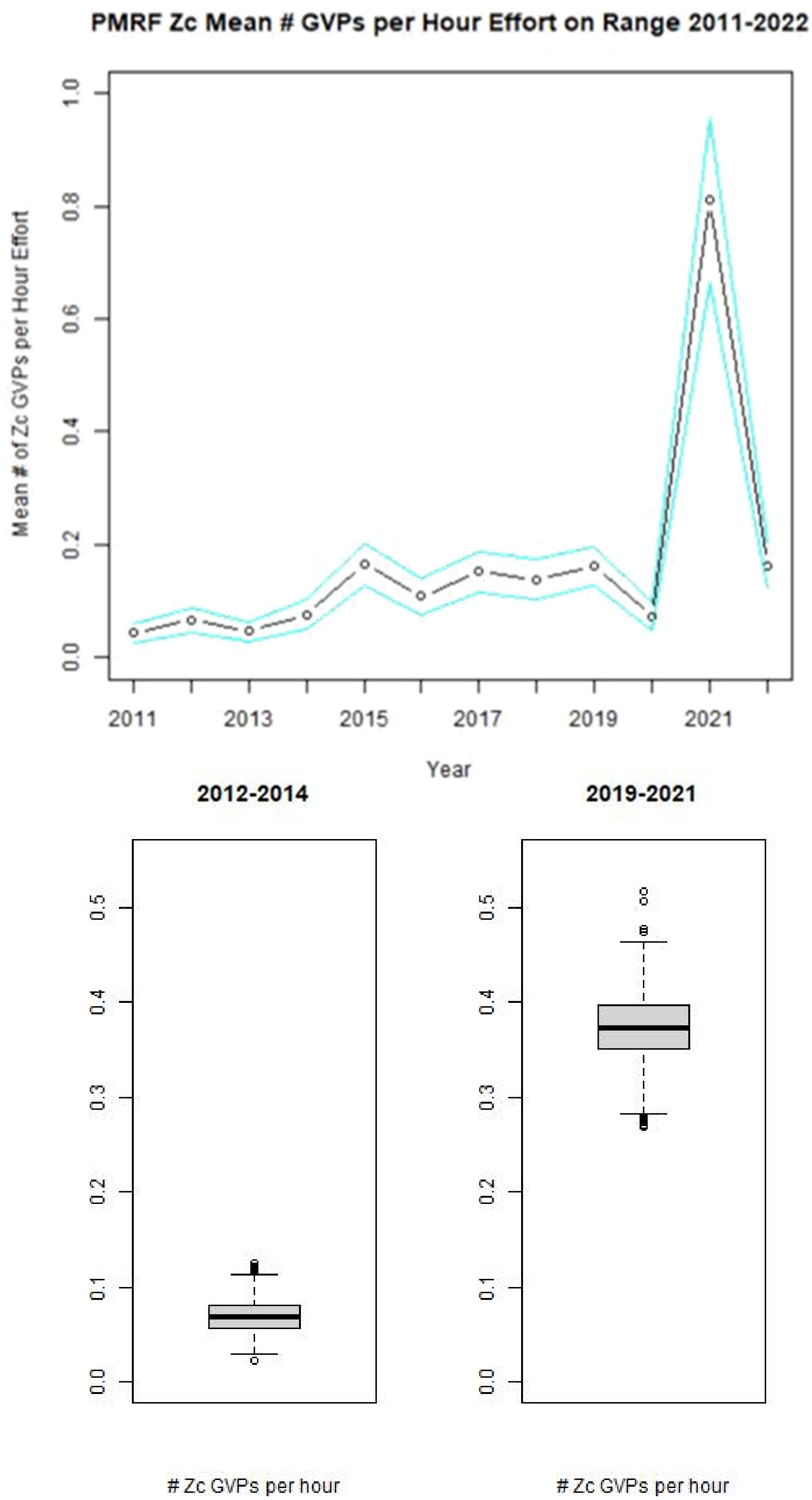
2.3.2.3.1 GVP Data for Cuvier's beaked whale at PMRF

GVPs were calculated on the same hourly basis as was used for Cuvier's beaked whales at SOAR. After accounting for effort, the average number of GVPs on any hydrophone in any hour varies from 0.001 to 0.006 with a maximum of 2 in 2021 (Table 20).

Table 20. PMRF: Statistics on the number of *Zc* GVPs per hydrophone-hour effort from 2011-2022.

Year	Hours of Effort	Zc GVP per hydrophone per hour effort				
		min	max	mean	median	stdev
2011	267	0.00	0.50	0.001	0.000	0.016
2012	685	0.00	1.00	0.001	0.000	0.020
2013	743	0.00	1.00	0.001	0.000	0.017
2014	2945	0.00	1.00	0.001	0.000	0.022
2015	2140	0.00	1.00	0.002	0.000	0.033
2016	454	0.00	1.00	0.001	0.000	0.027
2017	7829	0.00	1.50	0.002	0.000	0.032
2018	5650	0.00	1.50	0.002	0.000	0.030
2019	4941	0.00	1.50	0.002	0.000	0.033
2020	6753	0.00	1.50	0.001	0.000	0.022
2021	3870	0.00	2.00	0.006	0.000	0.073
2022	3804	0.00	1.50	0.000	0.000	0.013

The average number of GVPs in any hour across the whole range varies from 0.043 to 0.811 with a maximum of 9 GVPs per hour in 2021 (Table 21; Figure 14, left).


PMRF Zc Mean # GVPs per Hour Effort on Range 2011-2022
Mean # of Zc GVPs per Hour Effort
0.0
0.2
0.4
0.6
0.8
1.0
2011
2013
2015
2017
2019
2021
Year
2012-2014
2019-2021
0.0
0.1
0.2
0.3
0.4
0.5
Zc GVPs per hour
Zc GVPs per hour

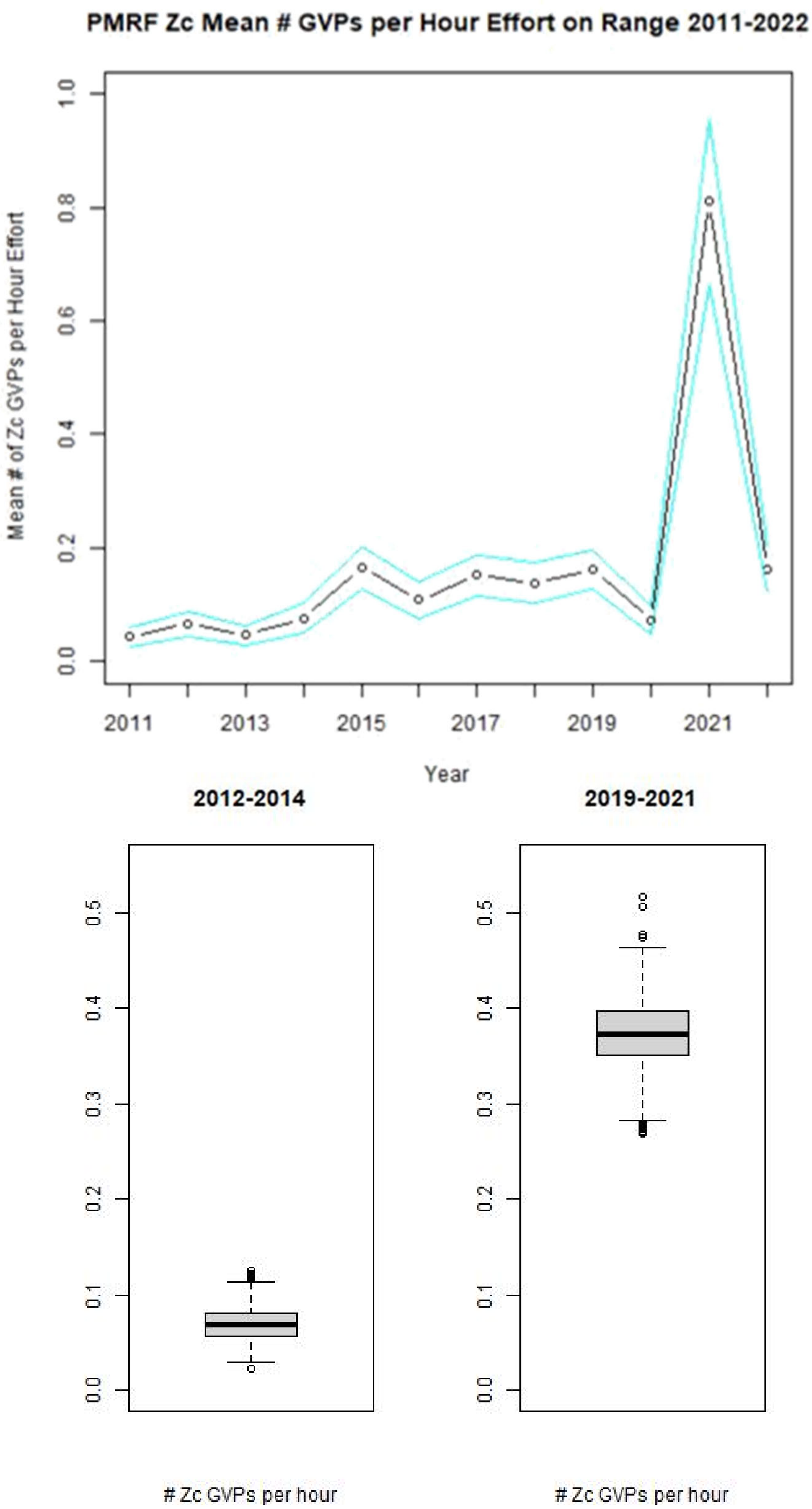

PMRF Zc Mean # GVPs per Hour Effort on Range 2011-2022
Mean # of Zc GVPs per Hour Effort
0.0
0.2
0.4
0.6
0.8
1.0
2011
2013
2015
2017
2019
2021
Year
2012-2014
2019-2021
0.0
0.1
0.2
0.3
0.4
0.5
Zc GVPs per hour
Zc GVPs per hour

Table 21. PMRF: Statistics on the number of Zc GVPs per hour of effort from 2011-2022.

Year	Hours of Effort	Zc GVP per hour effort				
		min	max	mean	median	stdev
2011	267	0.00	1.58	0.043	0.000	0.170
2012	685	0.00	1.58	0.066	0.000	0.211
2013	743	0.00	1.60	0.046	0.000	0.172
2014	2945	0.00	2.73	0.076	0.000	0.250
2015	2140	0.00	3.07	0.165	0.000	0.350
2016	454	0.00	2.08	0.108	0.000	0.312
2017	7829	0.00	3.50	0.152	0.000	0.350
2018	5650	0.00	4.50	0.138	0.000	0.346
2019	4941	0.00	3.50	0.161	0.000	0.336
2020	6753	0.00	2.56	0.072	0.000	0.235
2021	3870	0.00	8.65	0.811	0.000	1.434
2022	3804	0.00	4.27	0.162	0.000	0.401

A trend analysis was conducted for the number of Cuvier's beaked whale GVPs detected per hour at PMRF in the same manner as it was conducted for Blainville's beaked whales, comparing the bootstrap means from 2012-2014 with those from 2019-2021 (Table 22; Figure 14, right). A noticeable spike can be seen in 2021. We theorize this was resultant of a period of time data was collected only the deeper BSURE hydrophones, due to a software launch error. In FY23, we will investigate the spatial distribution of Zc and Md. We suspect Zc prefer the deep water, and this skewed our abundance estimate.

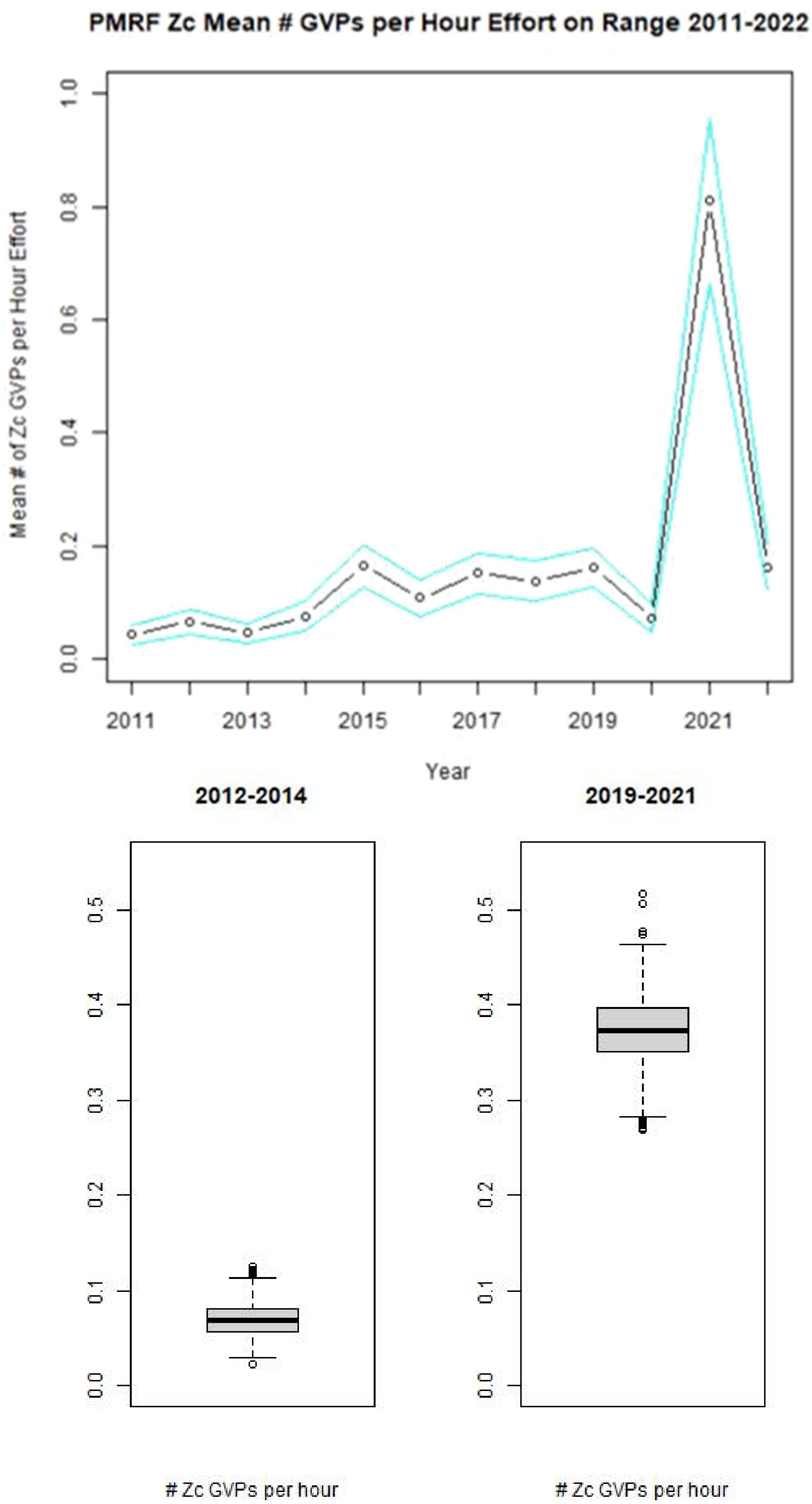


Figure 14. Mean number of *Zc* GVPs per hour of effort at PMRF. *Top:* For each year from 2011-2022; cyan lines indicate 95% confidence intervals. *Bottom:* Sample means from 1000 bootstrap samples for the periods 2012-2014 and 2019-2021.

Table 22. PMRF: Statistics for *Zc* bootstrap sample mean GVPs per hour.

Series	Min	Max	Mean	Median	StdDev
2012-2014	0.02	0.13	0.07	0.07	0.02
2019-2021	0.27	0.52	0.37	0.37	0.04

The Welch two sample t-test found a significant difference (p < 2.2e-16) in the bootstrap sample means generated from the years 2012-2014 (μ= 0.07) and the years 2019-2021 (μ= 0.37), a five-fold increase in the number of *Zc* GVPs detected per hour detected on range. The spike seen in 2021 likely exaggerates this effect. DiMarzio et. al. (2022) compared 2012-2014 to 2018-2020 and showed a six-fold increase in GVP per hour, suggesting this effect is not entirely the result of spike in 2021.

2.3.2.3.2 Statistical Model for Cuvier's beaked whale at PMRF

For the statistical modelling the mean number of GVPs per day after accounting for effort (per effort-day) were used. The number of *Zc* GVPs per effort-day across the PMRF range between 2011 and 2022 varies from 0 to 74 (μ=5.2, median=1.5) (Figure 15, left). (Figure 15, right) shows the variation from year to year in the number of *Zc* GVPs detected per effort-day across the PMRF range.

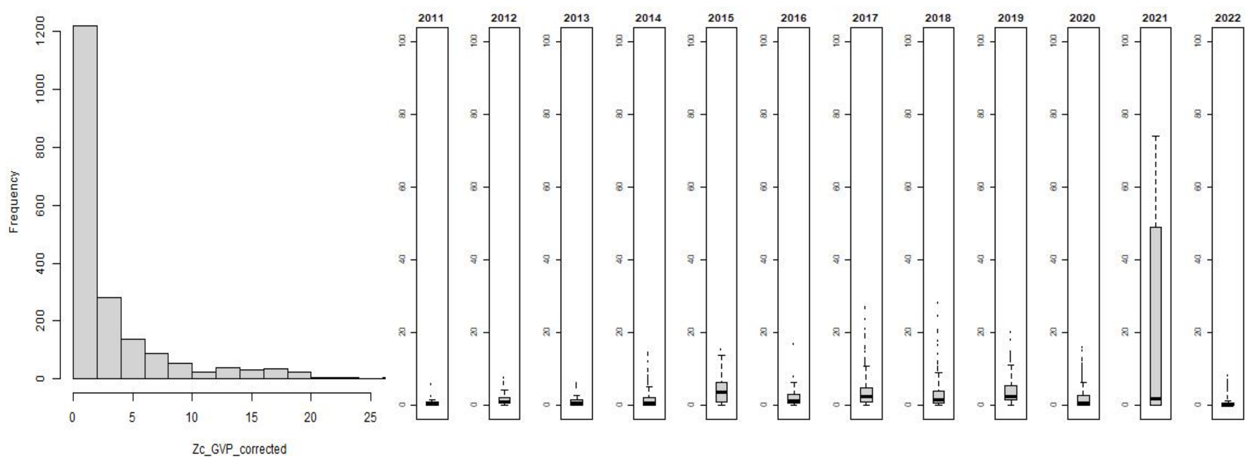


Figure 15. Number of *Zc* GVPs per day of effort on the PMRF range.
***Left:* Histogram of *Zc* GVPs for 2011 to 2022; *Right:* Boxplots for each year 2011 to 2022**

Both the Julian day (JDay) and Year were very significant ($p<2e^{-16}$) for predicting the number of Cuvier's beaked whale GVPs per day on the PMRF range from 2011 to 2022 (Table 23). The model had an R-squared value of 0.212 and explained 46.5% of the deviance, indicating that other factors besides time are important in determining the number of Cuvier's beaked whale GVPs detected on range. Figure 16 shows the smooths for cyclic JDay and Year.

Table 23. Results of the PMRF *Zc* gam in equation 3.

Parametric coefficients:				
	Estimate	Std Error	z value	Pr(>|z|)
(Intercept)	-7.01647	0.03019	-232.4	<2e-16 ***
Approximate significance of smooth terms:				
	edf	Ref df	Chi sq	p-value
s(JDay)	7.838	8.000	887.2	<2e-16 ***
s(Year)	8.977	9.000	1356.2	<2e-16 ***
Signif codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
R-sq (adj) = 0.212 Deviance explained = 46.5%				
UBRE = 0.59384 Scale est = 1 n = 1936				

The number of Cuvier’s beaked whale GVPs peak in March, during one of the low points for Blainville’s beaked whales, and then the numbers of Cuvier’s GVPs drop through to September, when they are lowest. They then start to increase until reaching the March peak. Though both species reach peaks at different times, their numbers are both lowest in September (Figure 16, top).

The number of Cuvier’s beaked whale GVPs detected on PMRF has fluctuated from 2011 to 2022, with the numbers highest about 2014 and 2017-2021, and lowest in 2015, followed by 2012 (Figure 16). A trend analysis on the number of *Zc* GVPs per hour effort was conducted earlier, in section 2.3.2.3.1.

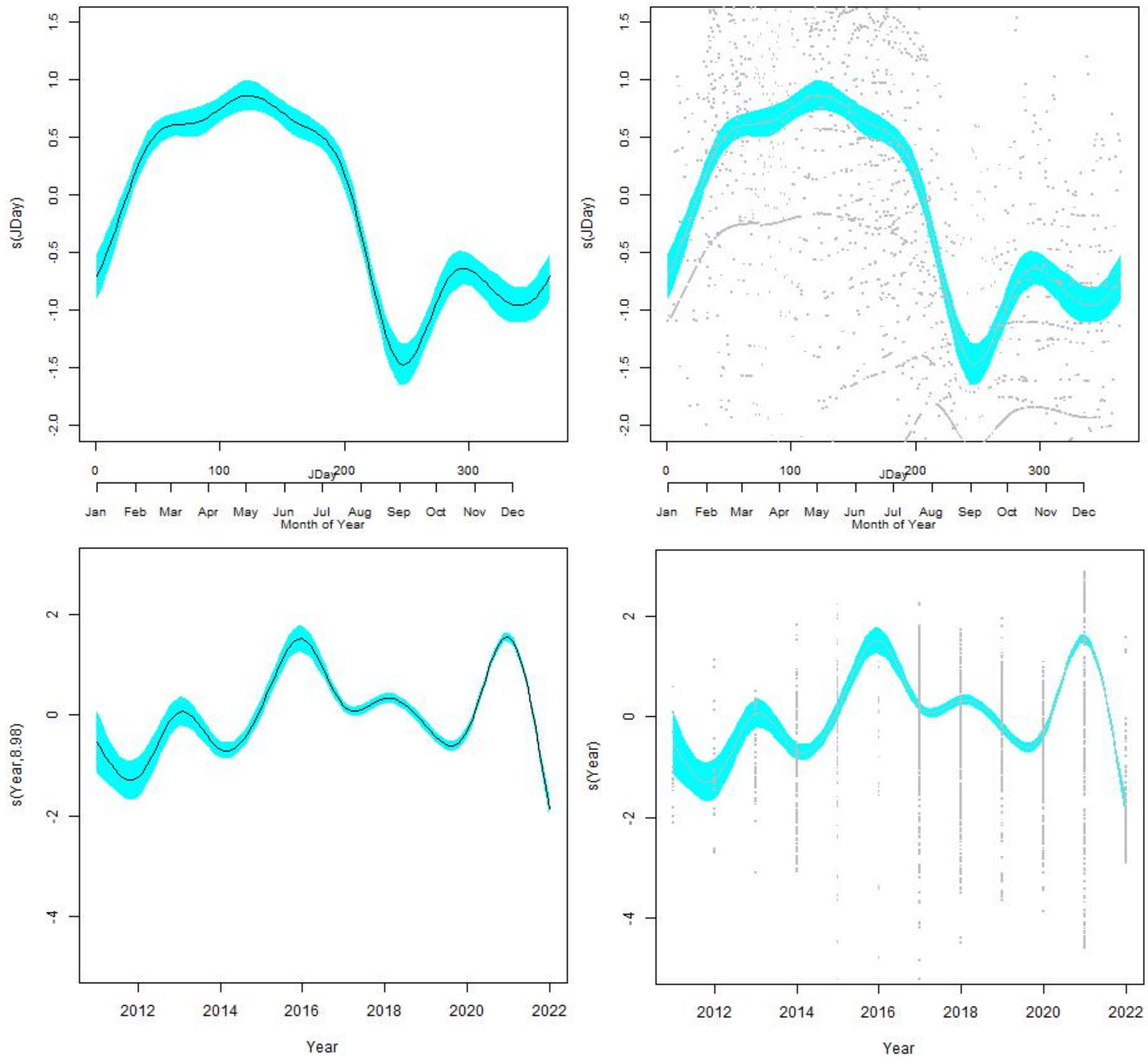


Figure 16. Smooths of the predictors for the number of *Zc* GVPs per day at PMRF.
***Top:* Seasonal distribution – smooth of JDay on left, smooth of JDay with residuals on right; *Bottom:* Long-term trend – smooth of Year on left, smooth of Year with residuals on right.**

2.3.2.4 PMRF: Cuvier's beaked whale abundance

The monthly Cuvier's beaked whale abundance was calculated using equation 5 in section 2.2.1.2. The mean abundance for any month, averaged from 2011 to 2022 peaks in April-July. The lowest abundance is in January (Table 24; Figure 17, left).

Table 24. Mean hourly Cuvier's beaked whale abundances at PMRF averaged monthly from 2011 to 2022.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
upper CI	5.86	17.97	17.58	29.81	44.69	38.93	35.41	6.12	6.92	9.56	6.72	8.42
mean abundance	1.64	8.38	8.46	12.74	20.56	16.41	14.48	1.91	2.05	3.33	2.36	3.22
lower CI	-2.59	-1.20	-0.66	-4.34	-3.57	-6.12	-6.45	-2.31	-2.82	-2.90	-2.00	-1.98

The mean hourly abundance for each month of each year can be seen in Table 25 and Figure 17. Abundances in from April through July 2021 are printed in red in Table 25 and seen on the yellow line for 2021 in Figure 17 (right). These estimates are believed to be inflated due to the fact data was only collected from the deeper BSURE hydrophones. Zc likely prefer the deeper water so the number of GVP detected was likely the same while the total effort hours decreased. A spatial distribution is planned in 2023 to further investigate this issue. Aside from this period the mean abundance in any month was highest at 14 animals in March 2018 and February 2018 (Table 25; Figure 17, right) and lowest at 0 during multiple time periods.

Table 25. Mean hourly PMRF Cuvier's beaked whale abundances for each month from 2011 - 2022. NAs indicate periods without data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	NA	NA	NA	NA	NA	0	1.53	3.68	NA	NA	NA	NA
2012	3.05	NA	NA	NA	NA	2.39	0.42	NA	NA	NA	NA	NA
2013	NA	4.27	NA	NA	NA	NA	2.16	0.48	NA	NA	NA	NA
2014	NA	5.97	2.60	NA	0.60	1.59	1.43	1.76	NA	6.39	NA	NA
2015	NA	10.27	6.20	6.66	NA	NA	NA	NA	2.80	1.74	NA	NA
2016	NA	7.10	NA	NA	NA	NA	NA	1.26	NA	NA	NA	NA
2017	NA	7.88	14.42	8.72	4.92	5.42	4.05	2.70	3.77	2.73	3.04	4.80
2018	0	14.43	9.92	6.82	7.94	4.96	3.14	1.53	1.46	3.37	2.25	NA
2019	5.72	11.30	9.68	7.55	5.38	4.98	3.86	NA	NA	NA	3.24	3.36
2020	3.75	8.86	7.98	10.22	4.25	3.02	0.95	0.03	0.13	0.34	0.27	0.26
2021	0.82	0.56	0.19	64.13	87.37	89.98	79.04	2.18	1.88	5.85	3.05	2.91
2022	1.34	11.31	8.33	2.87	6.89	6.51	1.84	10.32	NA	NA	NA	NA

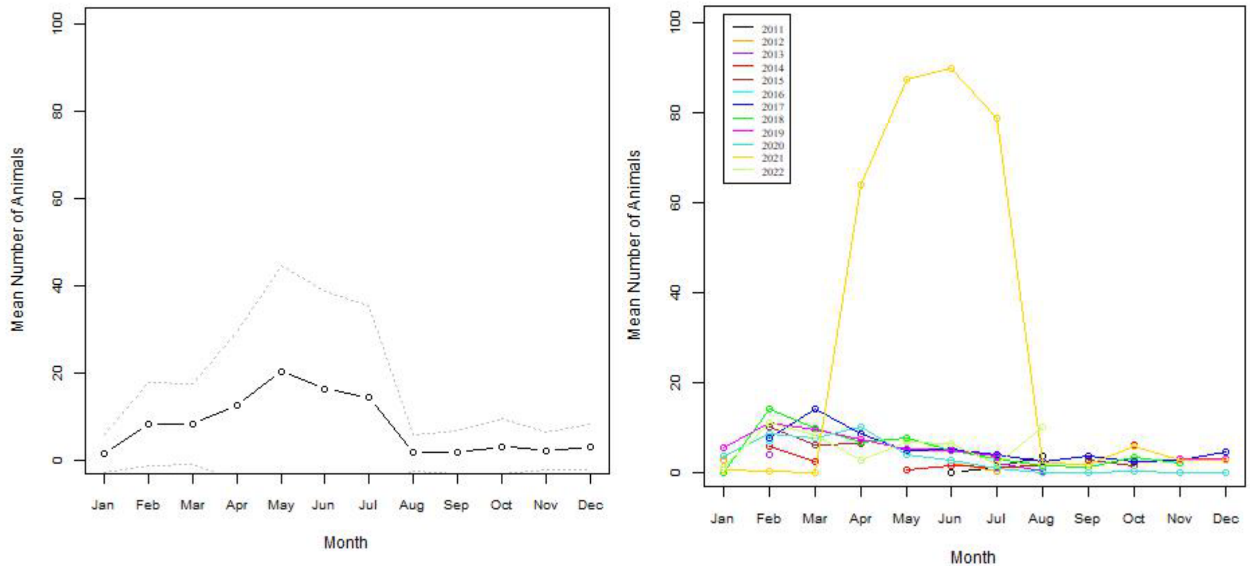


Figure 17. Mean monthly Cuvier's beaked whale abundance at PMRF.
***Left:* averaged between 2011 and 2022, *Right:* for the years 2011 through 2022. Dashed lines indicate 95% confidence intervals.**

The trend in the Cuvier's 's beaked whale abundance per hour at PMRF was calculated in the same manner as described for Cuvier's beaked whales GVPs in section 2.3.2.2.2.1 (Table 26;

Figure 18, right). Since abundance is proportional to the number of GVPs, similar trends are expected.

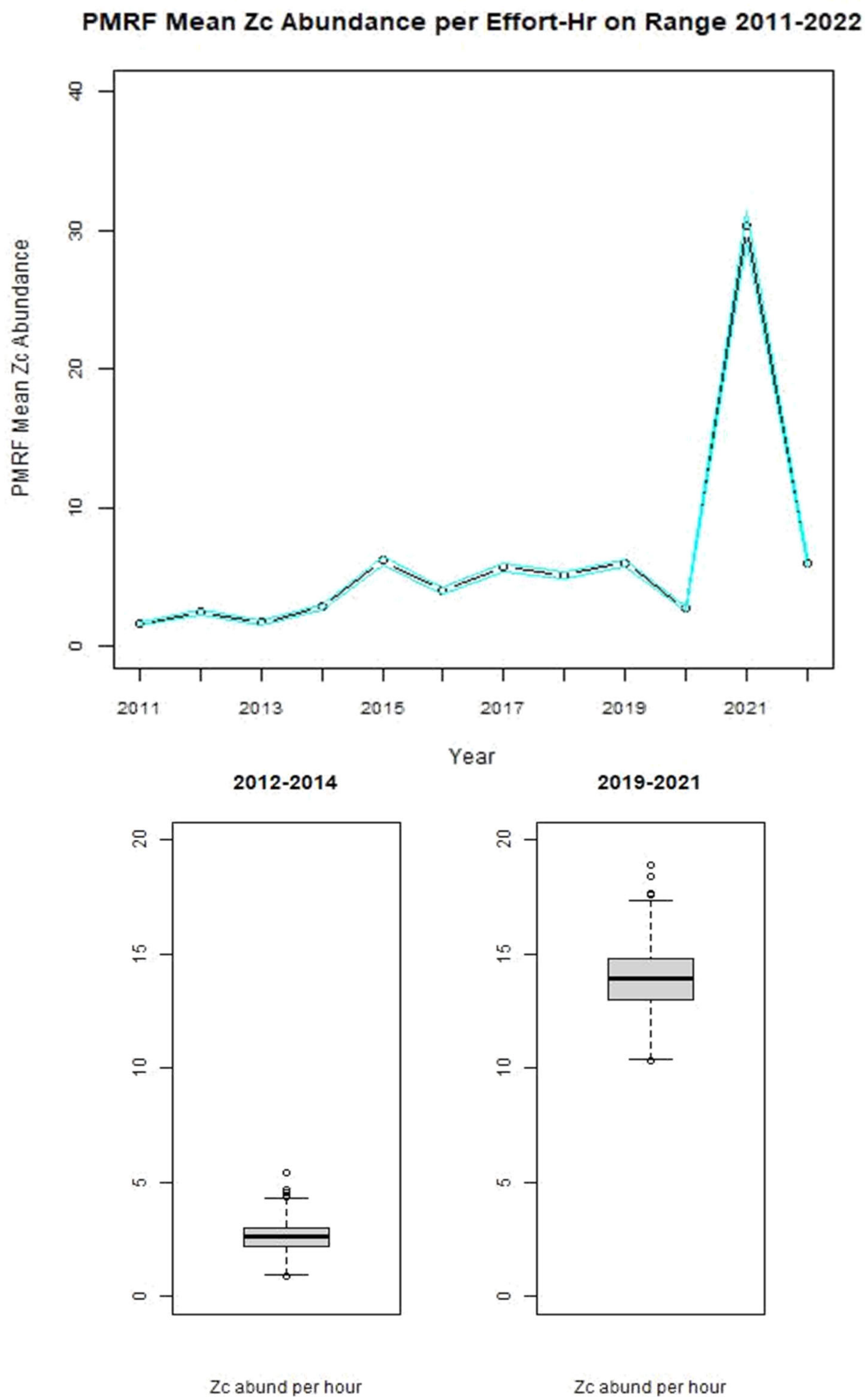


Figure 18. Mean abundance of *Zc* per hour of effort at PMRF.
Left: **For each year from 2011-2021; cyan lines indicate 95% confidence intervals.** ***Right:*** **Sample means from 1000 bootstrap samples for the periods 2012-2014 and 2018-2020.**

Table 26. PMRF: Statistics for *Zc* sample mean abundance per hour.

Series	Min	Max	Mean	Median	StdDev
2012-2014	0.81	5.14	2.57	2.53	0.65
2019-2021	10.65	18.68	14.06	14.00	1.33

The Welch two sample t-test found a significant difference ($p < 2.2e-16$) in the bootstrap sample means generated from the years 2012-2014 (μ= 2.57) and the years 2019-2021 (μ= 14.06), a five-fold increase in the Cuvier's beaked whale abundance detected per hour detected on range. The spike seen in 2021 likely exaggerates this effect. DiMarzio et. al. (2022) compared 2012-2014 to 2018-2020 and showed a two-fold increase in Zc abundance per hour, suggesting this effect is not entirely the result of spike in 2021.

2.4 Discussion

2.4.1 SOAR

Cuvier's beaked whales exhibit a seasonal pattern on the SOAR range, with the numbers of GVPs detected and abundance peaking in May, and in the December/January timeframe. The numbers are lowest in September, with a second, less pronounced dip in March. The peak in the beginning of the year coincides with a period in which there are typically no sonar exercises on range; thus, it would provide an opportunity for undisturbed foraging. Acoustic detections of Cuvier's beaked whale clicks on High Frequency Recording Packages (HARPs) located in Southern California (SOCAL) have shown a similar low point in September (Baumann-Pickering et al. 2014). From November 2018 to May 2020 data on four HARPS near SOAR, two west of SOAR (E and H) and two south of SOAR (N and U) show many more Cuvier's beaked whale detection on the western HARPS E and H than on sites N and U. Site H, located just to the west of SOAR, has Cuvier's beaked whale peaks in August 2019 and February to May 2020, while site E peaks in December 2019 (Rice, et al., 2021). These peaks overlap to some extent with the peaks on SOAR. For the time period July 2018 to May 2019 peaks on the HARP at site H was highest in spring 2019 and at site E highest in late fall 2018, while both were lowest in late summer/early fall (Rice, et al., 2020). The high point at site H in spring and low points in late summer/early fall coincide with our results on SOAR. Note, however, that the results presented for SOAR are averaged over the years 2010 to 2021, while the HARP data results are presented for the given years.

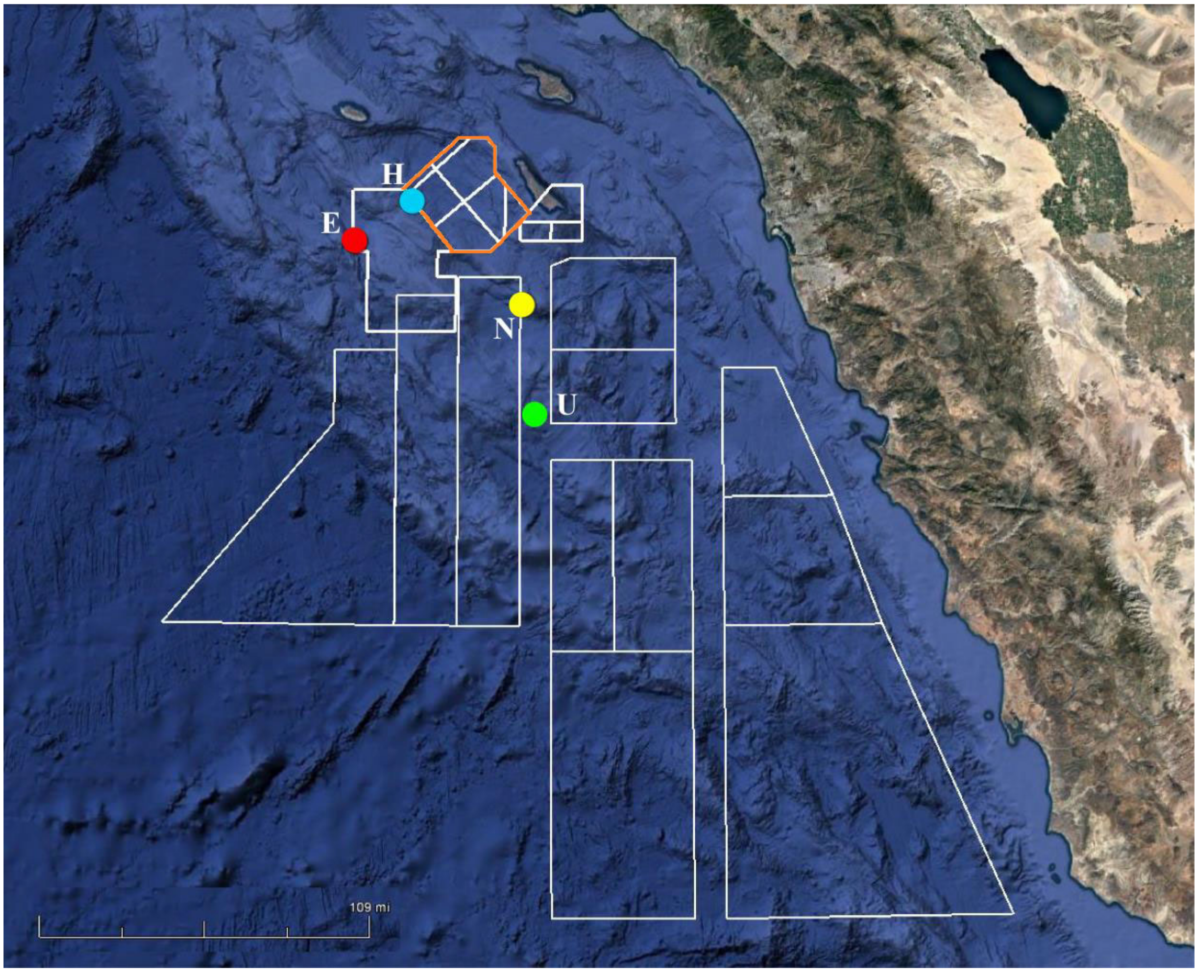


Figure 19: Locations of High-frequency Acoustic Recording Package (HARP) deployments in the SOCAL study area (colored circles) and US Naval Operation Areas (white boxes) with SOAR hydrophone range outlined in orange (Figure modified from Rice et al., 2021).

The mean number of Cuvier's beaked whale GVPs per hour has varied from 2.93 to 4.98 between 2010 and 2022, while the mean abundance per hour on range in any month, averaged from 2010 to 2022, is between 33 and 57 animals. As the SOAR range is about 1700 km^2, the average number of animals per 1000 km^2 averages at 24, which is higher than the mean density of 5.12 animals/1000 km^2 found with drifting buoys by Barlow, et al. 2021, supporting the notion that SOAR is an important foraging area for Cuvier's beaked whales (Falcone, et al., 2009). The Barlow results were over a much larger area off the U.S. West Coast, with all the drifting buoy deployments to the north and west of SOAR (Barlow, et al. 2021).

A trend analysis shows that the mean number of Cuvier's beaked whale GVPs detected on range per hour has dropped between the years of 2011-2013 and 2019-2021 from 4 to 3 GVPs, and the mean abundance per hour on range has dropped from 46 to 35 animals. However, in 2015, between these two periods, the mean number of GVPs on range was 1.7 while the mean number of animals was 20, both of which are lower than the estimates during these time periods. This would indicate either that 2015 had an unusually low number of animals, or possibly that the trend seen here could be within normal fluctuations if viewed over a longer time period. Curtis, et al., found an annual rate of change of -0.8% for Cuvier's beaked whales on SOAR, but also conducted simulations that indicated that additional years of data would be needed to reliably detect a trend. So, whereas their results indicated that abundance is either stable or slowly decreasing, they also point out that those results are not conclusive (Curtis, et al, 2020). Another explanation is the warm water "Blob" observed by Leising et. al (2015) and Cavole et al (2016). The "blob" refers to a time in 2013-2015 when he California Current saw below average costal upwelling, increases surfaces temperatures, and low productivity across the entire NE Pacific Ocean. Low productivity observed during the "blob" could have led to decreased food supply for Zc in the SOAR area, and therefor lower than average abundances. There are several things to consider with our results, as well. The CS-SVM classes were updated in 2014, and the effects of those updates have not yet been quantified or accounted for. Prior to the updates the classifier included Blainville's and Cuvier's beaked whale foraging click classes, sperm whale clicks, and several dolphin species. After updating in 2014, classes were added for Blainville's and Cuvier's beaked whale buzzes, the Blainville's class was removed from SOAR, the classifier better differentiated Cuvier's and Blainville's, and the dolphin classes were collapsed into a 'generalized dolphin' class. Since clicks could be misclassified (for instance, Cuvier's clicks misclassified as Blainville's, or dolphin detections impacting groupings), quantifying the effects of these changes is important for an accurate trend analysis. For the abundance calculations, an average group size is used, and the Autogrouper detection statistics were drawn from data from 2010 to 2015, so updating these statistics and including actual groups sizes could improve the estimates. Efforts to update SOAR detection statistics are planned in 2024.

2.4.2 PMRF

2.4.2.1 Blainville's beaked whales

The seasonal distribution of Blainville's beaked whales at PMRF appears to peak in May through July, and in the December/January timeframe, while it is lowest in April, with another dip in September. Henderson, et al. (2016) and Martin, et al. (2020, 2021) also examined the number of Blainville's beaked whale dives per hour on the PMRF range. Since Henderson et al., Martin et al., and our analysis all consider the number of beaked whale dives that start within an hour, the number of dives per hour reported by Henderson et al. and Martin et al. is equivalent to the number of GVPs per hour that we report. Henderson et al. examined three years (2011 to 2013) of data from 31 hydrophones and found seasonal variation that did not have a clear pattern, but may indicate increased activity in spring and late summer. Part of this pattern coincides with the higher numbers we see in May through July. Martin, et al. (2020, 2021) however, found no clear seasonal pattern.

Our results show a mean number of Blainville's GVPs per hour from 2011-2022 varying from 0.98 to 3.45, with a maximum of 31 in 2021. In the years 2011, 2012 and 2013 we calculate mean of 2.31 GVPs per hour. Henderson reported an average of 1.3 GVPs per hour of effort (1.3 to 3.3 GVPs per hour) during the same time period. Note that Henderson's results were analyzed using broadband recordings from 31 hydrophones, whereas ours are determined from reports from the M3R classifier on 83 hydrophones including the 31 used by Henderson. In more recent work on PMRF, Martin, et al. (2020, 2021) recorded 62 hydrophones at PMRF, a capability added in August 2012 (Martin, et. al. 2016), and used a random subset of four recordings in each year to manually validate the detections. These 62 hydrophones are a subset of the 83 hydrophones used in this analysis. Martin found the overall rate of Blainville's beaked whale GVPs per hour from August 2018 to August 2019 was 2.33, with a range from 1.38 to 2.62; while the overall rate for September 2019 to September 2020 was 1.79, with a range from 0.52 to 4.44. Our mean rates were 1.86 in 2019 and 1.3 in 2020, which are in line with those found by Martin et al. Martin et al. (2020) also reported an overall maximum of 10.53 GVPs/hour in August of 2019. Our maximum in 2019 15.65 GVPs/hour, which number is higher, but in the same vicinity, and our data incorporated more hydrophones.

The annual mean abundance per hour appears to fluctuate between of 10 and 35 Blainville's beaked whales, with highs occurring in 2011, 2017, and 2021, and a lows occurring in 2016 and 2020. A trend analysis on both the number of Blainville's beaked whale and abundance per hour shows similar populations between the time periods of 2012-2014 and 2019-2021 from 2.31 to 2.26 GVPs per hour and 22.55 to 24.87 animals per hour. The same caveat applies here as for SOAR, in that the CS-SVM classes were updated in 2014, and any effects of the changes have not yet been quantified; therefore, they could influence the trend. In addition, the Autogrouper detection statistics for Blainville's beaked whales are based on 17 samples, and the sample size should be increased for results that are more accurate. Efforts are underway in 2023 to increase the sample size for these calculations to be updated in the FY23 report.

2.4.2.2 Cuvier's beaked whales

The seasonal distribution of Cuvier's beaked whales peaks in March, during one of the low points for Blainville's beaked whales, and then drops through to September, when they are lowest. They then start to increase until reaching the March peak. Though both species reach peaks at different times, their numbers are both low in September.

The annual mean number of Cuvier's beaked whale GVPs per hour detected on PMRF varies from 0.043 to 0.811, with a maximum of 31 in 2021. In 2019 there was a mean GVP/hour rate of 0.161 and a maximum of 3.5, while the mean and maximum in 2020 were 0.072 and 2.56, respectively. Martin, et al. (2020, 2021) found an overall rate of Cuvier's beaked whale GVPs per hour from August 2018 to August 2019 was 0.09, with a range from 1.38 to 2.62; while the overall rate for September 2019 to September 2020 was 0.08, with a range from 0.0 to 0.19. In both reports the maximum number of GVPs per hour that Martin found was two. The numbers we found are higher, our estimates are calculated from a larger number of hydrophones on a more continuous basis.

The number of Cuvier's beaked whale GVPs detected on PMRF has fluctuated from 2011 to 2022, with the numbers highest about 2015 and 2021, and local minimums found at 2011, 2013, and 2020. The extreme spike seen in 2021 may be skewed due to a data collection error in 2021 where detections were not recorded for the BARSTUR hydrophones for approximately the first 6 months of 2021. Given Cuvier's preference the deeper waters of the BSURE hydrophones, we are likely seeing a larger average GVP per hour over all hydrophones available, thus skewing the estimates to be higher. Further investigations are planned in 2023 to look at the spatial trends of Zc, and potential conduct abundance estimates for BSURE and BARSTUR separately. Similar fluctuations occur in the Cuvier's beaked whale abundance. A trend analysis on the Cuvier's beaked whale mean GVPs/hour and mean abundance between the years of 2012-2014 and 2019-2021 shows both increasing: from 0.07 to 0.37 GVPs per hour, and from 2.5 to 14 animals on range per hour. However, similar caveats apply to the evaluation of the trend, in that the effects of the change in CS-SVM classes should be quantified, and Autogrouper detection statistics need to be refined and applied to the GVPs. The detection statistics for Blainville's beaked whales at PMRF were used in the abundance equation for Cuvier's beaked whales, and may have overestimated their numbers based on a cursory review of the data. Both studies found Blainville's and Cuvier's beaked whale present on the range year-round with similar mean abundances.

2.4.3 Summary

The distribution and abundance of Cuvier's beaked whales have been evaluated on SOAR from 2010-2022, and for Blainville's and Cuvier's beaked whales at PMRF from 2011-2022. The main recommendations for improvements are as follows:

1. Refine and apply Autogrouper detection statistics for Cuvier's beaked whales at PMRF, and increase the sample size for Blainville's beaked whale Autogrouper detection statistics at PMRF (efforts currently underway).
    a. Consider separate abundance estimates for BARSTUR and BSURE hydrophones to account for habitat changes (planned for FY23).
2. Include samples from more recent years in the Autogrouper detection statistics at SOAR.
3. Quantify the impact of the changes in CS-SVM classes circa 2014 on the beaked whale detections.

A direct comparison of the number of GVPs detected at PMRF by M3R and NIWC on the same subset of hydrophones may also be illustrative.

Despite these limitations, the long-term data collected by M3R on SOAR and PMRF remain an incredibly valuable resource for examining the distribution, abundance and trends of beaked whales and other species on the ranges.

3 FY22 Low Frequency Baleen Detector Validation – Improving M3R Real-time LF Localizations

3.1 Introduction

3.1.1 Summary

In FY20 and in FY21 we conducted a first assessment of the accuracy of localizations of low-frequency (LF) calls automatically generated by the Marine Mammal Monitoring on Navy Ranges (M3R) system installed at the So-Cal ASW Range (SOAR). This was done by comparing LF localizations extracted from M3R archive files to fin whale detections and localizations generated by researchers at NIWC, San Diego, through their post-processing of whole range acoustic recordings (M3R packet recorder data) for select days. During this assessment we discovered that M3R appeared to be localizing only a fraction of the many LF calls it was receiving and the automatically generated M3R tracks exhibited greater scatter than the NIWC post-processed tracks. The cause for the discrepancy in the number of localizations was found to be excessive processing load on the computer nodes that associate times of call arrival among neighboring hydrophones. The increased scatter in M3R LF localization relative to the NIWC post-processed tracks was assumed to be related to the coarser time resolution (170.67 ms) of M3R's LF FFT detector relative to the NIWC detector. This year we implemented a fix to our call association programs to reduce the processing load. We also modified our LF FFT detector to increase its time resolution by a factor of eight.

3.1.2 Background

M3R's low frequency detection and localization capability was developed under the AIST Marine Mammal Effects of Test and Evaluation on Ocean Ranges (METEOR) program. The low frequency spectrogram detector was incorporated into M3R's real-time processing stream in 2014-2015 and automated LF localization was added near the end of 2016. M3R localizes animals using multilateration which requires determining the difference in time of arrival (TDOA) of a given signal at widely spaced sensors whose positions are precisely known. For odontocete species like beaked whales, sperm whales and dolphins, M3R associates click trains, as received on neighboring hydrophones, to determine TDOAs. However, for dolphin whistles, M3R uses spectrogram cross correlation among neighboring hydrophones to determine the TDOA. M3R LF localization borrows from the whistle localization and performs cross correlation of hard-limited spectrograms produced by M3R's LF FFT detector. Specifically, it cross correlates 10 second long spectrograms of frequencies <600 Hz. The time delay associated with the correlation peak is the TDOA between that pair of hydrophones. All position points (posits) generated are sent to M3R displays and saved to the central archive file. During tagging surveys on SOAR, M3R's LF localization routine has been successfully used to acoustically localize baleen calls and direct on-water partners MarEcoTel to fin whales, gray whales, humpback whales and blue whales. While we have anecdotal evidence of accuracy of M3R LF posits (good enough to get a boat within visual spotting range) systematic review of the quality and quantity LF localization is limited. In FY 2020 we conducted the very first systematic review of M3R LF localizations. In that study, all posits were extracted from M3R archives over eight 24-hour periods spread throughout the year. We sought to verify that the LF posits generated were, in fact, localization of baleen calls vice anthropogenic sources. In the data examined we identified numerous posits resulting from calls from fin whales, gray whales and humpback whales and few from human-made sources.

In FY22 we conducted a direct comparison between the LF localizations automatically generated by M3R real-time algorithms, and the fin whale detections and localizations generated through post-processing raw acoustic recordings of the broadband hydrophones that comprise SOAR, generated by the M3R packet recorder. NIWC processed M3R packet recorder recordings from 2-6 January 2019. Over these days the only activity on-range was a side scan bathymetric survey and the NIWC analysis generated numerous high-quality fin whale tracks. Overlaying M3R LF posits and the NIWC results was initially disappointing. NIWC processing had produced orders of magnitude more posits than M3R for the same 24-hr period. Some discrepancy could be attributed to differences in the quality of the signal detectors used. NIWC's shallow neural net likely has better detection performance than M3R's hard-limited energy detector. Other differences might be attributed to difference in localization technique, model-based minimum mean square error fit (NIWC) versus M3R direct path multilateration. However, neither of these would account for the entirety of the problem. M3R was not localizing a large number of LF calls. Spot checks of M3R LF spectrograms during the times of NIWC track showed that fin whale calls were clearly visible. The calls could even be localized using manual localization tools in M3R spectrogram display software, Jacknife, yet there were no corresponding automated posits in the M3R archives. It was as if the LF call association process wasn't running. This observation led to a working theory that was borne out through experimentation – some of the computer nodes in the M3R localization processing path weren't keeping up with real-time.

During fieldwork at SOAR, M3R operators have regularly observed (on the M3R system health display) a heavy processing load on the computers that perform association of detections among hydrophones to find the TDOA – the Associator nodes. However, with the high number of posits continually being generated and displayed at SOAR, it is impossible to determine just by looking whether we are missing any. Furthermore, the amount of dolphin click activity increases dramatically at night leading to the possibility that associator nodes that are heavily loaded during the day are being overwhelmed by dolphin activity at night and are not able to keep up. To test this theory, we reprocessed just the LF FFT data from M3R archive files from 4-5 Jan 2019 through the LF call associator and localization code and the results were stored in new series of archive files. No association of any other call type was performed, and no loading of any computer nodes was observed. The LF posit were then extracted from the new archives. The reprocessed data contained over 59000 raw LF localizations which were filtered to exclude bogus posits and to form tracks. These M3R posit tracks compared much more favorably with the NIWC-generated fin tracks. However, close examination of the overlay of the M3R and NIWC track showed that the M3R posits exhibit more scatter than the NIWC localizations. We theorized that this was largely because the timing resolution of the M3R LF detector (170.67 ms) was much coarser that the timing resolution of the NIWC fin detector.

3.2 Results

This year we determined that Associator loading was being caused by the sheer volume of dolphin clicks detected at SOAR. M3R runs three types of call associators, one for odontocete click trains, one for small odontocete whistles and one for baleen calls below 600Hz. All three associators run on the same computer node for a subset of the SOAR hydrophones. There are currently three associator computer nodes at SOAR. The odontocete click associator works with detections from the M3R CS-SVM classifier forming click trains from the individual detections of Cuvier's beaked whale clicks and buzzes, sperm whale clicks or generalized dolphin clicks. When beaked whales and sperm whales are present M3R usually detects ~10 or fewer clicks per second. Even for dolphins at most ranges we generally receive 10s of clicks per second.

At SOAR, however, we see much more dolphin activity and can often detect several hundred clicks per second on a single hydrophone. The click associators were developed to try to localize every click detected. The algorithm assumes the current click is the first click in a pattern of clicks and that this pattern of clicks will be the same on neighboring hydrophone although offset in start time. We limited the dolphin click associator to only consider first clicks separated by at least 50 ms. This still allows the associator to consider 20 click trains per second per hydrophones while guarding against the overload of 100s of clicks per second. Figure 20 is an example of the M3R Jacknife display from 7 January 2019. It shows a fair number of real-time LF posits (dark blue whale icons) and is representative of what a daytime display of LF posits before the associator fix. We successfully directed MarEcoTel to various baleen species using displays like this. Figure 21 shows an example of the Jacknife display from 22 November 2022, after the associator fix. The dark blue whale icons still represent newest LF posits and the blue triangles are LF posit more than 5 minutes old. Here you can clearly see multiple LF posit tracks showing 20 minutes of posit history. These higher quality tracks make it easier to direct MarEcoTel to LF activity nearby as we can tell direction and speed of travel.

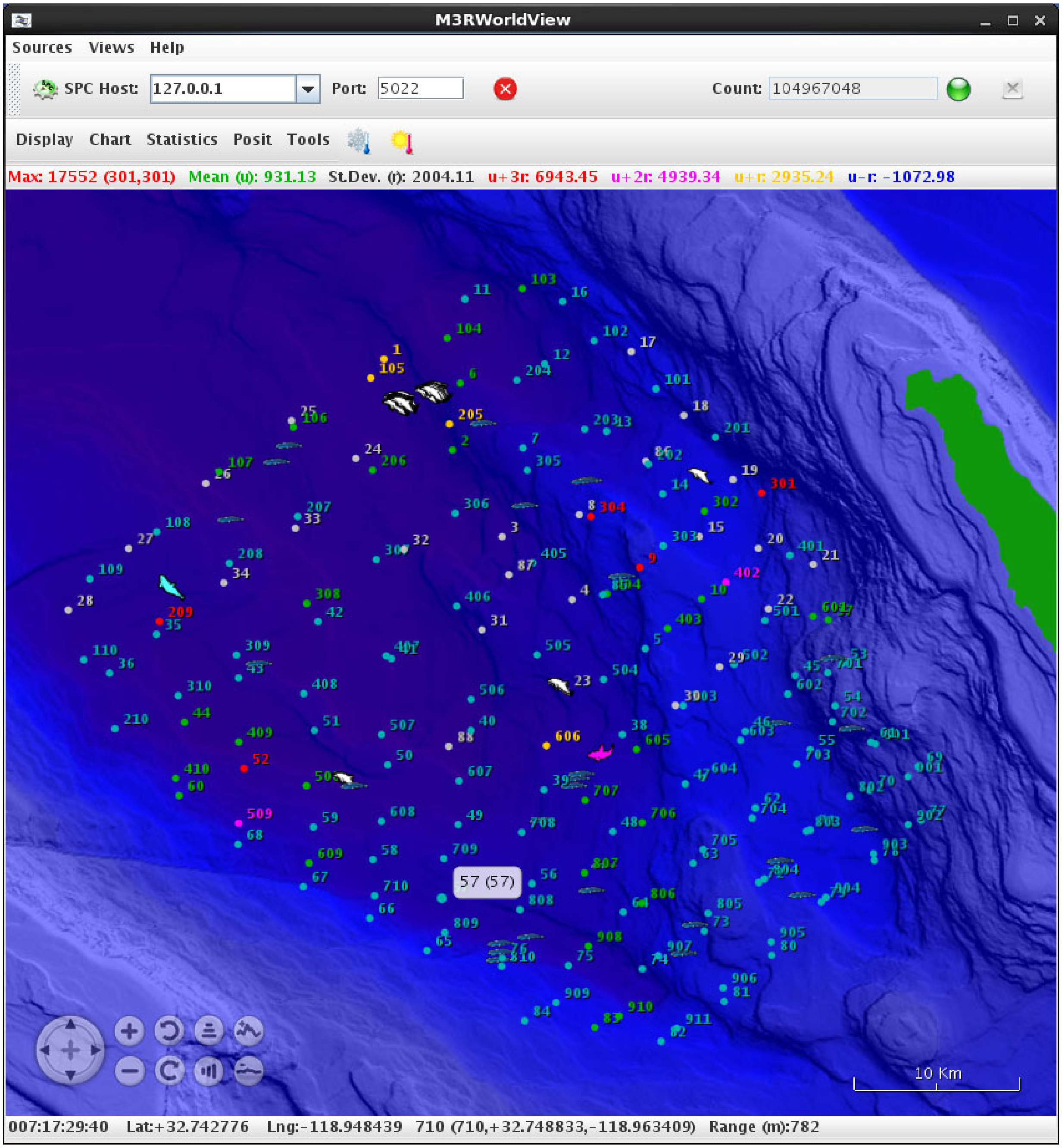


Figure 20. M3R Jacknife display from 7 January 2019 showing some LF posits (dark blue whale icons).

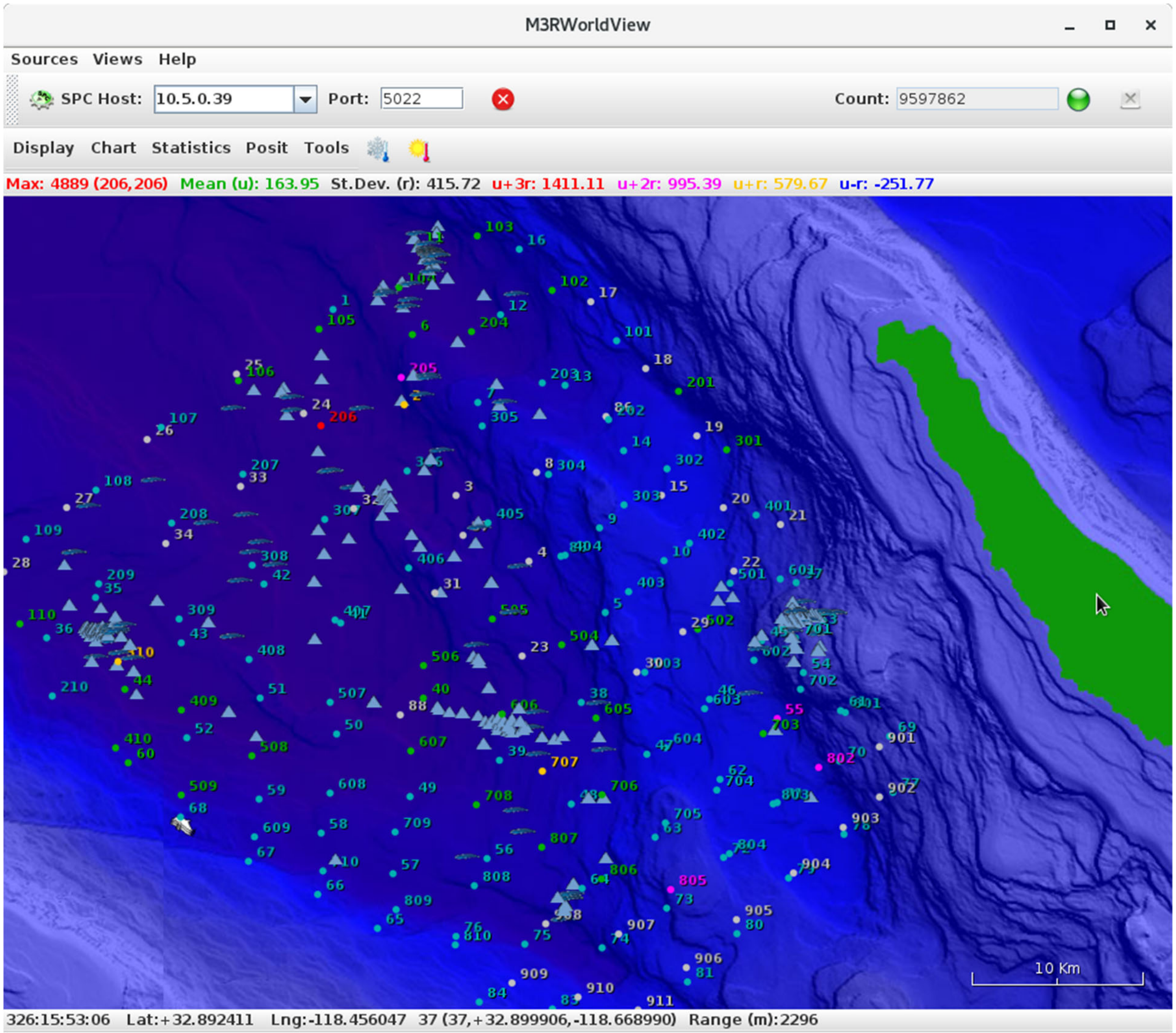


Figure 21. M3R Jacknife display from 22 November 2022 showing many LF posits (dark blue whale icons) growing into tracks over time (blue triangles are older posits) which more clearly indicate speed and direction of travel.

The other modification made this year was to the setting or our LF FFT detector. The LF spectrogram originally had a frequency resolution of 1.46Hz and a time resolution of 170.67 ms. This coarse time resolution resulted in blocky spectrograms which often did not follow call shape well (Figure 22). The 170.67ms time step also can contribute to uncertainty in localization. When the speed of sound is approximately 1500 m/s. Jitter on the order of 170ms can translate to 100-200 of meters of uncertainty in the localization. The new LF FFT settings allow for a frequency resolution of 2.92Hz and a time resolution of 21.33 ms (Figure 23). Spectrograms with these setting are better able to follow the shape of LF calls and the reduced timing uncertainty should improve TDOA estimation and localization accuracy.

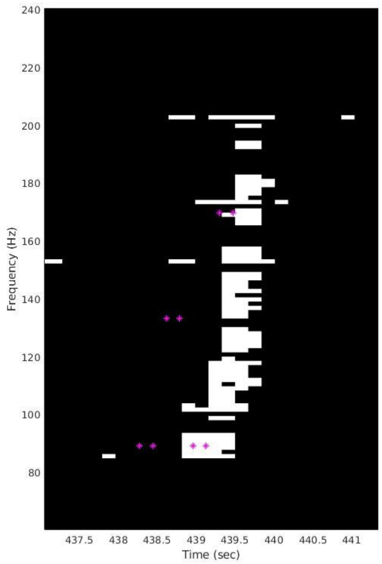


Figure 22. M3R LF hard-limited spectrogram with the original settings (dt = 170.67 ms, df = 1.46Hz). Coarse time resolution produces blocky spectrogram that does not follow up-sweep call well. Pink * are bins where peak magnitude was received.

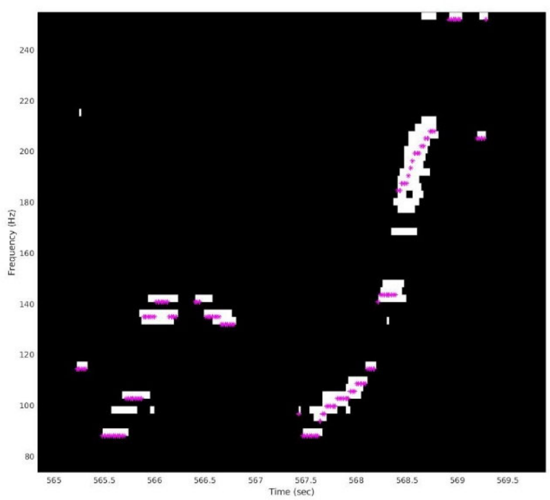


Figure 23. M3R LF hard-limited spectrogram with the new settings (dt = 21.33ms, df = 2.92Hz). Improved time resolution produces spectrogram that readily follows shape of complex call(s). Pink * are bins where peak magnitude was received.

3.3 Conclusion

In this project we implemented changes to M3R LF FFT detector and to the M3R dolphin click associator to correct issues identified during the FY21 review of the accuracy of automatically generated M3R LF localizations at SOAR. The dolphin click train associator was modified to open no more than one analysis window per 50 ms rather than trying to localize every click received on the master hydrophone (there can be several hundred per second). This eliminated the processing overload on the associator nodes at SOAR. As a result, many more LF posits are being displayed creating longer tracks of posits over time. The new associator was delivered in the FY22 builds to SOAR in June 2022, to PMRF in August 2022 and to the Jacksonville Shallow Water Training Range (JSWTR) on the East Coast in December 2022. Additionally, we modified the settings of the LF FFT detector to improve the timing resolution from 170.67ms to 21.33ms. The greater time resolution allows the LF FFT detector to better follow the shape of baleen calls, enabling better identification of species and call type. The improved timing will also improve the estimation of TDOA and should lead to improved accuracy and less scatter in M3R LF localizations. Builds with the new LF FFT settings were deployed to JSWTR in July 2022 and to PMRF in August 2022.

4 Real-time monitoring of on-water tagging operations

4.1 SOAR

Four field surveys were conducted in FY22 on SOAR in coordination with MarEcoTel. Others that were tentatively scheduled were cancelled due to issues with poor weather conditions. The field surveys were conducted in November 2021, and January, March, and June 2022 supporting the photo-ID, biopsy, and tagging of marine mammals. During these field surveys MarEcoTel personnel work from San Clemente Island (SCI), transiting daily at sunrise onto the SOAR range in their Rigid Hull Inflatable Boat (RHIB). M3R personnel use the M3R system to acoustically monitor animals on the range and direct MarEcoTel to their locations. Upon finding animals MarEcoTel would collect photo-ID and behavioral data and biopsy samples, and 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. This effort has been focused primarily on Cuvier's beaked and fin whales, though data on other species have been collected.

M3R personnel work from the Cable Termination Shed (CTS) at San Clemente Island North Island. The system is set up, and broken down and stored, at the beginning and end of each field survey. 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 CS-SVM classifier and FFT detector via a click train viewer display in order to identify relevant species. 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, which assists with species identification. 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 27 lists the marine mammal species acoustically identified using the M3R system during the four field surveys in FY22, along with summary information extracted from the associated SOAR field logs. More detailed information from these field logs can be found in Appendix A.

A total of 355 acoustic detections were logged, including 236+ of Cuvier's beaked whales, 46 of fin whales, 15+ humpback whales, 4+ risso's dolphins, 2 sperm whales, as well as single groups of sei, blue, gray, and killer whales and common dolphins. A rare sighting involved that of short-finned pilot whales which have not been observed in the area for a decade. There were acoustic sightings which were unable to be identified to the species level, including 41+ delphinids, 2 beaked and baleen whales, and a single pinniped. Note that the detections do not necessarily indicate unique groups; in fact, Cuvier's beaked whale sightings often recur in the same area periodically throughout the day, which may indicate a unique foraging group in a particular location. In addition, not all species that are present are logged. In particular, dolphins are always present on the range, particularly in the east, and are not always logged due to species priority and monitoring constraints. In addition, all fins and other baleen whales were not necessarily logged due to the same constraints.

Of these acoustic sightings, there were 45 cases in which M3R directed MarEcoTel to Cuvier's beaked whales and 15 instances of direction to fin whales. Additional posits were logged, and potentially sent to the field team, depending on conditions. Here 'directed' sightings are considered those in which a location was sent and the field team decided to go to the location. MarEcoTel visually verified 26 groups of Cuvier's beaked whales and 11 of fin whales, and collected numerous photos, biopsies and behavioral data from both species. Five Cuvier's beaked whales, and 2 fin whales were successfully tagged. The acoustic sighting of pilot whales was also directed, visually verified, and resulted in the successful deployment of a single tag.

Table 27. Species acoustically identified with the M3R system at SOAR. Data are extracted from field survey logs from four field surveys in FY22. Visual sightings without a corresponding acoustic sighting are noted below the table. Values with a '+' indicate more groups were present but not tracked due to limitations of the real-time monitoring staff.

Species			Acoustic Sightings Logged	Acoustic Sightings Directed	Acoustic Sightings Visually Verified	No. of Tags Deployed
ID	Common Name	Scientific Name				
Zc	Cuvier's beaked whale	*Ziphius cavirostris*	235-236+	45	26	5
Bp	Fin whale	*Balaenoptera physalus*	46	15	11	2
Bb	Sei whale	*Balaenoptera borealis*	1	0	0	0
Bm	Blue whale	*Balaenoptera musculus*	1	0	0	0
Mn	Humpback whale	*Megaptera novaeangliae*	15+	0	0	0
Pm	Sperm whale	*Physeter macrocephalus*	2	0	0	0
Gm	Short-finned pilot whale	*Globicephala macrorhynchus*	1	1	1	1
Gg	Risso's dolphin	*Grampus griseus*	4+	0	0	0
Oo	Killer whale	*Orcinus orca*	1	0	0	0
Dd	Common dolphin	*Delphinus delphinus*	1	0	0	0
Er	Gray whale	*Eschrichtius robustus*	1	0	0	0
UZ	Unidentified beaked whale	Ziphius sp.	2	0	0	0
UD	Unidentified dolphin	Delphinidae sp.	41+	1	0	0
UM	Unidentified baleen whale	Mysticeti sp.	2	0	0	0
UP	Unidentified pinniped	Pinniped sp.	1	0	0	0

Notes: A fin whale (Balaenoptera physalus) was seen near hydrophone 405 on 03/01/2022 at approximately 22:22:56 UTC, though no acoustic sighting was associated with this visual sighting. A humpback whale (*Megaptera novaeangliae*) seen 1.2 nmi SE of hydrophone 209 on 03/02/2022 at approximately 23:59:12 UTC. Several humpbacks were noted as present across the entire range, but due to not being a species of priority, were not acoustically monitored. Field team saw 3-4 humpback whales (Megaptera novaeangliae) near hyd 307 heading SW at 17:15:50 UTC on 11/07/2021. Another humpback whale was seen among 5 Fin whales near hyd 102 on the same day. On 11/11/2021, the field team found 2 Cuvier's beaked whales (Ziphius cavirostris) at 32 56N 119.1.1W at 18:50 UTC between hyds 208 and 308, but no acoustic detection was made.

4.2 PMRF

M3R conducted one field survey in 2022 in conjunction with the Cascadia Research Collective (CRC), from August 16th – 23rd. CRC personnel typically transit from Kikiaola Harbor at sunrise to the PMRF range. During this survey, 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.

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. Unfortunately, the field log files created during this survey were corrupted during transit and are still in the process of being recovered at the time of writing this report. Daily summary emails and separate log notes made during the trip were recovered, allowing the report of the estimated minimums of each marine mammal species acoustically identified by M3R system during the August 2022 field survey (Table 28).

An estimated minimum total number of 118 acoustic detections were logged, including 48 Blainville's beaked whales, one Cuvier's beaked whale, four melon-headed whales, 14 bottlenose dolphins, 13 rough-toothed dolphins, one false killer whale, eight short-finned pilot whales, one striped dolphins, and 28 of unidentified dolphins. Each acoustic detection may represent either a single animal or a group of animals; however, note that each detection is not necessarily a new individual or a new group, as the same animal or group could be detected more than once over the course of the day. In addition, individuals could potentially move between groups. Of the acoustic detections, a minimum of 12 were directed, and a minimum of 10 were visually verified. One satellite tag was placed on a Blainville's beaked whale, two on melon-headed whales, one on a bottlenose dolphin, and three on short-finned pilot whales (Table 28).

Table 28. Species acoustically identified with the M3R system on PMRF during the field survey completed in August of 2022. Data were extracted from summary email and notes from field logs that were recovered from the corrupted hard drive used to transport the data. All data presented are, therefore, estimated reported minimums. Visual sightings without a corresponding acoustic detection are noted below the table.

Species			Acoustic Sightings Logged	Acoustic Sightings Directed	Acoustic Sightings Visually Verified	No. of Tags Deployed
ID	Common Name	Scientific Name				
Md	Blainville's beaked whale	*Mesoplodon densirostris*	48	2	2	1
Zc	Cuvier's beaked whale	*Ziphius cavirostris*	1	0	0	0
Pe	Melon-headed whales	*Peponocephala electra*	4	1	1	2
Tt	Bottlenose dolphin	*Tursiops truncatus*	14	3	2	1
Sb	Rough-toothed dolphins	*Steno bredanensis*	13	3	2	0
Pc	False killer whales	*Pseudorca crassidens*	1	0	0	0
Gm	Short-finned pilot whale	*Globicephala macrorhynchus*	8	2	2	3
Sc	Striped dolphins	*Stenella coeruleoalba*	1	1	1	0
UD	unidentified dolphin	Delphinidae sp.	28	0	0	0

Note: Cascadia encountered Spinner dolphins (*Stenella longirostris*) east of the range on 08/21/2022.

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6 Appendix A: SOAR Field Work Logs

Table 29 through Table 32 show excerpts from the M3R log files from the four field efforts conducted with MarEcoTel in FY22 on SOAR. The excerpts indicate the species acoustically identified and the number of such detections, along with the number of detections to which the RHIB was directed, the number of species detections verified, and the number of tags deployed. Note the detections do not necessarily indicate the number of groups present, as the same group may be re-sighted 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 29. Excerpts from M3R log files from a field effort on SOAR from Nov 6 – 14 2021. An '*' indicates visual sightings occurred without an associated acoustic sighting, details for which can be found at the bottom of the table.

Survey Dates	Hours Monitored	Species	Acoustic Sightings Logged	Sightings Directed	Visually Verified	Tagged	Notes
11/06/2022	9.5	*Zc*	8	1	1	No	Group of 3 at 32.8273 -119.1901 at 15:05 UTC
		Bp	5	3	3	No	2 animals at 33.0393 -118.9125, single at 33.0062 -118.9363 and 33.0841 -118.8818.
		UD	4	0	0	No	Too many to monitor all, and not a species of focus
11/07/2021*	9	*Zc*	7	2	0	No	Group 1 near hyd 106, second near 307. Weather too rough to find them.
		Bp	6	3	2	2	Group of 4 near hyd 307, at 32.9257 -118.9036, one successfully tagged. Group of 5 with one humpback whale mixed in near 102. One Fin also successfully tagged.
		UM	1	0	0	No	On Hyd 407…Field team saw humpback whales SW of 307, so could have been this group.
		UD	4	0	0	No	Too many to monitor all, and not a species of focus
11/08/2021	4	*Zc*	2	0	0	No	Weather too rough. Near hyd 106 and 306.
		Bp	1	0	0	No	Near hyd 205
		UD	2	0	0	No	Too many to monitor all, and not a species of focus
11/09/2021	6	*Zc*	4	1	1	No	Single Zc seen just west of hyd 106.

		Bp	5	2	1	No	Single seen near H306
		Mn	2	0	0	No	Heard on hyds 306 and 106
		UD	3	0	0	No	Heard on hyds 105, 109, and 38.
11/11/2021*	5.5	*Zc*	10	2	2	No	2 animals seen diving near hyd 308 at 18:55 UTC. Group of 3 seen at 21:04UTC, got a tag on one animal, but it broke off the baseplate after deployment.
		Bp	7	2	2	No	Single animal seen at 32.9525 -118.9897 near hyd 207. Single animal seen heading towards hyd 307.
		UD	1	0	0	No	Heard on hyd 308.
11/12/2021	9.5	*Zc*	8	3	3	1	Pair at 32.8668 -119.1028. Group of 4 0.5mi SE of hyd 308. Tag and biopsy taken at 32.550 -118.591.Single animal seen near hyd 307.
		Bp	3	0	0	No	
		Mn	1	0	0	No	
		UD	3	0	0	No	
11/13/2021	9	*Zc*	9	4	3	1	Group of 2 seen at 32.8833 -119.0025. Group of 2 0.7mi NW of 310; tag on both animals but one forcefully removed theirs. Same group of 3 seen on 11th seen near hyd 309 at 32.8795 -119.0289.
		Bp	2	0	0	No	
		Mn	1	0	0	No	
		UD	2	0	0	No	
11/14/2021	8	*Zc*	11	5	4	1	Group of 5 on hyd 104, split into 2 groups at the surface. Pair near 406, possible calf. Group of 4 0.5mi west of hyd 306. Three separate groups of 1-3 animals near hyd 209, one a mom and calf, one animal tagged.
		Mn	1	0	0	No	
		UD	1	0	0	No	

Notes: Field team saw 3-4 humpback whales (*Megaptera novaeangliae*) near hyd 307 heading SW at 17:15:50 UTC on 11/07/2021. Another humpback whale was seen among 5 Fin whales near hyd 102 on the same day. Note the field team only had 4-6 hours of access to the northern portion or SOAR on 11/08-09 2021 due to navy training exercises. Also note, a power outage delayed acoustic monitoring until nearly noon on 11/11/2021. On 11/11/2021, the field team found 2 Cuvier's beaked whales (*Ziphius cavirostris*) at 32 56N 119.1.1W at 18:50 UTC between hyds 208 and 308, but no acoustic detection was made.

Table 30. Excerpts from M3R log files from a field effort on SOAR from Jan 5 – 17 2022.

Survey Dates	Hours Monitored	Species	Acoustic Sightings Logged	Sightings Directed	Visually Verified	Tagged	Notes
1/08/2022	8	*Zc*	29	2	0	No	Posit: 32.724953 -118.935608 @172857 - very good posit, Multiple posits here" 32.723892 -118.936127 @ 172929, more posits here: 32.724998 -118.933098 @ 173934. Gave Brenda this posit
		Bp	3	0	0	No	
		UD	2	0	0	No	
1/09/2022	8	*Zc*	15	2	2	No	Physalus just reported that they picked up a group of 5 animals 0.8 miles NW of last posit that was sent to them.
		Bp	1	0	0	No	Lat:+32.722341 Lng:-118.755524 Depth:278.600 Te:009:16:25:28.527932;; Lat:+32.721565 Lng:-118.767951 Depth:272.310 Te:009:16:25:27.753787, Lat:+32.716965 Lng:-118.752693 Depth:283.960 Te:009:16:34:16.632778
		UM	1	0	0	No	
		UD	4	0	0	No	
1/10/2022	8.5	*Zc*	9	3	0	No	posit: 32.834381 -119.120087 @ 1910, posit: 32.837139 -119.125511 @ 192653
		Bp	2	1	0	No	Lat:+33.048446 Lng:-118.953096 Depth:71.0769 Te:010:16:33:44.161515, Lat:+33.029135 Lng:-118.959282 Depth:70.9396 Te:010:16:57:52.058527, Lat:+33.023491 Lng:-118.959933 Depth:71.3650 Te:010:17:09:57.928653, Phoenix reported they picked up a single fin whale a few hundred meters south of the second to last posit. They are going to stay with the animal and try and get a limpet tag out., 33.017329, -118.960596 Depth:71.9140 Te:010:17:20:43.805771
		Mn	1	0	0	No	
1/11/2022	1	*Zc*	2	0	0	No	

		Bp	1	0	0	No	
1/12/2022	2	*Zc*	4	2	2	No	Phoenix has a single Zc 0.5 miles W of H805.
1/13/2022	2.75	*Zc*	5	1	1	No	Updated posit 32.686977 -118.817818 @ 165025, Physalus reported that Phoenix found a group of 5 animals between 909 and 910.
		Mn	2	0	0	No	
1/14/2022	3.25	*Zc*	20	2	1	1	Posit: 32.713299 -118.755783 @ 191150 & 32.723007 -118.750153 @ 191239, a bunch of posits here 32.719173 -118.736992 @ 191704, Phoenix found 3 animals. Got a limpet tag on one.
		Bp	1	0	0	No	32.725457, -118.854301 Depth:217.984 Te:014:20:12:48.503399
		Mn	1	0	0	No	
11/16/2022	7.5	*Zc*	14	3	3	0	posit: 32.756508 -118.832108 @ 221004, Physalus picked up 2 animals.
		Mn	3	0	0	No	
		UD	2	0	0	No	whistle posit: Lat:+32.691576 Lng:-118.860928 Depth:239.705
1/17/2022	7	*Zc*	23	4	1	1	posits here: 32.861916 -118.779282 @ 230457, 1.5 mi SW of posit. Got 1 tag out. Group of 5.
		Er	1	0	0	No	
		UD	2	1	0	No	

Notes: 11/12 -Phoenix reported that they had a total of 5 encounters with Zc this morning. So great morning but not great that they had to leave the range. Swell was still 9-10' but glassy otherwise. Forecast for tomorrow is not quite as good. 11/15 - Boats not on range today due to weather.

Table 31. Excerpts from M3R log files from a field effort on SOAR from March 1 – 2 2022. Acoustic sighting marked with an ‘X’ indicates a species was acoustically observed on the range, but group number was not tracked. An ‘*’

indicates visual sightings occurred without an associated acoustic sighting, details for which can be found at the bottom of the table.

Survey Dates	Hours Monitored	Species	Acoustic Sightings Logged	Sightings Directed	Visually Verified	Tagged	Notes
03/01/2022*	9.5	*Zc*	10-11	2	0	No	Gr 1 hyd 405, gr 2 at hyd 408 for directed (heard, not seen)
		Bp	1	1	0	No	Between Hyds 308, 307, 407 moving North towards 208
		Bb	1	0	0	No	Hyd 407
		UD	10+	0	0	No	Too many to monitor all, and not a species of focus
		Mn	3+	0	0	No	Too many to monitor all, and not a species of focus
		UZ	1	0	0	No	Possible Bairds beaked whale at Hyd 56,63. Too far south for field team.
03/02/2022*	11	*Zc*	14	2	1	No	Group of 4 1.4 nmi NW of Hyd 110 at 1125 local. Got photos for ID.
		Bp	1	0	0	No	Hyd 809, Too far south for field team.
		Gm	1	1	0	No	Hyds 308.
		Pm	1	0	0	No	Hyds 103 and 16 (off range), single individual
		Gg	4+	0	0	No	Too many to monitor all, and not a species of focus
		Mn	X	NA	NA	NA	Too many to monitor all, and not a species of focus
		UZ	1	0	0	No	Too far south again for field team to check out. Hyd 55 and 703. Hard freq limit at 40Hz for EC, ICI 0.34. Possible Bairds?
		UM	1	0	0	No	Interesting vocals on hyd 305 at 2345 UTC, 3kHz gunshot like
		UD	4+	0	0	0	Too many to monitor all, and not a species of focus

Notes: Field team was limited to the northern portion of the range only for monitoring. A fin whale (*Balaenoptera physalus*) was seen near hyd 405 on 03/01/2022 at approximately 22:22:56 UTC, though no acoustic sighting was associated with this visual sighting. Note that monitoring efforts were cut short to an unexpected severe storm that rolled into the area. Multiple humpback whales (*Megaptera novaeangliae*) seen 1.2 nmi SE of hydrophone 209 on 03/02/2022 at approximately 23:59:12 UTC.

Table 32. Excerpts from M3R log files from a field effort on SOAR from Jun 9 – 20 2022.

Survey Dates	Hours Monitored	Species	Acoustic Sightings	Sightings Directed	Visually Verified	Tagged	Notes
6/10/2022	9	*Zc*	3	0	0	No	
		Bp	1	1	0	No	LF posits, screenshots
		Lf	1	1	0	No	
6/11/2022	8	*Zc*	12	2	0	No	Strong on H908
		Bp	2	2	1	No	Found 3 adults and calf at posit following to south. Got one biopsy so far
		Seal	1	0	0	No	Sounds like seal barks in Raven, moving North
		UD	1	0	0	No	
6/12/2022	8	*Zc*	5	0	1	No	Phoenix reports 3 Ziiphius about 1 mile north of 207 on surface just went down. Don't hear yet
		Bp	3	0	1	No	Phoenix came across a fin while working the Zc group, No calls visible on 207
		Lf	1	0	0	No	New posit 32.8397; -119.0937 for 17:14UTC
		O. Orca	1	0	0	No	
6/15/2022	6	*Zc*	8	2	0	No	posit at 1509: 32.801098;- -119.039650 - pulse duration suggests Zc as well as vocal time period
		Bp	1	0	1	No	Fin whale found at Zc posit given biopsy and photos were taken
		Bm	1	0	0	No	Large number of low frequency posits. likely blue whale due to down sweeps 100-40 Hz
		Lf	1	0	0	No	
		Dd	1	0	0	No	
		Ud	3	0	0	No	
6/16/2022	8	*Zc*	5	0	0	No	posit at 1509: 32.801098; -119.039650, pulse duration suggests Zc as well as vocal time period
		Pm	1	0	0	No	taking screenshots and recordings
		UD	3	0	0	No	

Notes: Bad weather mixed throughout the trip limited monitoring day to just the ones presented in the table above.