CUVIER'S BEAKED WHALE AND FIN WHALE SURVEYS AT THE SOUTHERN CALIFORNIA OFFSHORE ANTI-SUBMARINE WARFARE RANGE (SOAR)

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14. ABSTRACT
The Southern California Range Complex (SOCAL) is one of the United States (US) Navy's most active training areas, particularly concerning the use of mid-frequency active sonar (MFAS). Much of SOCAL lies within the Southern California Bight, a productive oceanographic region that hosts a wide variety of marine species. As part of an ongoing study of the distribution and demographics of several marine mammal species within SOCAL, we conducted 11 days of survey effort from 4 January 2020 to 8 October 2020, specifically focusing on the Southern California Anti-submarine Warfare Range (SOAR). The primary goal of these surveys was sighting, photographing, and collecting biopsy samples from Cuvier's beaked whales and fin whales. With combined effort from ancillary projects funded by the US Navy's Living Marine Resources (LMR) program, we had 36 sightings of cetaceans, including six sightings totaling 15 Cuvier's beaked whales and five sightings totaling 10 fin whales. Reconciliation of identification photographs from these sightings and four whales photographed opportunistically outside of SOAR yielded 10 unique Cuvier's beaked whales in 2020; four of these whales were previously identified at SOAR, with sighting histories of up to 11 years. This included one mother-calf pair that remained associated 2.5 years after their first sighting together. We processed 268 fin whale identifications, with 39 from Navy-funded research in 2019 and the remainder from opportunistic contributions in 2019 or before. These represented sightings of 105 unique individuals, 97 of which were identified in 2019 on an average of 1.74 days each. Thirty-nine fin whales identified in 2019 (40%) had been sighted in a previous year. Three genetic samples were collected, including one from a Cuvier's beaked whale and two from fin whales. There were eight environmental DNA (eDNA) samples collected during Cuvier's sightings for an ancillary project funded by the Office of Naval Research in

collaboration with Oregon State University, but which may provide key data for monitoring efforts. One SMRT tag was deployed on a Cuvier's beaked whale during an ancillary effort.
Labor originally intended to support 2020 data processing was partially re-tasked (in consultation with the Navy) to analyses of previously collected data, given the limited data collected this year. These included an assessment of movements and diving behavior in Risso's dolphins in Southern California, which found that dives were deepest at night, and increased in depth during full moons and with increasing chlorophyll-a concentrations. Dive durations were longest and shortest around the first and third quarter moons, respectively. Movement models indicated that lunar phase, time of day, and month influence inshore/offshore movements. We also re-analyzed previously published diving data from Cuvier's beaked whales exposed to MFAS from 2011-2015 to better characterize the effects of exposure after MFAS use has ceased using an alternate approach to that presented in Schorr et al. (2020), which assessed response duration using a single behavioral metric (time between deep dives). Here, we used Mahalanobis distance to characterize behavior patterns using a suite of variables, and modeled behavior as a function of the previous exposure parameters. We found that some exposure contexts produced changes in behavior that persisted for up to several days after sonar use ceased.

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Abstract

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Labor originally intended to support 2020 data processing was partially re-tasked (in consultation with the Navy) to analyses of previously collected data, given the limited data collected this year. These included an assessment of movements and diving behavior in Risso's dolphins in Southern California, which found that dives were deepest at night, and increased in depth during full moons and with increasing chlorophyll-*a* concentrations. Dive durations were longest and shortest around the first and third quarter moons, respectively. Movement models indicated that lunar phase, time of day, and month influence inshore/offshore movements. We also re-analyzed previously published diving data from Cuvier's beaked whales exposed to MFAS from 2011-2015 to better characterize the effects of exposure after MFAS use has ceased using an alternate approach to that presented in Schorr et al. (2020), which assessed response duration using a single behavioral metric (time between deep dives). Here, we used Mahalanobis distance to characterize behavior patterns using a suite of variables, and modeled behavior as a function of the previous exposure parameters. We found that some exposure contexts produced changes in behavior that persisted for up to several days after sonar use ceased.

Introduction

The United States (US) Navy manages the Southern California Range Complex (SOCAL) a collection of nearshore and offshore training areas that include much of the navigable water from Santa Barbara Island, California (CA), to northern Baja California, Mexico, and extending several hundred miles to the west. It is among one of the most heavily used tactical training areas in the world, and is used for a variety of aerial, surface, and subsurface exercises. The Southern California Offshore Range (SCORE) is a subset of complexes within SOCAL centered on San Clemente Island and managed via the Range Operation Center (ROC) on North Island, Coronado. It includes the Southern California Anti-submarine Warfare Range (SOAR), a focal area for exercises involving mid-frequency active sonar (MFAS) systems within the San Nicolas Basin (Figure 1).

Through its N45 Living Marine Resources (LMR) research programs, and more recently in support of Pacific Fleet Monitoring efforts, the US Navy has funded directed studies on cetacean occurrence. These efforts have included demographic assessments, foraging ecology, and behavioral responses to MFAS for several key species. Initially, the primary objective of these surveys was visual verification of acoustic marine mammal detections on the SOAR hydrophone array in conjunction with the Marine Mammal Monitoring on Navy Ranges (M3R) program bv . These studies documented generally high cetacean diversity on SOAR year-round, with some seasonal fluctuations (Falcone & Schorr 2014). Photo-ID studies of both Cuvier's beaked whales and fin whales were initiated to better understand the structure of these poorly known populations. As the surveys progressed, a major goal became the deployment of dive-reporting satellite tags to study both the distribution and diving behavior of both these species, and to assess any changes associated with MFAS use.

This report summarizes ongoing data collection in support of these same objectives. While this report specifically covers surveys and analyses conducted in support of the Navy's Integrated Comprehensive Monitoring Program (ICMP, henceforth "Fleet monitoring") in 2020, it also includes ancillary data from a concurrent LMR-funded project. Survey effort from these projects is summarized separately; however, resulting sighting and photo-ID data are combined here. The COVID-19 pandemic and associated travel restrictions severely impacted data collection from all projects in 2020. Some funds were re-allocated from fieldwork to support additional analyses of previously collected data, the preliminary results of which are also included.

Both satellite tagging and photo-ID data from these studies have indicated individual site fidelity to the Southern California Bight for several species, including Cuvier's beaked whales on SOAR and fin whales in the greater Southern California Bight (Falcone et al., 2009, 2017; Scales et al., 2017; Schorr et al., 2014). Both findings were somewhat unexpected. Fin whales were believed to range broadly along the US West Coast with no population substructure. Virtually no information was available on stock structure of Cuvier's beaked whales, and individual Cuvier's beaked whale were not expected to preferentially use SOAR, as this species has been most frequently recorded in mass strandings associated with MFAS elsewhere (Bernaldo de Quirós et al., 2019; Cox et al., 2006; D'Amico et al., 2009). Despite a preference for the region by at least some individuals in the population, sensitivity to MFAS has been documented (DeRuiter et al., 2013; Falcone et al., 2017). Therefore, understanding the ecology, behavior, and population dynamics of these two populations in a region of such intense Navy training remains critical to effective management, including realistic estimation of takes.

The first of these was an analysis of movements and diving behavior of tagged Risso's dolphins. Risso's dolphins are commonly encountered within the SOCAL complex, but little is known about their distribution and behavior in the area. Smultea and Jefferson (2014) suggest a increase in prevalence in Risso's within the bight since the 1960's, with Risso's dolphins comprising the second most commonly seen cetacean during their surveys (Jefferson et al., 2014). However, movements of individuals throughout the bight using telemetry has not been reported. Several short-duration tags have been deployed on Risso's dolphins, but diving behavior over the course of days has not previously been assessed (Arranz et al., 2016).

The second analysis of previously collected data concerned the persistence of behavioral responses to sonar in Cuvier's beaked whales after exposure ceases. A similar analysis was included in our 2019 report; however, upon further consideration we felt an alternate analytical approach might provide additional insights given the complexity of both the behavioral and exposure data involved. Our 2019 report focused specifically on the interval between deep dives (IDDI, considered a proxy for foraging rate in this species), following an exposed IDDI. It confirmed the published findings (Falcone et al., 2017) that exposed IDDIs increase in duration as distance to an active source decreases, and also found a weak signal that IDDI may actually decrease for several dive cycles after an exposure. Post-exposure behavioral patterns may deviate in a variety of ways (e.g. changes in surface time; dive depths, durations, and frequency), and specific sonar use parameters may be mediating these changes in predictable ways. Thus, we took a more holistic approach to the question with this analysis, and used Mahalanobis distance (as was done in (DeRuiter et al., 2013)) to characterize multi-variate behavior patterns during exposed, post-exposure, and baseline deep dive cycles, and then modeled the changes in Mahalanobis distance over time as a function of the previous period of sonar use. The goal of this approach is to identify the time it takes for overall behavior patterns to return to a baseline range following a sonar response and identify any salient characteristics of sonar use that mediate it.

Navy Benefits

The primary focus of these surveys is to support long-term studies using photo-identification and genetics to elucidate population size, structure, and trends, which can in turn provide a particularly robust basis for assessing population-level impacts of Navy training. Demographic data, including the age-sex class structure of the population, often provide insights into cumulative impacts on long-lived species that might not show up in acoustic or visual density data (e.g., Whitehead & Gero 2015).

A recent Office of Naval Research (ONR)-supported analysis (Moore et al., 2017) determined that long-term photo-identification provided the best power to detect an actual decline in the Cuvier's beaked whale population at SOAR if one were occurring, and Booth et al. (2017) suggest photo-identification and biopsy are critical tools for accurately monitoring population health. Most recently, simulations by Curtis et al., 2020 show the probability of detecting abundance changes is currently low but will greatly improve through continued monitoring and increased effort. Further, there are specific inputs to Population Consequences of Disturbance (PCoD) models, currently being developed for beaked whales at SOAR and other Navy ranges, which can only be derived from the individual life history data this research program supports.

The continued deployment of satellite tags on species of interest within the SCORE region allows for long-term assessment of habitat use and changes over time.

Methods

Field Data Collection

Surveys were conducted using a 7.5m rigid-hulled inflatable boat (RHIB), powered by two outboard motors and equipped with a raised bow pulpit. The RHIB was launched from a shore base each morning and surveyed throughout daylight hours as conditions permitted. Surveys focused on SOAR were based at Wilson Cove on the northeast side of San Clemente Island. The RHIB was initially launched at Dana Point or Oceanside at the start of the survey period and remained moored in Wilson Cove for a period of 7-14 days, or until poor weather or conflicting range operations prevented further surveys at SOAR. When SOAR was available for our use, staff from the Naval Undersea Warfare Center's (NUWC) M3R program would monitor hydrophones from the ROC on North Island in San Diego and direct the RHIB via radio or satellite phone into areas where marine mammal vocalizations were detected. While the RHIB could be directed towards any vocalizations for visual verification, they were preferentially directed to those likely to be beaked whales when conditions were suitable for working with these species (typically winds at Beaufort 3 or less). In general, detections classified as other small odontocetes were bypassed in favor of those from beaked or baleen whales.

Effort and sighting data were collected using a custom-built MS Access (Microsoft, Redmond, WA) database on a ruggedized tablet with an integrated Global Positioning System (GPS). Each time a group of cetaceans was encountered, the species, time, latitude, longitude, group size and composition, and overall behavioral state were recorded.

For encounters with beaked whales, detailed records of surfacing patterns were also collected for as long as contact with the group was maintained. Photographs were taken for species verification when questionable, and for individual identification of species where this methodology is being employed by ourselves or collaborators (beaked, fin, blue, humpback, minke, and killer whales; bottlenose and Risso's dolphins). Remote tissue biopsies were collected from species of interest both to this study (beaked and fin whales) and on behalf of collaborators at the Southwest Fisheries Science Center (SWFSC) for use in ongoing assessments of population structure and stress hormone analyses. Additionally, a limited number of satellite tags were deployed on species which regularly inhabit the training range, and which may be impacted by training activities to provide additional information on distribution, behavior, and overlap with Navy activities.

Photo-ID

All photos collected during surveys were reviewed, and image metadata were updated with basic sighting and individual information using ACDSee Pro image management software. Best-of-sighting identification photographs of fin whales and beaked whales were internally reconciled across annual sightings and compared to existing photo-ID catalogs curated by MarEcoTel using methods described in Falcone and Schorr (2014) to build photographic sighting histories.

Analyses of previously collected tag data

Risso's dolphin movements and diving behavior

As part of this long-term monitoring effort on cetaceans in the Southern California Bight (SCB), 16 Argos-linked satellite tags were deployed on Risso's dolphins between 2009 and 2019 (Schorr et al., 2020). Diving behaviors and inshore/offshore movements were analyzed with generalized linear mixed models fit as gamma distributions with log-link functions using the maximum likelihood parameter estimation method from the *glmmTMB* package (Brooks, ME et al., 2017) in R. We modeled dive depth and duration as a function of time of day, sine and cosine of lunar phase (deBruyn and Meeuwigg, 2001), distance to shore, sea surface temperature (SST), and regression residuals of log chlorophyll-*a* over SST. To assess inshore/offshore movement patterns, we used the locations from all tags in this study to model both distance to nearest shore (km) and the distance to the mainland coast (km) as a function of time of day, sine and cosine of lunar phase, and month.

To account for differences between individuals, we included a random effect of the tagged individual in all models. Inspection of a plot of the residual autocorrelation function indicated that this random effect did not sufficiently reduce temporal residual autocorrelation. Thus, we incorporated secondary, nested random effects of different time increments (1, 2, 3, 4, 6, 8, and 12 h) within individuals, selecting the time period that minimized Akaike's information criterion (AIC) for each model. After determining the nested effect that minimized AIC, separate models were created for each possible combination of lunar phase predictors (no lunar phase predictors, only cosine, only sine, both cosine and sine), and the model that minimized AIC was chosen as the best-fit model that most accurately described the lunar phase shift.

Model predictor significance was determined using a Type II Wald Chi-Square Test ($\alpha < 0.05$) using the Anova function from the car R package (Fox, John, 2019). Model predictions were created for the average individual by setting all random effects to zero using the predict.glmmTMB function from the glmmTMB package (Brooks, ME et al., 2017) in R. Prediction plots were created to display the effects of each significant predictor on the response variables using the R packages, ggplot2 and ggformula (Kaplan and Pruim, 2020; Wickham, 2016). For these plots, as stated in each figure's caption, the values for other predictors in each model were fixed at the median (continuous variables) or modal value (categorical variables).

Duration of response to sonar by Cuvier's beaked whales

Using the same behavior and sonar use data as Falcone et al. (2017), we calculated Mahalanobis distances (MDs) to quantify the extent to which behaviors within each deep dive cycle—consisting of a deep dive and subsequent inter-deep dive interval (IDDI)—differed from 'baseline' behaviors recorded during an extended period without sonar use. We then assessed how long it takes whales to return to 'baseline' behaviors after exposure to MFAS. A detailed summary of methods for creating the behavioral and sonar datasets analyzed here are provided in Schorr et al. (2014) and Falcone et al. (2017). For the purposes of this analysis, deep dive cycles were considered "exposed" if high- or mid-power MFAS was used within 100 km of the whale's location at any point between the start one deep dive and the start of the one that followed it, following response characteristics described in Falcone et al. (2017).

All sonar use within 100 km of a tag during a deep dive cycle was summarized into "sonar exposure events"; periods of sonar use that spanned consecutive deep dive cycles were considered a single sonar exposure event. Because sonar exposure events were bounded by behavioral patterns of the whale, when sonar use coincided with tag data gaps (periods of behavior data that were not successfully received), adjacent sonar bouts were combined into the same sonar exposure event until a period of at least 234.5 minutes (the average exposed deep dive cycle duration) with no sonar use had elapsed. The following sonar exposure variables were calculated for each post-exposure deep dive cycle based on the preceding sonar exposure event: sonar type (high-power, mid-power, or both), total transmission duration (defined as the number of minutes during which one or more sources were in use), closest source distance, number of individual sonar bouts within the exposure event, the duration of sonar silence between the start of the previous exposure event and the end of the one before it, and the number of days since the end of the previous exposure event. Prior to modeling, all continuous sonar-related variables were mean-centered and scaled by the standard deviation for all sonar events of each type.

Squared MDs were calculated using the mahalanobis function in R (R Core Team, 2019) for each deep dive cycle using the variables deep dive duration, deep dive depth, total shallow dive duration, total surface duration, and the number of shallow dives within each deep dive cycle. Deep dive cycles that occurred prior to the first sonar exposure event for tags deployed in January were used to calculate baseline distribution centers and the baseline covariance matrix, because sonar use is limited or absent at SOAR from the December holidays and through a scheduled maintenance period that follows in early January (e.g. Hildebrand et al., 2010). No SPORTS reports were documented, and real-time monitoring of SOAR hydrophones in the days before tag deployments (range = 1-8 days across all January tags) further confirmed the lack of sonar use in the preceding days or weeks. To improve homoscedasticity of model residuals, the square root of the squared MDs was used in all analyses.

Mahalanobis distances for all post-exposure deep dive cycles were modeled using generalized additive models from the *mgcv* R package (R Core Team, 2019; Wood, 2011) to predict the extent to which unexposed deep dive cycles following sonar exposure events vary from baseline behaviors over time. The post-exposure model data was limited to deep dive cycles that occurred within 6 days of prior MFAS use, as the heavy operational tempo at SOAR limited sample sizes of behavior preceded by more than six MFAS-free days in a row (Figure 2). Deep dive cycles following sonar exposure events containing both high- and mid-power MFAS were also excluded due to limited sample size (n = 79) and interpretability concerns. The model was fit as gamma distributions with log link functions, with smoothing parameter estimation via maximum likelihood, and with an additional penalty on smooth terms ("gam" function input select = TRUE). The model included three categorical predictors from the original 2017 analysis: time of day, ocean basin, and tagged whale sex. The model included a smooth term for the number of days since the end of the previous exposure event fit using shrinkage cubic regression splines with basis dimension 5 and three tensor product interactions (cubic regression splines with basis dimension 3) between the number of days since sonar ended and the closest source distance, duration of sonar silence before the exposure event, and either total time sonar was used or the number of sonar bouts within the exposure event (see below). Different smooths and tensor product interactions were generated for each sonar type (s and te function input by = SonarType). Finally, a random effect term of group ID was included in the model to account for differences between whales while also accounting for synchronous behavior in groups. Tagged whales were assigned the same group ID if two of either the deep dive start times, end times, or deep dive cycle end times were within one minute of each other.

The number of sonar bouts within the exposure event and total time sonar was used are correlated as they both describe the amount of sonar that occurred during the exposure event, so a separate model was created for each and Akaike's information criteria (AIC) was used to determine which predictor describing the amount of sonar used created the best fit of the data. AIC comparison revealed that the predictor for the number of individual bouts within the exposure event produced a better fit of the observed data than the sonar duration predictor. Consequently, all model results presented are from the model containing the predictor for the number of individual bouts within the exposure event.

Significance of model predictors was determined by analysis of variance ($\alpha < 0.05$) using the anova.gam function in the *mgcv* R package (R Core Team, 2019; Wood, 2011). Model predictions were made for the average group ID using the predict.gam function in the *mgcv* R package (R Core Team, 2019; Wood, 2011). All figures were created using the *ggformula* R package (Kaplan and Pruim, 2020) or the vis.gam function from the *mgcv* R package (R Core Team, 2019; Wood, 2011).

Results and discussion

Survey effort and sightings

Our original 2020 survey schedule included trips in January, March, May, October, and December (under years 1 and 2 of the contract). However, federal and state guidelines and travel restrictions during the COVID-19 pandemic led to the cancellation of most efforts. A total of 11 on-water surveys were conducted for this project in January and October, with most survey effort occurring within SOAR (Table 1). One survey day in January and five field days in October were cancelled due to inclement weather. To ensure safe offshore operations after nine months in storage, we dedicated three days in October to thorough maintenance and field testing of equipment, including the RHIB.

Two additional survey days in January were conducted for an ancillary project (

Figure 2). The percentage of time by project within Navy range boundaries are presented in Table 3. During all survey effort in the region in 2020, 36 sightings of eight cetacean species were recorded (Figure 3, Table 1, Appendix 1). Cuvier's beaked whales were sighted in the deep waters of the San Nicolas Basin to the west of San Clemente Island in January only (Table 4, Figure 4,

Figure 5).

Fin whales were also sighted west of San Clemente Island, primarily along the western boundary, in October, though they were not sighted in January (Figure *4*, Figure 5, Figure 6, Table 5).

Table 1**.** Summary of Fleet Monitoring survey effort by day, January-October 2020, with associated data collection details.

Date	Vessels	Survey Effort (Hrs)	Survey Dist (nm)	Total Sightings	Biopsies	eDNA	Tags
1/4/2020	1	10.7	92	3	0	6	0
1/7/2020	1	8.2	68.8	3	0	0	0
1/8/2020	1	2.8	52.3	2	0	0	0
9/30/2020	1	.8	5	0	0	0	0
10/2/2020	1	3.5	61.4	5	0	0	0
10/3/2020	1	10.7	91.4	4	0	0	0
10/4/2020	1	11.5	80	5	0	0	0
10/5/2020	1	10.9	87.5	3	0	0	0
10/6/2020	1	9.3	68.1	1	0	0	0
10/7/2020	1	11.1	90.6	4	2	0	0
10/8/2020	1	3.1	60.3	0	0	0	0
Totals: 11		**82.6**	**757.4**	**30**	**2**	**6**	**0**

Table 2**.** Summary of ancillary survey effort by day in January 2020 with associated data collection details.

Date	Vessels	Survey Effort (Hrs)	Survey Dist (nm)	Total Sightings	Biopsies	eDNA	Tags
1/3/2020	1	5.3	71.3	4	0	0	0
1/6/2020	1	10.1	89.8	2	1	2	1
Totals: 2		**15.4**	**119.8**	**6**	**1**	**2**	**1**

Table 3**.** Percentage of effort spent within US Navy range boundaries.

	Pt. Mugu Sea Range	**SoCal Range Complex**	**SOAR**
Fleet Monitoring	0%	98%	75%
Ancillary	0%	98%	55%

Table 4**.** Details of Cuvier's beaked whale sightings in 2020.

*indicates surveys conducted under funding from LMR

Date	**Sighting**	**Est. Group Size**	**Num Calves**	**Unique IDs**	**Biopsies Collected**	**Tags Deployed***
1/4/2020	PHO-2	2	0	0	0	0
1/4/2020	PHO-3	3	0	3	0	0
1/6/2020*	PHO-1	3	1	3	1	1
1/6/2020*	PHO-2	3	0	1	0	0
1/7/2020	PHO-3	1	0	0	0	0
1/7/2020	PHO-2	3	1	3	0	0
Total: 6		**15**	**2**	**10**	**1**	**1**

Table 5**.** Details of fin whale sightings in 2020.

Date	**Sighting**	**Est. Group Size**	**Num Calves**	**Est. IDs**	**Biopsies Collected**	**Tags Deployed**
10/4/2020	PHO-3	2	1	2	0	0
10/4/2020	PHO-4	1	0	1	2	0
10/7/2020	PHO-3	2	0	2	0	0
10/7/2020	PHO-1	2	0	1	0	0
10/7/2020	PHO-2	3	0	2	2	0
Total: 5		**10**	**1**	**8**	**2**	**0**

Photo-Identification and biopsy sampling

Cuvier's beaked whales

Cuvier's beaked whales were encountered only during the January field effort although animals were acoustically detected on range by M3R during the October effort. In the 98 hours of combined effort, 6 sightings totaling 15 whales were made, for an overall average of one sighting per 16.3 hours of effort. Median group size was three, with a range of one to three individuals. Photo-IDs and biopsy samples collected during all efforts are summarized in (Table *4*, Table *6*).

All identification photos of Cuvier's beaked whales collected in Southern California in 2020 were internally reconciled and compared to our historical catalog. This included 10 identifications during surveys at SOAR and four opportunistic identifications made by whale watch boats off the coast of San Diego. These identifications represented 10 unique individuals, three of which were sighted together on two subsequent days. Four (40%) of these ten individuals had been sighted in Southern California in a previous year, with sighting histories ranging from 2.5 to 11.2 years in length (Table 6).

There were two sightings of a single mother-calf pair in 2020. This mother (ID 218) was first sighted in July 2017 with a very young calf (ID 221). She has been sighted each year since, always with a calf or juvenile in attendance. While image quality and indistinctiveness made confident calf identification between sightings a challenge, the growth over time, persistent association with ID 218, and consistent shape of the dorsal fin suggest ID 221 remained associated with its mother for 2.5 years as of their last sighting. While our low resighting rates limit our ability to characterize weaning times, this is well below our longest documented mother-calf association of 4.5 years and continues to suggest a prolonged period of maternal care may be common in this population.

In addition to a single biopsy sample, we collected eight eDNA water samples from the footprints of Cuvier's beaked whales at SOAR in 2020. These samples are collected on behalf of Oregon State University, where collaborators are developing this alternate method for collecting DNA samples from whales. To date, we have collected 84 eDNA samples, and as this technique is refined it may significantly augment our sample collection capacity in the future.

A manuscript titled "Abundance, survival, and annual rate of change in Cuvier's beaked whales (*Ziphius cavirostris*) on a Navy sonar range" by K. Alexandra Curtis et al. was published in the journal *Marine Mammal Science* in 2020. This manuscript, which expands upon the power analysis performed under a previous ONR award (Moore et al., 2017) incorporated our Cuvier's photo-ID data from M3R surveys at SOAR through 2018 to provide the first robust estimates of these key demographic rates for this population.

Table 6**.** Summarized sighting histories for 10 individual Cuvier's beaked whales identified in 2020.

ID	First Sighting	Last Sighting	Encounters	Year Span
56	10/24/2008	1/4/2020	5	11.2
152	1/7/2014	1/7/2020	6	6
218	7/24/2017	1/7/2020	6	2.5
221	7/24/2017	1/7/2020	6	2.5
286	1/4/2020	1/4/2020	1	0
287	1/4/2020	1/4/2020	1	0
288	2/19/2020	2/19/2020	1	0
289	6/11/2020	6/11/2020	1	0
290	6/11/2020	6/11/2020	1	0
291	6/11/2020	6/11/2020	1	0

Fin whales

Fin whales were sighted in SOAR in 2020, as whales continue to move back into the Southern California Bight after a marked decrease during the El Niño conditions of 2016-2017. Our photo-ID studies of this wide-ranging species are heavily augmented by contributions from citizen scientists and collaborating researchers. These contributions can be large, and we often receive them well into the year after the photos were collected; therefore, this report contains results of fin whale photographs from 2019 that were processed in 2020.

We processed 268 total fin whale identifications from 2019 (n =253) and previous years (n = 15) into our archive in 2020, bringing the total number of fin whale identifications in our collection to 3,952 as of the end of that year. The sample processed this year included 39 whales photographed by MarEcoTel during surveys supported by Fleet Monitoring and related efforts, 26 photographed by collaborating research groups (Cascadia Research, SWFSC), and the remainder by citizen scientists, including large contributions from the Aquarium of the Pacific (n = 92) and HappyWhale (n = 42).

All identifications were internally reconciled and compared to the historical fin whale catalog; 70 (26.1%) were not found in the historical catalog and of insufficient quality to constitute a new ID. The remaining 198 identifications represented 105 unique individuals, 97 of which were sighted in 2019. These whales were identified on an average of 1.74 days each that year (range 1-10 days). For the 26 individuals sighted on more than one day in 2019, the average span from first to last annual sighting was 65 days (range 1-204 d). Thirty-nine (40%) of the 97 whales identified in 2019 had been seen in a previous year, with sightings in 4.4 different years on average (range 2-11 years). These sightings spanned an average 6.5 years from first to last date (range 0.5-15.8 years) (Table *7***.** Summarized annual sightings histories for fin whales sighted in 2019 and any previous year.).

Southern California remains the focal region for our fin whale photo-ID study, with a catalog now totaling 746 individuals that have been identified there since the late 1980s. While extra-regional sampling remains more limited, these collections are also growing, and our US West Coast catalog now includes 133 individuals sighted off Central California, 176 individuals sighted between Northern California and the US-Canada border, and a smaller number of individuals seen off northern Mexico and Southern British Columbia. A manuscript is currently in the final stages of preparation, using movements of individual fin whales to characterize population level residency and interchange within and among these regions, which are currently managed as a single stock.

Two biopsy samples were collected from fin whales in 2020, bringing the total number of fin whale samples collected by MarEcoTel since 2016 to 29. Fin whale samples have been collected throughout other research by us and collaborators for many years, and to date 115 whales in our catalog have had at least one tissue sample collected. Eighty-six individuals in the catalog have been genetically sexed to date (39 female and 47 male). While still limited relative to the current estimated abundance of this stock (9,029 individuals along the contiguous US out to 300 nmi) (Nadeem et al., 2016),this growing sample may support preliminary assessments of sex-biased movements. All fin whale samples from this project are archived for use at SWFSC and have been used in a variety of population level genetic assessments in recent years, e.g (Archer et al., 2020, 2019, 2013).

Table 7**.** Summarized annual sightings histories for fin whales sighted in 2019 and any previous year.

ID	Years Sighted	First Year	Last Year	Year Span
4	2	2006	2019	13
11	2	2007	2019	12
85	6	2003	2019	16
151	2	2006	2019	13
291	6	2009	2019	10
304	6	2009	2019	10
323	8	2009	2019	10
326	9	2009	2019	10
353	10	2010	2019	9
354	11	2009	2019	10
356	4	2009	2019	10
368	8	2010	2019	9
387	5	2010	2019	9
398	5	2010	2019	9
429	4	2011	2019	8
456	7	2012	2019	7
460	4	2012	2019	7
511	6	2012	2019	7
512	8	2012	2019	7
546	5	2012	2019	7
552	3	2013	2019	6
587	5	2013	2019	6
598	6	2013	2019	6
623	2	2013	2019	6
630	6	2013	2019	6
791	3	2015	2019	4
796	3	2015	2019	4
896	2	2014	2019	5
915	2	2015	2019	4
918	4	2015	2019	4
958	2	2016	2019	3
993	2	2016	2019	3
1075	3	2017	2019	2
1079	2	2018	2019	1
1081	2	2018	2019	1
1087	2	2018	2019	1
1089	2	2018	2019	1
1098	2	2018	2019	1
1109	2	2018	2019	1
1159	1	2019	2019	0
1160	1	2019	2019	0
1161	1	2019	2019	0
1162	1	2019	2019	0
1163	1	2019	2019	0
1164	1	2019	2019	0
1165	1	2019	2019	0
1166	1	2019	2019	0
1167	1	2019	2019	0
1168	1	2019	2019	0
1169	1	2019	2019	0
1170	1	2019	2019	0
1171	1	2019	2019	0
1172	1	2019	2019	0
1173	1	2019	2019	0
1174	1	2019	2019	0
1175	1	2019	2019	0
1176	1	2019	2019	0
1177	1	2019	2019	0
1178	1	2019	2019	0
1179	1	2019	2019	0
1180	1	2019	2019	0
1181	1	2019	2019	0
1182	1	2019	2019	0
1183	1	2019	2019	0
1184	1	2019	2019	0
1185	1	2019	2019	0
1186	1	2019	2019	0
1187	1	2019	2019	0
1188	1	2019	2019	0
1189	1	2019	2019	0
1190	1	2019	2019	0
1191	1	2019	2019	0
1192	1	2019	2019	0
1193	1	2019	2019	0
1194	1	2019	2019	0
1195	1	2019	2019	0
1196	1	2019	2019	0
1197	1	2019	2019	0
1198	1	2019	2019	0
1199	1	2019	2019	0
1200	1	2019	2019	0
1201	1	2019	2019	0
1202	1	2019	2019	0
1203	1	2019	2019	0
1204	1	2019	2019	0
1205	1	2019	2019	0
1206	1	2019	2019	0
1207	1	2019	2019	0
1208	1	2019	2019	0
1209	1	2019	2019	0
1210	1	2019	2019	0
1211	1	2019	2019	0
1212	1	2019	2019	0
1213	1	2019	2019	0
1214	1	2019	2019	0
1215	1	2019	2019	0
1217	1	2019	2019	0

Analysis of previously collected tag data

Risso's Dolphins movements and diving behavior

Location data were collected across 9 years (n=16), in every month except October; dive behavior data were collected in 7 months across 5 years (n = 8) (Figure 7). The median tag transmission duration was 10.7 d (range = 0.3 – 19.7 d) with a combined total of 2,298 locations after filtering. All Risso's remained within the SCB throughout the duration of tag deployments (Schorr et al., 2020). Daily group median straight-line distances between consecutive locations were 75 km (range = 56 – 99 km). While cumulative group median straight-line distances moved for the duration of deployments was 805 km (range = 204 = 1836 km,), median distance displaced from the tagging location was only 41 km (maximum = 156 km), highlighting the degree to which Risso's dolphins move extensively throughout a relatively limited total area. Median dive depth was 166 m (range = 42-547 m) with a median dive duration of 6 min (range = 2-11.2 min).

Significant predictors of dive depth were time of day (Chisq = 51.0830, p = 8.854e-13), regression residuals of CHL over SST (Chisq = 5.3373, p = 2.087e-02), and cosine of the lunar phase (Chisq = 11.3835, p = 7.41e-04). Model predictions suggest that dive depths during the night were 50.44 m deeper than dives during the day (Figure 8a). Dive depths deepened as regression residuals of log CHL over SST increased (Figure 8b). The distribution of observed residual values were strongly right skewed due to high CHL concentrations for respective sea-surface temperatures for GgTag018. The deepest and shallowest dives occurred during full and new moons, respectively (Figure 8c). Dive duration was significantly predicted by the sine of lunar phase (Chisq = 5.1425, p = 2.34e-02); dive durations were longest around the first quarter with the shortest times occurring around the third quarter moon (Figure 8d). Wide 95% confidence intervals for dive duration predictions reflect low sample sizes at certain lunar phases (see hash marks along x-axis of Figure 6d).

Distance from shore was significantly predicted by the cosine of lunar phase (Chisq = 8.1479, p = 4.31e-03, Figure 9a) and month (Chisq = 21.7736, p = 1.63e-02, Figure 9b). Animals were predicted to be slightly further offshore during a full moon and closest during a new moon (Figure 9a), although the difference in distance between the two was 9.6 km and 95% confidence intervals were large (upwards of 40.1 km). The three predictors, sine of lunar phase (Chisq = 15.9786, p = 6.41e-05), time of day (Chisq = 20.3678, p = 6.39e-06), and month (Chisq = 43.0274, p = 4.92e-06), all significantly predicted distance to mainland. Although only sine of lunar phases was significant, cosine of lunar phase (Chisq = 2.5523, p = 0.11) was still included in the best-fit model following AIC comparisons and had a small effect on model predictions. Animals were found closer to the mainland between the phases of the first quarter and the full moon and furthest during the last phases before the new moon (Figure 9c). Time of day helped explain differences in movements, although minimally, with animals 1.88 km closer to mainland during the daylight hours versus night (Figure 9d). Seasonality influenced distance from mainland, although with some variability. Overall, animals were furthest from the coast during late winter into spring (Figure 9e).

Model results here are being prepared for a manuscript titled "Movements and dive behavior of Risso's dolphins (Grampus griseus) in the Southern California Bight" for a submission to a peer-reviewed journal.

Duration of response to sonar by Cuvier's beaked whales

Thirteen tags deployed on Cuvier's beaked whales at SOAR from 2011–2015 were used for this analysis (Table 8). The data included 206 baseline deep dive cycles from deployments in early January, 187 exposed deep dive cycles, and 1206 post-exposure deep dive cycles (616 following high-power, 511 following mid-power, 79 following a combination of both). A comparison of behavior variables used in the calculation of MDs between baseline, exposed, and post-exposure deep dive cycles is provided in Table 9. MDs from baseline deep dive cycles were normally distributed with a mean of 2.08 (SD = 0.82). Conversely, MDs from exposed and post-exposure deep dive cycles were right skewed with means of 3.30 (SD = 2.21) and 2.49 (SD = 1.77), respectively (Figure *10*).

There was a combined 29.0 days of MFAS use within 100 km of a tagged whale across these 13 deployments (24.8 of high-power and 4.2 of mid-power) (Table 10). Qualifying sonar use occurred both within (75.7%) and beyond (24.3%) SOAR boundaries; bouts outside SOAR were predominantly high-power (88%) and bouts within SOAR were predominantly mid-power (80%). The median duration of sonar silence preceding an exposure event was 21.1 hours (IQR = 44.0 hours, Figure *11*). The best-fit model of MDs following MFAS (Adjusted R^2=0.0943; Deviance explained = 17.1%) included the non-sonar predictors time of day, ocean basin, and sex. It included the interactions between days since sonar and both the sonar-free hours preceding and total number of bouts within high-power exposures. It included the interactions between days since sonar and both the number of bouts and the distance to nearest source for mid-power MFAS (Table 11). Thus, predicted returns to baseline behavior in the post-exposure period depended on multiple characteristics of the exposure event.

While statistically significant, the MD trends in the post-exposure periods predicted by sonar interactions were generally subtle. Most of the more extreme deviations were predicted at the outer reaches of the parameter space, where data were sparse and confidence intervals extremely wide. For example, dive cycles that followed high-power exposures that in turn followed periods of 0-50 hours without sonar showed an increase in MDs over three days before decreasing slowly, with the highest MD values associated with shortest preceding sonar-free periods (i.e., the highest operational tempos were associated with more lasting behavioral changes) (Figure 12). However, the predicted MD values throughout this range were within one SD of the baseline mean, and thus these persistent differences were apparently mild. Data were too sparse to make meaningful predictions for exposures following more than 150 hours without high-power MFAS.

The number of individual MFAS bouts within a high-power exposure event also significantly affected MDs over time, though again, there was limited data from events with multiple high-power bouts and correspondingly large confidence intervals for predictions beyond the more common exposure events with just one or two high-power bouts (Figure 13). However, the data suggest MDs are increasingly elevated in the hours immediately following events with two or more high-power bouts, and that events with more than two bouts may take up to a day to return to baseline levels. It is important to note that individual bouts of high-power MFAS may last many hours, and that events with multiple bouts often include multiple sources adding levels of spatial and temporal complexity beyond the scope of the variables considered here.

In contrast, individual bouts are typically much shorter (on the order of minutes) for mid-power sonar exposure events, but they almost always occur in series. Thus, there is a much greater spread in the number of MFAS bouts within an exposure event, and correspondingly better predictive power for the effect number of bouts has over time, especially in the first three days post-exposure (Figure 14). For exposure events with less than eight bouts, there was a decreasing trend in MDs over the first two days, with lowest number of bouts predicting the highest MDs in the immediate post-exposure period. MDs following exposure events with 8-12 mid-power bouts, the most common scenario, showed minimal change over time. Data from exposure events with more than 12 bouts was too sparse to yield meaningful predictions. While the finding that fewer mid-power bouts may yield the strongest persistent responses is initially counter-intuitive, these relatively rare instances may be providing a valuable insight into response onset. If whales sometimes respond to exposure by conducting an avoidance dive following the first short bout of mid-power, then those avoidance dives, which may be deep enough to classify as deep dives and thus trigger the start of a new deep dive cycle, will fall in the *post-exposure* period if no subsequent bouts occur. However, in most cases multiple subsequent bouts will ensue, and those avoidance dives will fall in the sample of *exposed* dive cycles instead, where much larger MDs are expected (Figure 10).

The final significant sonar interaction was between the distance to the nearest mid-power source and days since the end of exposure (Figure *15*). There was a slight decreasing trend in MD with distance over the first day following exposures within 60 km of the source suggesting the closest exposures may have mildly persistent responses, though predicted values were again within the baseline range. The model predicted the largest deviances for the most distant exposures, which also displayed a strongly increasing trend over five days post-exposure. However, the samples at distances beyond 60 km were limited and confidence intervals so wide at this range that these trends may simply be artifacts and not indicative of a salient response.

Taken in total, these results suggest that there are some circumstances under which altered behavioral patterns persist beyond the exposed dive cycles in which primary responses occur, but these are typically limited in their extent and duration. We predicted the overall trends in post-exposure MDs, by sonar type, holding all non-sonar variables to their modal values and fixing all sonar predictors at values that yielded the strongest effect in their interactions with Days Since Sonar (Figure 16). This model of "worst-case" exposure scenarios suggests it could take up to two days for behavior to return to within the baseline range. It is important to remember that MD is a simplified metric used to characterize complex behavioral patterns. Post-exposure MDs outside the baseline range do not necessarily mean that whales continue the same response to the initial exposure hours or even days later, just that they are behaving in some way differently than is typical during extended periods without sonar use. This can be due to any number of finer scale behavioral changes within the deep dive cycle, from increased surface time to change in dive rates. If, as suggested, foraging disruption remains a major component of primary response, then these mild, lingering effects after the initial response may reflect recovery periods in which whales increase their foraging rate to compensate, as our initial analysis of the data implied. If so, it underscores the increasing cost of extended periods with high operational tempo, where whales may not get enough time between responses to catch up. It is also important to note that in these data, deep dives are considered a proxy for foraging in the absence of collateral data that confirm actual foraging is occurring (e.g. Schorr et al., 2014, Shearer et al., 2019). But if whales conduct deep dives without foraging to avoid sonar or reduce exposure, these effects will be amplified.

The full results are being worked up for submission as a manuscript with the target journal of Endangered Species Research.

Table 8. Summary of MFAS during Cuvier's tag deployments used in analyses.

			Number of bouts		Median and range bout durations (mins)		Median and range source distances (km)	
Tag ID	Deployment date	Tag duration (days)	High-power	Mid-power	High-power	Mid-power	High-power	Mid-power
14	1/6/2011	20.1	24	10	37 (0-235)	9 (1-15)	51.05 (13.53-81.65)	21.73 (11.45-38.32)
15	1/6/2011	67.8	46	54	117 (3-1439)	6 (0-39)	46.34 (19.49-98.66)	44.15 (17.02-99.16)
16	1/6/2011	87.2	89	85	109 (0-1439)	8 (0-1418)	54.83 (13.12-99.5)	35.64 (11.29-99.85)
19	1/15/2012	11.1	2	6	736.67 (34.33-1439)	8.5 (0-13)	39.8 (28.62-50.98)	22.75 (19.94-26.91)
20	1/15/2012	25.5	16	6	106.5 (34.33-1439)	8.5 (0-13)	47.63 (6.98-85.95)	34.2 (32.49-37.37)
21	3/29/2013	47.2	15	22	59 (9-216)	6.5 (0-81)	35.93 (13.29-87.93)	17.71 (9.71-83.36)
22	3/30/2013	23.8	12	15	60.5 (10-216)	10 (0-81)	31.39 (18.81-70.88)	15.41 (10.02-25.26)
26	1/7/2014	46.6	16	40	73 (5-233)	5.5 (1-32.85)	60.89 (25.74-88.54)	50.47 (26.97-80.96)
28	1/11/2014	48.2	37	82	59 (2-445)	6 (1-39)	55.43 (22.37-90.59)	22.27 (5.95-86.16)
34	1/3/2015	16.1	2	40	23 (20-26)	6 (0-52)	44.65 (27.56-61.73)	10.59 (2.55-26.56)
35	1/7/2015	13.5	2	26	23 (20-26)	7 (0-36)	39.3 (20.71-57.89)	25.01 (16.45-53)
36	1/9/2015	41.9	29	96	43 (2-449)	6 (0-36)	55.78 (7.89-91.09)	31.88 (2.2-68.4)
37	1/9/2015	13.4	12	38	28.5 (2-91)	6 (0-36)	26.03 (6.14-99.64)	18.61 (1.89-31.95)

Table 9. Observed data summary for variables used in the calculation of Mahalanobis distances for baseline, exposed, and post-exposure deep dive cycles.

	Exposed		Post-exposure		Baseline	
	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range
Deep Dive Duration	68.9 (14.1)	39.9-163.3	64.5 (11.7)	27.1-114.7	63.7 (11.5)	36.8-100.2
Deep Dive Depth	1381.2 (263.9)	767.5-1999.5	1398.4 (270.3)	703.5-2991.5	1437.4 (256.4)	879.5-1871.5
Number of Shallow Dives	5.9 (3.4)	0-19	4.3 (2.3)	0-21.0	4.6 (2.1)	0-10
Total Shallow Dive Duration	144.7 (103.9)	0.0-609.6	87.1 (55.0)	0-568.0	90.7 (47.6)	0-266.4
Total Surface Duration	21.0 (18.8)	4.1-137.4	22.9 (25.6)	1.3-270.7	18.8 (12.9)	3.7-82.8

Table 10. Summary of Sonar event groupings, by sonar type

		Exposure Event Duration (min)		Source Distance (km)		Sonar Duration (min)		Number of Bouts		Preceding Silence Duration (hr)	
Sonar Type	No. of Events	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range
High-power	84	211.5 (298.6)	2-1439	57.8 (22.4)	7.0-98.3	186.7 (285.5)	2.0-1439.0	1.8 (1.4)	1-6	42. 6 (54.6)	3.5-305.8
Mid-power	40	150.2 (128.7)	1-544	30.4 (20.5)	2.6-99.2	53.8 (32. 6)	1.0-113.1	6.5 (3.7)	1-18	46.5 (49. 5)	2.8-164.2
Both	18	522.4 (412.2)	21-1825	22. 6 (18.9)	2.2-86.2	301.8 (383.6)	21.0-1737.1	10.3 (5.2)	2-21	47.8 (45.3)	6.1-137.6

Table 11. F statistics and significance values for all predictors in model. Predictors with p-values less than 0.05 were deemed significant, an * represents a significant interaction between the predictor the number of days since the end of sonar.

	High-power F (p-value)	Mid-power F (p-value)
Days Since Sonar	0.090 (0.320)	0.816 (0.050)
Closest Source Distance*	0.000 (0.809)	4.382 (0.000)
Number of Bouts*	4.725 (0.000)	2.024 (0.007)
Preceding Silence*	2.137 (0.015)	0.786 (0.066)
Time of Day	10.677 (0.000)	
Ocean Basin	6.850 (0.000)	
Sex	6.267 (0.002)	

In addition to the above analysis of tag data, one peer-reviewed paper was published in 2020 using dive data from Cuvier's beaked whales tagged during previous Navy-funded projects (Barlow et al., 2020). This paper explored the variations in diving behavior within the Southern California Bight in relation to environmental and habitat parameters and is available from the Marine Ecology Progress Series website.

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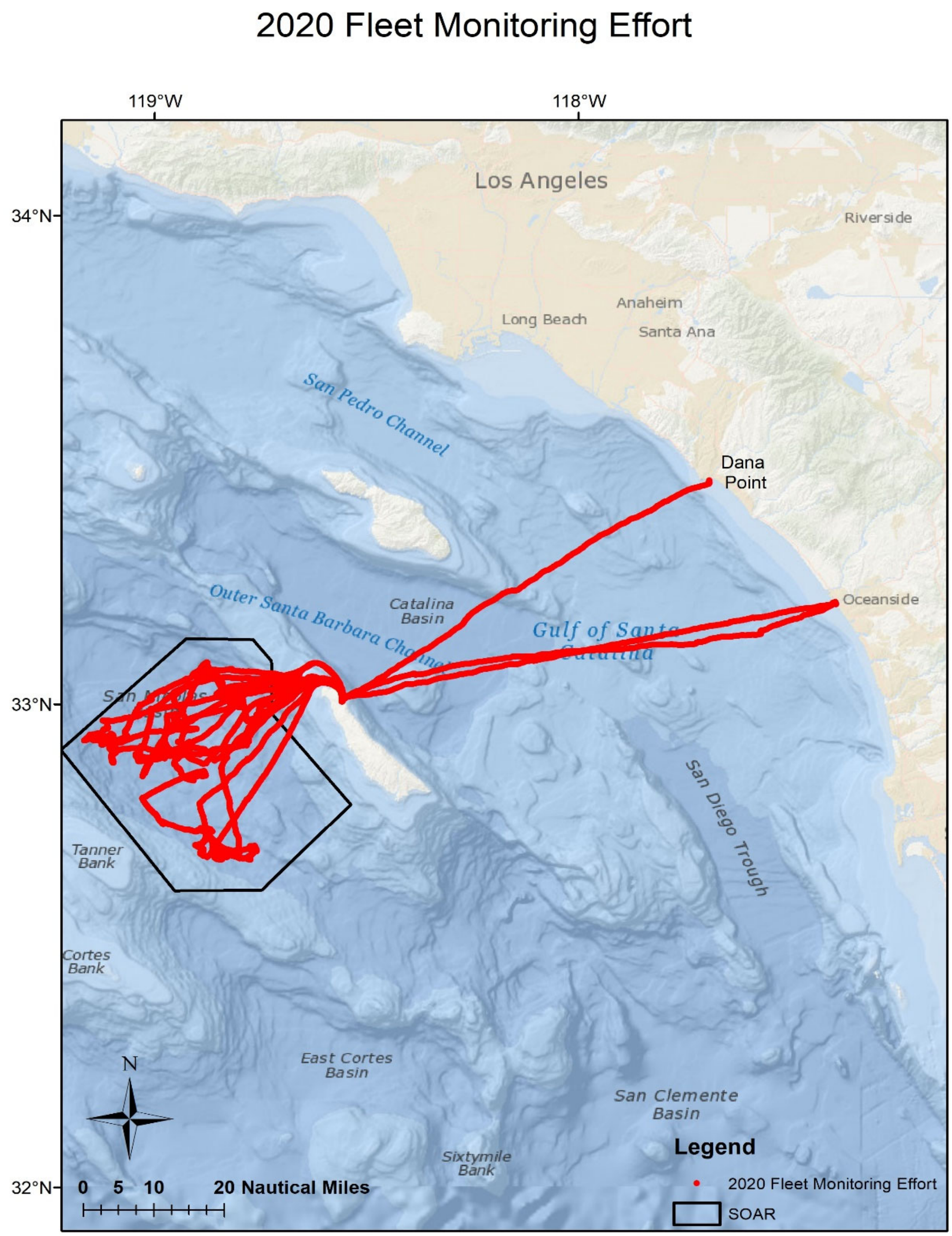

Figure 1. Vessel track lines from Fleet Monitoring surveys conducted from 4 January 2020 through 8 October 2020. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone

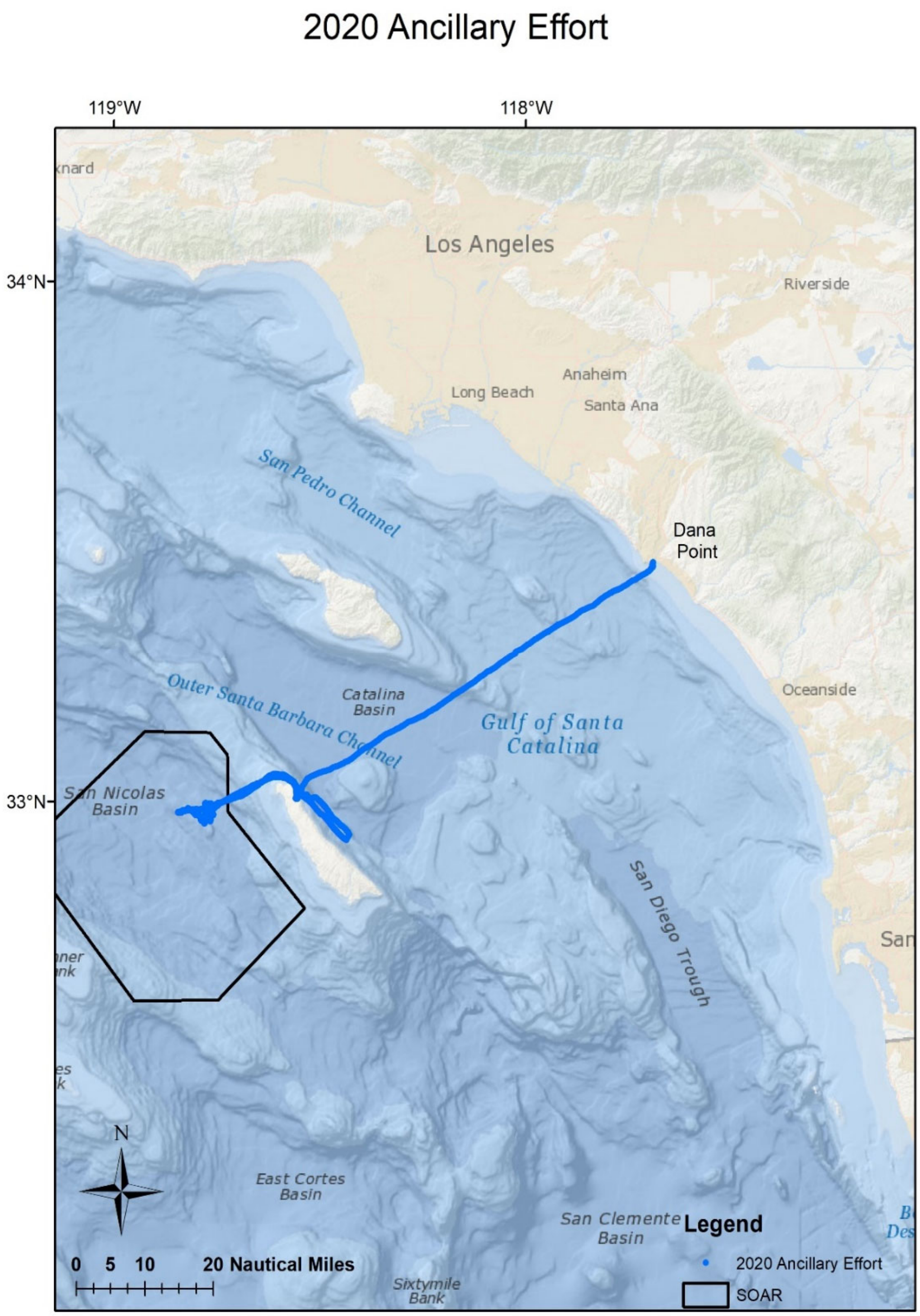

Figure 2. Vessel track lines from ancillary surveys conducted 3 January 2020 through 6 January 2020. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone

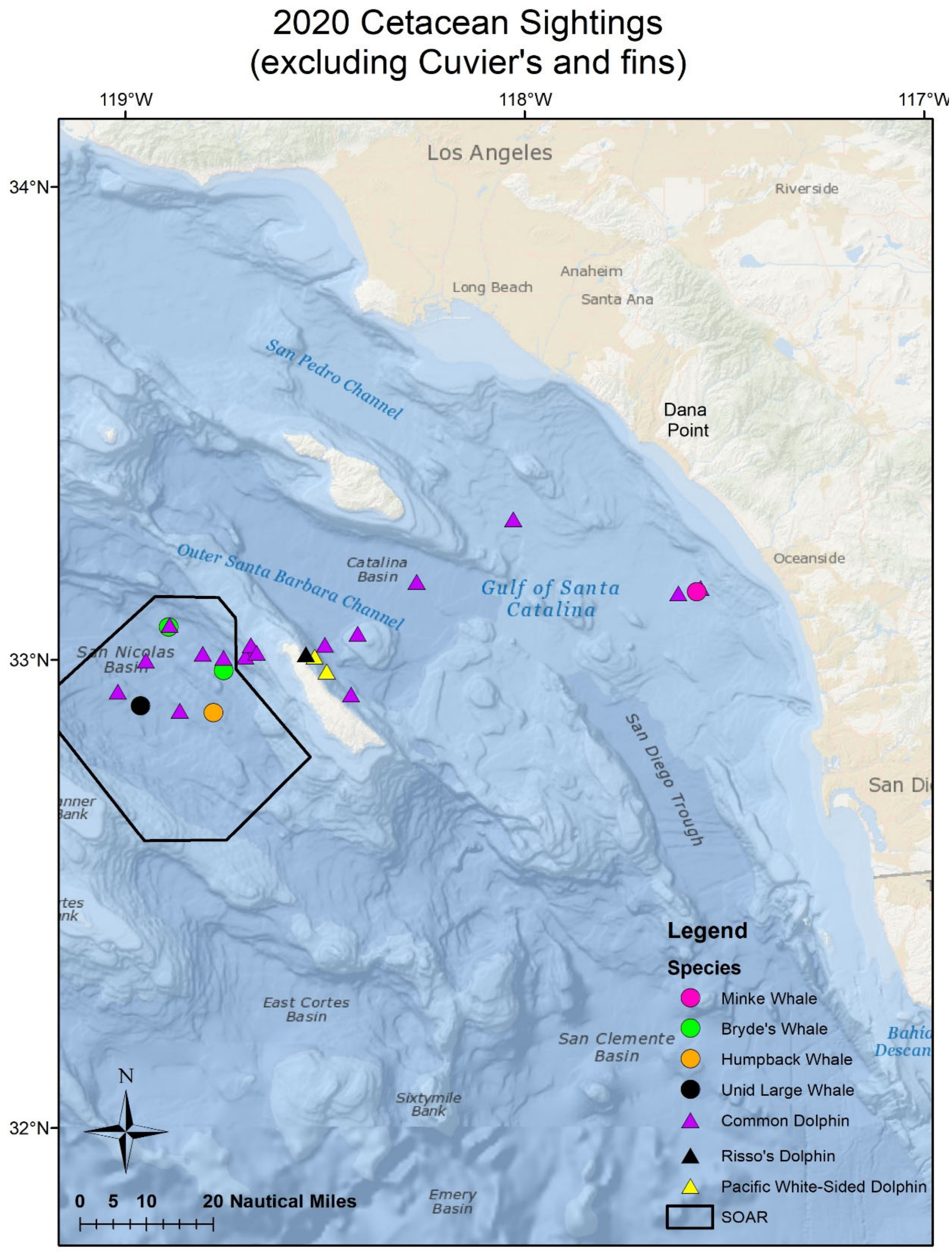

Figure 3. Sighting locations of cetaceans (except Cuvier's beaked whales and fin whales) by species from surveys conducted in 2020. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone.

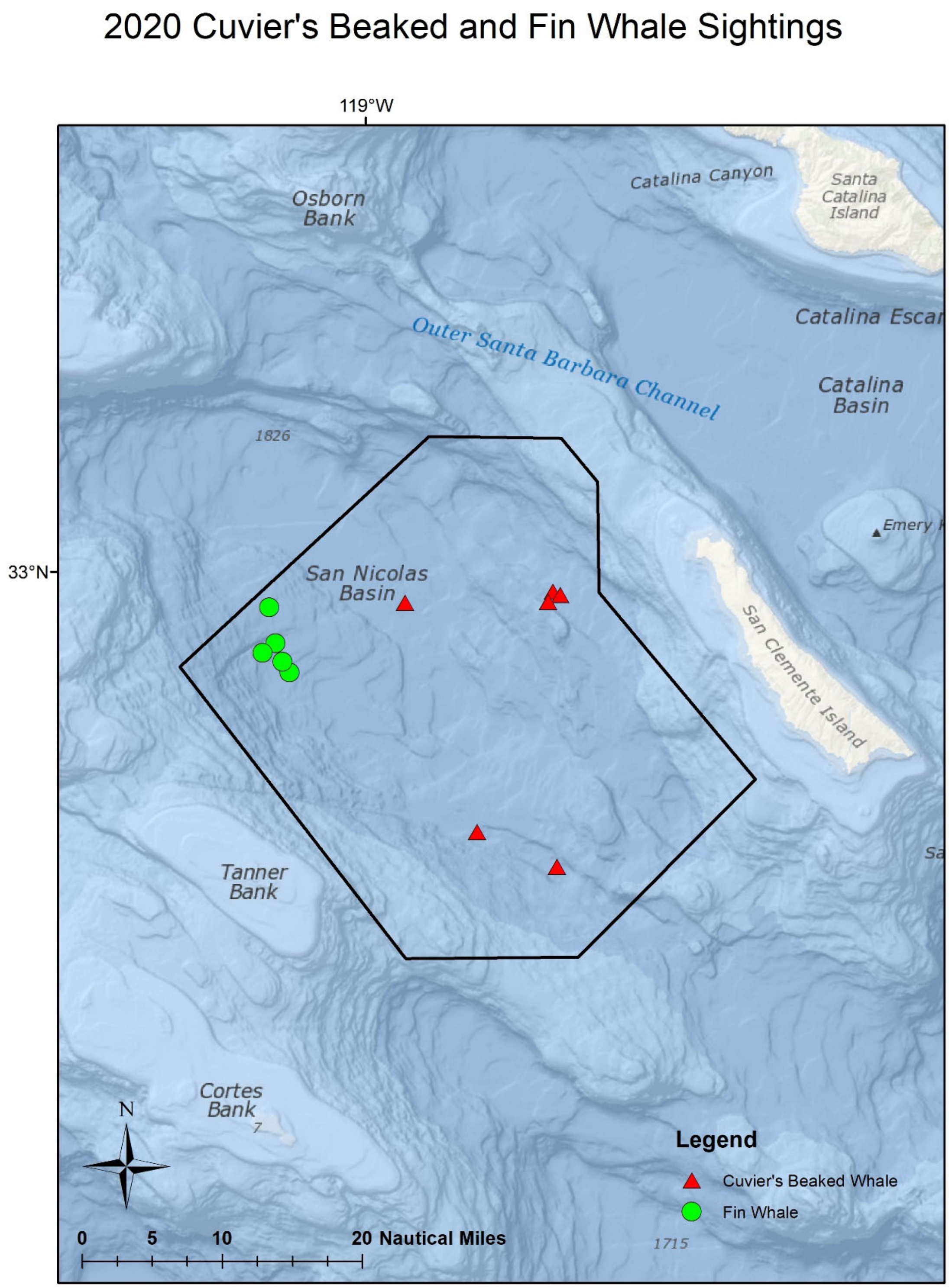

Figure 4. Cuvier's beaked and fin whale sightings from surveys conducted in 2020. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone.

2020 Seasonal Cuvier's Beaked and Fin Whale Sightings

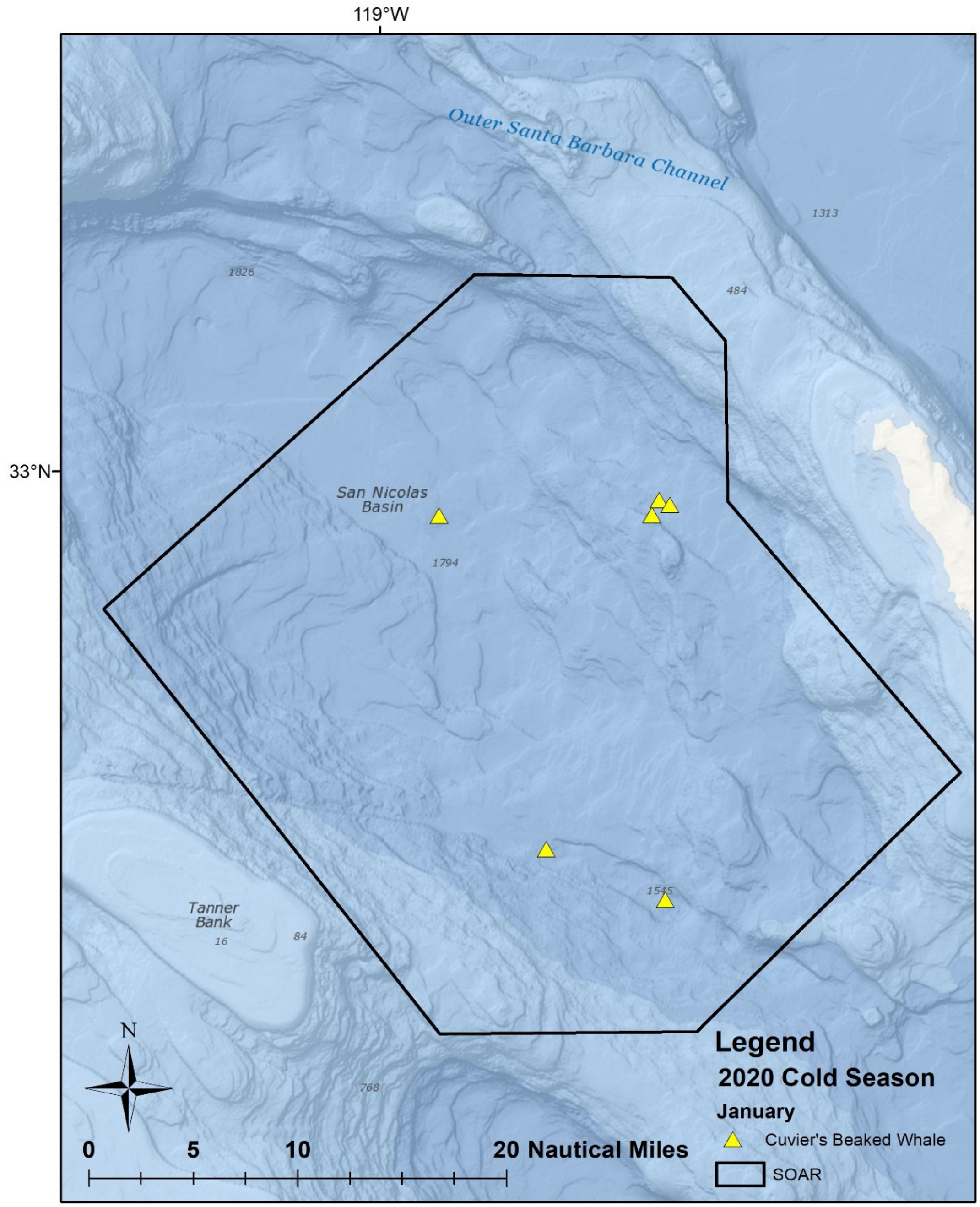

Figure 5. Cold season (January – May) locations of Cuvier's beaked whales from surveys conducted in 2020. Fin whales were not sighted during the one survey conducted in the cold season. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone

2020 Seasonal Cuvier's Beaked and Fin Whale Sightings

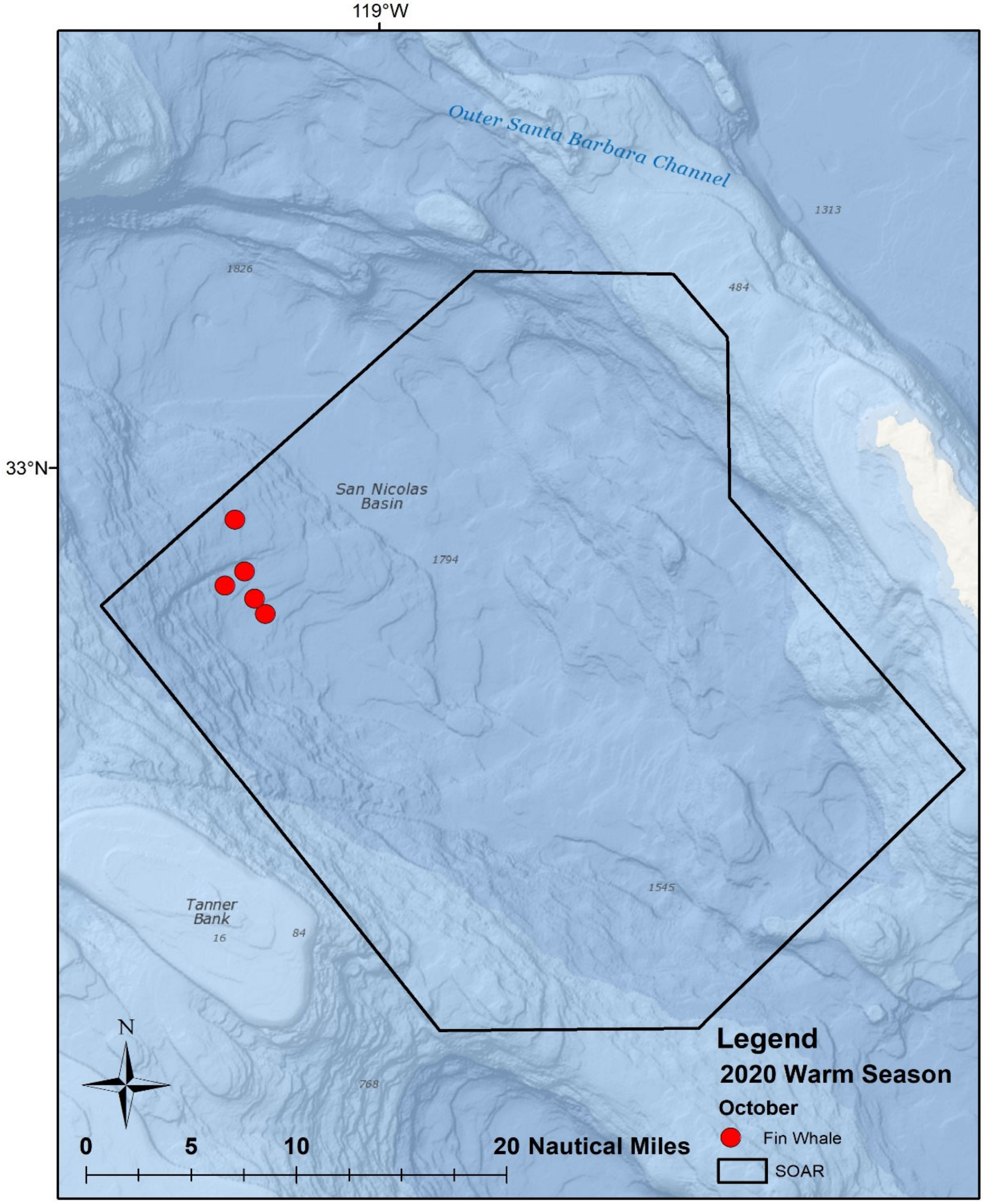

Figure 6. Warm season (June – November) locations of fin whale sightings from surveys conducted in 2020. Cuvier's beaked whales were not sighted during the one survey in the warm season. SOAR = Southern California Anti-submarine Warfare Range. Prepared by B. Rone

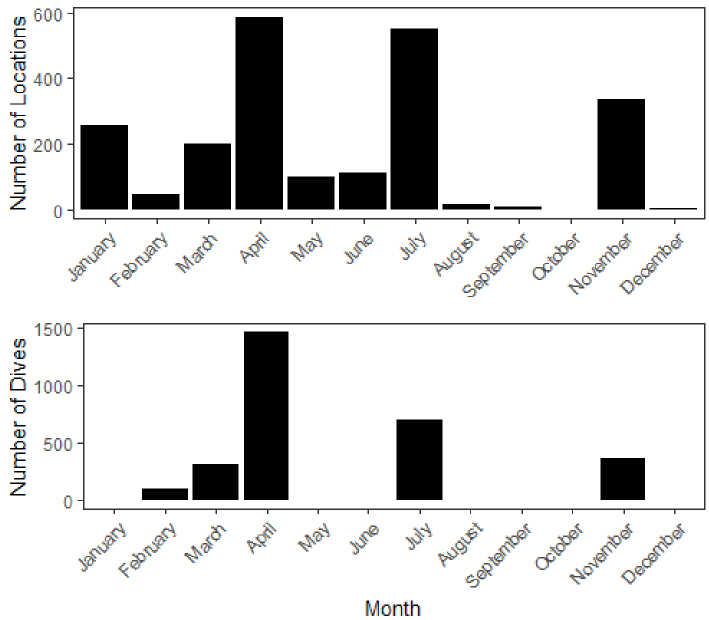

Figure 7. Distribution of filtered locations (top, 16 tags) and dives (bottom, 8 tags) across months from satellite tags deployed on Risso's dolphins in the Southern California Bight between 2009 – 2019. Prepared by B. Rone.

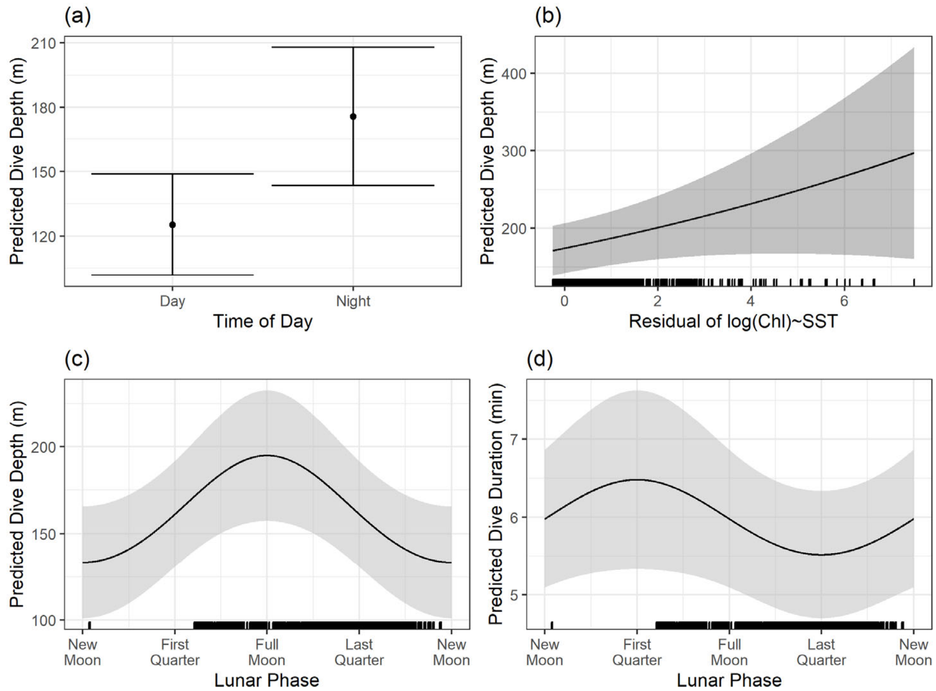

Figure 8. Prediction plots from the fitted models for dive depth (a-c) and dive duration (d). Solid black lines/dots represent mean predicted values with shaded areas/error bars representing the 95% CI. Hash marks along the x-axis shows the spread of data. For the creation of these plots, values for other predictors in each model were set as follows: time of day = night, CHL over SST residual = 0.123, SST = 15.81, distance to shore = 24.31 km, sine of lunar phase = -0.728, cosine of lunar phase = -0.452. Prepared by D. Sweeney.

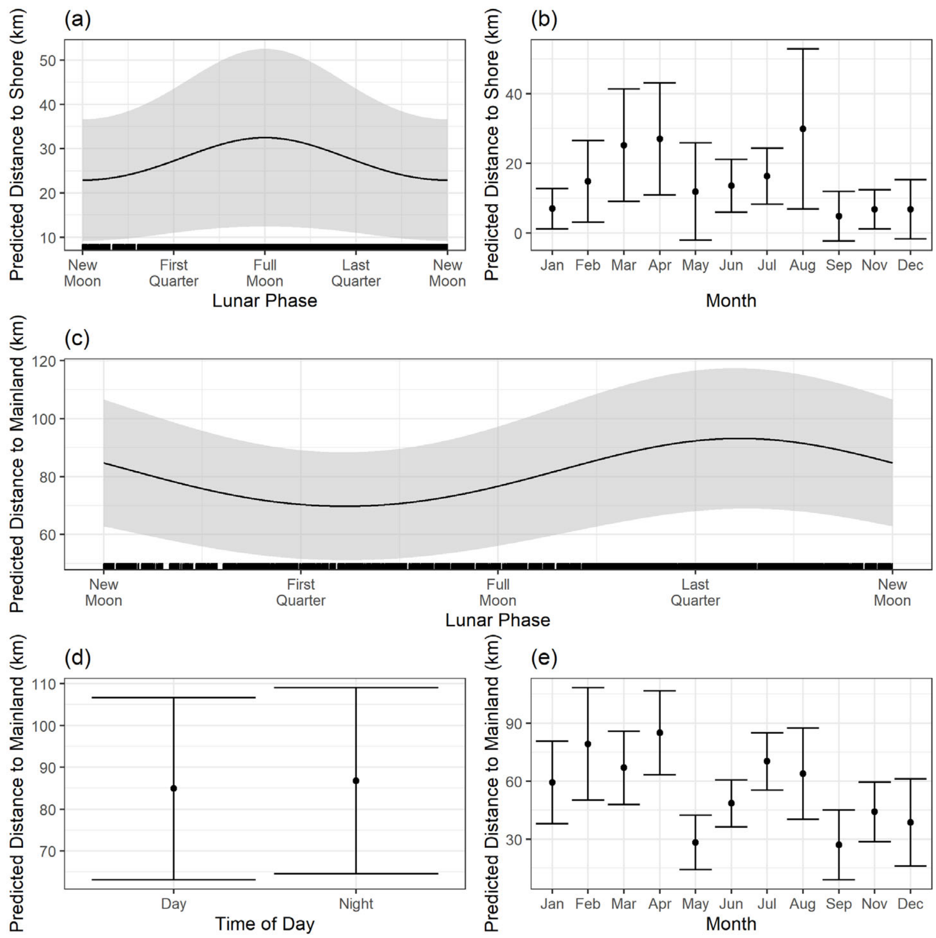

Figure 9. Prediction plots from the fitted models for distance to shore (a-b) and distance to mainland (c-e). Solid black lines/dots represent mean predicted values with shaded areas/error bars representing the 95% CI. Hash marks along the x-axis shows the spread of data. For the creation of these plots, values for other predictors in each model were set as follows: time of day = day, month = April, sine of lunar phase = -0.369, cosine of lunar phase = 0.048. Prepared by D. Sweeney.

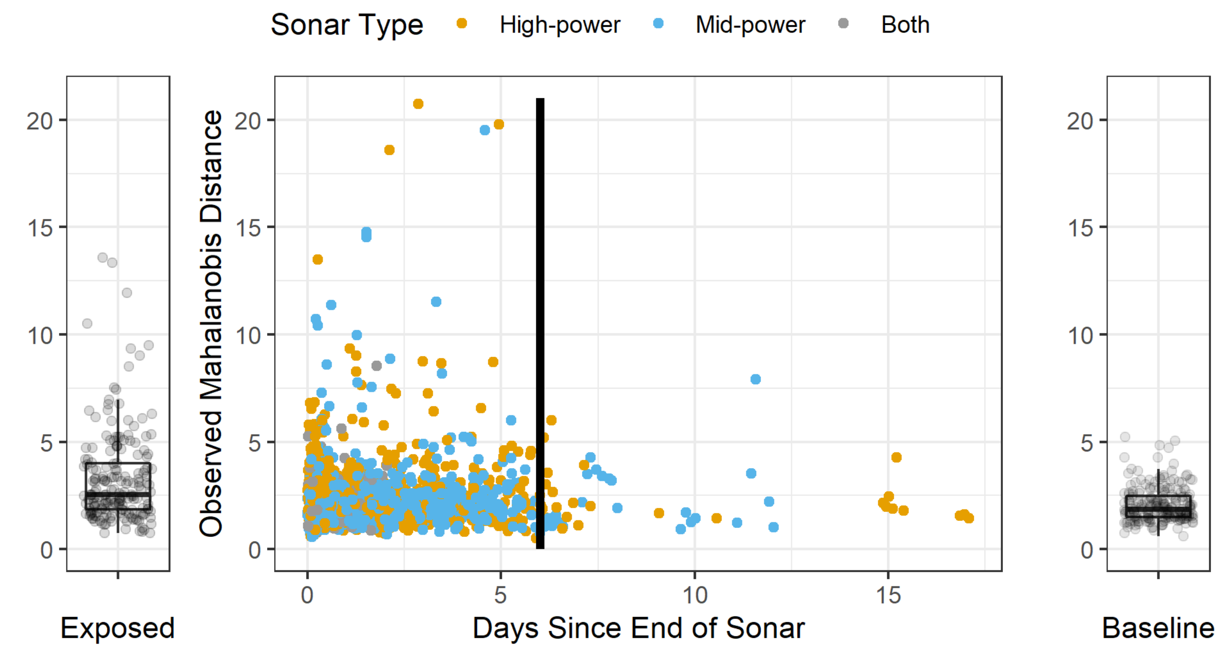

Figure 10. Plots of observed Mahalanobis distances. The center panel contains Mahalanobis distances from post-exposure deep dive cycles. The black line displays the 6-day cutoff after which data were excluded from modeling. The distributions of Mahalanobis distances from exposed deep dive cycles (left plot) and early-January baseline deep dive cycles (right plot) are shown for comparison. Prepared by D. Sweeney.

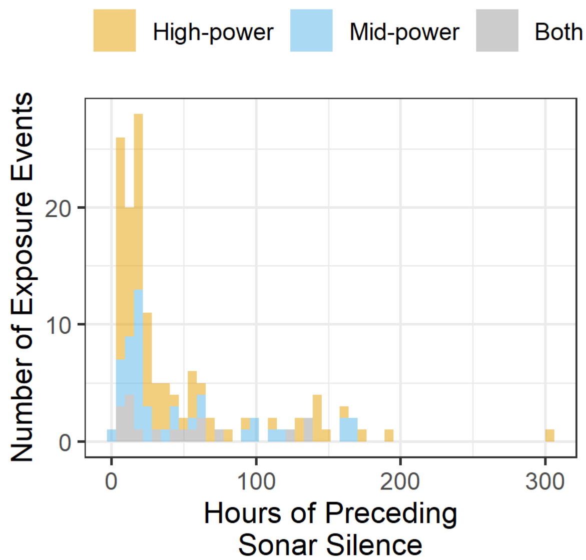

Figure 11. Histogram showing the durations of sonar silence preceding MFAS exposure events. Prepared by D. Sweeney.

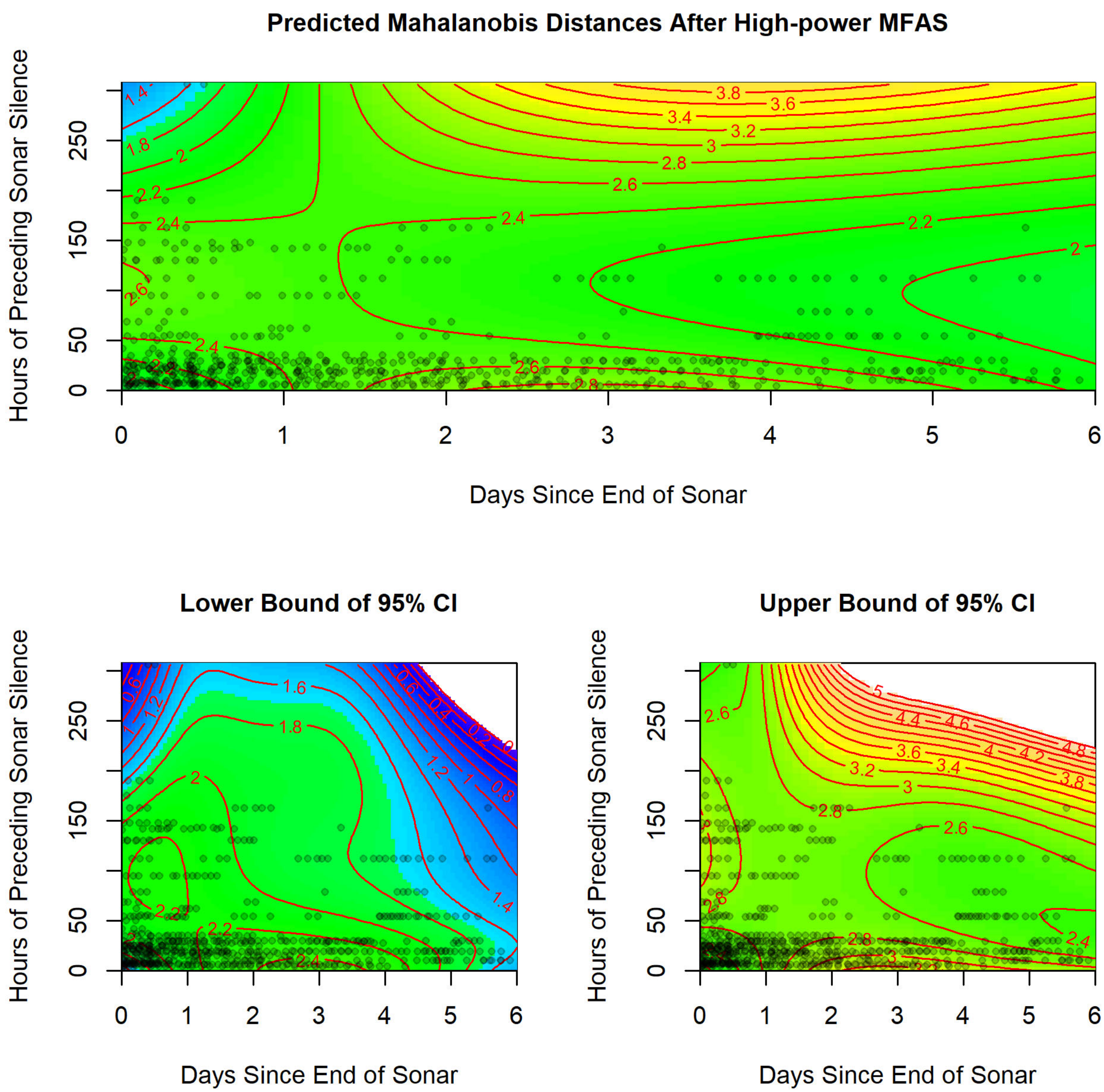

Figure 12. Model prediction contour plots for Mahalanobis distances as a function of the interaction between days since the end of high-power MFAS and the duration of sonar silence preceding the exposure event. The top panel shows predicted values while the bottom panels show the lower (bottom left) and upper (bottom right) boundaries of the 95% confidence intervals. Predicted Mahalanobis distances less than 0 and greater than 5 are not shaded to allow the full color spectrum to cover a vast majority of predicted values. Black points represent the distribution of observed predictor values. The values for other variables used to make these predictions were held constant as follows: time of day is night (modal value), ocean basin is San Nicolas (modal value), sex is female (modal value), source distance is 59.4 km (median high-power value), and number of bouts is 1 (median high-power value). Prepared by D. Sweeney.

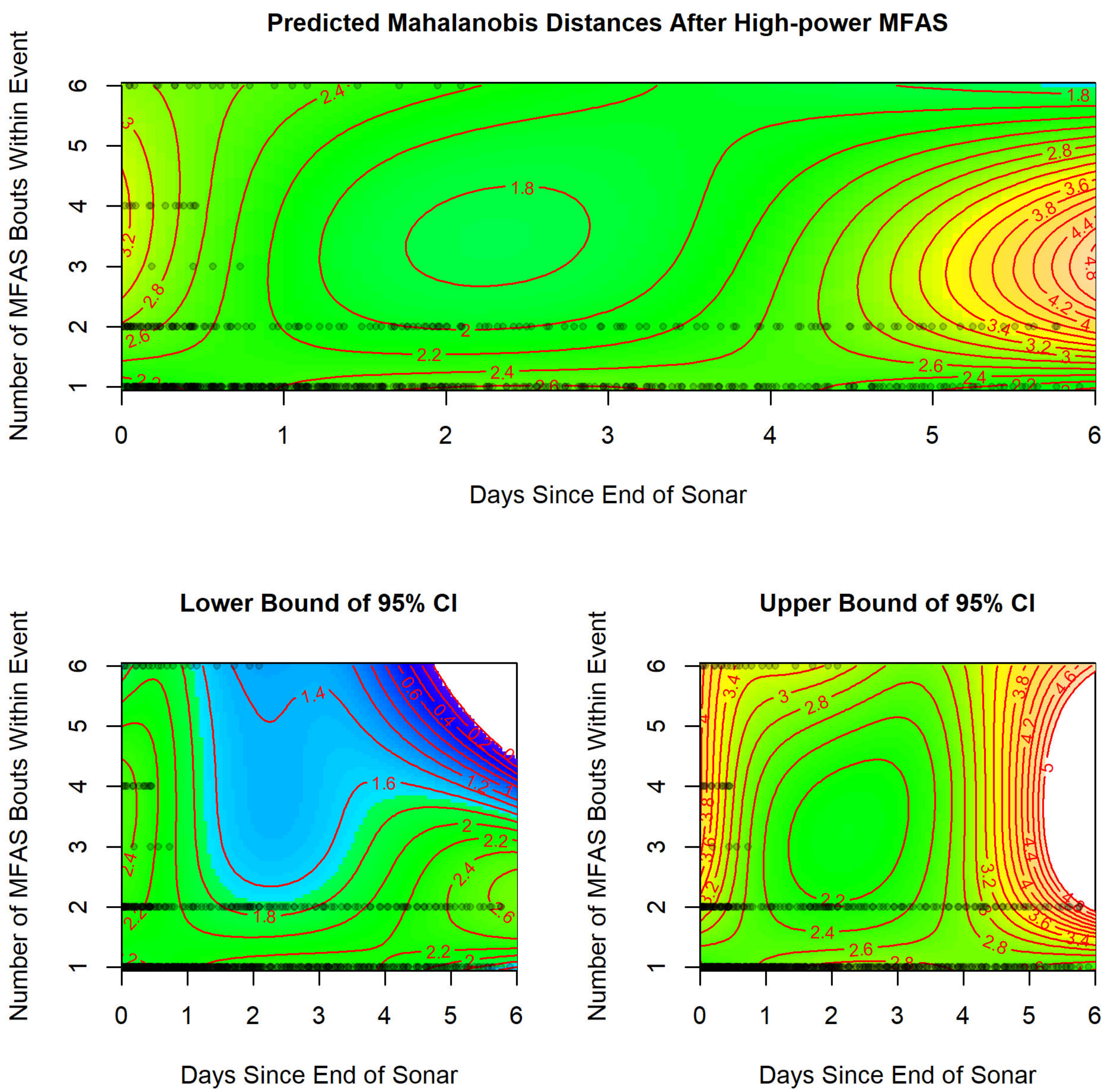

Figure 13. Model prediction contour plots for Mahalanobis distances as a function of the interaction between days since the end of high-power MFAS and the number of individual sonar bouts within the exposure event. The top panel shows predicted values while the bottom panels show the lower (bottom left) and upper (bottom right) boundaries of the 95% confidence intervals. Predicted Mahalanobis distances less than 0 and greater than 5 are not shaded to allow the full color spectrum to cover a vast majority of predicted values. Black points represent the distribution of observed predictor values. The values for other variables used to make these predictions were held constant as follows: time of day is night (modal value), ocean basin is San Nicolas (modal value), sex is female (modal value), source distance is 59.4 km (median high-power value), and preceding sonar silence is 21.3 hours (median high-power value). Prepared by D. Sweeney.

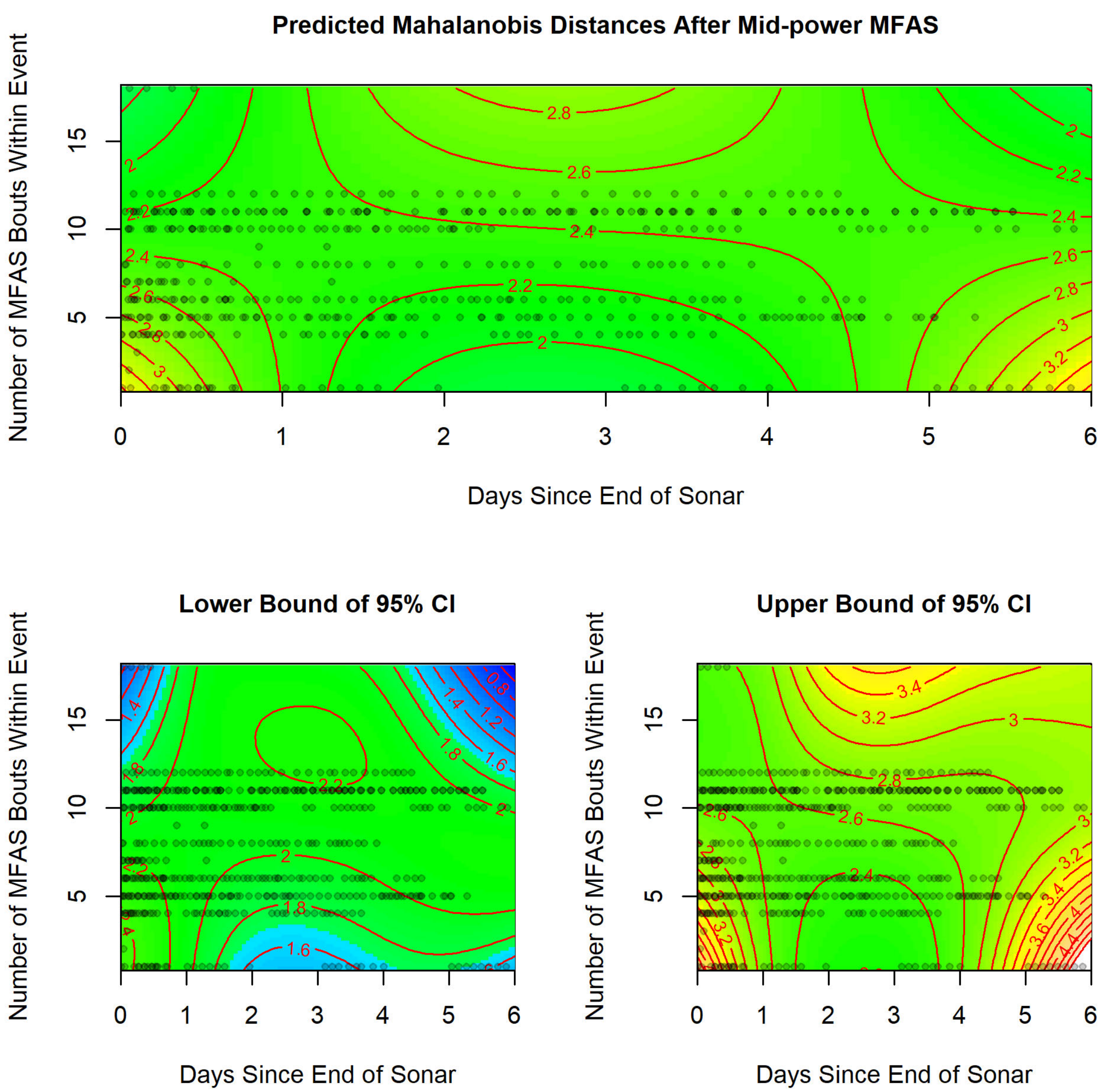

Figure 14. Model prediction contour plots for Mahalanobis distances as a function of the interaction between days since the end of mid-power MFAS and the number of individual sonar bouts within the exposure event. The top panel shows predicted values while the bottom panels show the lower (bottom left) and upper (bottom right) boundaries of the 95% confidence intervals. Predicted Mahalanobis distances less than 0 and greater than 5 are not shaded to allow the full color spectrum to cover a vast majority of predicted values. Black points represent the distribution of observed predictor values. The values for other variables used to make these predictions were held constant as follows: time of day is night (modal value), ocean basin is San Nicolas (modal value), sex is female (modal value), source distance is 24.1 km (median mid-power value), and preceding sonar silence is 17.6 hours (median mid-power value). Prepared by D. Sweeney.

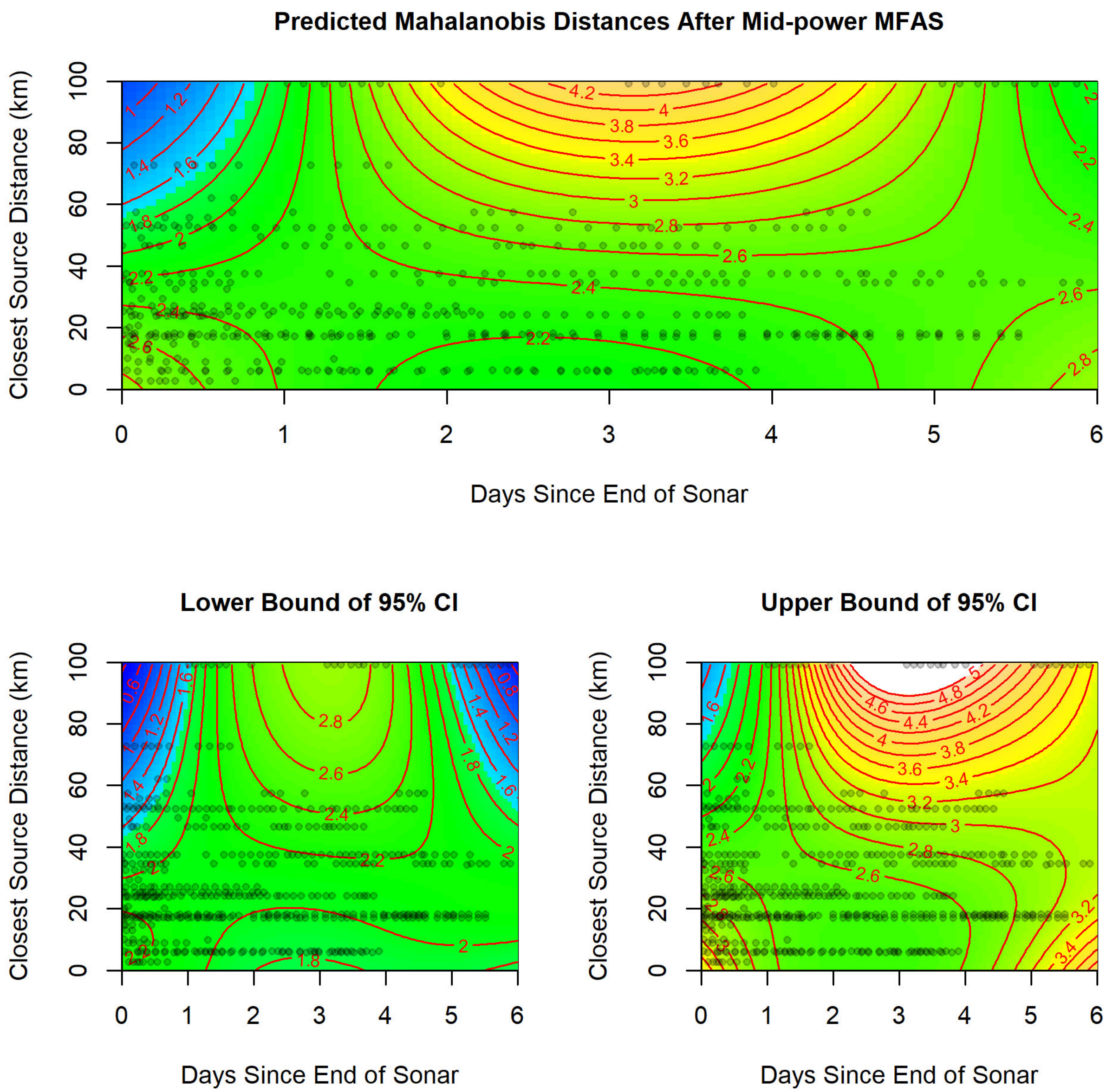

Figure 15. Model prediction contour plots for Mahalanobis distances as a function of the interaction between days since the end of mid-power MFAS and the closest source distance. The top panel shows predicted values while the bottom panels show the lower (bottom left) and upper (bottom right) boundaries of the 95% confidence intervals. Predicted Mahalanobis distances less than 0 and greater than 5 are not shaded to allow the full color spectrum to cover a vast majority of predicted values. Black points represent the distribution of observed predictor values. The values for other variables used to make these predictions were held constant as follows: time of day is night (modal value), ocean basin is San Nicolas (modal value), sex is female (modal value), number of bouts is 8 (median mid-power value), and preceding sonar silence is 17.6 hours (median mid-power value). Prepared by D. Sweeney.

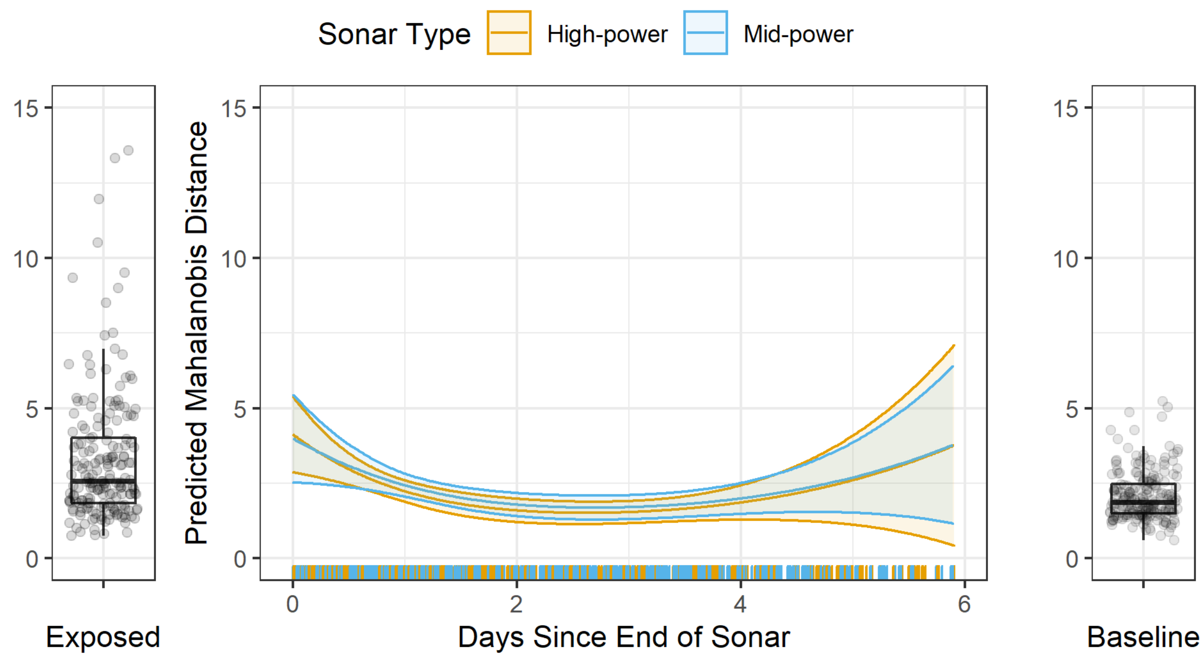

Figure 16. Model prediction plot for Mahalanobis distances as a function of the number of days since the end of both high-power and mid-power MFAS. The values for other variables used to make these predictions were held constant as follows: time of day is night, ocean basin is San Nicolas, sex is female, source distances are 10 km (high-power) and 5 km (mid-power), preceding sonar silence is 100 hours (high-power) and 10 hours (mid-power), and number of bouts is 5 (high-power) and 1 (mid-power). Hash marks along the horizontal axis indicate the spread of observed data and the shaded regions represent the 95% confidence intervals. The left and right panels show the distributions of Mahalanobis distances during exposed deep dive cycles (left) and early-January baseline deep dive cycles (right). Prepared by D. Sweeney.

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Appendices

Appendix 1. Sighting details from effort conducted in 2020, including effort from Fleet Monitoring and the ancillary effort.

Date	Common Name	Lat	Long	Group Size	Est ID's	Biopsies Collected	Tags Deployed
03-Jan-20	Risso's Dolphin	N33 00.70	W118 32.92	16	0	0	0
03-Jan-20	Pacific White-Sided Dolphin	N32 58.50	W118 29.81	20	0	0	0
03-Jan-20	Common Dolphin	N32 55.54	W118 26.13	40	0	0	0
03-Jan-20	Pacific White-Sided Dolphin	N33 00.38	W118 31.61	15	0	0	0
04-Jan-20	Cuvier's Beaked Whale	N32 44.43	W118 52.07	3	3	0	0
04-Jan-20	Cuvier's Beaked Whale	N32 42.35	W118 46.37	2	1	0	0
04-Jan-20	Humpback Whale	N32 53.21	W118 46.80	2	0	0	0
06-Jan-20	Cuvier's Beaked Whale	N32 58.61	W118 46.16	3	0	0	0
06-Jan-20	Cuvier's Beaked Whale	N32 58.80	W118 46.66	3	2	1	1
07-Jan-20	Cuvier's Beaked Whale	N32 58.15	W118 57.20	1	0	0	0
07-Jan-20	Cuvier's Beaked Whale	N32 58.20	W118 47.01	3	3	0	0
07-Jan-20	Common Dolphin	N33 00.88	W118 40.31	70	0	0	0
08-Jan-20	Common Dolphin	N33 17.90	W118 01.77	6	0	0	0
08-Jan-20	Common Dolphin	N33 09.92	W118 16.28	60	0	0	0
02-Oct-20	Common Dolphin	N33 01.89	W118 30.04	100	0	0	0
02-Oct-20	Common Dolphin	N33 03.32	W118 25.15	22	0	0	0
02-Oct-20	Common Dolphin	N33 08.45	W117 36.99	15	0	0	0
02-Oct-20	Minke Whale	N33 08.64	W117 34.21	1	1	0	0
02-Oct-20	Common Dolphin	N33 09.15	W117 33.61	12	0	0	0

Date	Common Name	Lat	Long	Group Size	Est ID's	Biopsies Collected	Tags Deployed
03-Oct-20	Common Dolphin	N33 00.40	W118 41.97	475	0	0	0
03-Oct-20	Bryde's Whale	N32 58.59	W118 45.29	1	1	0	0
03-Oct-20	Common Dolphin	N32 53.50	W118 51.84	80	0	0	0
03-Oct-20	Common Dolphin	N33 01.15	W118 40.70	1000	0	0	0
04-Oct-20	Common Dolphin	N33 00.23	W118 45.25	16	0	0	0
04-Oct-20	Fin Whale	N32 54.62	W119 05.95	1	1	0	0
04-Oct-20	Fin Whale	N32 53.98	W119 05.45	2	2	0	0
04-Oct-20	Common Dolphin	N33 04.42	W118 53.38	80	0	0	0
04-Oct-20	Bryde's Whale	N33 04.12	W118 53.53	1	0	0	0
05-Oct-20	Common Dolphin	N32 55.91	W119 01.14	30	0	0	0
05-Oct-20	Unid Large Whale	N32 54.09	W118 57.72	1	0	0	0
05-Oct-20	Common Dolphin	N33 01.85	W118 41.16	30	0	0	0
06-Oct-20	Common Dolphin	N32 59.87	W118 56.91	80	0	0	0
07-Oct-20	Common Dolphin	N33 00.74	W118 48.38	50	0	0	0
07-Oct-20	Fin Whale	N32 55.14	W119 07.35	2	2	2	0
07-Oct-20	Fin Whale	N32 55.72	W119 06.44	3	3	0	0
07-Oct-20	Fin Whale	N32 57.86	W119 06.88	2	1	0	0

Appendix 2. List of Acronyms

CA	California
eDNA	environmental DNA
GAM	generalized additive model
GPS	Global Positioning System
ICMP	Integrated Comprehensive Monitoring Program
IDDI	Inter-Deep-Dive-Interval
km	kilometer
LMR	Living Marine Resources
LIMPET	Low-Impact Minimally Percutaneous External –electronics Transmitting
m	meter
M3R	Marine Mammal Monitoring on Navy ranges
MarEcoTel	Marine Ecology and Telemetry Research
MD	Mahalanobis distance
MFAS	mid-frequency active sonar
NUWC	Naval Undersea Warfare Center
ONR	Office of Naval Research
PCoD	Population Consequences of Disturbance
ROC	Range Operation Center
RHIB	rigid-hulled inflatable boat
SCORE	Southern California Offshore Range
SOCAL	Southern California Range Complex
SWFSC	Southwest Fisheries Science Center
US	United States