

Blue and Fin Whale Habitat Modeling from Long-Term Year-Round Passive Acoustic Data from the Southern California Bight

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LONG-TERM GOALS

During this project, we will develop predictive, year-round habitat models of the presence of calling blue and fin whales in the Southern California Bight, to facilitate Navy's operational needs in this area.

OBJECTIVES

The primary objective of this research is to develop predictive, year-round habitat models of the presence of calling blue and fin whales in the Southern California Bight (SCB). We will also investigate the scales over which blue and fin whales respond to their environment to better understand the functionality of the predictive relationships in those models. We will base our models on the available passive acoustic and remotely sensed data, as well as the lunar and buoy data available for the SCB.

APPROACH

Passive acoustic data have been collected using High-frequency Acoustic Recording Packages (HARPs) deployed at sixteen locations in the Southern California Bight (Figure 1). We have been using automatic detectors to determine the presence of blue and fin whale calls in the area of the SCB between 32° and 34° 20' N from passive acoustic recordings collected year-round between 2005 and 2012. This temporally extensive data set will allow us to investigate the effects of environmental, remotely sensed variables, as well as a number of temporal variables, such as time-of-day, month, season, and year, on the distribution of these two species of whales. Such temporal variables are rarely included into models based exclusively on visual survey data thus our models are likely to offer new insights on the importance of these time scales on blue and fin whale habitat preferences.

Environmental variables obtained from remotely sensed data to be used for habitat modeling include sea surface temperature (SST), salinity, sea surface height, and chlorophyll *a* concentration. These data are available on similar temporal (daily, weekly, monthly) and spatial scales (1 to hundreds of km) as passive acoustic whale monitoring. Data that are contemporaneous spatially and temporally for each deployment location and period are being downloaded using the database tools developed by M. Roch (ONR grant N000141110697). Additional variables to be used include the solar and lunar cycle data

from the U.S. Naval Observatory, and weather buoy data (e.g. wave height, wind) collected through the National Data Buoy Center for the parts of the SCB region with HARP deployments.

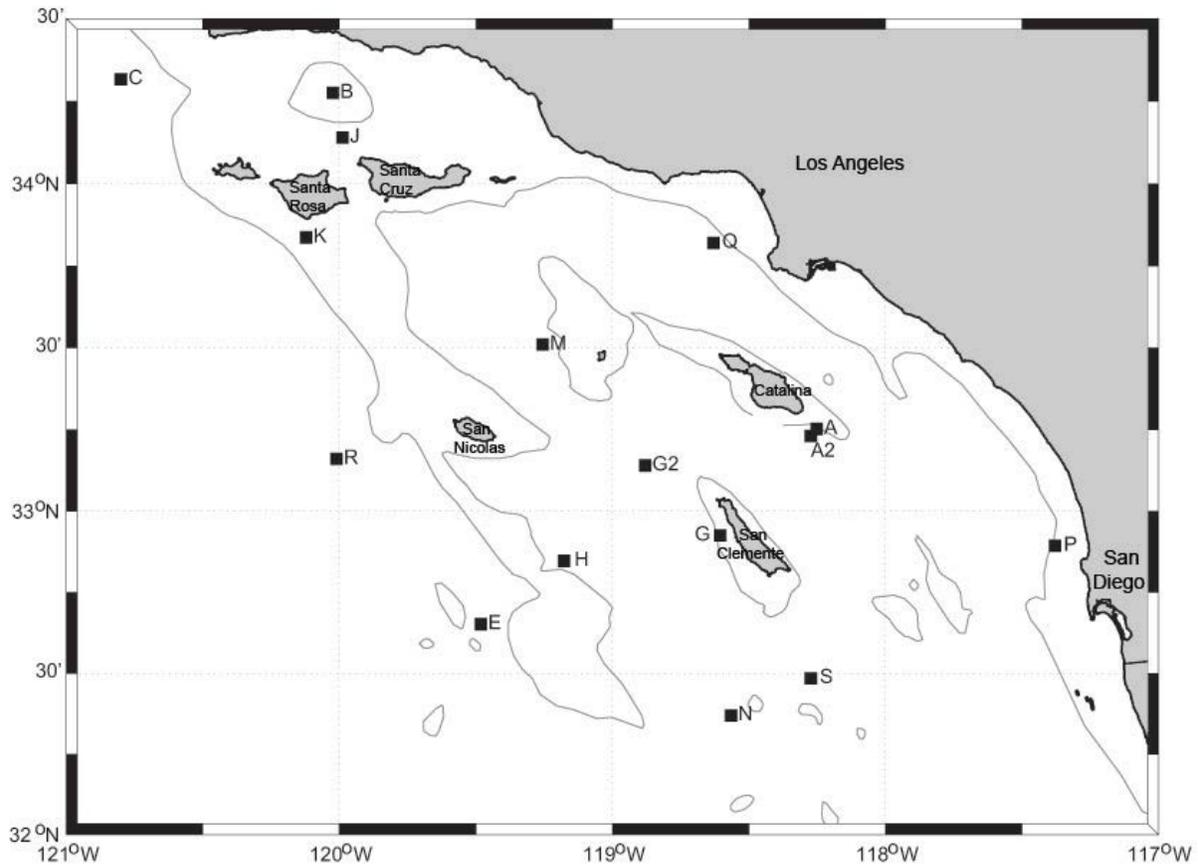


Figure 1. Sixteen HARP deployment locations (black squares) throughout the Southern California Bight between 2005 and 2012 from which data are processed for habitat modeling in this study. Light grey line denotes the 500 m bathymetry contour.

When comparing acoustic and remotely sensed data, and for meaningful habitat modeling, one of the major problems is determining the appropriate spatial scale on which to conduct the analysis. On the one hand, the choice of scale is limited by the spatial resolution in collected data, but in theory, it should also be driven by the scale of the whale's response to the environment. We will explore the effect of different spatial scales on blue and fin whale habitat models further in this study. To use call detections for such an analysis, however, we first must determine the scale (range) over which blue and fin whale calls can be detected. Using ESME workbench (developed under ONR grant to Dr. Mountain), we developed propagation models for areas around each of the HARP deployment locations to investigate the characteristics of propagation loss in the area. These models allow us to estimate propagation loss at low frequencies over different spatial scales and over different seasons (spring, summer, fall, and winter).

We will use the information from propagation loss modeling to fine-tune our automatic detectors and thus create presence indices for e.g. high amplitude (nearby), intermediate, and low amplitude (distant) calls. By obtaining multiple sets of detections for each call corresponding to the presence of calling

whales in three different areas around each HARP, we will be able to investigate the effects of range on the functional models affecting blue and fin whale distribution.

First, all data will be spatially and temporally aligned to compare the presence of blue and fin whale calls with the environmental. Next, we will use generalized additive modeling (GAM) framework to identify the most significant habitat variables that affect the presence of these whales in the SCB. Independent environmental variables that will be used for selection in the models will likely include: SST, sea surface height, chlorophyll *a* concentration, distance to SST and chlorophyll *a* fronts, distance to shore, depth, tidal level, and, when available, wave height and wind speed. The advantage of this method over the habitat models that have been developed from more traditional ship-based visual surveys is that passive acoustic data provide a much finer temporal resolution. Therefore, we will also be able to investigate the effects of temporal variables, such as time-of-day, month, and year on the distribution of blue and fin whales. We will construct separate GAMs for different call types, detection ranges, and seasons.

We plan to include the metadata for all detected calls (location, time, and type of call) and our final, best habitat models into the Ocean Biogeographic Information System – Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) database for access by the larger community. Work on detector development and implementation, as well as habitat modeling, will be headed by Dr. Ana Širović (SIO).

WORK COMPLETED

- Developed blue whale B and fin whale 20 Hz call detectors for Southern California data.
- Completed running detectors for fin whale calls on all data and integrating data into Tethys database.
- Developed strategies for implementing spectrogram correlation to blue whale call detection, taking into account seasonal and interannual variability in calls and detector performance.
- Started preparation of the manuscript on the seasonal variation in the performance of automatic spectrogram correlation detector.
- Completed spectrogram correlation of blue whale B calls across 50% of overall data and started integrating detections into Tethys database.
- Conducted analysis of seasonal variation in sound propagation in the SCB and developed propagation models for all deployment sites.
- Started downloading environmental data and running quality checks on the SST data set.

RESULTS

During the past year of work on the project, we have had four major results or breakthroughs that have influenced our further development and progress in this project. Below are more details on each of those results.

1. *Seasonal variability in the performance of spectrogram correlation detector*

Spectrogram correlation (Mellinger and Clark, 2000) has been established as a reliable method for automatic detection of blue whale calls (e.g., Širović *et al.*, 2004; Oleson *et al.*, 2007). Usually when automatic detectors are applied to data, however, a single metric of the performance is reported. We have found that the performance of a spectrogram correlation detector for blue whale calls in the SCB varies seasonally. Generally, the best performance of the detector occurs during the peak calling season, but it is diminished during times with lower calling presence (Figure 2). Therefore, it has been necessary to perform groundtruthing of multiple segments in each of the years of data to finding the optimal threshold for different seasons. As a practical implementation to our very large dataset, that has meant developing groundtruths for three different times of the year: June, October, and December (start and low season, peak season, and late season, respectively). This more detailed groundtruthing will allow a much more accurate characterization of the precision-recall performance of the detector and increase our confidence in the accuracy of the detections.

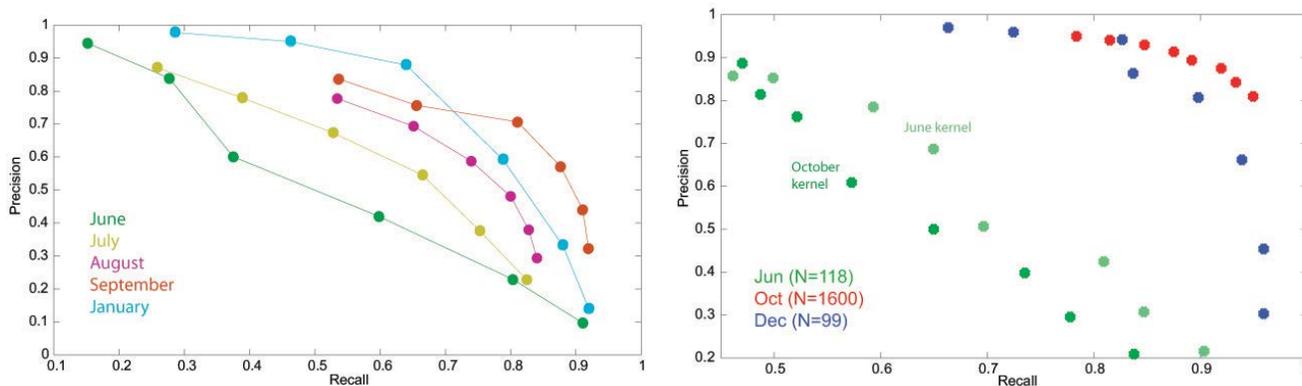


Figure 2. Examples of recall-precision plots for individual months from two different years (2009 on left panel and 2010 on right panel). In addition to varying threshold to optimize performance during the year, it may also be necessary to adjust the kernel as seen in the right panel where dark green dots represent performance of the detector on a June dataset with a kernel based on October data, and light green dots are results on the same data of a detector run with a June kernel.

2. *Fine-scale changes in the frequency of blue whale B call*

Shifting of blue whale call frequency has been documented over the long term (McDonald *et al.*, 2009), and a recent study from the southern hemisphere indicated there is a fine-scale variation in the overall trend (Gavrilov *et al.*, 2012). We have found a similar fine-scale pattern in blue whale B calls in the SCB: call frequency decreases gradually during the year at a rate of approximately 0.1 Hz/month at the third harmonic and 0.3 Hz/year at the third harmonic between years (Figure 3). These numbers indicate that this is not an entirely linear decrease, but at a start of each new calling season in the SCB, there is a reset to frequency that is somewhat higher than the lowest frequency from the previous season.

The broader implication of this trend is significant for the implementation of automatic detectors for analysis of the presence of blue whale B calls. We have found there is a need to implement not only year-specific kernels for spectrogram correlation (Figure 4), but also overall detection performance is improved by the implementation of two kernels during a single calling season (Figure 2 right panel).

Thus in the detection process for blue whale B calls, we have implemented a process by which one kernel is developed based on “early season” calls (June – September) and it is applied for detection up to October 1 of that year. A second “late season” kernel is developed based on calls detected between October and December. The late season kernel is applied to the remainder of the data for the particular calling season. The switch from one season’s kernel to the next is implemented in May of each year.

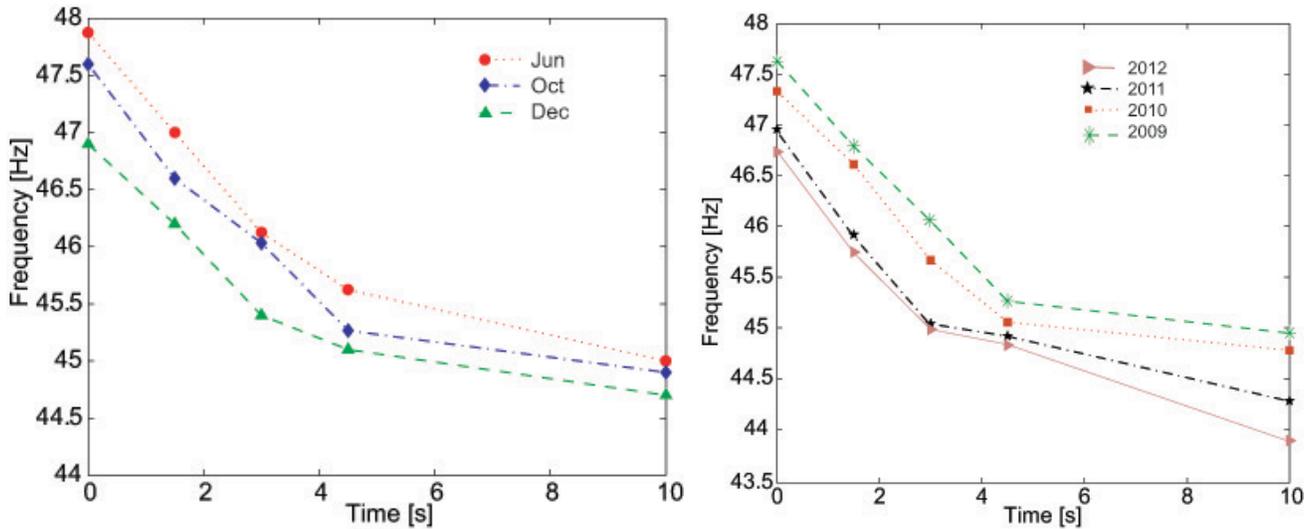


Figure 3. Detector kernels for blue whale B calls based on three different months of one year (left panel) and one month (October) of four different years (right panel), showing frequency change in the calls.

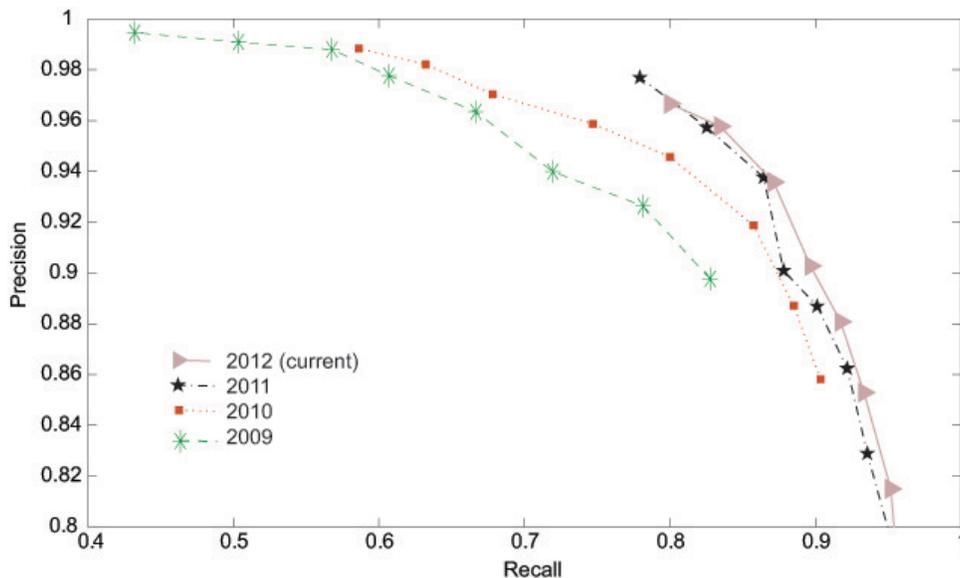


Figure 4. Recall-precision plots from detections that used a kernel developed from 2012 data on datasets from three previous years (2009-2011), as well as that year.

3. *Spatial and temporal variation in the presence of calling fin whales in the Southern California Bight*

We used acoustic energy to detect fin whale 20 Hz calls (Širović *et al.*, 2004) in the SCB and applied acoustic fin index as a metric for estimating fin whale calling presence (Nieukirk *et al.*, 2012). Fin whale 20 Hz calls were present in the SCB year-round, but their overall abundance varied across sites, as well as from year to year. All sites showed peak calling presence during the winter and fall, and decrease in the summer (Figure 5). Site H had a generally high absolute index relative to others (such as site M, see Figures 5 and 6), but that may be due to the fact that site H monitors a relatively large area over which low frequency sound propagates well (see Figure 9 below). There was as much variation in the monthly calling index between years at an individual site as there was across sites within a year (Figure 5). Since the SCB is a very dynamic environment, it is likely changes in the habitat over time and space will account for the some of that variability in the detection of calling animals.

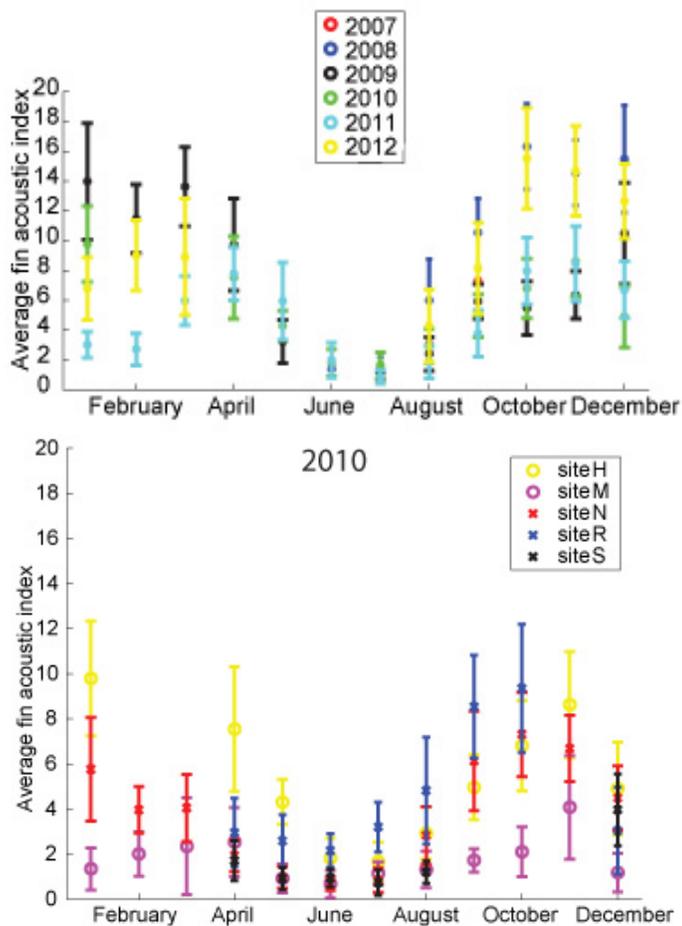


Figure 5. Variation in average monthly fin whale acoustic index at site H across six years (top) and across five sites with deployments in 2010 (bottom).

One of the advantages of this large dataset is the availability of multiple concurrent data points across the SCB. By investigating the change in the spatial distribution of calling over time, it might be possible to gain insights to the general movement of the animals and their use of the SCB. As illustrated in Figure 7, there was a switch in the acoustic index between sites H and M at two peak

calling periods of 2009 (spring and fall), with the highest acoustic index at site H in March, but peak at site M in the fall. From these long-term data, we will evaluate overall trends in use of the SCB by fin (and blue) whales.

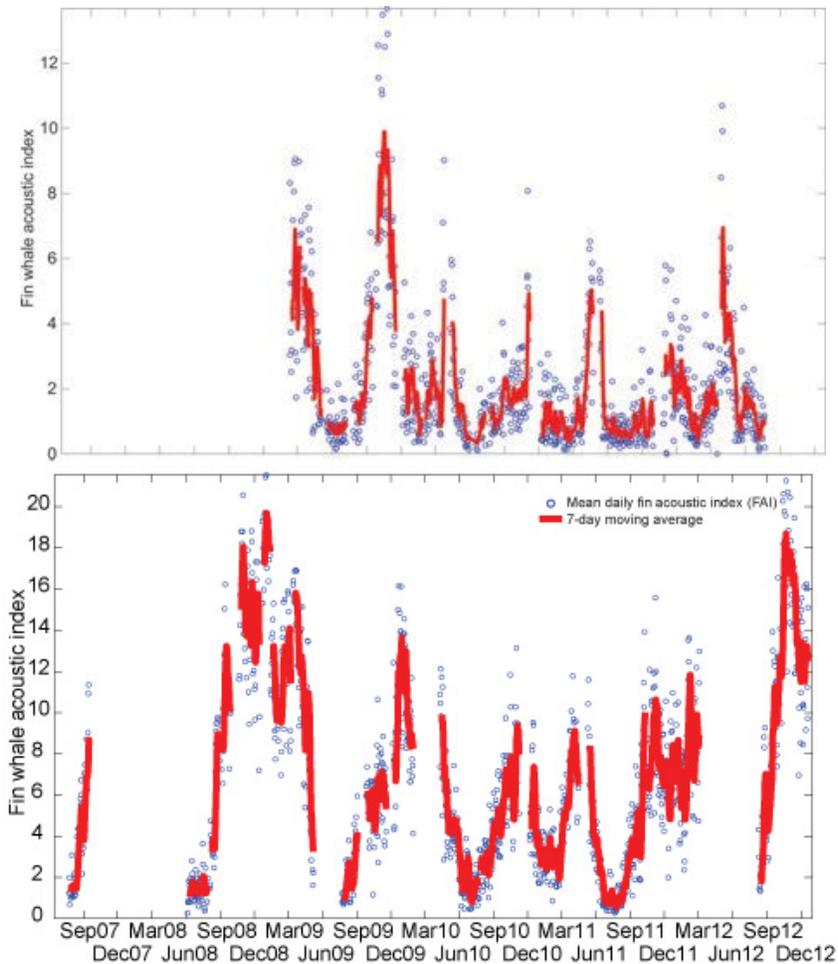


Figure 6. Time series from 15 June 2007 until 31 December 2012 of fin whale acoustic index at sites M (top panel) and H (bottom panel). Circles represent daily mean fin acoustic index, while the red line is a 7-day moving average of that index. Note that blanks are gaps in available data.

4. Propagation modeling in the Southern California Bight

Using ESME workbench, we compared changes in propagation modeling in the SCB among four seasons. We found little variation seasonally (Figure 8), but major differences in areas over which sounds are detected at each site are due to bathymetry. Generally speaking, the propagation of sound is enhanced in the basin where the instrument is located, but is quickly attenuated outside the basin (Figure 9). As a result of this finding, we will need to apply site-specific detection ranges for the normalization of call counts and acoustic index values, as well as estimate areas for the extraction of environmental data. This will allow direct comparison of the overall use of each site by these two different species of calling whales.

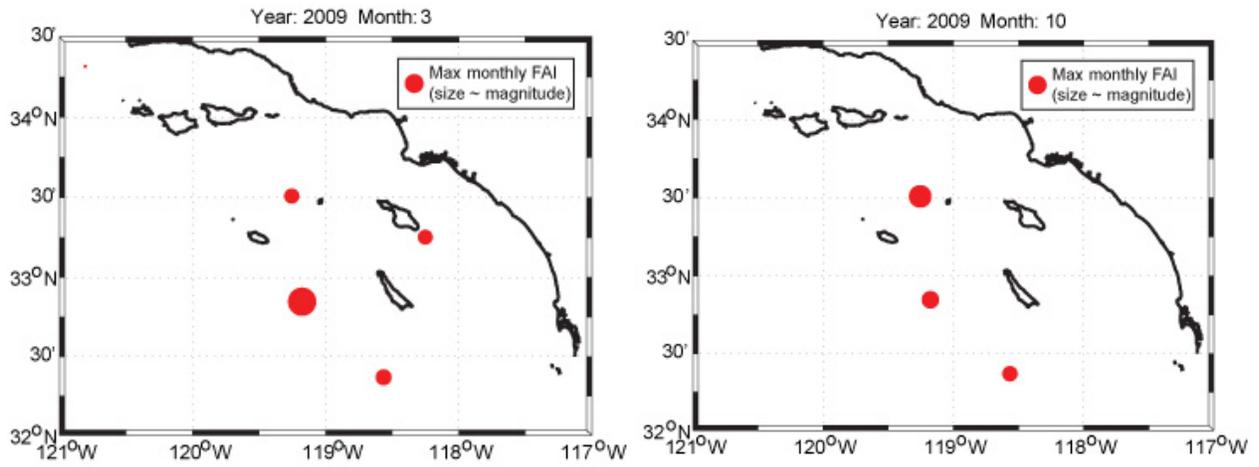


Figure 7. Maximum daily acoustic fin index for the months of March (left panel) and October (right panel) 2010, illustrating tempo-spatial variation in calling.

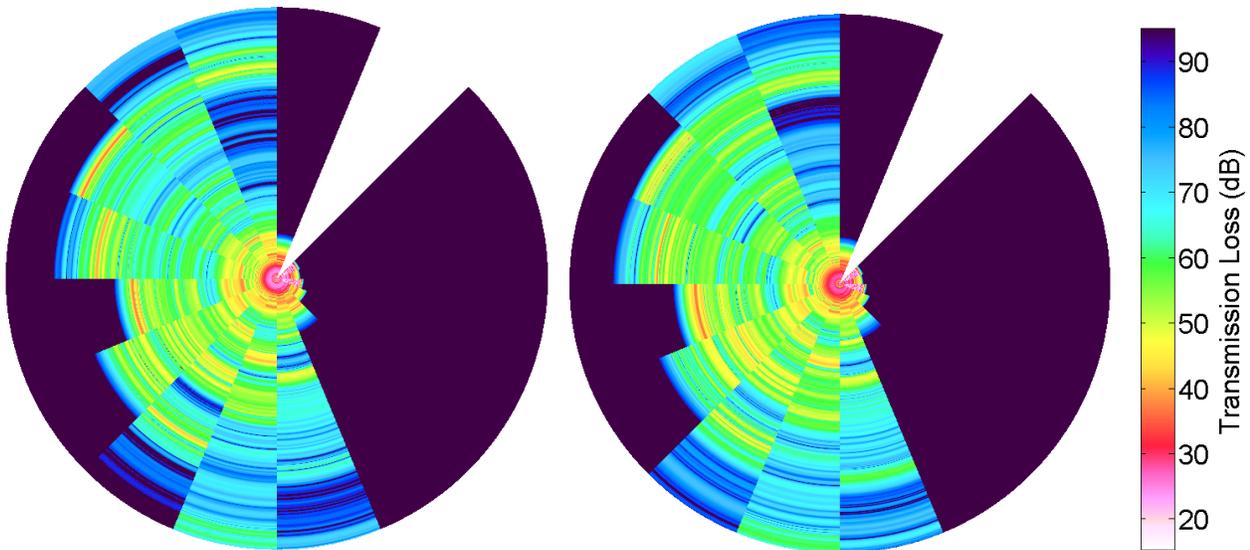


Figure 8. Transmission loss (TL) at a 100 km radius around site G for the third harmonics of blue whale B call in January (left) and July (right). Dark purple denotes region with $TL > 90$ dB. TL is influenced by the bathymetry more than seasonal changes in propagation properties of water.

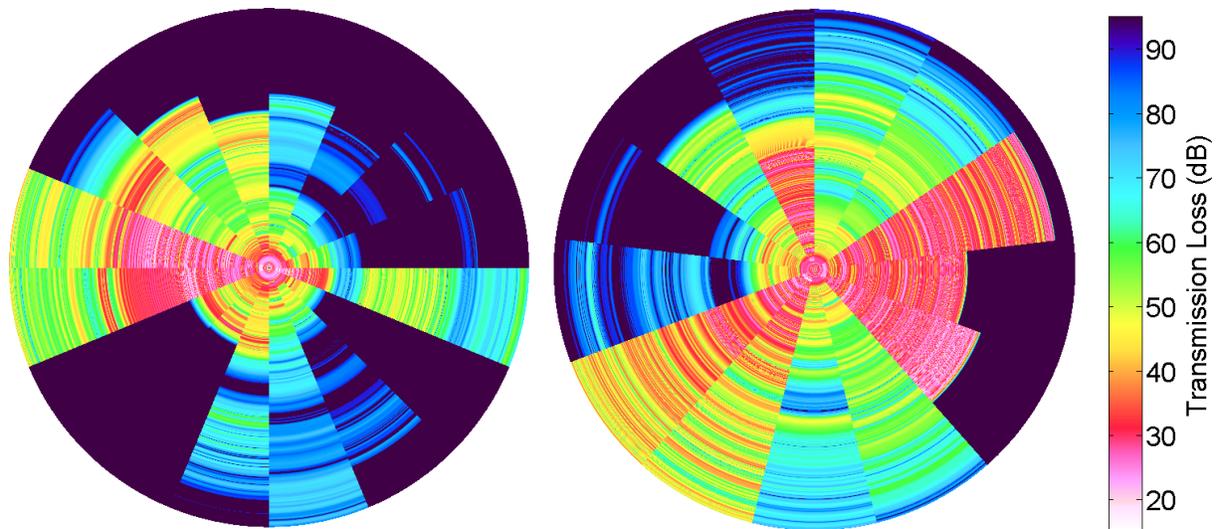


Figure 9. Transmission loss (TL) at a 100 km radius around sites M (left panel) and H (right panel) for the third harmonics of blue whale B call in July (right). Dark purple denotes region with TL > 90 dB, generally corresponding to shallow areas.

IMPACT/APPLICATIONS

Understanding the distribution of cetaceans over space and time is relevant for the Navy's operational needs in Southern California. Unlike visual observations that generally provide limited temporal resolution, passive acoustic methods have the potential to resolve changes in the distribution of marine mammals on both short and long-term temporal scales. Therefore, passive acoustic methods have the potential to be used to improve our understanding of the dynamics of habitat use and population distributions of vocalizing cetaceans. The proposed development of spatially-explicit habitat models for calling blue and fin whales, once completed, will enhance the ability of the Navy to predict blue and fin whale occurrence in the SCB region year-round. Incorporation of the models to the OBIS-SEAMAP environment will improve their utility for other users.

RELATED PROJECTS

During this project, we have been using the Tethys database (<http://tethys.sdsu.edu>) developed under the project "Acoustic metadata management and transparent access to networked oceanographic data sets" (ONR grant N000141110697, PI: M. Roch) for data management as well as easy access to oceanographic data needed for habitat modeling. We have also been using the ESME workbench (esme.bu.edu/index.shtml) for propagation modeling at sites in the SCB (ONR grants N0001411C0448, N000141210390, N000141310641, PI: D. Mountain).

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