Marine Mammal Monitoring on Navy Ranges 2014 Summary Report
February, 2015

P.O.C David Moretti
Naval Undersea Warfare Center
Newport, RI 02879
401-832-5749
david.moretti@navy.mil

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Via funding from the Living Marine Resource (LMR) program, ONR and U.S. Pacific Fleet, the Marine Mammal Monitoring on Navy Ranges (M3R) program is developing and implementing the requisite tools and methods to assess the long-term effect of Navy operations on cetaceans in the Southern California (SOCAL) Range Complex, particularly those operations using Mid-Frequency Active (MFA) sonar, with a focus on Cuvier's beaked whales and fin whales.

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Introduction

Via funding from the Living Marine Resource (LMR) program and ONR, the Marine Mammal Monitoring on Navy Ranges (M3R) program is developing and implementing the requisite tools and methods to assess the long-term effect of Navy operations on cetaceans in the Southern California (SOCAL) Range Complex, particularly those operations using Mid-Frequency Active (MFA) sonar, with a focus on Cuvier's beaked whales (*Ziphius cavirostris*), hereafter *Zc*.

The program is concentrating on

1. Modifying prototype M3R passive acoustic tools to allow Range operation in the Southern California Antisubmarine warfare Range (SOAR) acoustic environment.

2. Conducting visual surveys and photo-identification to define population size and structure for *Zc* and Endangered Species Act (ESA)-listed fin whales (*Balaenoptera physalus, Bp*) in the Southern California Bight for estimating population level-impacts.

3. Deploying satellite tags to document the medium term movements and dive behavior (weeks to months) on cetaceans including *Zc* and *Bp* for estimating individual and population level responses and impacts.

4. Using the information from steps 1 through 3, complete a set of prototype passive acoustic tools to estimate *Zc* density, and document the spatial and temporal reaction of cetaceans to MFA operations, and combine these data to produce a *Zc* risk curve.

Background

The Southern California Offshore Range (SCORE) encompasses a broad area extending over 200 miles south from the northern end of San Clemente Island (SCI), west beyond Cortez Bank, and southeast into the international waters off the northern Baja California coast (Fig 1). Within these boundaries, off the western shore of SCI, lies the Southern California Antisubmarine warfare Range (SOAR). Located in the San Nicolas basin, the range consists of 172 bottom-mounted hydrophones designed to track underwater vehicles equipped with an acoustic pinger that emits a known signal at a known repetition rate (Figure 1). The range covers an area of over 1,100 square kilometers (km^2) in water that ranges from approximately 1,200 to 2,000 meters in depth. These hydrophones are being leveraged to develop marine mammal passive acoustic monitoring tools [1].

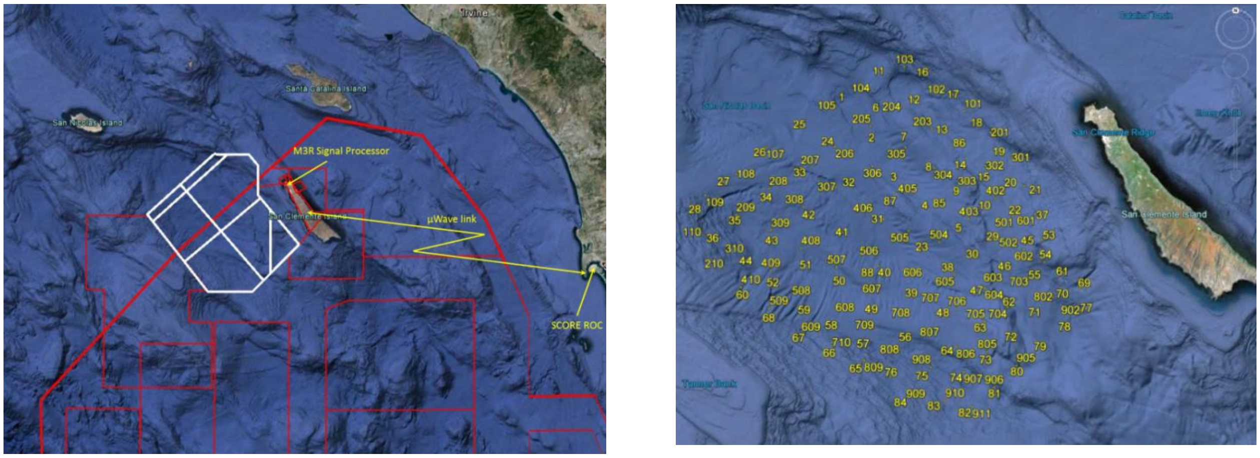


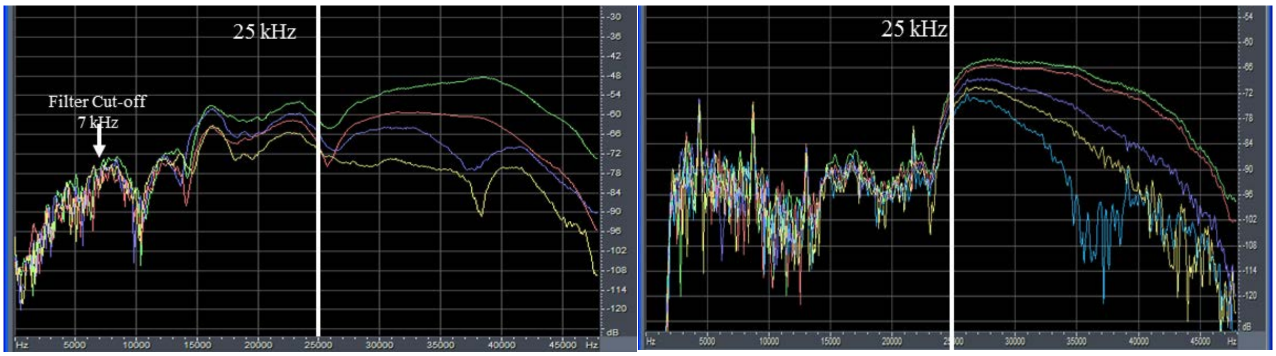
Figure 1. Overview of SCORE (left) with San Clemente Island in the center; the SOAR range boundaries are outlined in white, with additional SCORE operating areas outlined in blue and red. The site of the Digital Signal Processor (DSP) on San Clemente Island and Range Operations Center (ROC) on North Island Naval Air Station are indicated with yellow arrows. The right image shows the SOAR hydrophone field in the San Nicolas basin west of San Clemente Island.

The SOAR hydrophone cables are terminated on SCI. A Marine Mammal Monitoring on Navy Ranges (M3R) digital signal processor (DSP) monitors the hydrophones from the Cable Termination Shelter (CTS) located on the island. Processed data are transmitted to the SCORE Range Operations Center (ROC) located on the mainland at the North Island Naval Air Station (NAS) via a microwave link (Figure. 1).

The M3R tools allow real-time, passive acoustic monitoring of all range hydrophones for transient signals including marine mammal vocalizations. A series of species verification tests have been conducted, starting in 2006, where expert observers from Cascadia Research Collective are vectored to vocalizing animals that have been isolated with M3R passive acoustics [2], to determine the species, group size, and behavior of the animals. In this manner, vocalizations recorded on the hydrophones are cataloged for future use in the development of species detection, localization, classification, and density estimation (DCLD) algorithms.

The diversity and population sizes of vocal cetacean species at SCORE are significant. Common dolphins (*Delphinus delphis and D. capensis*) are nearly always present in large numbers. Risso's (*Grampus griseus*) and bottlenose (*Tursiops truncatus*) dolphins are common year-round, and Pacific white-sided (*Lagenorhynchus obliquidens*) and northern right whale (*Lissodelphis borealis*) dolphins may be seasonally abundant. Baleen whale species are also present; fin whales (*Balaeanoptera physalus*) can occur year-round, though their movements and seasonal distribution are not well understood. Large numbers of migrating gray whales (*Eschrichtius robustus*) may be present in winter and spring, as well as blue whales (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) during both migratory and feeding seasons. This high diversity provides opportunities to study the effects of Navy operations on a variety of species, but also presents technical challenges- particularly with respect to our focal species, *Zc*.

Past research has described the vocal and diving and movement behavior of both *Zc* and Blainville's beaked whales (*Mesoplodon densirostris, Md*) relatively well. The vocal characteristics of these two species differ in ways that complicate *Zc* click detection. The typical Inter-Click Interval (ICI) is approximately 0.5 seconds (sec) in *Zc* as compared to 0.3 sec for *Md* and has a lower frequency bound of approximately 16 kilohertz (kHz) as compared to 24 kHz for *Md* [3, 4] (Figure 2). The spread of energy below 25 kHz provides an additional challenge classifying *Zc* clicks in the species rich environment at SCORE where clicks from other species are nearly always present and have a similar distribution of energy across this frequency range.



Zc ***Md***

Figure 2. Time (x) vs. frequency (y) for individual echolocation clicks (*Zc* left, *Md* right) for sequences of clicks at different angles relative to the beam center as the animals sweep their head in relation to the hydrophone. The highest level represents clicks closest to the center of the beam, the lowest the furthest from the beam center.

Despite this, M3R has been increasingly successful at localizing *Zc* on SOAR. The introduction of the Jarvis Support Vector Classifier (SVMJ) has greatly improved the system's ability to detect and correctly classify *Zc* foraging dives. In FY13, an initial density estimate for *Zc* at SCORE of 26 animals/1,000 km^2 was obtained using M3R passive acoustic data and group sizes from visually verified detections. It is virtually impossible to derive such an estimate without these combined methods, as visual surveys without acoustic support yield too few sightings, and acoustics without visual verification yield no data on group sizes. While the most attention has been paid to *Zc* in this effort, the same technique can be applied to any vocal species on the range where there is a sufficient number of visually verified acoustic detections to provide data on group sizes and behavioral states as they affect vocal activity. Significant strides have already been made with odontocetes and mysticete species common to SOCAL including Risso's dolphins, Pacific white-sided dolphins, sperm whales, and minke whales and DCL algorithms for these species are being incorporated into M3R tools.

With the 2010 installation of new hydrophones with low frequency capability, the M3R system was expanded to provide low frequency monitoring. The current baleen whale detector is a low frequency variant of the Fast Fourier Transform (FFT)-based detector and provides an analysis bandwidth of 3 kHz with a bin width of 1.46 Hertz (Hz). This has provided the capability of monitoring large baleen whale species such as *Bp* (Figure 3). However, automatic localization of low frequency calls has yet to be implemented and will be addressed by this program.

Figure 3. 2D spectrogram showing fin whale downsweep from approximately 30 to 20 Hz. The x-axis spans 30 seconds with frequency from 0 to 50 Hz on the y-axis.

As part of these tests, researchers from Cascadia are also collecting identification photographs and affixing tracking and depth recording tags to animals to document the movements, and in some cases diving behavior, of tagged individuals both on and off the SOAR range. Prior to this project, there were virtually no data regarding the population structure of *Zc* or *Bp* in the outer waters of the Southern California Bight. Animals in the SCORE area have been managed as part of low-density populations distributed along the western US coast based on the best available data prior to the methods being developed here. Photo-identification of these species can be challenging. Both have relatively low and variable sighting rates, and *Bp* can be notoriously difficult to individually identify. Work to date suggests that the current population definitions are inaccurate, and that smaller local sub-populations exist at higher densities than previously reported.

The satellite tags used in this study are designed to collect and transmit data for periods of weeks or months. Since 2008, Cascadia Research staff have deployed 96 tags on eight species during this and other related projects in Southern California (Table 1), with an emphasis on *Zc* (2 location-only and 17 location-depth tags) and fin whales (40 location-only, 13 depth-location). Using both photo-ID [2] and tags [5, 6], this study has documented the recurrent and prolonged use of the waters off southern California by both species, but *Zc* in particular exhibit unusually high site fidelity to SOAR . For *Zc* tags deployed on SOAR, the average distance to tagging location was less than 50 km throughout the transmission period for 18 tagged whales, despite occasional long-range movements and the frequent use of MFA sonar in the region (Figure 4). Two *Zc* tagged in the Catalina Basin further demonstrate the degree of site-fidelity this species may exhibit (Figure 4). This is of particular importance given the evidence of *Zc* strandings in association with navy sonar elsewhere [7, 8]. This combination of site fidelity and operational tempo creates opportunities to observe the movements and diving behavior of tagged whales during actual MFA sonar operations, and document any associated change in movement and dive behavior with extended samples of unbiased baseline behavior before and after the exposure. This process is currently underway for tags deployed in 2010-2014.

In total, the methods developed and the datasets collected to date can provide the basis for long-term monitoring of cetaceans at a variety of temporal and spatial scales. Both visual and acoustic data are being used to document the temporal and spatial trends in species assemblages, and their continued use can begin to document changes therein. Photo-ID catalogs are being compiled to improve our understanding of population size and structure. Satellite tags provide unbiased measures of habitat usage and refine the assumption and range boundaries essential to successful mark-recapture estimates based on photo-ID data, in addition to measuring foraging rates and reactivity to naval operations. All these pieces are required to derive accurate risk functions for the future management of these populations, and this proposal represents a proven, integrated path forward.

Table 1. Tags deployed by Cascadia Research in Southern California from 2008 to present, during previous efforts at SCORE or other collaborative efforts in the region

Species	Tags Deployed	Mean Transmission Duration (Days)	Range Transmission Durations (Days)
Baird's Beaked Whale	1	31	31
Blue whale	3	104	23-189
Bottlenose Dolphin	1	6	6
Cuvier's Beaked Whale	23	44	7-122
Fin Whale	53	35	1-240
Killer Whale	7	51	9-147
Risso's Dolphin	10	12	5-20
Sperm Whale	2	51	10-91

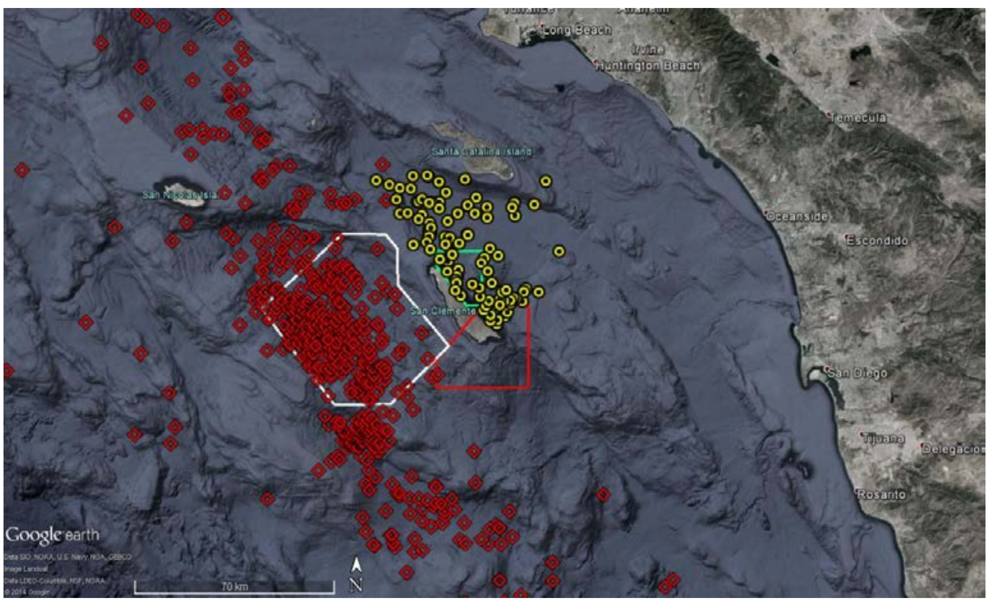


Figure 4. ***Map of Zc daily tag locations centered around the study area*****. Red circles indicate locations from 16 whales tagged within the SOAR boundary (outlined in white) Yellow circles represent locations from two whales tagged in the Catalina Basin. Some whales tagged on SOAR conducted extra-regional movements, but the vast majority of locations were received from within the San Nicolas Basin**

Localization and Tracking

Significant development of both classification and localization algorithms occurred via parallel programs. The SVMJ classifier has been ported to the system [9]. The SVMJ has proven particularly effective at classifying *Zc*. This has enabled the development of semi-automated tools for the identification of *Zc* groups and by doing so enabled estimation of *Zc* density and habitat mapping.

In 2013 an advanced beaked whale localization algorithm was developed [10] and a prototype real-time version was completed. The algorithm will potentially increase the localizations of beaked whales thus improving our ability to study these animals during exposures and increasing the probability of vectoring tagging RHIBs to the animals.

Zc-Grouping Software

A week of detection archives from 2012 were manually analyzed. From the manually extracted data, an initial density estimate of approximately 26 animals/1,000 km^2 was calculated based on the group counting method described in Moretti *et al.* (2010). An estimate for 2013 and 2014 is underway.

Semi-automated auto-grouper code that isolates Zc groups of foraging beaked whale from M3R detection archives is being examined for correct grouping to species. Data are being examined by hand through 2D spectrogram examination and compared to groups isolated by the auto-grouper software. 94% of the auto-grouper groups were correctly identified as *Zc*. The Group Vocal Period (GVP) distribution as produced by the auto-grouper code is shown in Figure 5.

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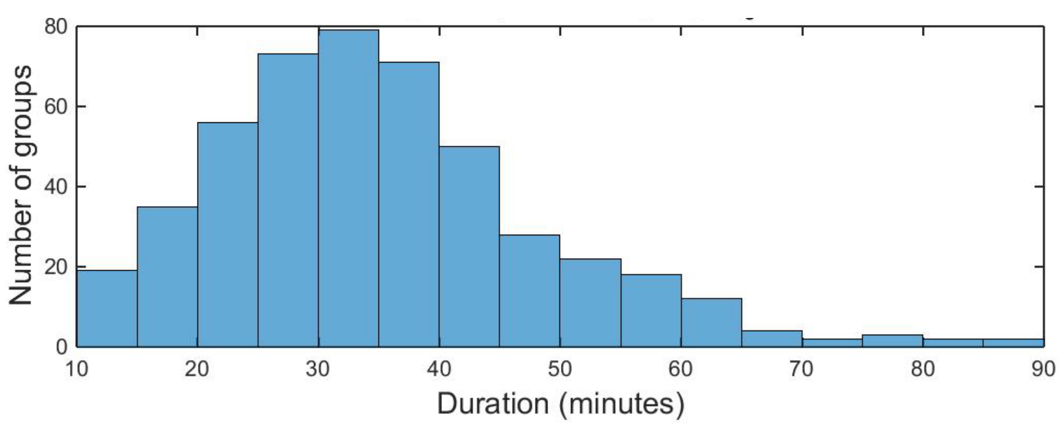

Figure 5. Distribution of Group Vocal Period (GVP) duration as produced by auto-grouper code.

The long-term measurement of abundance, habitat use, and the population level response to sonar can be inferred from *Zc* GVPs, For example, eight months of 2013 M3R detection archives were analyzed for GVPs. These data suggest a reduction in abundance during the summer with a minimum in August. These data are being combined with the mean group size derived from on-site sighting data and mean dive rate derived from satellite tag data. A significant photo-ID database is being compiled. An initial abundance estimate based on mark/recapture may be possible. When available, the estimate derived from passive acoustics will be cross-validated with estimates based on sighting data.

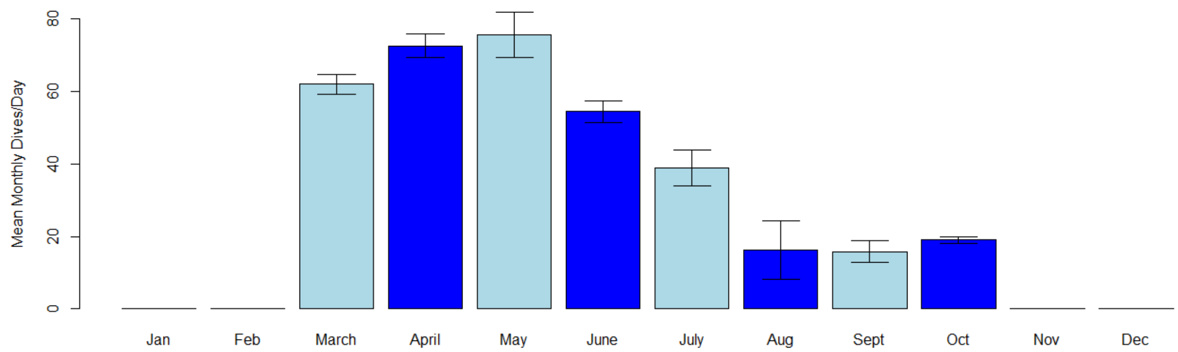

Figure 6. Mean daily dive rate per month derived via M3R passive acoustic detection archives and auto-grouper code. Note: the months of November to February were not analyzed.

Zc Risk Function

In 2013 and 2014 data collected around sonar operations and ship tracks were obtained from SCORE. The SVMJ and the validated auto-grouper tool are being used to extract *Zc* groups before, during, and after these periods. These data will be used to investigate large scale movements of *Zc* along the lines of McCarthy *et al.* (2010).

A risk function of *Zc* using the method described for *Md* by Moretti *et al*. [11] was initiated in FY14. M3R detection archives were collected along with ship tracks during active sonar operations. The ship track data are being combined with sonar data derived from the acoustic archives and used in the NAEMO effects model to estimate the level at the location of detected *Zc* groups. This analysis will be extended to include levels on the hydrophones throughout SOAR were coincident M3R archives are available. *Zc* groups are being extracted and the maximum exposure level for each dive estimated. These data will then be applied in an effort to estimate the *Zc* risk function.

Mid-term reaction (days to weeks) to MFA sonar

Acoustic monitoring can capture data on group foraging cessation in association with sonar exposure, and previous studies of *Md* suggest they likely move off the range when foraging ceases. However, if this also occurs with *Zc* on SOAR, the extent of their movement and the duration of foraging disruption cannot be derived from passive acoustic monitoring. To overcome this limitation, satellite tags with depth recording capabilities will be affixed to animals, with a focus on *Zc*. These tags can provide a record of X,Y movement with diving behavior for up to two months.

A block diagram of the general methodology for using tag data to assess reaction to MFA is presented in Figure 7. Tags are attached to animals and provide both X,Y track and dive data. Instances of coincident sonar activity are obtained from SCORE. Based on both the animal and source ship position, the receive level at the animal is estimated through the application of the Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS/GRAB) propagation model. Both the track and dive data are then analyzed for behavioral changes as compared to baseline data with no sonar present.

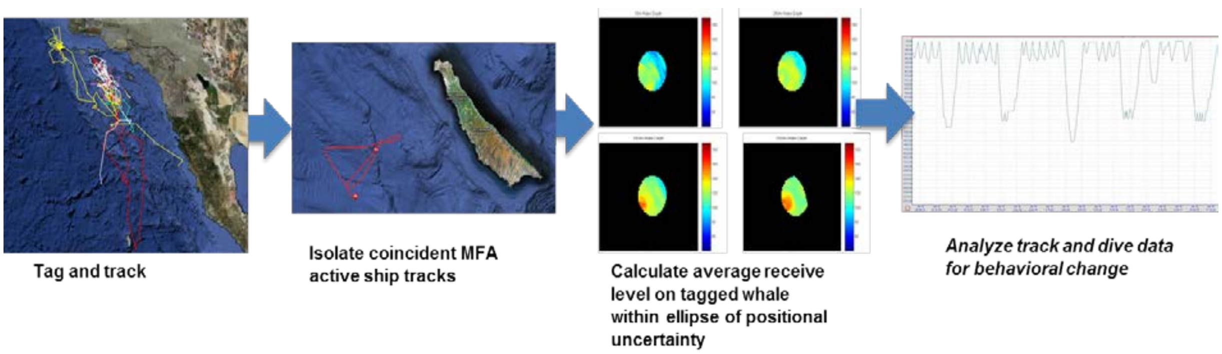

Figure 7. Satellite tag analysis of *Zc* reaction to MFA . The first image on the left shows *Zc* X,Y tracks with each color representing a unique individual. The second image shows the X,Y location of a ship with known times of MFA sonar ping emission. The third image shows the maximum RMS receive level at a 4 depths over the duration of the exercise at a concurrent animal location estimate. The fourth image is time vs depth during a tag deployment on *Zc*.

The Wildlife Computers SPLASH10 (previously referred to as the MK10A) tag remains a relatively new and developing technology, and was recently redesigned to address some hardware failures in earlier versions. During good conditions with range support we have deployed up to three tags on this species in a single day. Deployment of tags provides a means of investigating the reactive behavior in other range species (see below).

The lossy nature of Argos data, particularly from *Zc*, is a factor that has confounded analyses of sonar reactions in earlier tags, but is being addressed in this work. Tag positions derived solely from Argos transmissions (as is the case for the existing technology, though an improved GPS-based system is under development now) may have high uncertainty and thus need to be filtered and/or modeled to provide a comprehensive track with an estimate of location error. Dive data consist of both behavioral logs that provide the start, stop and maximum dive depth, and a time-series of depth at a 1.25 or 2.5 min interval. Dive data are packaged into Argos messages and transmitted at the surface. While messages are sent multiple times to increase the probability of a satellite being overhead to receive the message during the brief periods when a beaked whale is at the surface, some messages are not received and dive data are lost when data are received by satellites alone. In November 2012, experiments began with a pair of land-based Argos-receiving stations on SCI to improve dive data recovery. In 2014, a new Argos receiving station was beta-tested with extremely positive results. Funding for the new technology for the San Clemente station needs to be identified as the unit is currently on loan. A second installation on San Nicolas Island completed in January 2015 will dramatically increase dive data recovery throughout the range most tagged animals have historically used, and effectively reduce the limitations data gaps have presented in earlier analyses.

The second body of data needed to track reactions to sonar using satellite tags is a comprehensive record of sonar use from the times and locations that tags are active. Navy sonar logs have not been consistent enough to ensure that ships are not transmitting when off-range. Therefore, this analysis has been, and will likely continue to be, limited to instances of sonar use on or near SOAR, where transmissions can be verified using passive acoustics (2010-2011 are nearly complete, 2012-2013 are in process). For these exercises, sonar pings are isolated from the M3R detection archives. These sonar ping times are being combined with precise ship tracks provided by range archives. Exposure RMS levels are then estimated using CASS/GRAB. This was initially done at 5 different depths randomly distributed throughout an ellipse of uncertainty around the animal's position, as derived from a state-space model. A new method is currently being tested, where levels would instead be modeled across a standardized grid which would allow for more flexibility in post-processing and statistical analyses.

Alternate Species and Tag Types

As the "most sonar sensitive" species, *Zc* is the focus of this study. However, low sea-state conditions are required to sight and tag *Zc* and a minority of weather days provides such conditions. The new hydrophones at SCORE allow monitoring of baleen whale species with low-frequency vocalization, as well as additional odontocete species. During scheduled tests, alternate species, especially *Bp* (given their prevalence on the range and endangered status) and Risso's dolphins (as another deep water odontocete that is not well-studied) are being targeted with SPLASH10 tags when conditions do not support *Zc* tagging.

Data from a March 2012 *Bp* tag are presented in Figure 8 as an example. The data indicated the animal moved primarily along the western half of the range. Its dive profile shows the animal spent over 70% of the time within 20 m of the surface, which may have significant implications regarding the possibility of ship strikes. All depth-reporting tags have been deployed on *Bp* during winter or very early spring. Therefore, *Bp* will be specifically targeted for tag deployments in the summer and fall to compliment this dataset. As with *Zc*, these track and depth data are being combined with opportunistic sonar exercises to begin to characterize the animals' reactions to MFA sonar and other types of exercises.

We also propose to deploy a smaller number of SPOT5 location-only transmitters on *Bp* and less-common species on the range whose distribution is poorly understood in the region (Baird's beaked whales, pilot whales, and killer whales if sighted). SPOT5 tags cost 30% less than SPLASH10 tags, and though they cannot provide dive data, previous deployments had average transmission durations that are three times longer- with several tags lasting 6 months- and are thus more suitable for addressing movement and distribution patterns over longer distances and durations. This will augment previous long-term data from fin whales in Southern California, which have thus far failed to reveal any obvious migratory patterns, and which may be an important finding in and of itself.

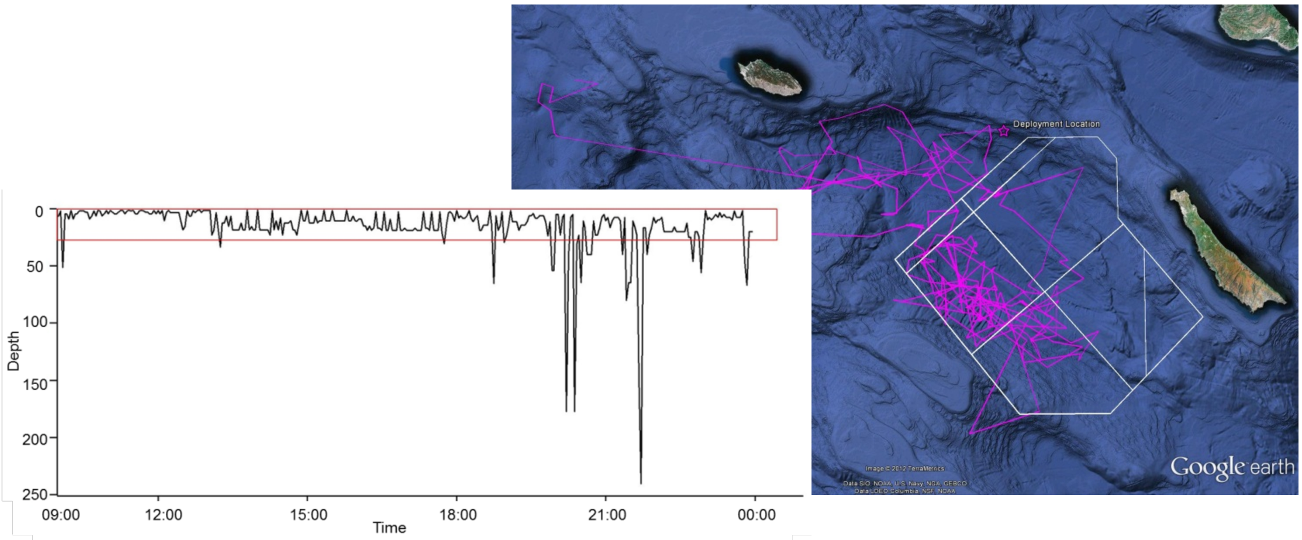

Figure 8. Fin whale depth plot from 0900 to 0000 (left). The animal spent 70% of the time above 20 m as highlighted in red. The satellite track is presented on the right with the SOAR boundaries shown in white.

Defining affected populations using photo-identification

We hope to continue collecting, processing, and integrating identification photographs from *Zc* and fin whales into existing catalogs at Cascadia. When adequate samples are obtained for range populations, these data will be used to refine population estimates and stock identity, assess site-fidelity (a key parameter in understanding cumulative population level impacts) and describe demographics, such as reproductive rates.

Summary

Analysis of these data provide a means of addressing the ultimate "so what" questions: what impact does military training have on sensitive species, how long does it last, and what does it mean for the population? This study has documented the persistent presence of *Zc* in an area of repeated sonar use, and suggests these whales may actually be part of a smaller regional subpopulation rather than transient members of a large and dispersed west coast stock. By applying the methodology developed at AUTEC and combing passive acoustic data with ship track data, a risk function can be derived which maps RMS exposure level to disturbance where disturbance is defined as foraging cessation. To quantify disturbance, changes in dive behavior and movement as a function of exposure level must be determined. Satellite tags provide a means measuring these changes.

Although individual *Zc* are observed persistently and repeatedly inside SOAR boundaries, it is unclear if the operations there affect population health. Preliminary analyses of behavior in the presence of sonar have captured some potential responses, but these appear to be complex and contextual, involving varying degrees of displacement and changes in diving behavior. It is possible that although animals may be displaced by sonar use, the extent of their movement is minimal and their foraging is unperturbed- though without additional data on prey density or capture rates, it can't be certain if productivity and/or foraging success are equal in adjacent areas. It is also possible the area represents a population sink and that new animals from outside the area or younger animals are more negatively affected by sonar exposure than older, resident animals that are familiar with the signal. The animal tracks and photo-identification data can help answer these essential questions.

A Population Consequence of Acoustic Disturbance (PCAD) model uses an energetics approach to determine the cumulative effect of repeated disturbance due to sonar. The model will apply the risk function to sonar operations over an entire year, and knowledge of the number of dives lost as a function of sonar exposure. The total daily caloric intake is represented by the foraging dives the animal completes in a day. Given the repetitive nature of beaked whale dives, by considering the extent of disruption for each exposure, the number of dives lost and hence calories lost can be estimated. By focusing along maternal lines, the effect on calf production can be estimated. This in-turn is used to predict population health.

With a defined risk function, an understanding of disturbance, and a refined population definition, PCAD model may eventually be applied to *Zc* at SCORE.

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