Progress Report on the Application of Passive Acoustic Monitoring Data for Assessing the Potential Impact of Mid-Frequency Active Sonar on Whales

Simone Baumann-Pickering, Ana Širović, John A. Hildebrand,

Jennifer S. Trickey, Anna Meyer-Löbbecke, and Sean M. Wiggins

Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA

Marie A. Roch

Department of Computer Science, San Diego State University, San Diego CA

Mark A. McDonald

WhaleAcoustics, Bellvue, CO

MPL TECHNICAL MEMORANDUM # 605
March 2016

Table of Contents

Executive Summary

Passive acoustic monitoring (PAM) provides extensive datasets to examine the behavioral response of cetaceans to anthropogenic sound. Using broadband passive acoustic monitoring, the full range of cetacean sounds and the sounds of naval and other anthropogenic sources are recorded. We have been collecting high-frequency PAM data in the Southern California (SOCAL) region since 2006. Within this dataset are many instances of anthropogenic sound as well as cetacean presence at the locations of naval training.

We present a progress report on the detailed analysis of sonar impact on blue whales and beaked whales, and the development of methods to investigate the potential impacts of sonar and other anthropogenic activities on calling animals. The basis for this effort is previously collected PAM data from four sites in the years 2006 to 2015. Recording effort at these sites varied between 674 and 2,284 days per site, resulting in 19 years of continuous acoustic recording during 79 instrument deployments and 227 TB of acoustic data. As part of the work in this progress report, automated routines have been established and/or modified to detect and classify acoustic signals of blue whales (*Balaenoptera musculus*) and Cuvier's beaked whales (*Ziphius caviostris*) as well as Mid-Frequency Active (MFA) sonar pings and explosions. This has the advantage to minimize bias known to occur when multiple human analysts annotate acoustic data manually. It will allow a finer granularity of acoustic detections, in the case of blue whales to the call level of B and D calls, beaked whales to the individual click level, for MFA sonar to single ping events, and for explosions to the single explosion level. With this granularity we will be able to compute detailed signal parameter descriptions for a subsequent multi-variate statistical analysis. The complete data preparation requires a total of ~1,100 days of computing time and ~300 person-days of manual editing. We are currently about 66% of the way through this process.

After this preparatory process is completed, future analysis will address the range ambiguity. Beaked whales have a narrow detection range of <2 km around the sensor yet blue whales can be heard over several tens of km. We will reduce detection range for blue whales to reach a range similar to beaked whales by selecting for high received level calls of animals near the sensor. Range of the MFA sonar source can be estimated assuming a nominal source level of 235 dB re 1 μPa @ 1 m. In the case of a sonar detection, which tends to be much further away from the recorder than the animal, the received level at the recorder can be used as a proxy for the received level at the animal. We are in the process of determining appropriate thresholds for received levels to define and reduce this range and received level discrepancy.

Several multi-variate statistical approaches will be explored to account for natural temporal and spatial variability in call densities, e.g., caused by species or population level variability in seasonality, habitat preference, behavioral context of calling, and individual variability. Equally, a statistical framework to document and quantify potential changes in the acoustic behavior due to MFA sonar needs to incorporate potential impact of other anthropogenic signals, such as explosions and ship noise.

I. INTRODUCTION

The potential for anthropogenic sound to disrupt activities of marine mammals is an issue of concern to the Navy, particularly with regard to Mid-Frequency Active (MFA) sonar (NRC, 2003). Traditional studies of anthropogenic impact have measured disturbance by either visually observing an absence of whales near a sound source, observing whales travelling away from a sound source, or whales acting in an unusual manner while exposed to a man-made sound. More recently, attaching electronic tags to the animals during controlled exposure experiments has allowed more detailed measures of reaction to disturbance (Tyack *et al.*, 2011; DeRuiter *et al.*, 2013; Goldbogen *et al.*, 2013).

Passive acoustic monitoring (PAM) is an alternative approach to examine the behavioral response of marine mammals to anthropogenic sound. Acoustic recorders are used to document both the production of sound by the animals, and the presence of the potentially disturbing anthropogenic sound. PAM data overcome several of the limitations of controlled exposure experiments, namely the availability of realistic sound sources, the relatively small sample sizes on a limited range of species and the specter of possible research effects. To date, we have barely scratched the surface of the PAM data that are available for behavioral response research. Melcon *et al.* (2012) analyzed data from one species (blue whale), one call type (D call) at site M (Figure 1), covering a single season over a period of two years; their results suggest that naval sonar may suppress blue whale vocal activity at received levels of >120-130 dB re: 1µPa.

The purpose of this effort is to expand the analysis of behavioral impact of sonar using PAM data collected in the SOCAL region to four strategic sites where there are long-term recordings and different levels of MFA sonar detections. A major advantage of these long-term data sets is the large sample size for signals of interest. There have been 100,000s of sonar pings recorded during these deployments. Their received levels at the recorders range from ~100 dB re: 1µPa up to 165 dB re: 1 µPa, thus providing a broad range of intensities to assess sonar impacts at different levels.

The goal of this study is to examine existing PAM data for acoustic behavioral response of blue whales (*Balaenoptera musculus*) and Cuvier's beaked whales (*Ziphius caviostris*) to sonar operations in an area of frequent naval activity. We will develop models to investigate the interplay between acoustic behavior and sonar parameters such as duration of sonar event, sound exposure level (SEL), and maximum received sonar sound pressure level (SPL). Within this report we will document progress in data preparation, on the development of automated detection methods, and in defining signal parameters for future model development.

II. METHODS

A. Acoustic data collection

Since 2006 high-frequency acoustic recording packages (HARPs) have been deployed in the Southern California Bight, the continental shelf region between Point Conception and the Mexican border. This area includes the Southern California Offshore Range Complex, a zone of frequent naval training exercises, with San Clemente Island as a focal point for much of this activity. HARPs recorded underwater sounds from 10 Hz up to 100 kHz, covering all cetacean and anthropogenic signals of interest. Four sites (designated E, H, M, N) were chosen for the MFA sonar impact analysis (Figure 1) that have either high (H, N), medium (M), or low (E) numbers of MFA sonar detections and intensities (e.g., Debich *et al.*, 2015). Previous ONR-funded work showed that blue whale calls are regularly detected at these sites using PAM (Širović *et al.*, 2015) and they are within primary habitat for Cuvier's beaked whales in SOCAL (Baumann-Pickering *et al.*, in prep.).

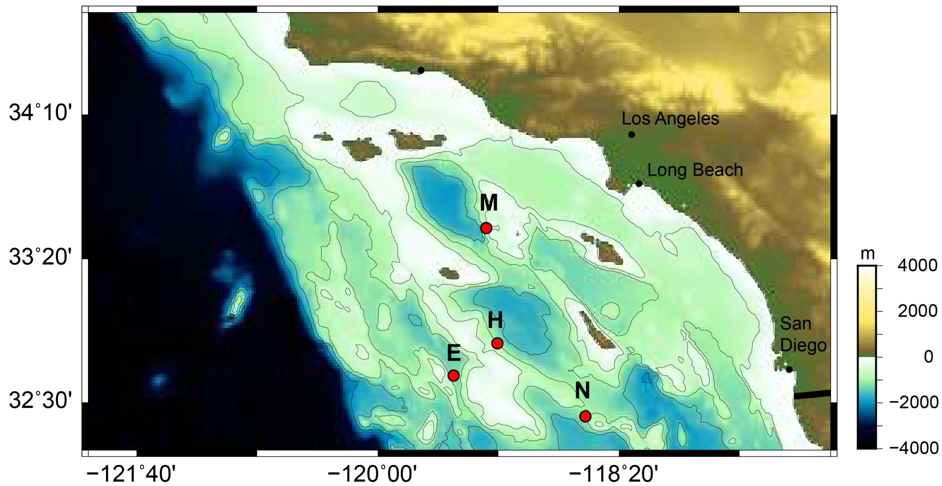

Figure 1. *Acoustic recorder sites off Southern California used in this study.*

B. Automated detection of acoustic signals

We are in the process of detecting and classifying the acoustic signals with automated routines to minimize the bias known to occur when multiple human analysts annotate acoustic data manually. This additional processing will allow a finer granularity of acoustic detections, in case of beaked whales to the individual click level and for MFA to single ping event, and will thus enable detailed signal parameter descriptions to be computed.

1. Cetacean signals

Blue whale B calls (Širović *et al.*, 2015) and Cuvier's beaked whale echolocation click encounters (Baumann-Pickering *et al.*, in prep.) recorded through the end of 2012 were processed previously under ONR grants. Additional years of data were analyzed as a part of this project's effort and for Cuvier's beaked whale density estimation effort also supported by U.S. Pacific Fleet (Hildebrand *et al.*, 2016).

Blue whale B and D calls

Blue whale B calls were automatically detected using spectrogram correlation (Mellinger and Clark, 2000). This method cross-correlates a time-frequency kernel representation of a call with a spectrogram of the recording; a detection event occurs when the correlation value exceeds the specified threshold for a specified duration, in the case of this detector, 5 s. The performance of the automatic detector is affected by seasonal and inter-annual shifts in call frequency (McDonald *et al.*, 2009) and seasonal changes in call abundance (Širović, 2016). To account for these changes and keep rates of missed and false calls as consistent as possible, multiple kernels and thresholds were used for each year and site.

To achieve a more complete view of blue whale calling behavior, an effort to detect blue whale D calls was also expended for this project. To automatically detect these, a generalized power-law (GPL) detector (Helble *et al.*, 2012) was adapted. A unique feature of the GPL detector is that it performs well on non-stereotypical calls, such as D calls. The detector was fine-tuned to perform at less than 9% missed call rate. However, all detections had to be verified to identify any false detections. The verification was performed using a graphical user interface tool that enables the analyst to review time-condensed spectrograms containing the detections and to accept or reject each detection. Through this process, only true calls remain in the dataset for subsequent analysis.

Cuvier's beaked whale FM pulses

Beaked whales are known to produce frequency-modulated (FM) echolocation pulses that are distinguishable to the species or FM pulse type level (Baumann-Pickering *et al.*, 2013b). Beaked whale encounters (start and end times of acoustic FM pulse bouts separated by one hour) were initially automatically detected and then classified to the species or signal type level with an analyst-assisted software (Baumann-Pickering *et al.*, 2013b), also eliminating false encounters. The rate of missed encounters for this detector has been shown to be approximately 5% in SOCAL recordings. All Cuvier's beaked whale acoustic encounters were reviewed in a second analysis stage to remove false detections of individual FM pulses and provide a consistent detection threshold. FM pulse detections occurred when the signal in a 10 – 100 kHz band exceeded a detection threshold of 121 dB pp re: 1μPa. FM pulses within the acoustic encounters were manually reviewed using comparative panels showing long-term spectral average, received level, and inter-pulse interval of individual FM pulses over time, as well as spectral and waveform plots of selected individual signals. Within each encounter, false detections were removed by manual editing, for instance, when the detections were identified as being from vessels, sonars, sperm whales or delphinids, owing to inappropriate spectral amplitude, inter-click interval, or waveform. In addition, this step provided another check on beaked whale species classification, and remaining misidentified or false encounters were corrected or removed.

2. Anthropogenic signals

Mid-Frequency Active (MFA) Sonar

Wiggins (2015) defined metrics for quantifying MFA sonar occurrence and levels within PAM data collected by HARPs. MFA sonar was determined to be comprised of constant-frequency and frequency modulated 'pings' that often occurred in groups of pings, termed 'packets' (Figure 2). These packets repeated with intervals >20s over periods of hours, termed 'wave train events'. Parameters that were defined as relevant to describe pings were MFA sonar peak-to-peak (pp) and root-mean-square (rms) received levels (RL_{pp} and RL_{rms}, respectively), sound exposure levels (SEL), and signal duration. Inter-ping and inter-packet intervals were examined. A cumulative SEL (CSEL) was defined as the sum of the ping SELs for each wave train event. All of these parameters may be relevant in the context of multi-variate statistical modeling as they each contain information of different granularity that may be explanatory for a potential acoustic response of blue or Cuvier's beaked whales.

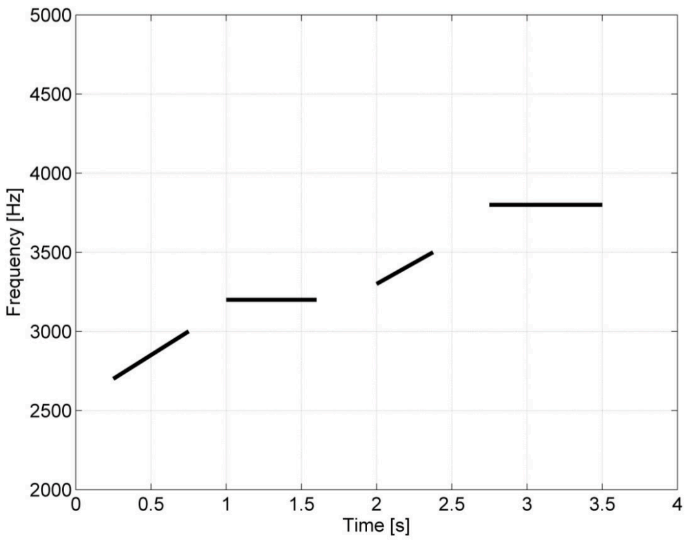

Figure 2. *Example synthetic spectrogram from Wiggins (2015) showing a four-pings MFA sonar packet composed of two frequency-modulated and two constant-frequency pings.*

The Wiggins (2015) report identified the need for further automation of MFA sonar detections as manual identification of MFA sonar activity was required, resulting in considerable effort hours expended by trained analysts and potential discrepancies in analysis threshold and accuracy between analysts.

As an improvement to this process, MFA sonar was detected using a modified version of the *silbido* detection system (Roch *et al.*, 2011) designed for characterizing toothed whale whistles. The algorithm identifies peaks in time-frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal drop-outs or interfering signals. Detection graphs are then examined to identify individual tonal contours looking at trajectories from both sides of time-frequency intersection points. ONR-funded modifications to the published system consisted of a noise regime change detection system, and statistical analyses of graphs and tonal contours for characteristics that removed 57% of the false positives with negligible impact on detected calls (MacFadden, 2015; MacFadden and Roch, in prep.).

For MFA sonar detection, parameters in *silbido* were adjusted to detect tonal contours ≥ 2 kHz (in data decimated to a 10 kHz sample rate) with a signal to noise ratio ≥ 5 dB and contour durations > 200 ms with a frequency resolution of 100 Hz (Figure 3). The primary MFA sonar in use by the United States Navy, the AN/SQS-53C, is operated on surface ships and generates tones and sweeps having typical durations of 0.5 to 2 s with frequencies near 3.5 kHz, at nominal source levels of 235 dB re 1 µPa @ 1 m (United States Navy, 2008 ,Vol. 2). This type sonar dominates the data set used in this study; however, the filtering process and signal data rate in this detection process excluded a number of lower or higher frequency MFA sonar devices.

In this frequency range, the detector frequently triggered on noise produced by instrument disk writes that occurred at 75 s intervals. Over several months, disk write detections dominated the detections, but they were eliminated using an outlier test. Histograms of the detection start times, modulo the disk write period, were constructed and outliers as identified by a non-parametric outlier test (Emerson and Strenio, 1983) were discarded. This removed some valid detections that occurred during disk writes, but as the disk writes and sonar signals are uncorrelated, this process is expected to only have a minor impact on analysis. As the detector did not distinguish between sonar and other tonal signals within the operating band, analysts manually examined detection output. The manual examination was performed using a graphic user interface that displayed 30-min panels showing long-term spectral average, received level, and inter-detection interval of individual detections. Analysts would accept or reject contiguous sets of detections based on those displayed characteristics.

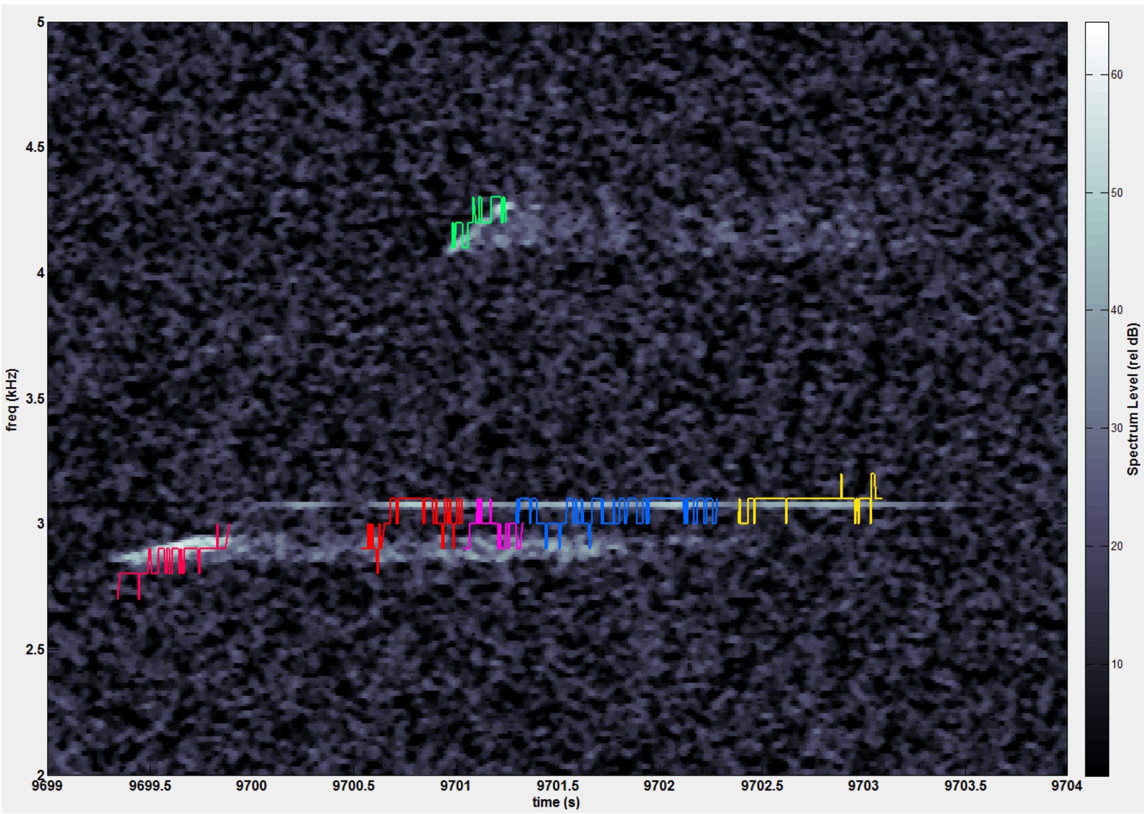

Figure 3*. MFA sonar ping detections. Detections (colored lines) are shown over a gray scale spectrogram. Detector has a 100 Hz resolution, while spectrogram is plotted with 10 Hz resolution. The MFA sonar pings are in general well detected, however some are fragmented, for instance, with multiple segments covering the long ping.*

Explosions
Effort was also directed toward finding explosive sounds in the data including military explosions, shots from sub-seafloor exploration, and seal bombs used by the fishing industry (Figure 4). Explosions were detected automatically using a matched filter detector on data decimated to 10 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2,000 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s,

Hann windowed) as the matched filter signal. The cross correlation was squared to ‘sharpen’ peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of $3*10^{-6}$ above the median was set. Consecutive explosions had to be separated by at least 0.5 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and root-mean-square (rms) received levels (RL) were computed over the potential explosion period and a time series of the length of the explosion template before and after the explosion. The potential explosion was classified as a false detection and deleted if: 1) the dB difference pp and rms between signal and time AFTER the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference pp and rms between signal and time BEFORE signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 or longer than 0.55 seconds. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining potential explosions for accuracy. Explosions have energy as low as 10 Hz and often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation.

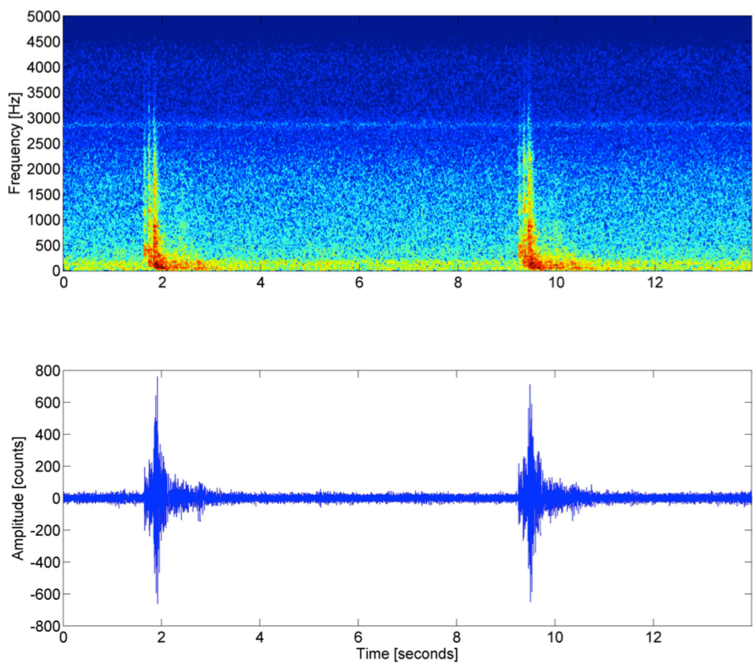

Figure 4. *Two explosions, most likely seal bombs, are shown as (above) spectrogram, and (below) time series.*

III. PROGRESS

The recording effort at sites H, M, N, and E from 2006 to 2015 varied between 674 and 2,284 days per site, cumulatively resulting in 19 years of continuous recordings over 79 instrument deployments and 227 TB of acoustic data.

Automatic detectors are being run on all deployments and output is being manually scrutinized as described within the Methods section. This generated millions of counts of acoustic signal detections to date. The complete data analysis requires a total of ~1,100 days of computing time and ~300 person-days of manual editing, not including the upkeep of computing infrastructure or potential trouble-shooting of computing irregularities. We are currently about 66% of the way through this process (Figure 5).

Detectors for blue whale B calls, Cuvier's beaked whales, and explosions have been well tested and are fully operational. New detectors developed and applied for the first time within this effort are detectors for blue whale D calls and MFA sonar. The detector performance for D calls was optimized (see Methods section). The performance of the MFA sonar detector has yet to be quantified in detail using manually ground-truthed data. An initial inspection showed that the detector operated well at identifying MFA sonar activity. In the 11 deployments analyzed to date, false positives were due to humpback whale calls, delphinid whistles, nearby ship passages, and some explosions. As all of these signals overlap in frequency with the MFA, this overlap was not surprising. The new approach using a modified version of *silbido* as MFA sonar detector is a first step towards full automation. However, the detector frequently fragments MFA sonar pings into multiple detections and it traces MFA sonar ping echoes (Figure 3). In order to compute previously defined MFA sonar parameters, we are currently working on resolving this issue and quantifying possible errors. Another improvement offered with the *silbido* MFA sonar detector is the possibility to extract frequency content and determine number of sweeps and tones. Optimally, the analysis will be expanded to include MFA sonar > 5 kHz (e.g., AN/SSQ-62 DICASS sonobuoys) and low frequency active (LFA) sonar < 1 kHz.

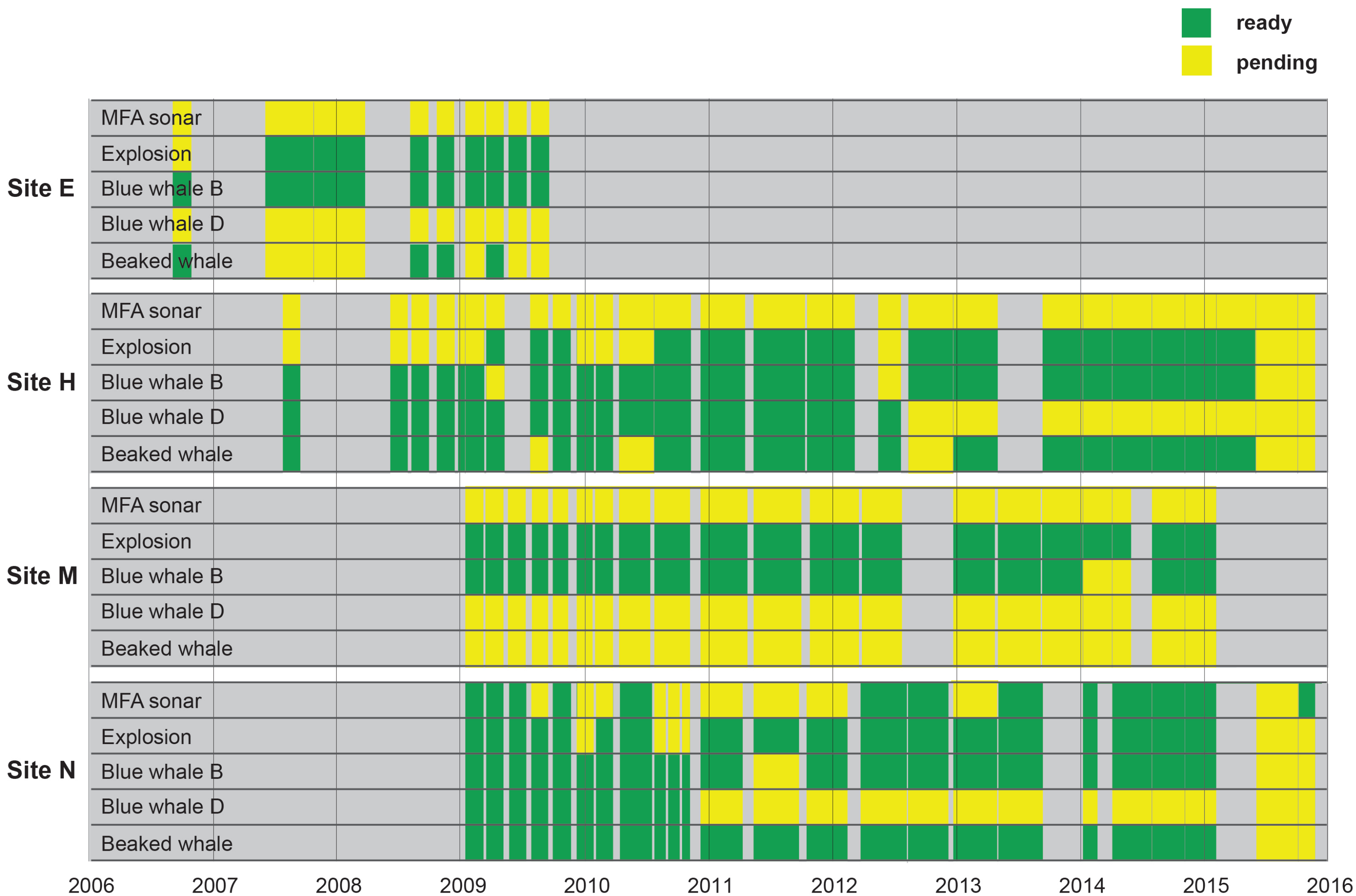

Figure 5. *Status of analysis for MFA sonar, explosions, blue whale B and D calls, and Cuvier's beaked whales over 19 years of continuous acoustic recordings, consisting of 227 TB of data in 79 deployments.*

A potential advantage of controlled exposure experiments over PAM impact analysis approaches is the precise knowledge of the location of the source and the animal being studied. This can be addressed in a PAM impact analysis by using received sound level as a proxy for the range between the sensor and the sonar. If we assume a nominal source level of 235 dB re 1 μPa @ 1 m (United States Navy, 2008 ,Vol. 2), sonar can be detected at a large distance (~20-50 km). Likewise, it is possible to estimate the animal range from the sensor using received level and other call characteristics. The detection range to Cuvier's beaked whales is generally small based on the high-frequency content of the signal (<2 km). In the case of blue whales, detection range can be restricted to calls with high received levels and hence animals close to the sensor within similar distances as beaked whales. By limiting the range to detected animals, we can limit the sonar-animal range ambiguity to a few kilometers. In the case of a sonar detection that is much further away from the recorder than the animal, the received level at the recorder can be used as a proxy for the received level at the animal. We are in the process of determining appropriate thresholds for received levels to define and reduce this range and received level discrepancy.

Preliminary data screening of acoustic encounters of blue whales (B calls) and Cuvier's beaked whales (FM pulses) in relation to MFA sonar wave train events shows numerous accounts of overlapping whale signaling during periods of MFA sonar activity (Figure 6 and 7). It quickly becomes apparent that the relationship of MFA sonar and the acoustic behavior of these whales is complex and requires inclusion of several potentially relevant variables. A multi-variate statistical approach will be needed to account for natural temporal and spatial variability in call densities, e.g., caused by species or population level variability in seasonality, habitat preference, behavioral context of calling, and individual variability. Equally, a statistical framework to document and quantify potential changes in the acoustic behavior due to MFA sonar needs to incorporate potential impact of other anthropogenic signals, such as explosions (Figure 8) and ship noise.

IV. Conclusion

Major progress has been achieved on standardized, automated detection of all acoustic signals of interest to generate an unbiased dataset with reproducible output. We are automating the detection of MFA sonar pings to better quantify single pings and further improve MFA metrics. Processing of the remaining data sets is underway. Relevant acoustic parameters for all signals have been defined and subsets of data are ready to start the exploration of multi-variate statistical methods to test for impact of MFA sonar on the acoustic behavior of blue whales and Cuvier's beaked whales.

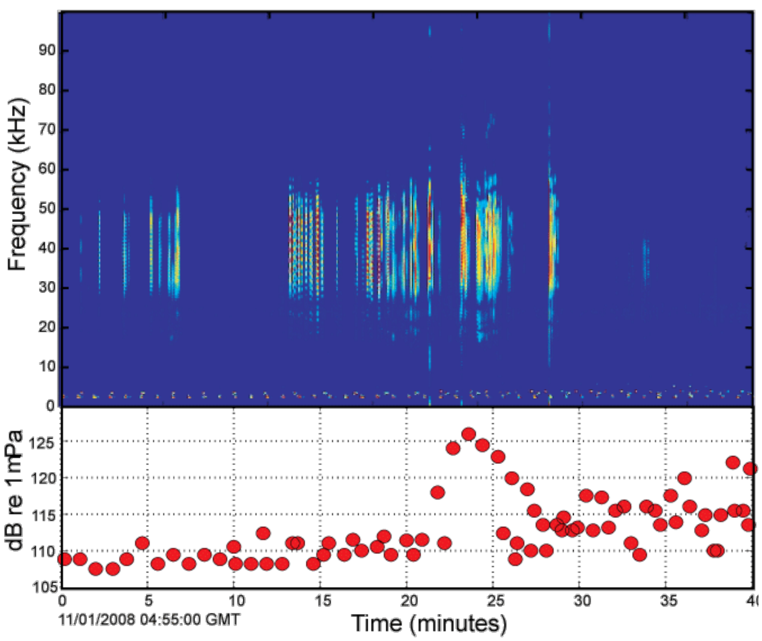

Figure 6. *Spectrogram (upper panel) of Cuvier's beaked whale FM pulses (vertical lines, peak at ~40 kHz) along with MFA sonar wave train event near 3 kHz. Received level of each MFA sonar ping over the same time is shown on the lower panel.*

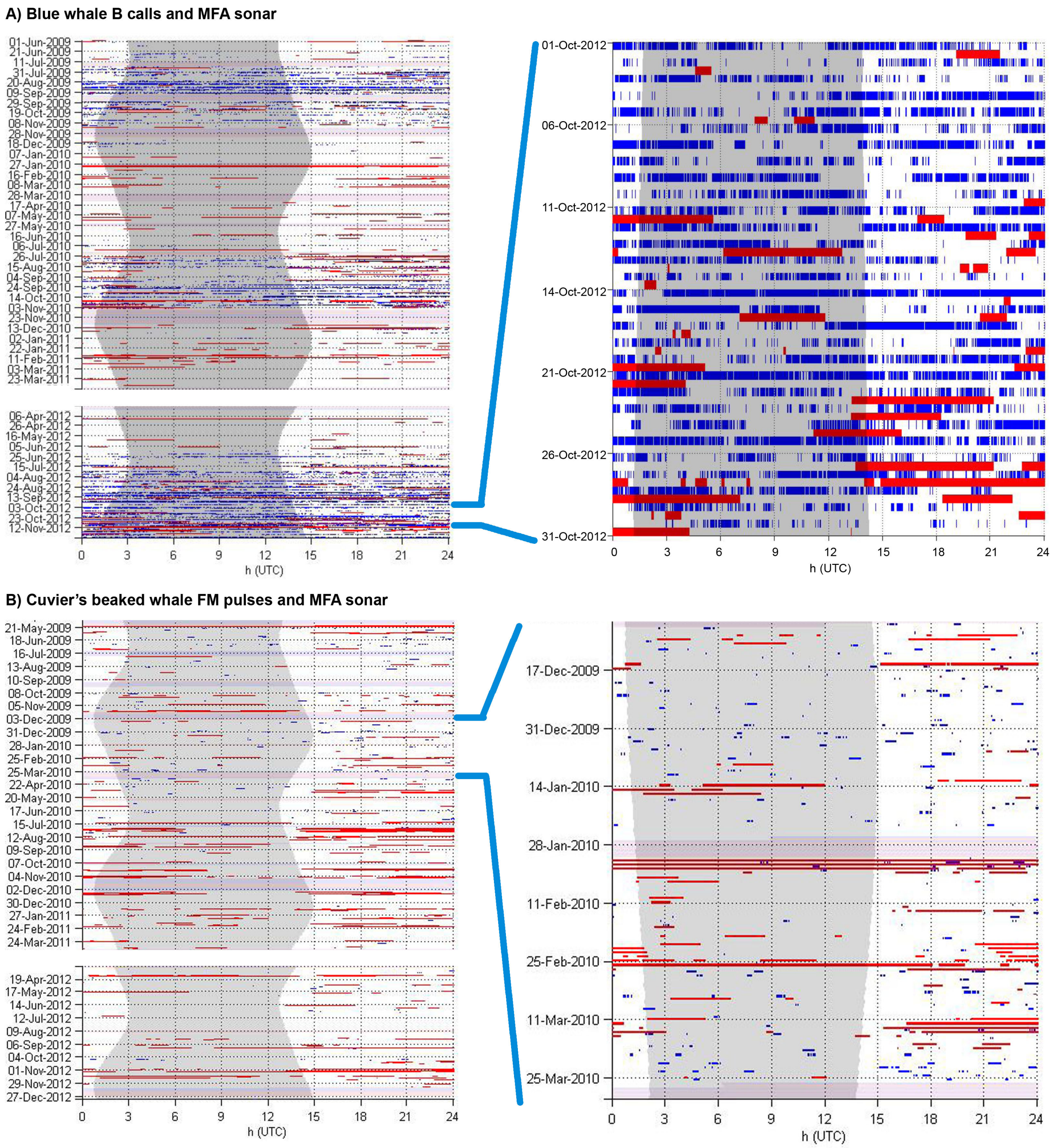

__Figure 7.__ Daily acoustic encounters of A) blue whale B calls (blue bars) and B) Cuvier's beaked whale FM pulses (blue bars) and daily wave train events of MFA sonar (red bars) during each day of deployment. Grey shading indicates nighttime. Horizontal pink shading indicates no data.

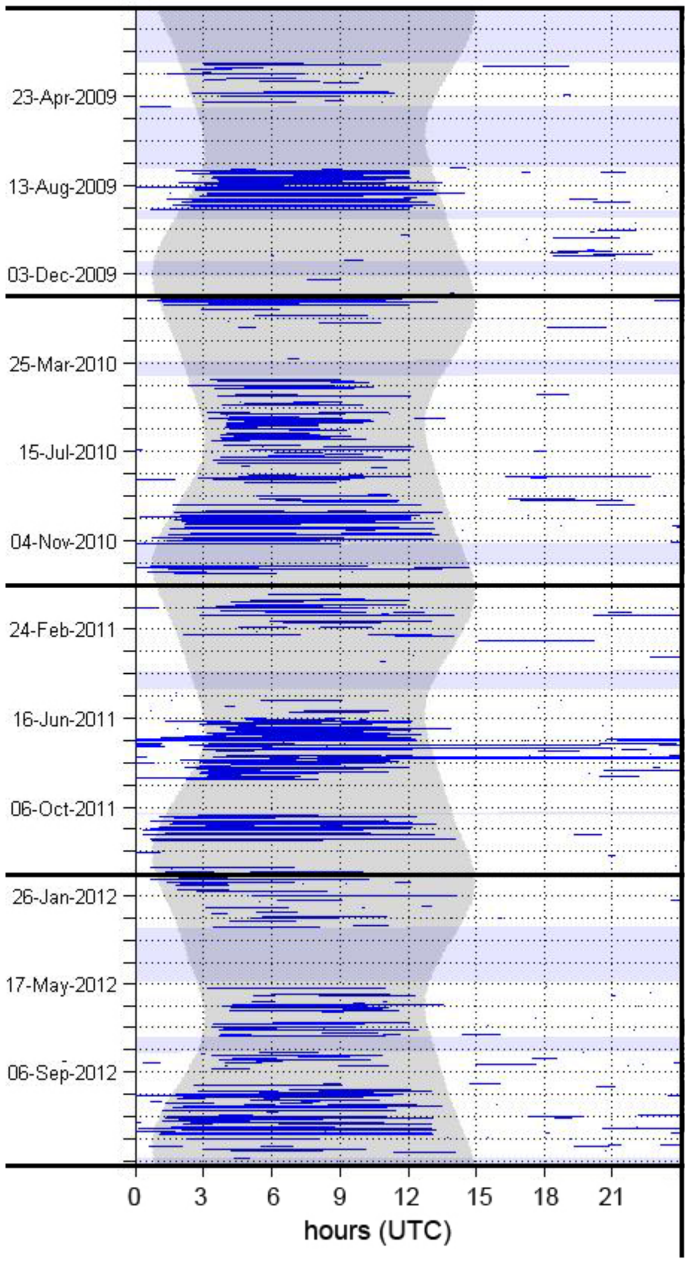

Figure 8. *Occurrences of explosions (blue) over four years at site H, west of San Clemente Island. Explosions were predominantly detected at night, indicating relation to fishery activity and use of 'seal bombs' (from Baumann-Pickering et al., 2013a).*

REFERENCES

Baumann-Pickering, S., Debich, A. J., Širović, A., Carretta, J. V., Trickey, J. S., Gresalfi, R., Roch, M. A., Wiggins, S. M., and Hildebrand, J. A. (**2013a**). "Potential impact of underwater explosions on cetaceans," The Journal of the Acoustical Society of America **134**, 4045-4045.

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Solsona Berga, A., Merkens, K. P. B., Oleson, E. M., Roch, M. A., Wiggins, S. M., Rankin, S., Yack, T. M., and Hildebrand, J. A. (**2013b**). "Species-specific beaked whale echolocation signals," J. Acoust. Soc. Am. **134**, 2293-2301.

Baumann-Pickering, S., Trickey, J. S., Roch, M. A., Hildebrand, J. A. and Wiggins, S. M. (in prep.). "Beaked whale distribution, relative abundance, and behavior in Southern California waters."

Debich, A. J., Baumann-Pickering, S., Sirovic, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Thayre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (2015). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area Dec 2012 – Jan 2014," Marine Physical Laboratory Technical Memorandum #552 (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA).

DeRuiter, S. L., Southall, B. L., Calambokidis, J., Zimmer, W. M. X., Sadykova, D., Falcone, E. A., Friedlaender, A. S., Joseph, J. E., Moretti, D., Schorr, G. S., Thomas, L., and Tyack, P. L. (**2013**). "First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar," Biol. Lett. **9**, 1-5.

Emerson, J. D., and Strenio, J. (**1983**). "Boxplots and Batch Comparison," in *Undertanding Robust and Exploratory Data Analysis*, edited by D. C. Hoaglin, F. Mosteller, and J. W. Tukey (John Wiley & Sons, Inc., New York, NY), pp. 58-96.

Goldbogen, J. A., Southall, B. L., DeRuiter, S. L., Calambokidis, J., Friedlaender, A. S., Hazen, E. L., Falcone, E. A., Schorr, G. S., Douglas, A., Moretti, D. J., Kyburg, C., McKenna, M. F., and Tyack, P. L. (**2013**). "Blue whales respond to simulated mid-frequency military sonar," Proc. R. Soc. B **280**, 1-8.

Helble, T. A., Ierley, G. R., D'Spain, G. L., Roch, M. A., and Hildebrand, J. A. (**2012**). "A generalized power-law detection algorithm for humpback whale vocalizations," The Journal of the Acoustical Society of America **131**, 2682-2699.

Hildebrand, J. A., Baumann-Pickering, S., Giddings, A., Brewer, A., Jacobs, E. R., Trickey, J. S., Wiggins, S. M., and McDonald, M. A. (2016). "Progress Report on the Application of Passive Acoustic Monitoring to Density Estimation of Cuvier's Beaked Whales," Marine Physical Laboratory Technical Memorandum #606 (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA), p. 14.

MacFadden, M. S. (**2015**). "Improving performance in graph-based eetection of odontocete whistles through graph analysis and noise regime-change," in *MS Thesis, Department of Computer Science* (San Diego State University), p. 75.

MacFadden, M. S., and Roch, M. A. (**in prep.**). "Reduction in false positive rates of an odontocete whistle detection system using distributional analysis of intermediate graph structures and noise regime change detection."

McDonald, M. A., Hildebrand, J. A., and Mesnick, S. L. (**2009**). "Worldwide decline in tonal frequencies of blue whale songs," Endangered Species Research **9**, 13-21.

Melcon, M. L., Cummins, A. J., Kerosky, S. M., Roche, L. K., Wiggins, S. M., and Hildebrand, J. A. (**2012**). "Blue Whales Respond to Anthropogenic Noise," Plos One **7**, e32681.

Mellinger, D. K., and Clark, C. W. (**2000**). "Recognizing transient low-frequency whale sounds by spectrogram correlation," The Journal of the Acoustical Society of America **107**, 3518-3529.

NRC (**2003**). *Ocean Noise and Marine Mammals* (Washington, D. C.), pp. 192.

Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (**2011**). "Automated extraction of odontocete whistle contours," J. Acoust. Soc. Am. **130**, 2212-2223.

Širović, A. (**2016**). "Variability in the performance of the spectrogram correlation detector for North-east Pacific blue whale calls," Bioacoustics **25**, 145-160.

Širović, A., Rice, A., Chou, E., Hildebrand, J., Wiggins, S., and Roch, M. (**2015**). "Seven years of blue and fin whale call abundance in the Southern California Bight," Endangered Species Research **28**, 61-76.

Tyack, P. L., Zimmer, W. M. X., Moretti, D., Southall, B. L., Claridge, D. E., Durban, J. W., Clark, C. W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J., and Boyd, I. L. (**2011**). "Beaked Whales Respond to Simulated and Actual Navy Sonar," PLoS ONE **6**, e17009.

United States Navy, Commander, Pacific Fleet (**2008**). "Southern California Range Complex Final Environmental Impact Statement / Overseas Environmental Impact Statement," p. 1952.

Wiggins, S. M. (2015). "Methods for quantifying mid-frequency active sonar in the SOCAL Range Complex," Marine Physical Laboratory Technical Memorandum 553. Scripps Institution of Oceanography, University of California San Diego, (La Jolla, CA).