Modeling of Habitat and Foraging Behavior of Beaked Whales in the Southern California Bight

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LONG-TERM GOALS

The overall goal of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. We are developing habitat models for multiple beaked whale species in the Southern California Bight using visual and passive acoustic detections acquired from visual and acoustic line transect surveys and autonomous recorders, in correlation with oceanographic and geographic habitat variables. We aim to compare habitat models using visual and acoustic line transect data with those generated using autonomous acoustic recorder detections alone. The goal is to draw on the strengths of these two beaked whale detection datasets to construct habitat models that are superior to what might be developed using either dataset in isolation. Furthermore, we aim to model the foraging behavior of beaked whales with respect to spatio-temporal occurrence on a diel or seasonal basis and in correlation to oceanographic or geographic variables.

OBJECTIVES

The objective of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. Knowledge about foraging and habitat preference and potential shifts due to seasonal or oceanographic factors are crucial for conservation and management as well as mitigation of potential effects for naval activities. Previous experience shows that modeling habitat preference of poorly known species, such as beaked whales, can lead to their visual identification during fieldwork and refine understanding of their vocal behavior.

APPROACH

High-Frequency Acoustic Recording Packages (HARPs, Wiggins and Hildebrand, 2007) have been collecting acoustic data at multiple sites within the Southern California Bight (SCB) since 2005. Sites

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ranged from 200 to 3600 m of depth and were located at a variety of environments such as coastal, canyons, basins, islands, shelf break, seamounts and open ocean, covering a broad range of habitats.

Acoustic signal processing for HARP data is performed using the MATLAB (Mathworks, Natick, MA) based custom program Triton (Wiggins and Hildebrand, 2007) and other MATLAB custom routines. We expect to find up to ten different beaked whale type signals in the acoustic data (Figure 1) and will assume that each unique signal type is species-specific, as has been found for other beaked whale species (Zimmer *et al.*, 2005; Johnson *et al.*, 2006; McDonald *et al.*, 2009; Baumann-Pickering *et al.*, 2010; Rankin *et al.*, 2011; Baumann-Pickering *et al.*, 2012b). Data was screened manually and with automated detectors.

Data from acoustic line-transect surveys (2008-2011) carried out by NOAA Southwest Fisheries Science Center (Jay Barlow) in collaboration with Bio-Waves (Tina Yack), supplies the second beaked whale data set for the habitat modeling effort. These data were post-processed using PAMGUARD and Rainbow Click Software to verify beaked whale detections and assign acoustic detections to species when possible.

Foraging bouts will be automatically detected by investigating consecutive low inter-click intervals (5-10 ms) and low received levels (~20dB lower than prior FM pulses during search and approach phase) (Madsen *et al.*, 2005; Johnson *et al.*, 2006; Baumann-Pickering *et al.*, 2010). Criteria will have to be established for estimating distance of the animals to the recorder to account for detection probability of a foraging event in an echolocation sequence. The relative abundance of foraging events throughout the SCB will be quantified.

The manual and automatic detection time stamps of both HARP data and acoustic line-transect data are stored with the remainder of metadata (e.g. project name, instrument location, detection settings, detection effort) in a database for acoustic metadata management. The database allows storage of acoustic metadata and interacts with outside sources to retrieve physical or biological oceanographic data for habitat model development. A version of the database is in use by the Scripps Whale Acoustics Lab and is in development under a grant issued through the National Oceanographic Partnership Program (NOPP) to Marie Roch (PI), San Diego State University, with Baumann-Pickering, Hildebrand et al. as co-PIs. We will be able to benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

WORK COMPLETED

Automatic detectors were run on HARP data collected between mid 2008 and mid 2012, primarily detecting FM pulses (Figure 1) from Cuvier's beaked whales but also possible acoustic encounters from Blainville's and Deraniyagala's beaked whale as well as two signal types of unknown origin (BW40 and BW43). Automatic detectors for Baird's, Longman's, and Stejneger's beaked whales as well as two signal types of unknown origin (BW 70 and BWC) have yet to be developed. Manual inspection of the automatic detections were performed on a subset of detector output with the help of a machine-assisted classification tool (Figure 2), which was developed to provide the user with relevant information about known and suspected spectral shapes. This effort will be continued for the rest of the dataset.

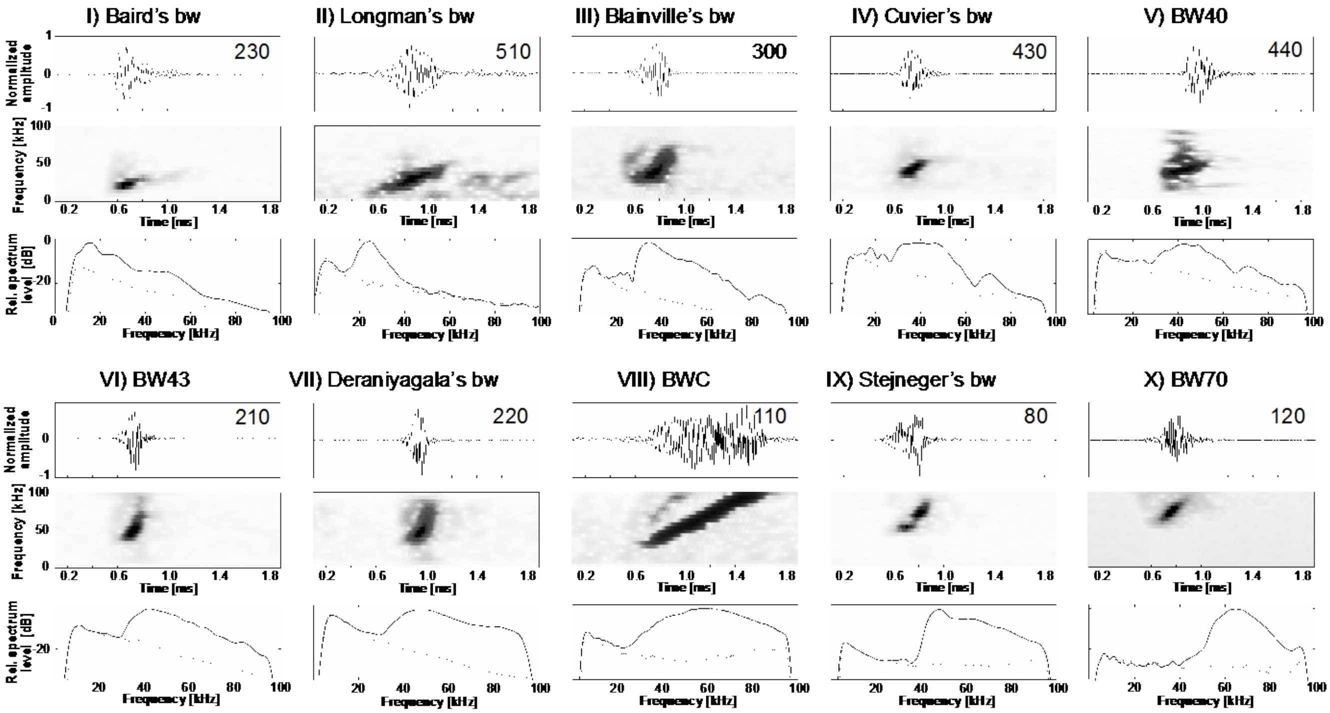

Figure 1: Frequency-modulated (FM) pulses in HARP data from known (I-IV, VII, IX) and unknown origin (V, VI, VIII, X). Each type is shown with one example FM pulse, its time series (top, given with inter-pulse interval) and spectrogram (middle), as well as mean spectra (bottom) of all FM pulses (solid line) and noise preceding all FM pulses (dashed line).

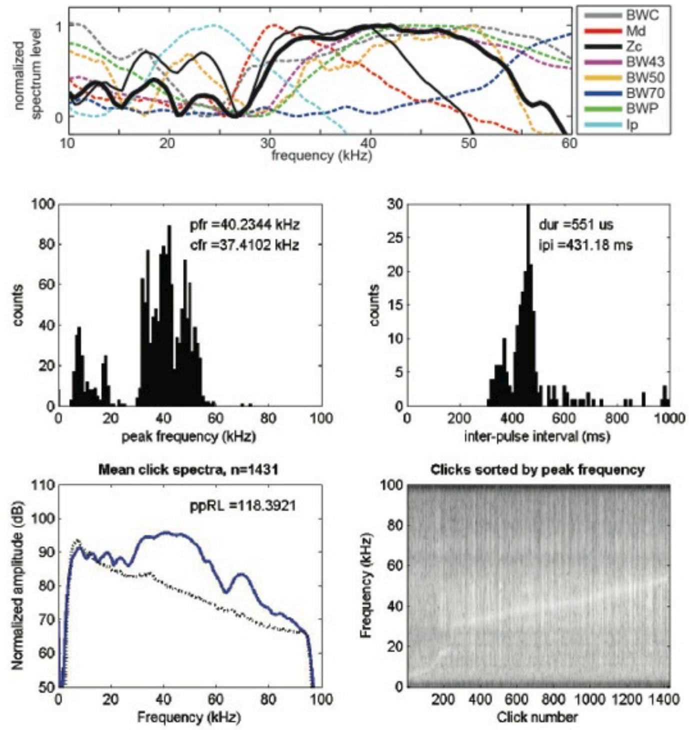

Figure 2. Example of classification tool used to label an acoustic encounter consisting of 1,431 Cuvier's beaked whale FM pulses (Baumann-Pickering et al. 2012). Top panel: Mean spectra of all automatically detected FM pulses of the example encounter denoted by black bold line. Mean spectra of templates for all other FM pulse types are denoted as thin dashed lines with the exception of Cuvier's beaked whale, which is shown as a thin solid black line to highlight the similarity with the example encounter. Middle panel: Histograms of peak frequency (left, pfr) and inter-pulse interval (right, ipi) with median values for pfr, center frequency (cfr), duration (dur), and IPI. Bottom panel: Mean spectra of encounter (left, solid line) and mean noise before each FM pulse (left, dashed line). Concatenated spectrogram of all FM pulses sorted by peak-frequency showing variability (right).

Diel and seasonal presence of beaked whale type signals was analyzed (Figure 3) for eleven sites in the SCB and an additional fifteen sites within the North Pacific reaching from the Aleutian Islands (north) to Northern Line Islands (south) and from Gulf of California (east) to Northern Mariana Islands (west). The geographic distribution of the different signal types was compared to what is known of the distribution from beaked whale strandings and sightings at sea. There is suggestive evidence to link unknown signal types to certain species of beaked whales.

The towed-array recordings from 2008 have been post-processed and final quantifications of beaked whale encounters have been obtained for the dataset. The remaining datasets (~5 weeks of data 2009-2011) are currently in the post-processing stage. All acoustic and visual effort for the towed array surveys have been compiled into separate databases. A code has been developed to divide all of the towed array effort into 5km segments, and this code has been successfully applied to the 2008 acoustic effort database. Once visual and acoustic effort databases are combined this code will be run on the data. Oceanographic and bathymetric variables will then be added to the resulting segment database.

Methods for acquiring and incorporating these variables into the dataset have been developed and successfully implemented using the 2008 towed-array dataset. Independent acoustic and visual habitat models for the California Current ecosystem have been developed for a small species guild of beaked whales and Baird's beaked whales using the 2008 datasets. These independent models will be available for comparison to the combined visual and acoustic habitat models that will be developed for this study.

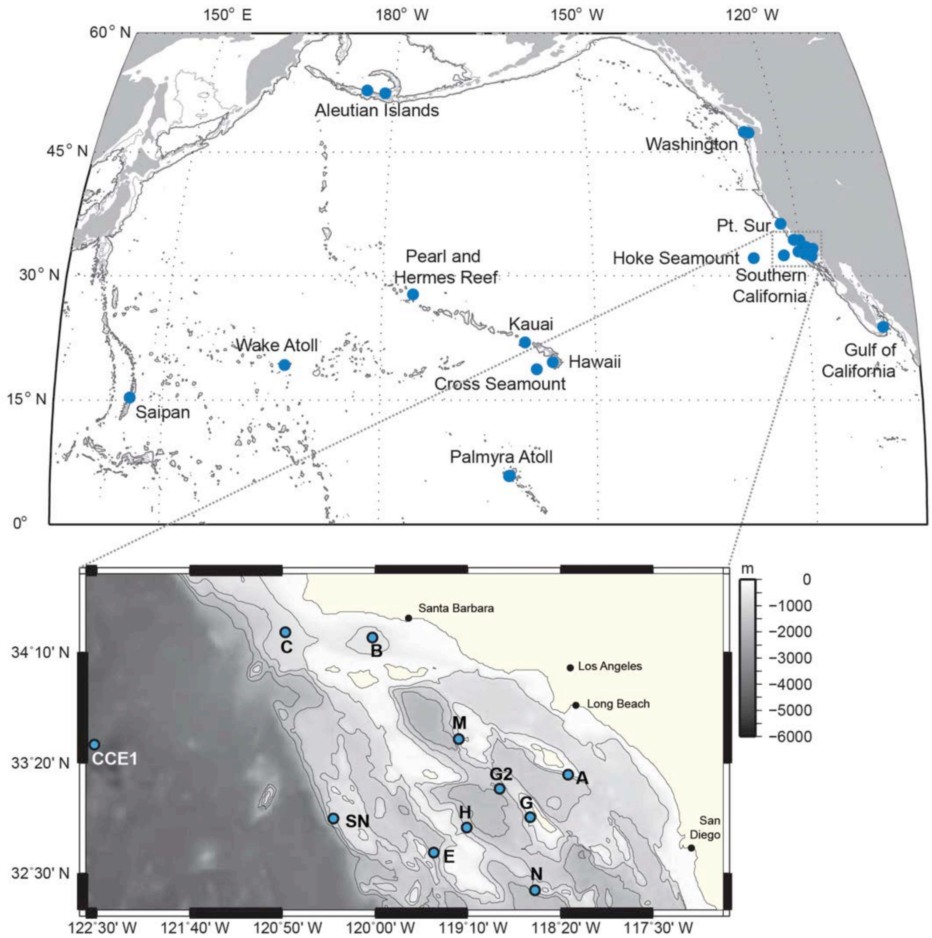

Figure 3. Locations of HARP recording sites (blue points) across the North Pacific (top) and within the Southern California Bight (bottom).

RESULTS

A detailed description of Baird's beaked whale echolocation signals based on visual and acoustic survey as well as HARP data (Figure 4, Baumann-Pickering, Yack et al. *in prep.*) was the basis for detections in long term data.

An interactive software tool was developed to verify automatic detections and classifications to species level (Figure 2). This tool was used in preparation of beaked whale data (Baumann-Pickering *et al.*, 2012a) and has also been modified for both delphinids and beaked whales in the Atlantic ocean.

The analysis of spatio-temporal patterns of beaked whale echolocation signals in the North Pacific over 26 sites (Figure 3) (Baumann-Pickering *et al.*, 2012a) revealed that Wake Atoll, Cross Seamount, Pearl and Hermes Reef, and a site in the Southern California Bight near the shelf break had the highest overall beaked whale presence. Most sites had a dominant FM pulse type and no or a small number of acoustic encounters were registered from other types (Figure 5). There does not seem to be a strong seasonal influence on the occurrence of these FM pulses at all sites but longer time series may reveal smaller, consistent fluctuations (Figure 6). Local effects on prey abundance and preferred habitat structures likely drive most of their presence at a site. Only the species producing signals first described at Cross Seamount (BWC), detected broadly throughout the Pacific Islands region, consistently showed a strong diel cycle with nocturnal foraging activity (Figure 7). Cuvier and Blainville's beaked whales diel pattern varied regionally and were less pronounced. The most dominant pattern in their acoustic activity in some regions was higher counts from midnight to midday. This indicates that BWC must have a very different foraging strategy and possibly targeting different prey items than most other beaked whales. In comparing stranding and sighting information for all species with the geographic distribution of acoustic findings, we hypothesize that BWC signals are likely to be produced by Ginkgo-toothed beaked whales. Based on new insights we collapsed the signal types BW40 and BW50 given in Baumann-Pickering *et al.* (2012a) into one category BW40. Hubb's beaked whale might have produced the BW40 signal type, however, the subtropical to tropical detections at Pearl and Hermes Reef and Wake Atoll are not considered typical territory for this species and would be a surprising finding. BW43 signal encounters were restricted to the Southern California Bight and offshore, and could likely be produced by Perrin's beaked whale. The only signal detected in the Gulf of California was the BW70 type and it was found in the core habitat of Pygmy beaked whales.

IMPACT/APPLICATIONS

The software tool developed to verify automated classification has proven useful for a variety of projects to date. Habitat models will provide knowledge about foraging and habitat preference and potential shifts due to seasonal or oceanographic factors. This is crucial information for conservation and management as well as mitigation of potential effects of naval activities.

RELATED PROJECTS

ONR N001210904 Habitat modeling of fin and blue whales in the Southern California Bight. PI Ana Širović and John Hildebrand. The same HARP sites are used for the modeling, but looking at the low frequency range of the acoustic recordings. Efforts in gathering external oceanographic data as well as thoughts on modeling methods overlap.

ONR N0001411WX21401 Advanced Methods for Passive Acoustic Detection, Classification, and Localization of Marine Mammals. PI Jonathan Klay, Co-PI Marie Roch et al. We will be able to take advantage of expected advances in beaked whale classification through our collaboration with Marie Roch.

NOPP N00014-11-1-0697 Acoustic Metadata Management and Transparent Access to Networked Oceanographic Data Sets. PI Marie Roch, Co-PI Simone Baumann-Pickering, John A. Hildebrand et al. A metadata management system is being developed, which allows access to locally stored acoustic detections and metadata and links in a standardized way to external sources, such as oceanographic or ephemeris data. We will be able to benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

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Baumann-Pickering, S., Simonis, A. E., Roch, M. A., McDonald, M. A., Solsona-Berga, A., Oleson, E. M., Wiggins, S. M., Brownell, J., Robert L., and Hildebrand, J. A. (**2012a**). "Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific," in *International Whaling Commission* (Panama City), p. SC/64/SM21.

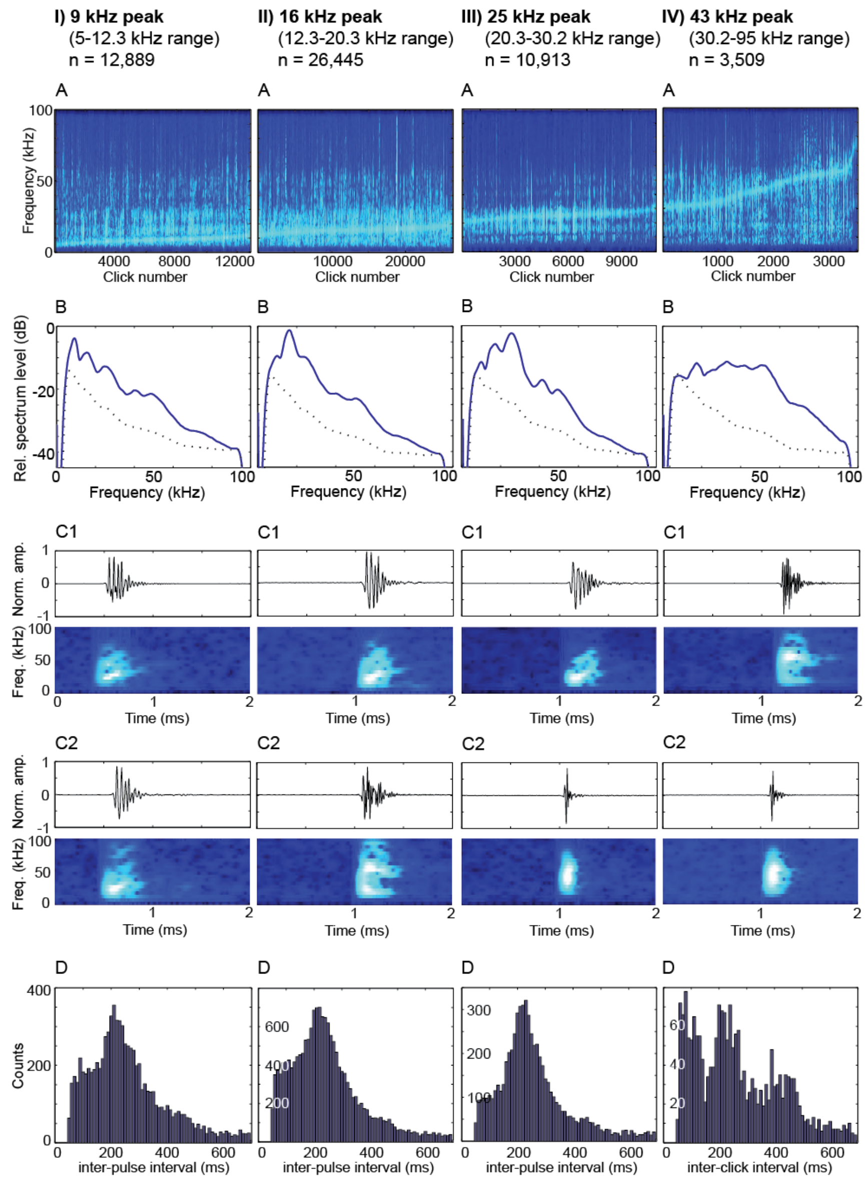

Figure 2: Description of echolocation signals extracted from HARP recordings, split into four subsets (I-IV). A) Concatenated spectrograms with signals sorted by peak frequency. B) Spectra with mean signal (solid line) and mean noise before signal (dashed line). C) Two signal examples with waveform (normalized amplitude, top) and spectrogram (100 points FFT, 99% overlap, bottom). D) Histogram of inter-pulse/inter-click interval.

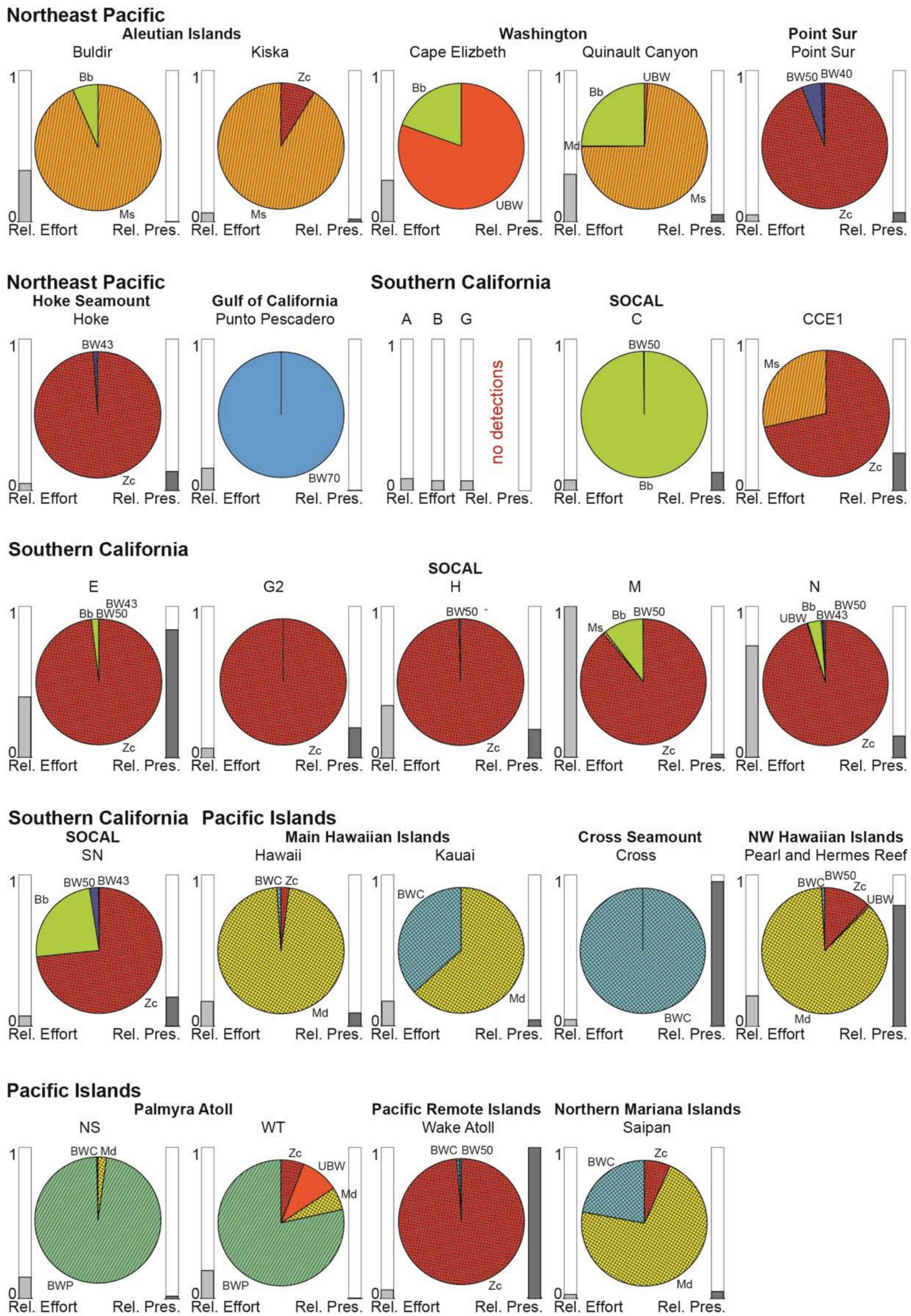

Figure 3: Relative sum of acoustic encounter durations of all FM pulse types by site (pie chart, see Table 2). For each pie chart, the relative detection effort is displayed on the left, and the relative presence on the right. Site M in the Southern California Bight had the highest effort (relative effort of 1) and Wake Atoll had the greatest sum of acoustic encounter durations (relative presence of 1). Sites A, B, and G in the Southern California Bight did not have any detection of beaked whale calls and are thus grouped in the figure.

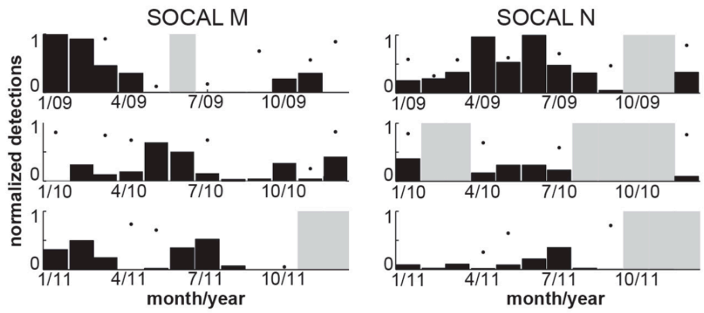

Figure 4: Seasonality of Cuvier's beaked whales at sites SOCAL M and N with a tendency for higher acoustic encounter rates in spring and summer (exception site M in 2009). A point indicates partial monthly recording effort and data in that month was adjusted for reduced effort. Grey shaded areas show no monthly effort.

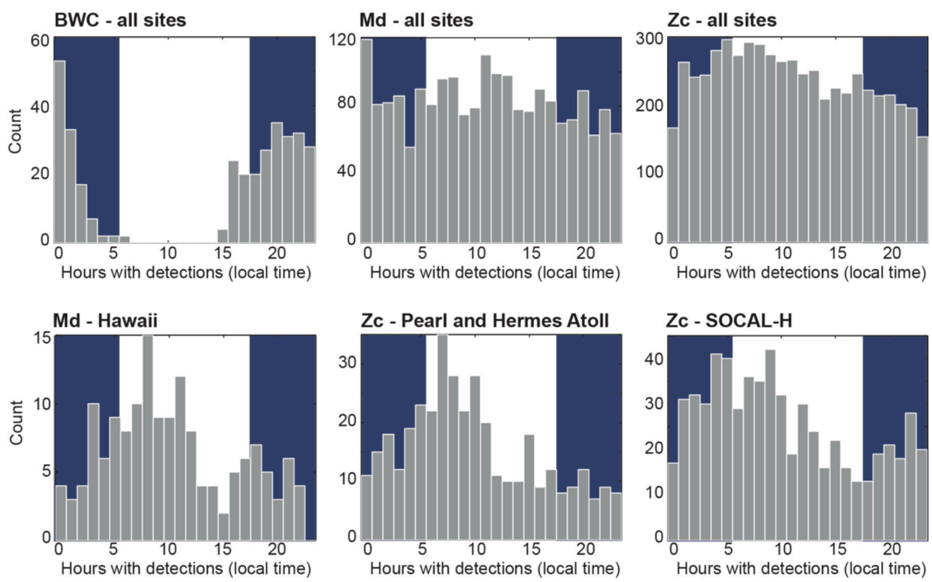

Figure 5: Diel cycle of Cross beaked whale (BWC), M. densirostris (Md), and Z. cavirostris (Zc) pooled over all sites and geographic regions (top panel), as well as for Md and Zc at select sites. Dark blue areas indicate nighttime. BWC displayed a clear nocturnal activity over all sites, Zc had a slight diel pattern with higher activity in the early morning hours to mid day over all sites, particularly pronounced at Pearl and Hermes Reef and SOCAL H. Md did not have a diel pattern, except at Hawaii, where the pattern was similar to Zc. Dark blue areas indicate night time.