Marine Mammal Monitoring on Navy Ranges (M3R)-

Southern California Offshore Anti-submarine Warfare Range (SOAR)

FY12 Test Summary

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Introduction

During FY2012, with funding provided by the Chief of Naval Operations (CNO) N45 Energy and Environmental Readiness Division, the Marine Mammal Monitoring on Navy Ranges (M3R) program carried out several acoustic monitoring efforts to determine the spatial and temporal distribution of cetacean species on the Southern California Anti-Submarine Warfare (ASW) Range (SOAR) , to document the reaction of these species to sonar with a focus on beaked whales, and to provide a means of long-term passive acoustic monitoring. Specifically, M3R participated in a number of marine mammal species visual verification and tagging tests, ONR-sponsored glider tests, the SOCAL 2011-12 Behavioral Response Study (BRS), and for the first time conducted low-frequency acoustic monitoring of baleen whales.

M3R Hardware and Software

The Southern California Range Complex (SOCAL) provides tactical training and test services to U.S. Navy units of the Pacific Fleet. Within SOCAL, SOAR is located 68 miles from San Diego in the San Nicolas basin west of San Clemente Island and encompasses a 3-D underwater tracking area of approximately 670 square nautical miles (Figure 1).

SOAR is equipped with 172 bottom-mounted hydrophones deployed in offset rows to form hexagonal arrays. The array design is optimized for tracking undersea vehicles equipped with a pinger that emits a signal at a known repetition rate with a source level of ~192 dB re µPa@1m and frequency of ~37 kHz. This arrangement of hydrophones is also well suited for detection of marine mammal vocalizations including those produced by beaked whales.

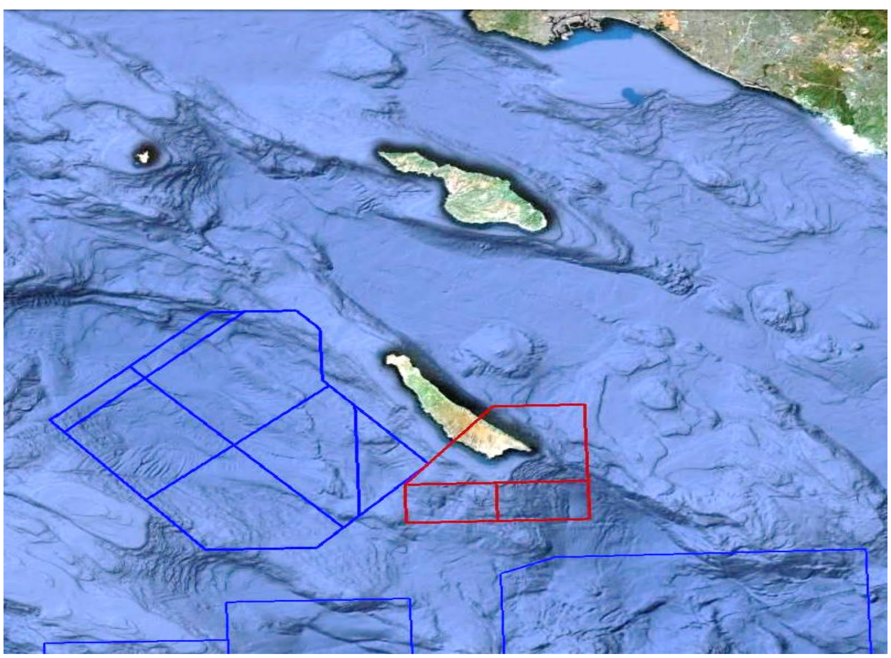

Figure 1. The SOAR range is defined by the blue boundary to the west of San Clemente Island.

Analog data from the bottom mounted hydrophones are processed by the M3R system as shown in the system configuration diagram, Figure 2 (Jarvis *et al*., in review). Processed data from the hydrophones, including precisely time-tagged detection reports, are stored in an integrated archive file. M3R tools are used to monitor these data in real-time and for post-exercise analysis.

During the tests, on-shore analysts observed and characterized species' vocalizations using the M3R utility "MMammal". This utility allows the user to monitor range activity and to view, on demand, binary spectrograms (2D time-frequency plots) for hydrophones of interest. Hydrophones are sampled at 96 kHz which provides an analysis bandwidth up to 48 kHz. Detection reports are generated from the output of a simple Fast Fourier Transform (FFT) based detector. An adaptive threshold (exponential average) is run in each bin of the FFT. If there is energy over the adaptive threshold, the bin(s) is set to a "one" and a detection report is generated. These reports are then archived and used to form the range monitoring displays. Animal vocalizations are detected, classified and localized automatically using the methods described in Morrissey *et al*. 2006. The data are then interpreted by a trained M3R analyst and used to direct at-sea observers to locations of marine mammals on the SOAR acoustic range.

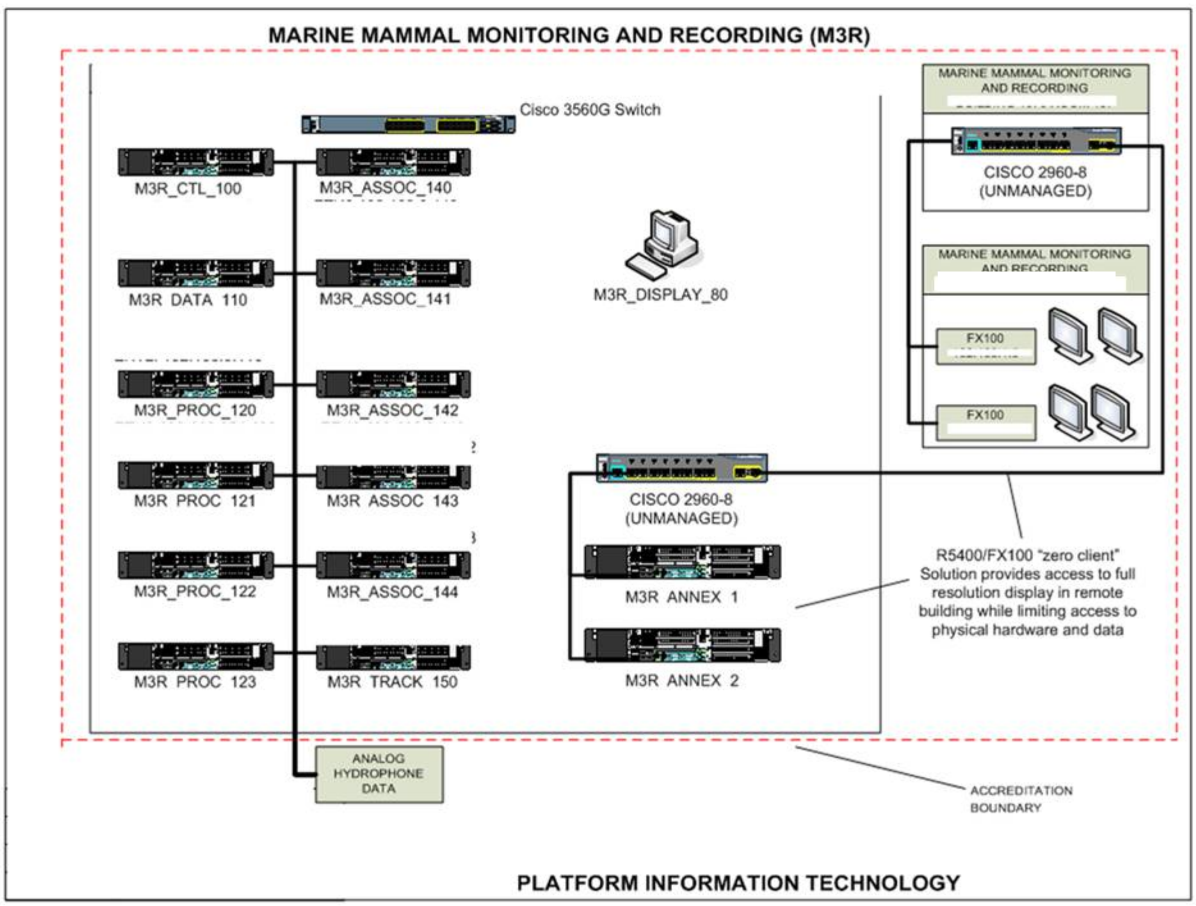

Figure 2-SOAR M3R System Configuration Diagram

Results

Species Verification and Marine Mammal Sighting Logs

Marine mammal sighting logs were provided by two groups. COMPACFLT provided aerial sighting logs for the SOCAL region for 2011-2012 as part of the on-going Integrated Comprehensive Monitoring Plan (ICMP) and Cascadia Research Collective (CRC) provided shipboard marine mammal visual sightings logs from SOCAL for 2011-2012. Table 1 contains the total number of aerial observations carried out by COMPACFLT over the entire SOCAL region. The observations are further broken down into those that occurred on the instrumented SOAR range, and into the number of observations that occurred when hydrophone data were being recorded and archived. When both data sets were available, visual observations were compared to acoustic observations. Table 2 documents those species which were identified both visually and acoustically. A similar breakdown is provided in Tables 3 and 4 for the at-sea observations carried out by CRC on the SOAR range.

2011 Aerial Surveys: 14 Feb- 14 May 2011	**number of observations**
Total aerial visual sighting	n=371
Aerial Sighting on SOAR	n=9
Aerial Sighting on SOAR with hydrophone data	n=1
2012 Aerial Surveys: 30 Jan- 1 Apr 2012	**number of observations**
Total aerial visual sighting	n=513
Aerial Sighting on SOAR	n=13
Aerial Sighting on SOAR with hydrophone data	n=13

Table 1. Aerial Survey Data for 2011 and 2012 (courtesy of Smultea et al. 2012)

Year	**Common name**	**Scientific name**
2012	Risso's Dolphin	*Grampus griseus*
2012	Gray whale	*Eschrichtius robustus*
2012	Fin whale	*Balaenoptera physalus*
2012	Northern right whale dolphin	*Lissodelphis borealis*
2012	Unidentifiable species	
2011	Short-beaked common dolphin	*Delphinus delphis*

Table 1-Species sighted aerially and acoustically observed

2011-Jan, May, Jul and Sep	**number of observations**
Total shipboard visual sightings in SOAR region	n=65
Total shipboard visual sightings on SOAR with corresponding hydrophone data	n=13
2012- Jan and Mar Shipboard visual sightings	
Total shipboard visual sightings in SOAR region	n=67
Total shipboard visual sightings on SOAR with corresponding hydrophone data	n=26

Table 2-Shipboard marine mammal visual verification on SOAR region (courtesy of Erin Falcone and Greg Schorr, Cascadia Research Collective)

Year	Common name	Scientific name
2012	Risso's Dolphin	*Grampus griseus*
2012	Humpback Whale	*Megaptera novaeangliae*
2012	Cuvier's Beaked Whale	*Ziphius cavirostris*
2012	Northern right whale dolphin	*Lissodelphis borealis*
2012	Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
2012	Gray whale	*Eschrichtius robustus*
2012	Killer whale	*Orcinus orca*
2012	Common dolphin	*Delphinus sp.*
2012	Fin whale	*Balaenoptera physalus*
2011	Cuvier's Beaked Whale	*Ziphius cavirostris*
2011	Gray whale	*Eschrichtius robustus*
2011	Dall's Porpoise	*Phocoenoides dalli*

Table 3-Species sighted from shipboard surveys and acoustically observed

Those species which were detected both visually and acoustically on the M3R hydrophones are discussed below.

Short-Beaked Common Dolphin (Delphinus delphis)

Delphinus delphis is routinely acoustically detected and visually verified at SOAR. *D. delphis* produces both whistles and clicks. Whistles are often used to identify this species as described by Oswald *et al., 2003*. The whistles may consist of both downsweeps and upsweeps that typically span a frequency bandwidth of 8.0-16.0 kHz as shown in Figure 3 and Figure 4.

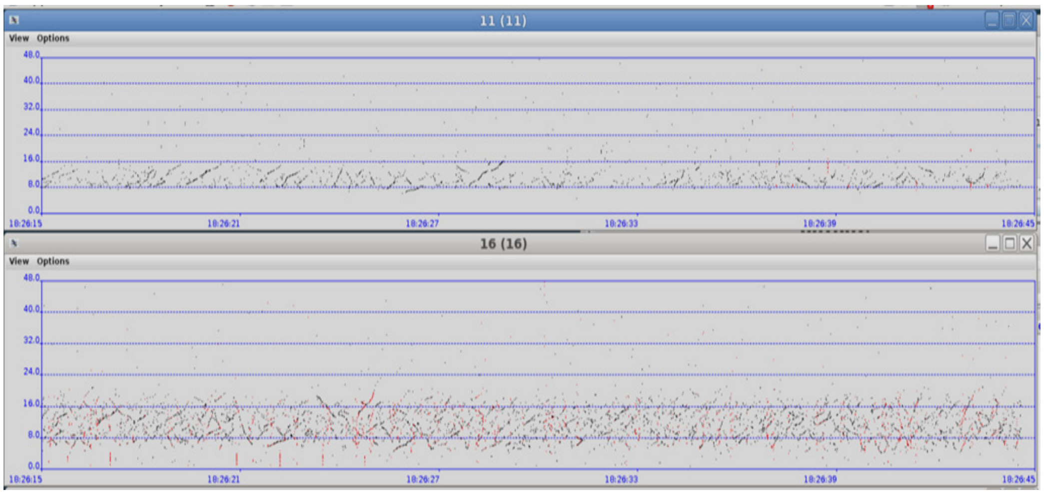

Figure 3. Whistles from *D. delphinus* detected on hydrophones 11 and 16.

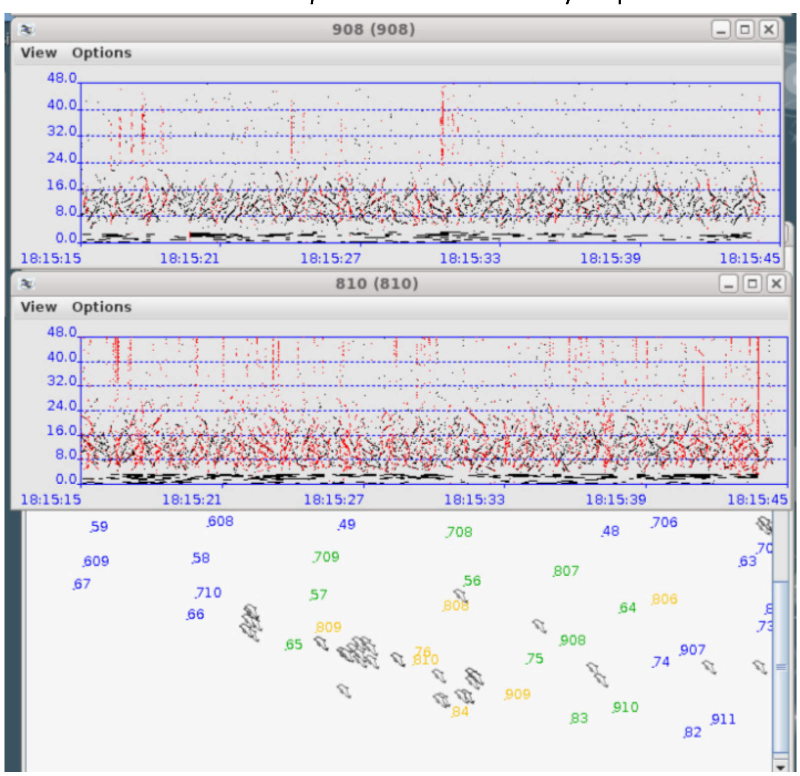

Figure 4- *D. delphis* whistles as shown on 2-D spectrograms (top and middle) with localized position (dolphin icons) on bottom

Risso's Dolphin- *Grampus griseus*

Figure 5 includes three binary spectrograms along with an estimate of position based on click time-of arrivals on three hydrophones of visually verified, *G. griseus* vocalizations. The position is in the vicinity of the visually observed *animals*. *G. griseus* vocalizations are similar to other sub-species such as Pacific white-sided dolphin (*Lagenorhynchus obliquidens)*, (Soldevilla *et al*. 2008).

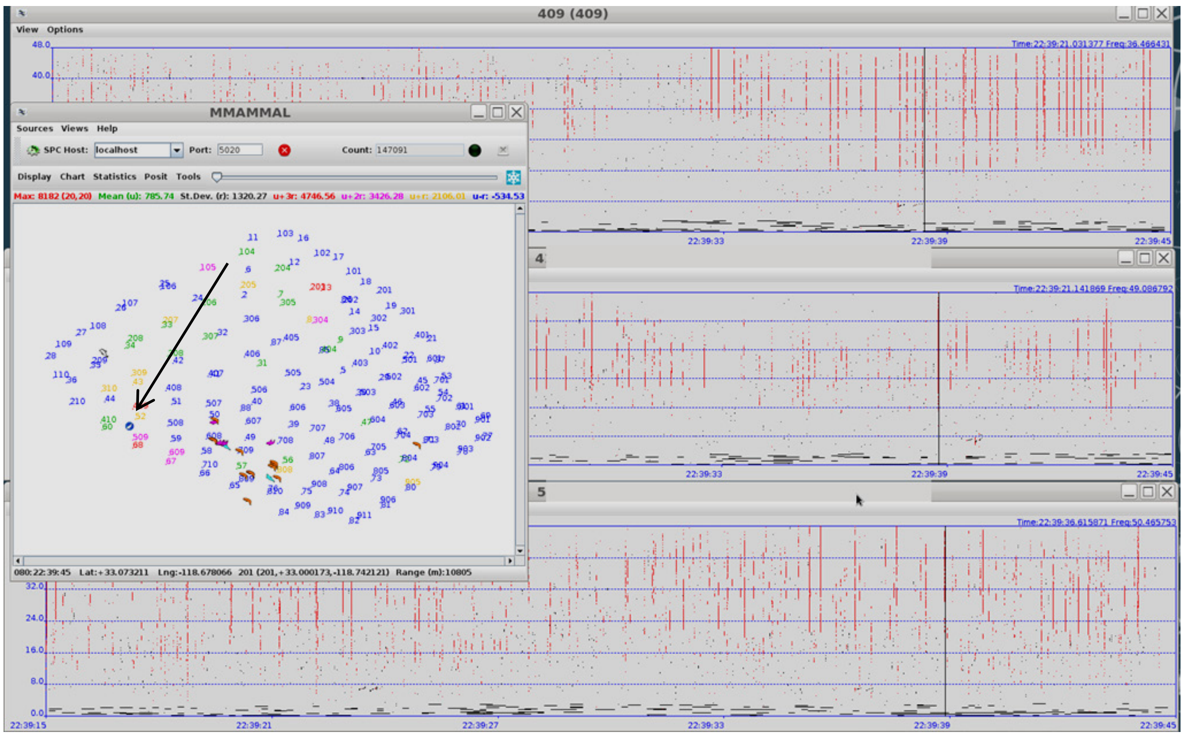

Figure 5- Binary spectrograms of *G. griseus* clicks with a localized position in the vicinity of the visual sighting (left) as indicated by the arrow.

Gray Whale-*Eschrichtius robustus*

Visually verified *Eschrichtius robustus* vocalizations consistent with documented *E. robustus* vocalizations (Crane *et al*., 1996) were isolated using passive acoustics. Crane *et al.* (1996) separated *E. robustus* vocalizations into four categories: pulses and bonging, low-frequency moans, moans with a zipper like sound, and subsurface exhalations and bubble blasts. Low-frequency moans, pulses and bonging are among the most commonly observed and were also observed on SOAR.   Figure 6 illustrates pulses and/or bong signal types with an observed frequency range between 30-1400 Hz (left). The arrow points to the localization derived from time of arrivals in the vicinity of the position reported by the visual observers. Figure 7 represents an *E. robustus* low-frequency moan.

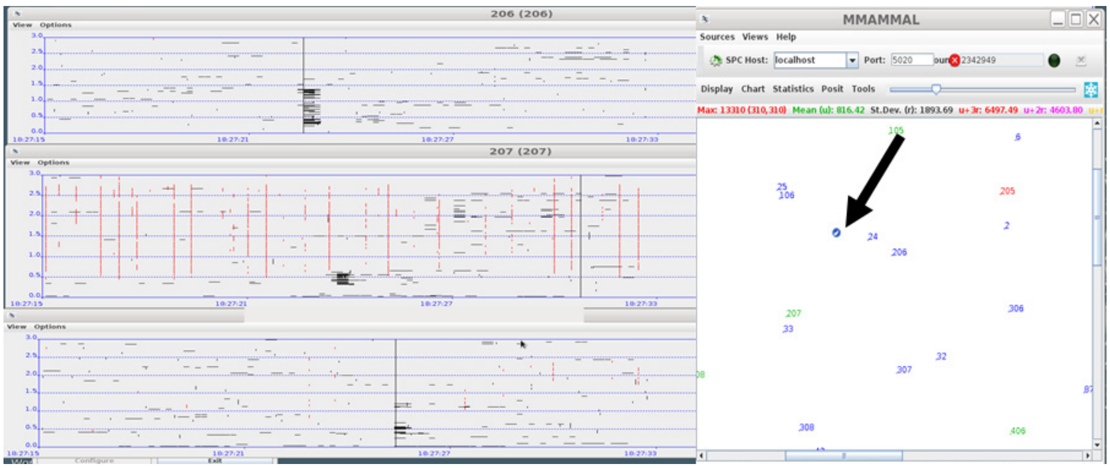

Figure 6- *E. robustus* bond/pulse call on left with a localized position using TDOA on the right .

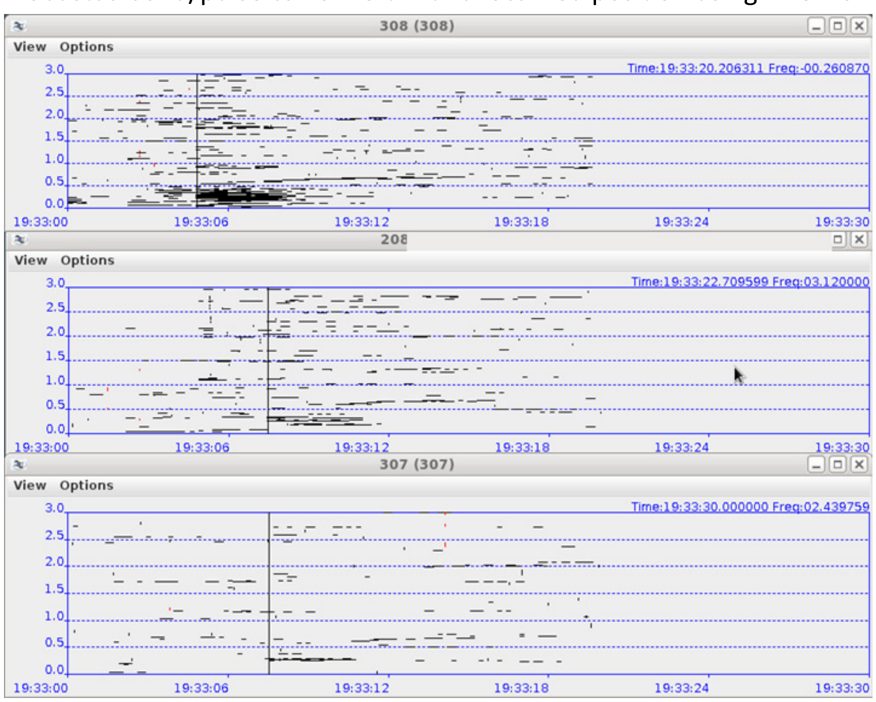

Figure 7- Low-frequency moan of *E. robustus* most apparent in H308 (top).

Northern Right Whale Dolphin *(Lissodelphis borealis)*

Lissodelphis borealis was acoustically observed by the burst-pulse vocalization as described in Rankin *et al.*, 2007(Figure 8). The red box indicated the area of the visual observation. The Inter-Click Interval (ICI) (~180 msec) and click frequency (>20 kHz) are consistent with past visually verified observations of this species on SOAR.

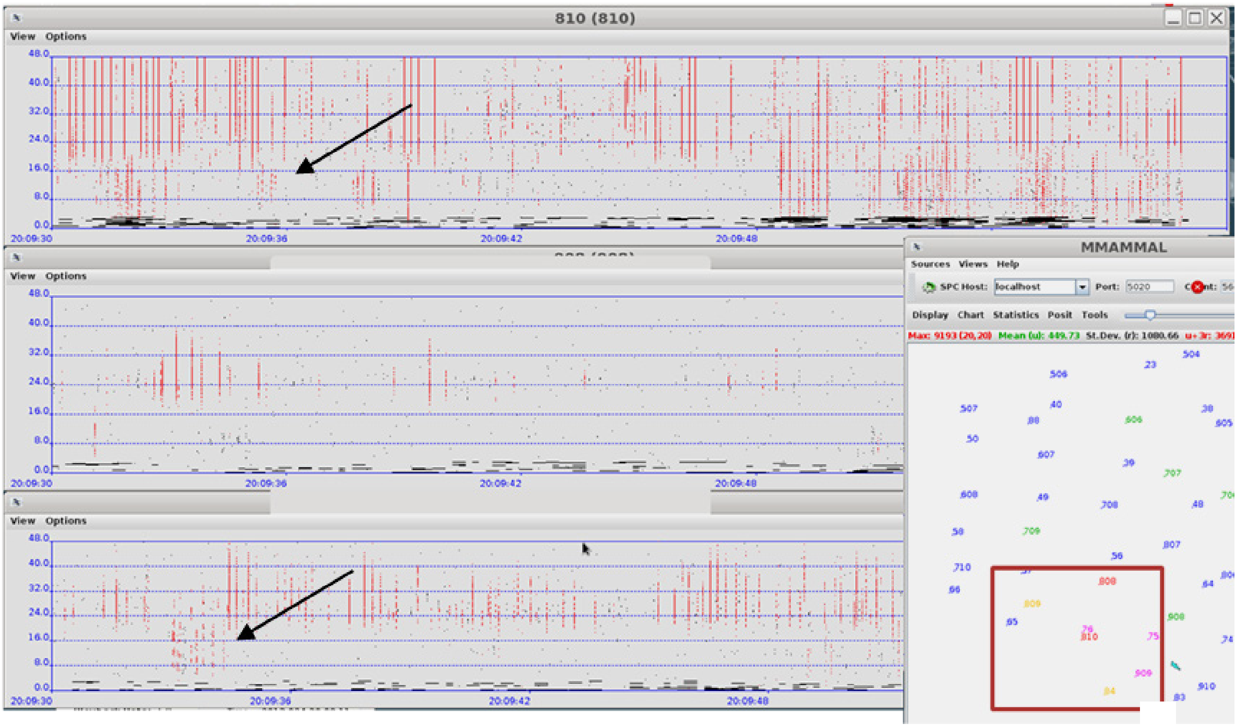

Figure 8- *Lissodelphis borealis* burst-pulse vocalization (arrows) and observed area indicated by with the red box.

Fin Whale (*Balaenoptera physalus*)

Balaenoptera physalus vocalizations have a distinct downswept 20Hz pulse as observed by Thompson *et al*., 1992. Figure 9 illustrates the downswept 20Hz pulse with a frequency range between 30-20 Hz. The vocalizations were used to localize individuals and vector observers to verify the species.

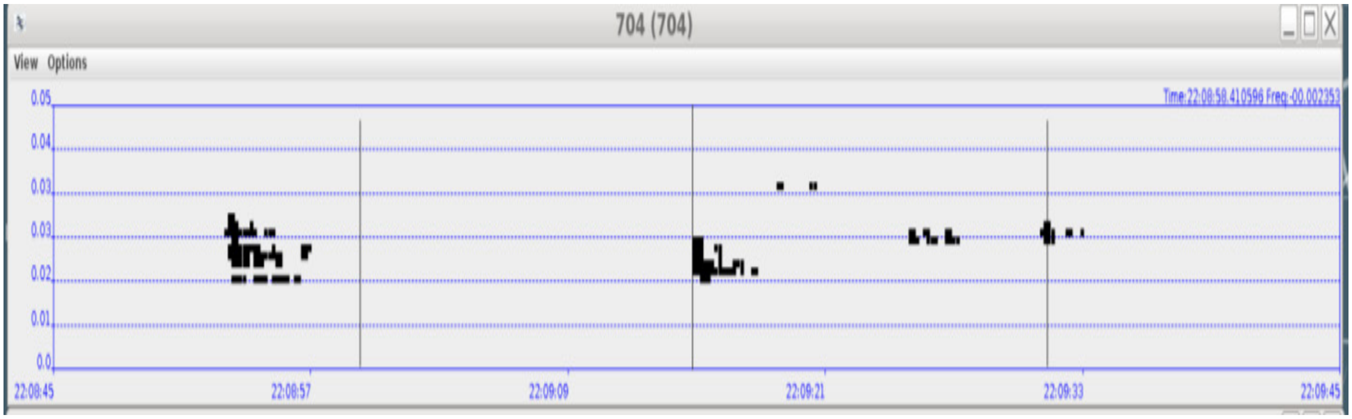

Figure 9- *B*. *physalus* 30-20Hz downsweep.

Humpback Whale (*Megaptera novaeangliae*)

Megaptera novaeangliae are known for their extensive acoustic repertoire. Figure 10 are assume to be the vocalization of *M. novaeangliae* which was localized in the vicinity of the visual observed species and was within frequency range that was reported by Stimpert *et al.*, 2011.

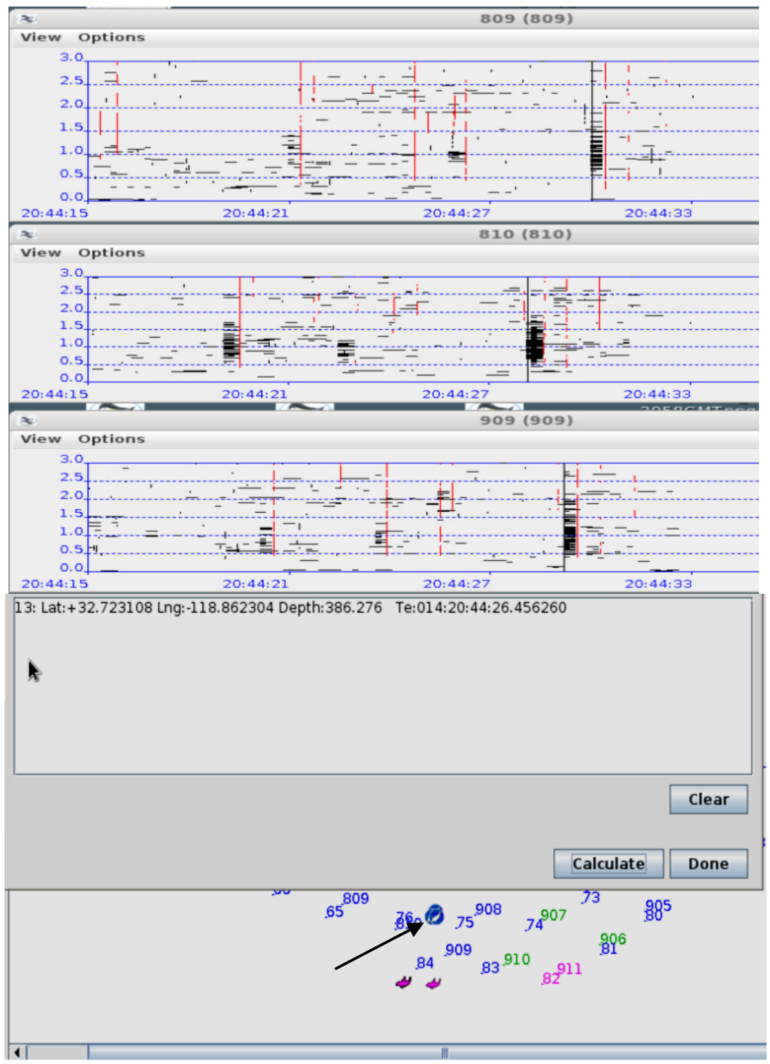

Figure 10- *Megaptera novaeangliae* vocalizations on three hydrophones (top) with calculated latitude and longitude (lower-top) and localized position (lower arrow)

Cuvier's beaked whale (*Ziphius cavirostris*)

Z. cavirostris is routinely detected and isolated on SOAR using M3R passive acoustics (Figure 11). Passive acoustics was used successfully to direct observers to animals for both the attachment of satellite tags and to animals during the 2011 BRS for attachment of a suction-cup recording tag. Currently, passive acoustics is being used to identify the spatial and temporal distribution of this species before, during, and after sonar. In addition, a density estimate for Z. cavirostris on the SOAR range is being compiled using passive acoustic methods.

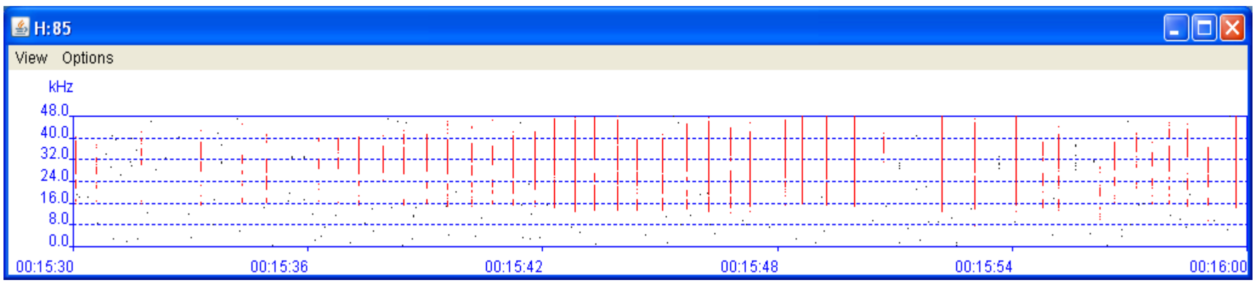

Figure 11. 2D *Z. cavirostris* spectrogram.

Killer whale (*Orcinus ocra*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Dall's porpoise (*Phocoenoides dalli*)

During the initial 2011-2012 data analysis, three species could not be identified using passive acoustics. These included killer whales (*Orcinus ocra*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and Dall's porpoise (*Phocoenoides dalli*).

It should be noted that during past tests, *L. obliquidens* has been visually identified and full bandwidth recordings have been made. Because of the similarity with other subspecies, especially *G. griseus*, analysis with full, wideband data may be necessary. M3R provides the ability to monitor selected hydrophones in real-time with full time and frequency domain analysis tools including Cornell University's Raven software. Also, there are multiple active programs that are working on the development of real-time small odontocete classifiers to run under the M3R architecture.

Passive Acoustic Density Estimation

Multiple techniques for estimating the density of Blainville's beaked whales (*Mesoplodon densirostris*) have been developed at the Undersea Test and Evaluation Center (AUTEC) and are being adapted for Z. cavirostris at SOAR. Passive acoustic techniques for estimating the density of other small odontocetes, especially delphinid species, is an ongoing challenge. The aerial surveys that were completed as part of the ICMP can be combined with M3R passive acoustic data and used to develop methods of passive acoustic density estimation. The critical first step in this development is to correlate acoustic behavior to physical behavior and group size.

Tests with Tags

Tagging efforts required the use of real-time M3R passive acoustic monitoring to detect, classify and localize vocalizing marine mammals on the SOAR range. Once a species of interest was detected, typically Cuvier's beaked whale, personnel from CRC were vectored to the animals in an attempt to attach satellite tags. The tags provide a record of animal movement and dive behavior that is being studied during before, during, and after sonar operations. In FY12, opportunistic passive acoustic and tag data were collected with and without active sources present on range and are being compared to ship tracks associated with Mid-Frequency Active (MFA) sonar. Satellite tags were successfully placed on individual "sonar sensitive" Cuvier's beaked whales (*Ziphius cavirostris*) along with several additional species. Data from these opportunistic experiments are presently being analyzed and will include a calculation of receive level on individual tagged animals in the presence of active MFA.

ONR Glider Test

M3R passive acoustics methods were used to locate and identify beaked whales in support of the ONR glider tests for the detection of beaked whales at SOAR. Such semi-autonomous devices may provide a future means of acoustic density estimation, but it is critical to measure the detection capability as a function of distance before such survey methods can be developed. Comparison of *in-situ* glider detection statistics to M3R baseline data provides a means of estimating this detection capability.

Figure 12 illustrates both the number and distribution of groups of vocalizing Z. cavirostris present on the SOAR range during a 5-day time period in January 2011.

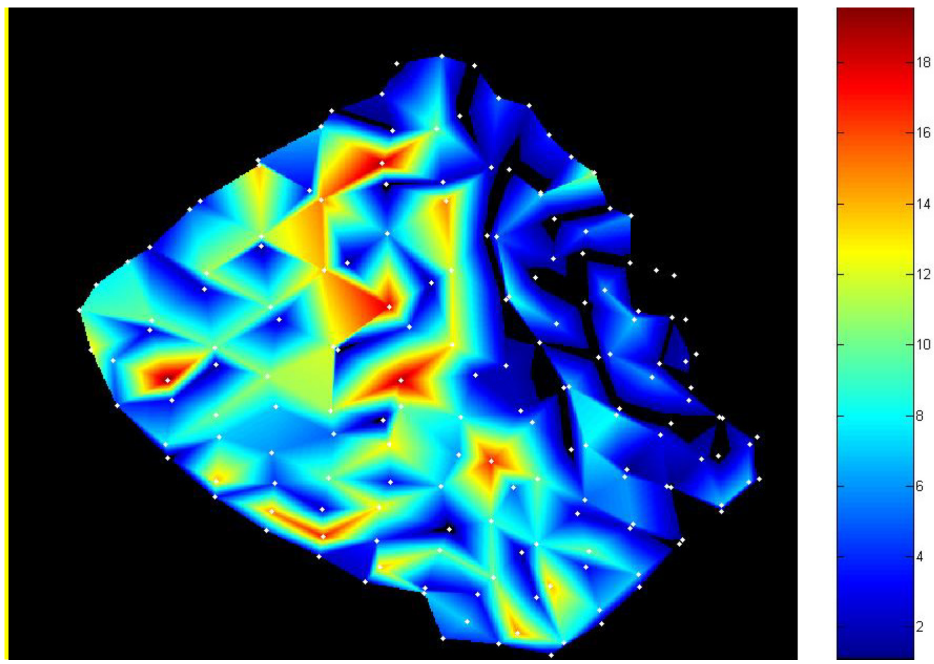

Figure 12. Number of vocal groups present on the SOAR range during the ONR-sponsored glider tests. This image was created by plotting the number of times a hydrophone was at the center of a vocalizing group and using a linear interpolation in MATLAB. The color bar indicated the number of center hydrophones per vocal group period

SOCAL Behavioral Response Study

M3R's ability to monitor acoustic activity on range in real-time contributed to the on-going SOCAL Behavioral Response Study (BRS) experiment. The BRS is designed to measure the reaction of animals to directed playbacks of sound. Recording tags are attached to animals of interest and a playback is executed from a portable sound source deployed off a ship. M3R provided real-time monitoring of hydrophones in an effort to direct tagging vessels to vocalizing animals. M3R was also responsible for designing and operating the playback source during these controlled-exposure experiments. (Southall *et al.*, 2012).

Low-frequency Detection of Baleen Whales

In parallel with the SOAR hydrophone replacement program which provided low frequency capability (~20 Hz), software to detect and localize baleen species was developed and installed. The software provides an extension of the existing M3R FFT-based detector. A frequency bandwidth of 0-3 kHz is monitored with a bandwidth resolution of 1.46 Hz. Localization software was developed and integrated into the “MMammal” monitoring software. The prototype software was used to isolate baleen vocalizations that were verified by the on-water observers.

A semi-automated tracking tool was developed to determine the position of distinct acoustic transient signals including marine mammal vocalizations. When the same signal is observed on three or more hydrophones, this tool was used to localize the position of the animal. Figure 13 displays the same fin whale call selected on each of three hydrophones, its calculated latitude and longitude, and its position relative to the SOAR hydrophones.

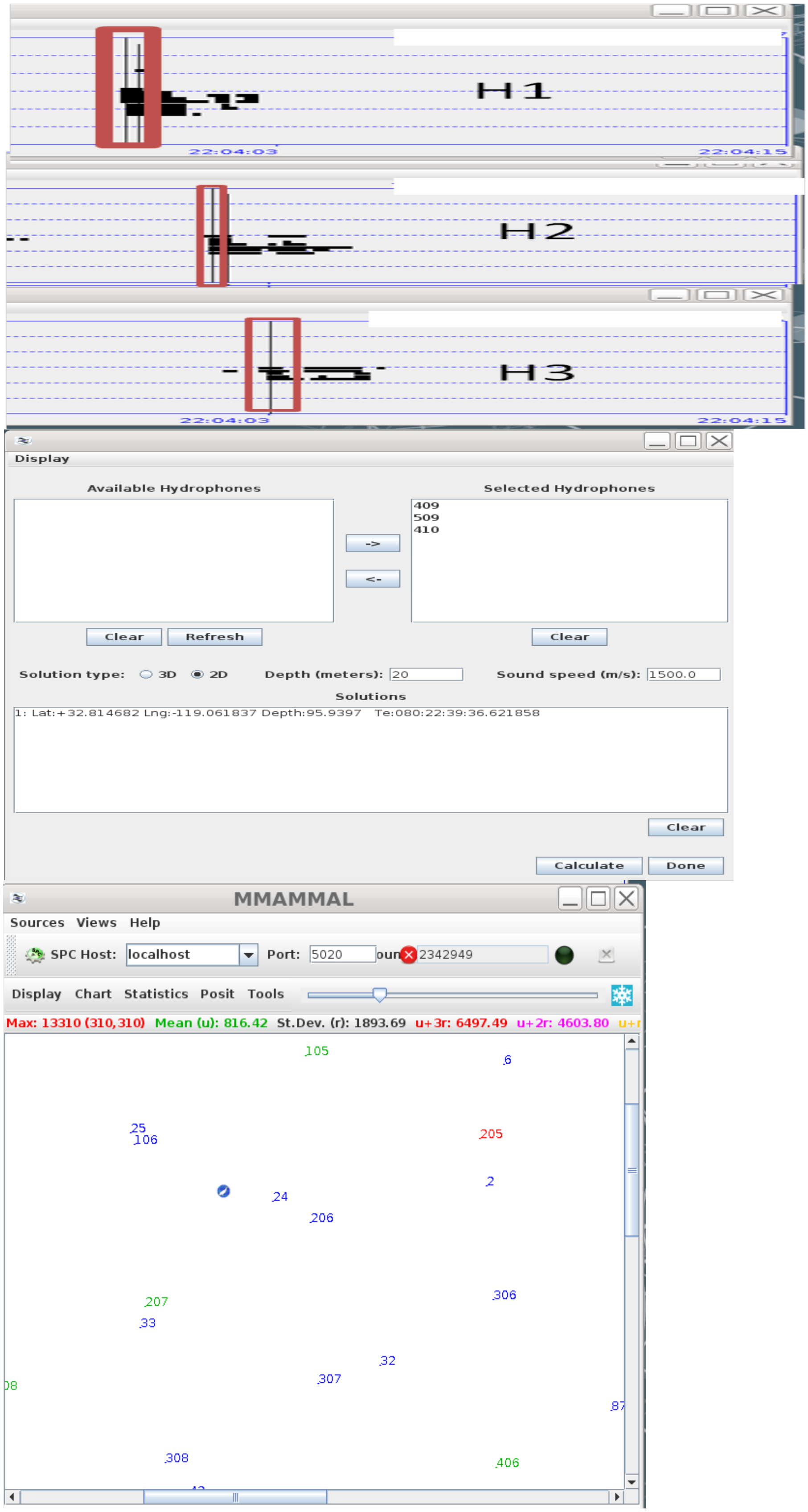

Figure 13. *B. physalus* vocalization on three hydrophones (top), the tracking utility and resultant latitude and longitude (middle), and the plotted localization (bottom)

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