

Remote Monitoring of Dolphins and Whales in the High Naval Activity Areas in Hawaiian Waters

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LONG-TERM GOALS

The axiom that knowledge is power applies directly to the problems experienced by the U.S. Navy in encountering dolphins and whales. These encounters can be avoided if more knowledge and understanding of the behavior, distribution, and movements of these animals. Simply stated, if the Navy had more knowledge of the **what, where, when** and **why** of marine mammals in a given body of water, encounters between Naval vessels and marine mammals could be reduced or avoided all together. The ocean is large and the chances of avoiding any interaction with any sizable group of marine mammals are probably much greater than the probability of encountering marine mammals. However, the cost of negative encounters is disproportionately high in terms of negative publicity and law suits so it would be prudent to take steps to increase the odds against any encounters. Therefore, basic information on the biology, natural history, and behavior of cetaceans that frequent waters of high Navy activity are needed to understand ways to avoid encounters. A robust database of this information currently does not exist. There is a higher probability of Naval encounters with marine mammals in Hawaiian waters than in most other regions of the world because of the large number of cetacean species that inhabit or frequent these waters. Approximately 16-20 species of cetaceans can be found in Hawaiian waters. This is a large number of species for such a small geographic area. Knowing **what** animals are present in a given body of water is important because different species utilize their habitat in different ways. Therefore, it is important to understand the distribution, abundance and movement of dolphins and whales over the day-night cycles and seasonal periods.

OBJECTIVES

The objective of this study is to map the distribution and abundance of whales and dolphins in selected regions of Hawaiian waters. The waters surrounding the islands of Kauai and Oahu, where most Naval activities occur, will be the focus of this study. The Pacific Missile Range is in the waters of Kauai and the Pearl Harbor Naval Base is the home of the U.S. Pacific Fleet.

APPROACH

Five relatively low-cost autonomous, remote acoustic recorders denoted as the **EAR** (Ecological Acoustic Recorder) have been deployed around the island of Kauai and five more EARs are moored around Oahu, to simultaneously monitor for the presence of dolphins and whales. The EARs are retrieved, refurbished and redeployed after a battery change and swapping of hard drive on a periodic

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basis. The data disks are taken back to the laboratory for analysis. Various species of cetaceans are of interest, but for the first two years, the effort has been concentrated on deep diving beaked whales around Kauai and at one location off Oahu.

The EAR, jointly developed by the Hawaii Institute of Marine Biology (HIMB) and the Coral Reef Ecological Division of NOAA's Pacific Islands Fisheries Science Center has a maximum sampling rate of 80 kHz with a hydrophone that is functional up to 40 kHz and records data to a 120 Gbyte laptop recorder. It can be deployed to depths of up to 1000 m. The EAR is controlled with a Persistor Instrument CF2 microcontroller. Its deployment life is determined by the programmable recording duty cycle and the number of battery packs included, but typical deployment durations range between 3-12 months. At its maximum sampling rate, it is capable of recording the calls of all cetacean species found in Hawaiian waters, including beaked whales. A pictorial description of the interior electronics and power supply is shown in Figure 1a along with a picture of a deployed EAR on an acoustic release device in Figure 1b. Map of deployment sites around the islands of Kauai and Oahu are shown in Figure 2.

WORK COMPLETED

Kauai EARS

The project received one of the M3R nodes (same node used in the Navy underwater test ranges at AUTEK, SCOR and PMRF) in late August, 2010, courtesy of David Moretti, of the Naval Undersea Warfare Center Division in Newport, R.I. and Dr. Frank Stone, of N45. The node is currently being used to process the data from EARs deployed off Kauai and off Barbers Point, Oahu, which is at a depth of 581 m. The M3R system is designed to detect both Blainville's and Cuvier's beaked whales, as well as pilot whales, Risso's dolphins, sperm whales and small dolphins. The energy ratio mapping algorithm (ERMA) developed by Holger Klinck and David Mellinger at Oregon State University to detect beaked (Cuvier's and Blainville's) whale biosonar signals is also being used to analyze the data. The beaked whale detections from the M3R system are compared with the beaked whale detection from ERMA and if the detections agree we accept the fact that beaked whale signals are present in a given file. If both detectors do not agree, we examine each of the files visually. Beaked whale and sperm whale signals are relatively simple to detect and classify visually. An example of the waveform, frequency spectrum and the time-frequency distribution of a beaked whale signal are shown in Figure 3. Beaked whales are the only odontocetes that produce biosonar signals with durations greater than approximately 250 μ s. They are also the only odontocetes that produce frequency modulated clicks which can be seen in the Wigner-Ville distribution on the bottom of Figure 3. Finally, the repetition rate of the signals tends to be relatively constant between 250 and 400 ms, depending on the species.

The biosonar signals of sperm whales are also easy to discriminate visually from other deep diving odontocetes. The waveform, frequency spectrum and time-frequency distribution of a sperm whale signal are shown in Figure 4. Only sperm whales produce signals in which the peak-frequency fall lower than approximately 15 kHz.

Deep Diving Odontocete

We have analyzed the 2nd, 3rd and 4th deployment, using the M3R system along with the ERMA algorithm. The sample rate for these deployment was increased from 64 kHz used in the 1st and 2nd deployment to 80 kHz. Examples of the number of files in which different species of deep diving echolocating odontocetes were detected, for the 5th deployment to the SW Kauai location are shown in Figure 5. The data period was from October 20, 2010 until January 26, 2011. The vertical axis is the per-

cent of observation periods (OSBP) containing biosonar signals from a given species. Each OSBP is 30 seconds in duration and occurred every 5 minutes so that there are 288 OSBP per day. The vertical axis for all species is the same so that the relative number of OSBP that contained biosonar signals from the different species can be compared directly. The histogram data indicate that at this SW Kauai location, deep diving echolocators were present almost every day during this period. The results for the 3rd and 4th deployment were similar to that shown in Fig. 5 indicating that at least one species was detected every day with the same pattern of short-finned pilot whales being detected the most and beaked whales the least. Not all species were detected every day, but at least one species was present almost every day. The maximum percent of pilot whale detection during a day was approximately 16% of the total observation period of December 29, 2010 and January 20, 2011 at this location. The small dolphin category consists of dolphin signals that did not fit into the other 4 categories.

The percentage of OSBP with biosonar signals detected for the five species at three locations is shown in Figure 6. All the OSBP with biosonar signals for all species were first determined and the percent biosonar signals that can be attributed to the different species was then calculated. The results for the three location followed a general pattern in which biosonar signals from short-finned pilot whales were detected the most followed by sperm whales and Risso's dolphin with biosonar signals from beaked whales being detected the least. The data in Figure 6 can be used as a first order estimate of the relative abundance of the different deep diving echolocating species only if several assumptions are made. Some of the major assumptions include the source level of each species and the beam patterns are similar and the different species were diving to approximately the same depths. Unfortunately our understanding of how these different species use their biosonar in foraging for prey is not sufficient to pursue these issues further. However, it would be difficult to argue that the data does not represent within a certain margin of error the relative abundance of the five species. Unfortunately, the magnitude of the margin of error is not known. Perhaps the most important consequence of the data presented in this figure is the fact the percentage of files with beaked whale signals are very low, the lowest of the five species considered. Another important property of the data is that pilot whales, Risso's dolphins and sperm whales (all known to be deep divers) produced signals that were captured in 78% of the files from the SW location.

The summary of the percent of OSBP with biosonar signals from all the locations and for the three time periods being considered is shown in Fig. 7. The composite results in Fig. 7 are not much different than the results shown in Fig. 6 for a single time period and three locations. The results suggest that the relative abundance of the five species around the island of Kauai is relatively stable with short-finned pilot whales being the most abundant, followed by sperm whales, Risso's dolphins, small unknown dolphin species and with beaked whales being the least abundant of the deep diving odontocetes.

The per day average of OSBP with biosonar signals is shown in Fig. 8 for four locations around Kauai as a function of month for the different species of deep diving odontocetes. The results for the NW location only went up to September. Unfortunately the ORE/Edgetech CART acoustic release used with the EAR at the NW did not separate from the bottom anchor although acoustic communications between the release and surface unit indicated that that the CART jaw was opened. The results of Fig. 8 suggest that the SW location was a "hot spot" around Kauai. The percentage of OSBP with deep diving odontocetes detected was close to double that of the location with the next highest percentage. The results indicated that the NW location was second to the SW location in the largest number of deep diving odontocetes detection. The detection rate for the SW and NW locations indicate the more animals were around during the first half of the year (Jan – June) than the second half of the year but

with one exception for the month of Sept at the NW location. This trend was seen for all the species involved. However, there is sufficient variability in the results to arrive at many general conclusions.

The low number of files containing beaked whale clicks suggests that beaked whales are not very abundant in the waters around Kauai. Only 1% of the files from the NE location contained beaked whale clicks. At the SE and SW locations, the percentage was 4 and 5%, respectively.

An example of the diurnal variation of click detection for the different species at the SW location is shown in Figure 9. The shaded areas of each plot represent the dawn-dusk (crepuscular hours) and night hours of each day. The percentage shown in the middle of each plot is the percentage of files with clicks detected in the crepuscular and night hours. The percentage of night time detection at the SW location varied from 62 to 78%, indicating a strong diurnal dependency of foraging for these deep diving odontocetes. The majority of the biosonar signals were detected at night.

When the three sites around Kauai are considered, the crepuscular and night time foraging trend becomes even more apparent as can be seen in the data shown in Table 1. A fourth data set from an EAR deployed off the island of Niihau during the biennial Rim of Pacific naval exercise is included. This night time trend was reported in the 2010 progress report with the main difference being the individual species are separated in this report whereas all the species were lumped together in the 2010 report.

The EARs locations were changed in April of 2011 from deploying them around Kauai to having a string of them along a coast line. The four EARs are at about the same depth of 750m. We hope to obtain a deeper understanding of how animals utilize a shore line.

Table 1. The percentage of OSBP containing biosonar clicks from the different species during the crepuscular and night hours for the three locations around Kauai during the October 20, 2010 - January 26, 2011 period and for a location off the island of Niihau during the July - October, 2010 time period.

	Pilot whale	Risso's dolphin	Sperm whale	Small dolphin	Beaked whale
NE	80%	89%	80%	85%	91%
SE	62%	80%	62%	74%	82%
SW	68%	78%	62%	76%	75%
Niihau Jul-Oct 2010	78%	83%	77%	85%	89%

Baleen Whales

A baleen whale detector that can detect blue, fin, sei, minke and humpback whales have been encoded in Matlab. The raw data sampling at 64 kHz is decimated by a factor of 16 to achieve an effective

sampling rate of 4 kHz for minke whale boing sounds, by a factor of 32 to achieve a 2 kHz sample rate for humpback whale sounds, and by 64 to achieve a sampling rate of 1 kHz for other species. After decimation, the data is filtered to the desired frequency range (listed in Table 1) specific to each species. The resulting frequency band is narrow enough such that the bio-acoustic signals can be detected by applying a threshold on the waveform amplitudes. To reduce the effect of pulse-like noise, the thresholding is applied on the envelope of the signal instead of directly on the waveform. The threshold is obtained adaptively for each observation period, i.e. each 30-seconds EAR data file. Currently, the threshold is set to be 3 dB higher than the ambient sound amplitude. The last step is a species identification, which verifies whether the signals extracted by the envelope-detector match with the time-frequency characteristics of each species. Table 1 summarizes the key characteristics for each of five baleen whale species analyzed. The validation of frequency range is conducted using Fourier transform for minke whale, blue whale, and humpback whale. For fin whale and sei whale sounds that have much shorter time durations, the pseudo Wigner-Ville Distribution (PWVD) is used to provide high-resolution, precise measurements.

The baleen detection algorithm is still being refined so increase the accurate of detection, especially for blue whales. The preliminary results are shown here in order to convey the fact that progress is being made on baleen whale detection. One of the surprising results is the possibility that baleen whales may travel to the Hawaiian archipelago during the winter months. Results for the N and NE locations suggest this finding.

Table 2. Parameters for the baleen whale detectors. For minke whale, the frequency range limits are 1375 – 1430 Hz for the main band, and 116 ± 7.5 Hz for the separation between main band and side bands. For sei whale, instead of using the time duration, the time-frequency slope (i.e., frequency range divided by the time duration) is used for identification. The slope range limit for sei whale is 110 – 199 (Hz/s).

Species	Decimation Factor	Bandpass Filter Range (Hz)	Characteristics for Species Validation		
			Frequency Range Limits (Hz)	Time Duration (s)	Method
Blue Whale	64	5 - 50	15 - 22	12 - 30	Fourier
Fin Whale	64	10 - 150	< 25	0.05 – 0.5	WVD
Sei Whale	64	10 - 150	30 - 110	N/A	WVD
Minke Whale	16	1000 - 2000	1375 – 1430	1.2 – 6.5	Fourier
Humpback Whale	32	200 - 600	200 - 600	0.1 - 2	Fourier

Oahu EARS

Data from Oahu EAR deployments were analyzed using the Matlab™ script Triton, developed by Sean Wiggins (Scripps Institute of Oceanography) and adapted for use with EAR data. Triton was used to create Long-Term Spectral Averages (LTSA) of the recordings for each deployment. LTSAs provide a visual representation of the acoustic energy across frequency and time over the deployment period. The LTSA is a composite spectrogram made up of Fourier Transforms averaged over a user-defined period. For this study, 10 seconds of recording time were used for each average. LTSAs were binned hourly and odontocete encounters were located by visually examining the LTSA for the presence of

“hot spots” of acoustic energy in the frequency bands associated with their signals as shown in Figure 9. Suspected odontocete calls were confirmed by examining a 1024-point, Hanning -windowed spectrogram of the original recording. Within each hour period, the three recordings with the greatest number of acoustic signals were given a call abundance score between 1 and 4 and these were averaged to give an hourly call abundance (HCA) score for the hour. This provided a normalized, quantitative metric for comparing calling rates over time and across locations. In addition, recordings were characterized on the basis of whether they contained echolocation click trains, mostly low frequency (< 10 kHz) whistles, mostly high frequency (> 10 kHz) whistles, or a combination of the three. Low frequency whistles were considered to be indicative of the presence of one or more of the following species: false killer whales (*Pseudorca crassidens*), short-finned pilot whales (*Globicephala macrorhynchus*), melon-headed whales (*Peponocephala electra*), Risso’s dolphins (*Grampus griseus*) and rough-toothed dolphins (*Steno bredanensis*) (J. Oswald, pers. com.). High frequency whistles, on the other hand, were considered to be indicative of the presence of one or more of the following species: spinner dolphins (*Stenella longirostris*), spotted dolphins (*Stenella attenuate*), striped dolphins (*Stenella coeruleoalba*), and bottlenose dolphins (*Tursiops truncatus*) (J. Oswald, pers. com.).

In Fig. 13 are the number of recording days between February 7, 2009 and April 17, 2011 that were analyzed from each location. Data from all deployments have been analyzed, except the second year from East Oahu, for which the analysis is still ongoing. Figure 14 shows the daily summed HCA of echolocation activity recorded at each site over the course of the study. Echolocation activity was detected on 93% of recording days across the five sites. A statistical comparison of the average daily echolocation HCA reveals that there was significant variation between sites (Kruskal-Wallis, $p < 0.001$). The highest echolocation activity was at the NW, North and East Oahu sites and the lowest at the SW and SE sites. There was no evidence of seasonal variability in the occurrence of echolocation; however, individual sites experienced large periodic variations not tied to seasonality

Echolocation activity at all five sites exhibited a strong diel trend (Fig. 15). Substantially more echolocation was recorded at night (1800h to 0600h) than during the day (0600h to 1800h) at all sites except at East Oahu where the main peak of activity was in the afternoon between 1500h and 1700h. This trend suggests that most odontocete foraging around Oahu takes place at night, probably in relation to the nocturnal vertical migration of the mesopelagic boundary community. The peak in activity observed in the afternoon at the East Oahu site suggests that a different dynamic may be present at this site, but further investigation is needed to resolve the cause of this difference.

Figure 16 shows the daily summed HCA of whistling activity recorded at each site over the course of the study. Across the five sites, high frequency (HF) whistles were detected on 76% of recording days, low frequency (LF) whistles on 26% of days and recordings with both were made on 10% of days. Both LF and HF whistling occurred at all Oahu sites. However, LF whistles were significantly more common along SE Oahu (Kruskal-Wallis, $p < 0.001$) while HF whistles were most common at the NW Oahu site and least common along SW Oahu (Kruskal-Wallis, $p < 0.001$). There was a significant seasonal variation in the occurrence of LF whistles (Kruskal-Wallis, $p < 0.001$), with the lowest occurrence (pooled across the five sites) during winter (January-March) and the highest during spring and summer (April-September). A seasonal variation was also observed for HF whistles, with significantly lower occurrence in winter than in summer (Mann-Whitney, $p < 0.0017$).

There was not a clear diel trend in the occurrence of LF whistles across sites (Fig. 17A). However, there was a diel pattern in HF whistling activity. This pattern closely matched the occurrence of echo-

location activity seen in Figure 13, suggesting that HF whistling species produced much of the echolocation activity recorded.

In order to help further resolve the species identity of whistling animals, the Real-time Odontocete Call Classification Algorithm (ROCCA) (Oswald et al, 2007) was used to identify LF whistles from NW Oahu. For this analysis, 732 whistles from 77 encounters were extracted from the recordings and classified using ROCCA. Data from the other four sites were not analyzed with ROCCA due to funding limitations. The algorithm classified 60% of the analyzed whistles as belonging to false killer whales (*Pseudorca crassidens*), 9% as rough-toothed dolphins (*Steno bredanensis*), 4% as pilot whales (*Globicephala macrorhynchus*) and 27% were undetermined. However, ROCCA's confusion matrix reveals a tendency to misclassify pilot whale signals as false killer whale whistles. Therefore, we combine the two classifications into one 'false killer whale/pilot whale' category, resulting in 64% of LF whistles from NW Oahu being attributed to these two species.

The results obtained suggest that odontocete foraging activity, which is mediated by echolocation, varies around Oahu and is greatest on the northwestern, northern and eastern sides of the island and lowest on the southwestern and southeastern sides. This may be driven by the availability of prey at the different locations, or it may be indicative of an ecological response to the higher urbanization and anthropogenic activity occurring along Oahu's south shore. In addition, there are both spatial and seasonal variations in the occurrence of different species. Species producing high frequency whistles (e.g. *Stenella longirostris*, *S. attenuata*) followed the spatial pattern described for echolocation activity (i.e. high occurrence at the NW, North and East sites, lower occurrence SW and SE) and were most commonly detected during summer months. Species producing lower frequency whistles (e.g. *Globicephala macrorhynchus*, *Pseudorca crassidens*) were recorded predominantly on the SW and SE sides of Oahu and were detected most frequently in spring and significantly less in winter. The factors driving seasonal variations in detections remain unclear. The moderately higher detection rates in summer of HF species could reflect higher calling rates tied to seasonal reproductive activity, or perhaps represent a response to a shift in prey distribution. On the other hand, the rather substantial decrease in winter-time occurrence of LF whistles suggests a more fundamental seasonal shift in occurrence. The results obtained from the ROCCA analysis suggest that, at least at the NW site, false killer whales and pilot whales are the two predominant LF whistling species present. False killer whales in the Hawaiian archipelago are known to range widely between islands (Baird et al, 2012) so it is possible that lower LF whistle detections rates in winter may reflect a seasonal redistribution of this and/or other species.

Although echolocation rates overall did not show a seasonal trend, there was substantial variation across sites on time scales of multiple days. This suggests that odontocetes make frequent adjustments in their local distribution, likely because their prey is patchy and variable in distribution. On several occasions, daily summed echolocation HCA values were an order of magnitude greater than normal (e.g. Aug 2009 at SE Oahu & January 2011 at North Oahu). This suggests that local pulses in productivity may have occurred during these times causing an influx of odontocetes. From a Naval perspective, this is of importance because understanding and ideally predicting the conditions promoting such pulses in productivity could help the Navy plan activities to avoid areas and/or times with predicted high odontocete presence.

Finally, several of the sites monitored have historically received little or no visual survey effort (e.g. North and East Oahu), but are clearly important odontocete habitats. The north side of Oahu in particular appears to be a more important area for HF whistling species than previously thought. The results obtained in this study have provided an unprecedented perspective on the occurrence of odontocetes

around the island of Oahu and illustrate the value of applying a long-term acoustic monitoring approach to investigating odontocete occurrence and distribution.

RESULTS

Kauai Data

1. The data from the 5th deployment has provided a good beginning understanding on the what, when and where issue in terms of deep diving odontocetes around the island of Kauai. The data indicate that at least one of the five species is regularly present during part of almost each day. At the NE Kauai site, at least one species was present on 99% of the days between October 20, 2010 and January 26, 2011. At the SE and SW Kauai locations, at least one species was present 93% and 90% of the days respectively during the recording period. These high rates of occurrence have not been observed visually since animals can appear during any time of a day which include nights.
2. Of all the deep diving odontocetes, beaked whales are the least abundant.
3. The night time foraging behavior of beaked whales is not consistent with beaked whale diving behavior at the AUTEK range in Tongue of the Ocean, Bahamas, and at the Josephine seamount off the coast of Portugal. The reasons for these differences are probably associated with the behavior of the prey field and related to differences in habitat. The islands of Hawaii are in the tropics and are the tips of mountains that rise from the ocean bottom into the sky. The AUTEK range is in an underwater canyon in the subtropics and the Josephine seamount is totally submerged. Therefore, the bottom topography and current flow are probably very different in TOTO and off Portugal than off Kauai.
4. The results of 2011 EARs suggest that these deep diving odontocetes may be more abundant than previously realized. Being able to observe the presence of marine mammals throughout a 24 hour period seems to be very important since it seems that more animals are present or perhaps active at night, during periods in which visual observation is difficult or impossible.
5. The amount of detection of deep diving odontocetes was highest at the SW location followed by the NW location. The SW location was definitely a “hot spot” around Kauai. More detection of all five species occurred at the SW location and in some cases there close to double the amount of detections at the NW location which was the locations with the second largest amount of detections.
6. There is a good possibility that some baleen whale species spend their winter months in the Hawaiian archipelago. Further analysis of the remaining data and better accuracy of the blue whale detector will certainly shed more light on this issue.

Oahu Data

1. The northern and eastern shores of Oahu appear more important for HF whistling species than previously known, presumably due to foraging.
2. LF whistling species occur all around Oahu, but are especially common along SE Oahu
3. No clear seasonal foraging patterns exist, but periods of intense foraging activity lasting several days are common.

4. LF and to some degree HF whistling species have reduced occurrence/activity off Oahu during winter months (Jan – Mar)
5. False killer whales and/or pilot whales are the predominant LF whistling species detected around NW Oahu

Table 3 – Call abundance scores assigned for 30-second recordings

Category	Call abundance score
1-5 whistles	1
Burst pulse (BP) only <5	1
Sonar only <1/2 recording	1
6-10 whistles	1.5
Sonar only >1/2 recording	1.5
BP only >5	1.5
Sonar & BP <5	1.5
1-5 whistles & sonar or BP	2
>10 whistles	2.5
Sonar & BP >5	2.5
1-5 whistles, sonar & BP	3
6-10 whistles & sonar or BP	3
6-10 whistles, sonar & BP	3.5
>10 whistles & sonar or BP	3.5
>10 whistles, sonar & BP	4

IMPACT/APPLICATIONS

Potential future impact for Science and/or Systems Applications is gaining knowledge of how dolphins and whales utilize the waters surrounding Kauai and Oahu, two areas of high Naval activities and from that knowledge, operations can be planned that would maximize the probability of avoiding marine mammals. Successful results and methods used in this project could also be applied to other areas of high Naval activities.

RELATED PROJECTS

None

PUBLICATIONS

Au, W. W. L., Giorli, G., Chen, J., Copeland, A., Jarvis, S., Morrissey, R., Moretti, D., and Klinck, H. (2012). “Nighttime Foraging by Deep Diving Echolocating Odontocetes off the Hawaiian Islands of Kauai and Ni’iahu as Determined by Passive Acoustic Monitors,” submitted to J. Acoust. Soc. Am.

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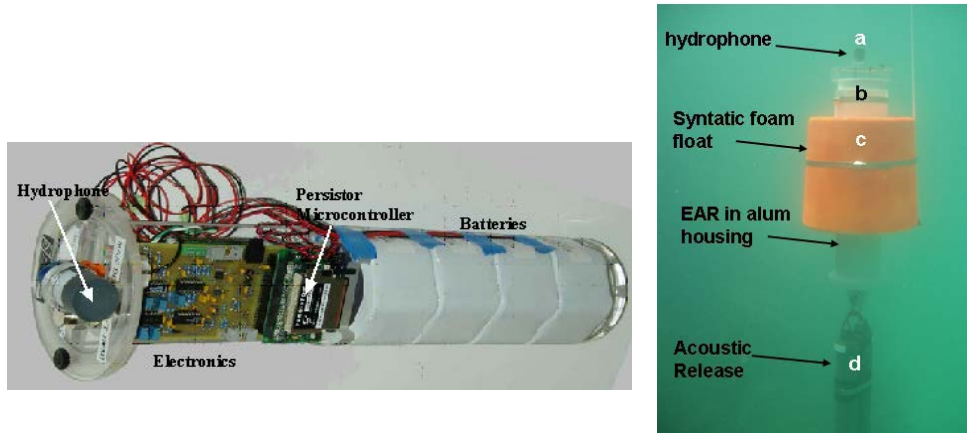


Figure 1. (left) The internal parts of the EAR with the electronics, Persistor microcontroller and the battery pack, (right) EAR in deep mooring configuration showing an acoustic release, EAR in an aluminum housing and a syntactic foam collar.

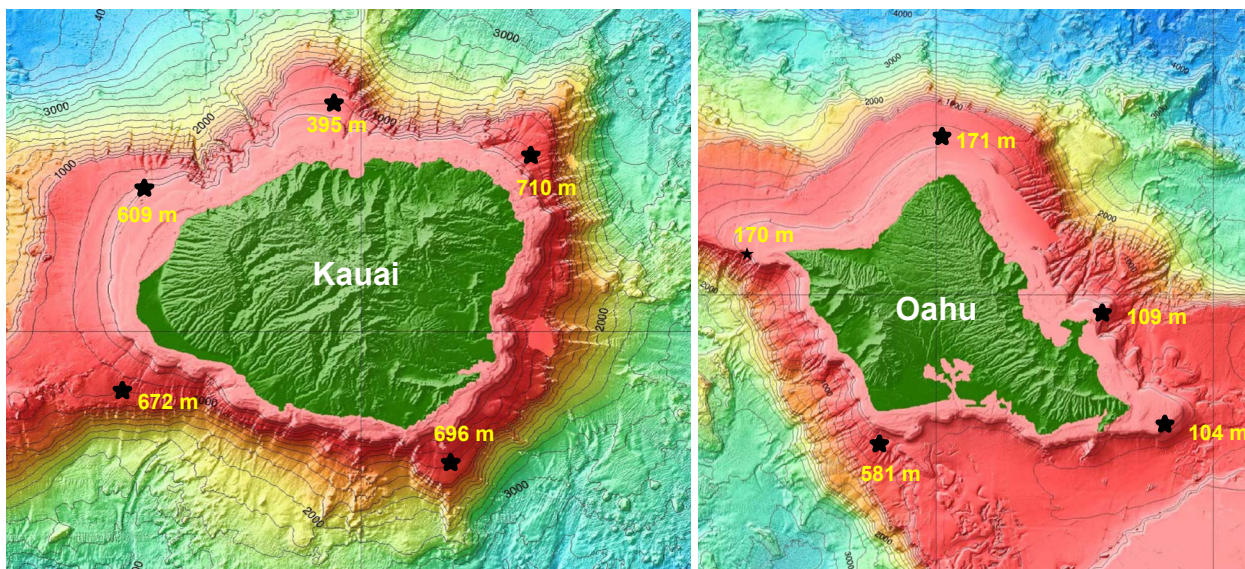


Figure 2. The potential locations around the islands of Kauai and Oahu where EARs (stars) operating simultaneously will be deployed during the first year.

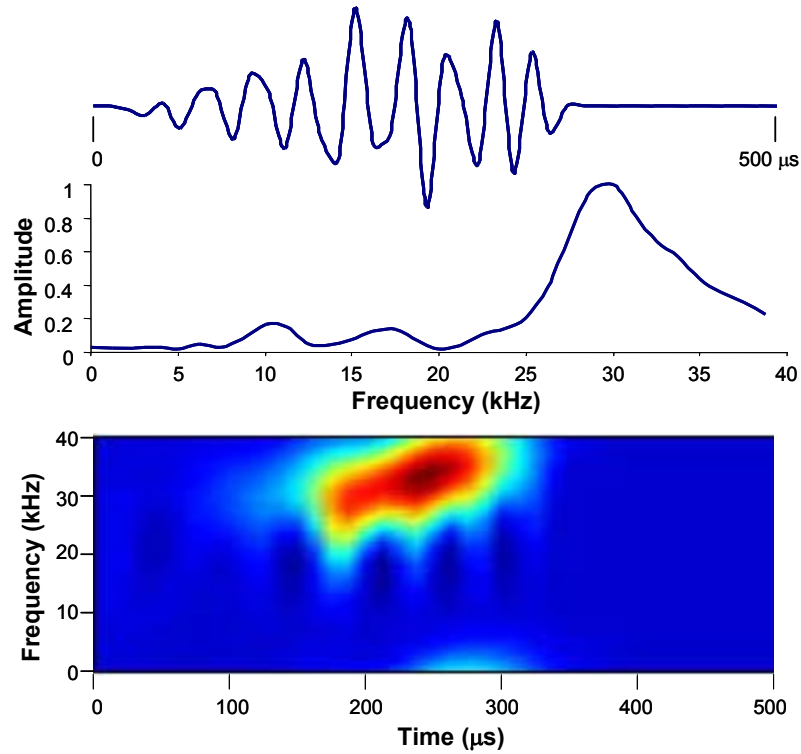


Figure 3. Example of a biosonar signal waveform, frequency spectrum and time-frequency distribution of a beaked whale. The Wigner-Ville distribution for the click on the bottom emphasizes the fm nature of beaked whale clicks.

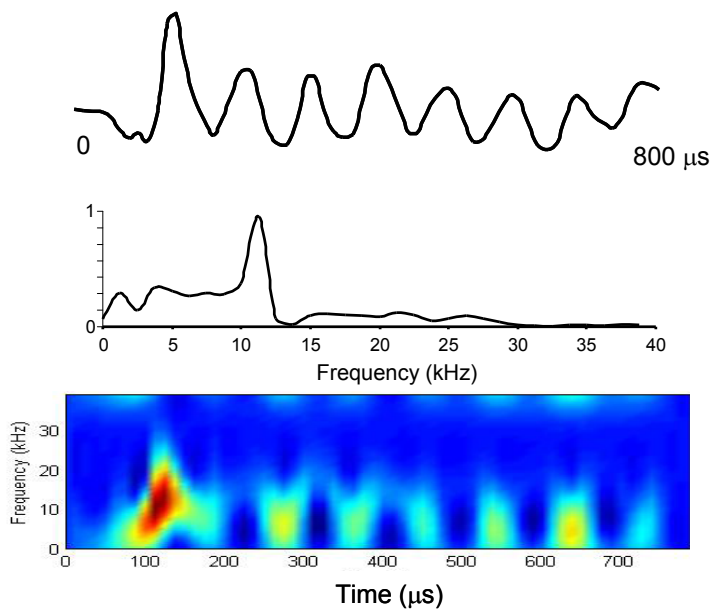


Figure 4. Example of a biosonar signal waveform, frequency spectrum and time-frequency distribution of a sperm whale

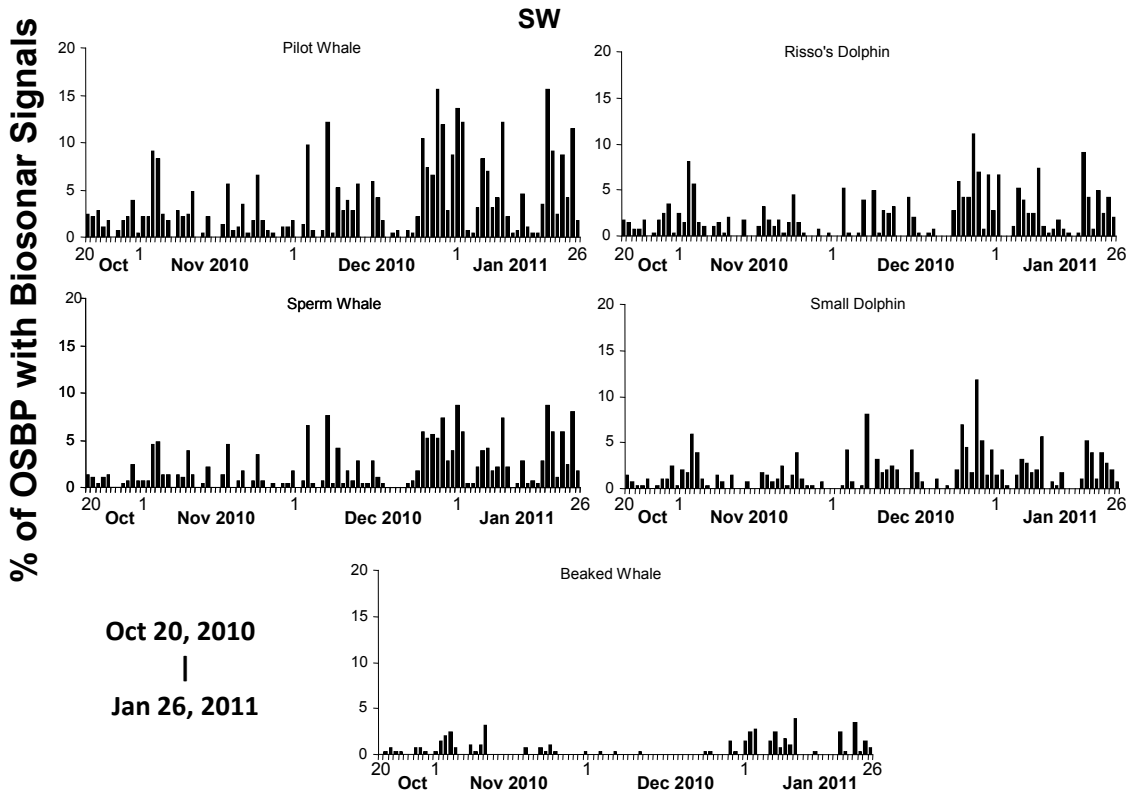


Figure 5. Histograms showing the number of observation periods (OSBP) containing biosonar signals from the different species of deep diving odontocetes were detected during the October 20, 2010 – January 26, 2011 time period. Signals from several species of animals are often found in a single file.

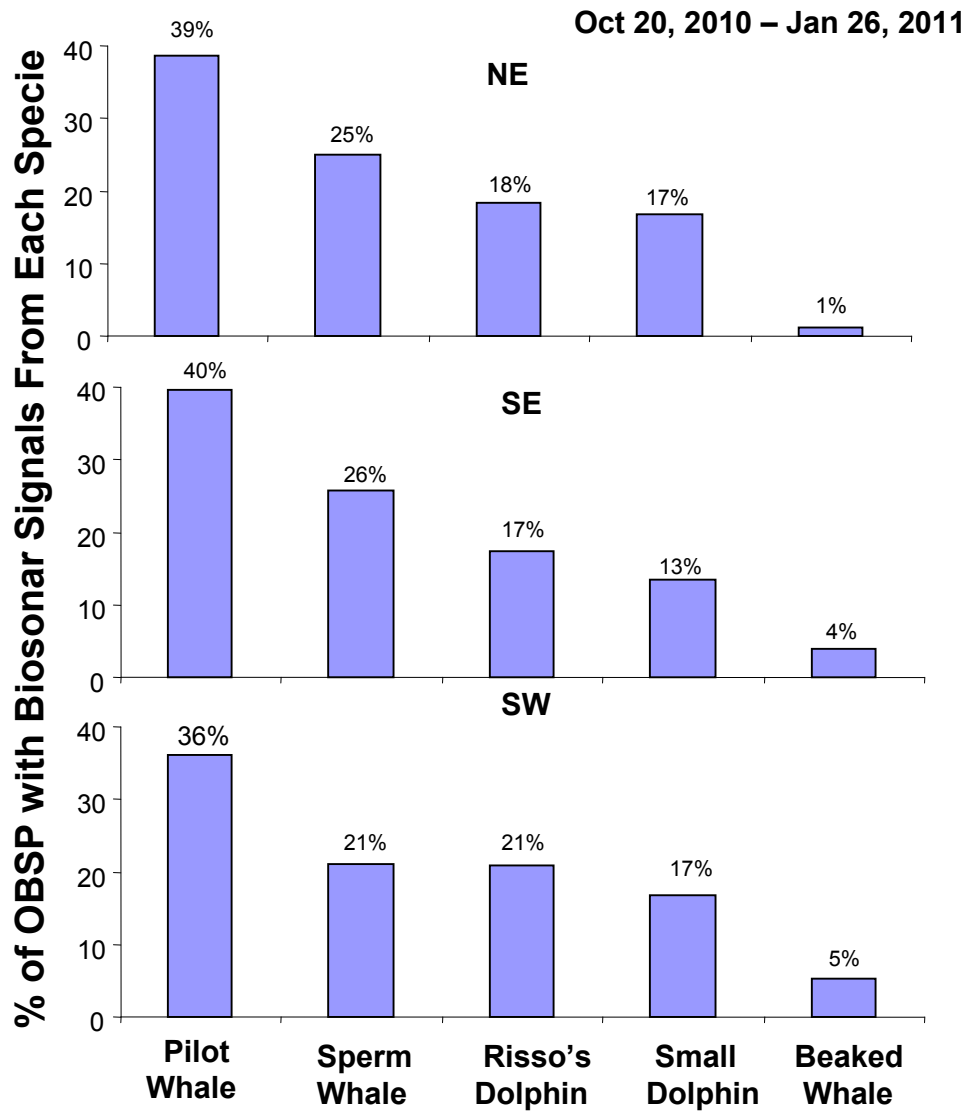


Figure 6. Percentage of observation period containing biosonar signals from the different specie of deep diving odontocetes during the time period of October 20, 2010 – January 26, 2011.

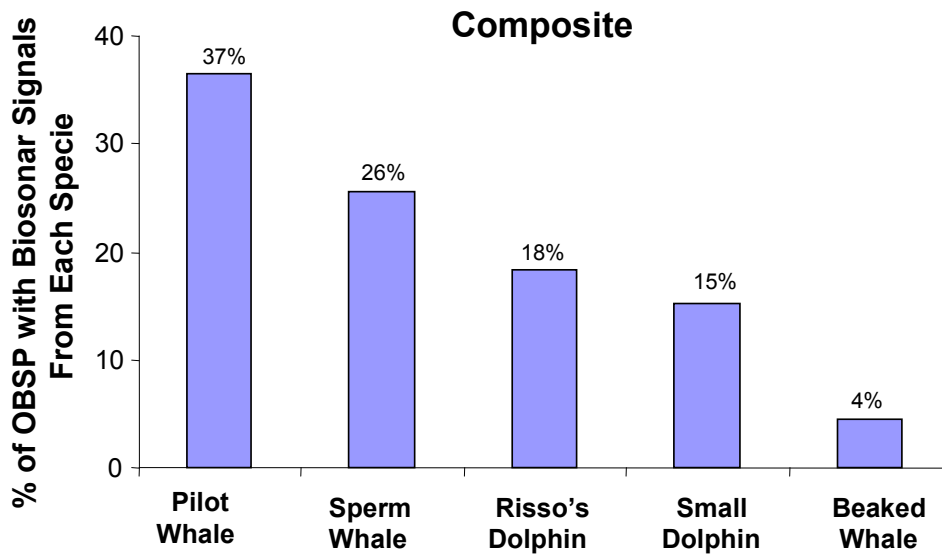


Figure 7. The percentage of all OSBP that contained biosonar signals from the five different species of deep diving odontocetes for the SW Kauai location during the time period between October 20 – January 26, 2011.

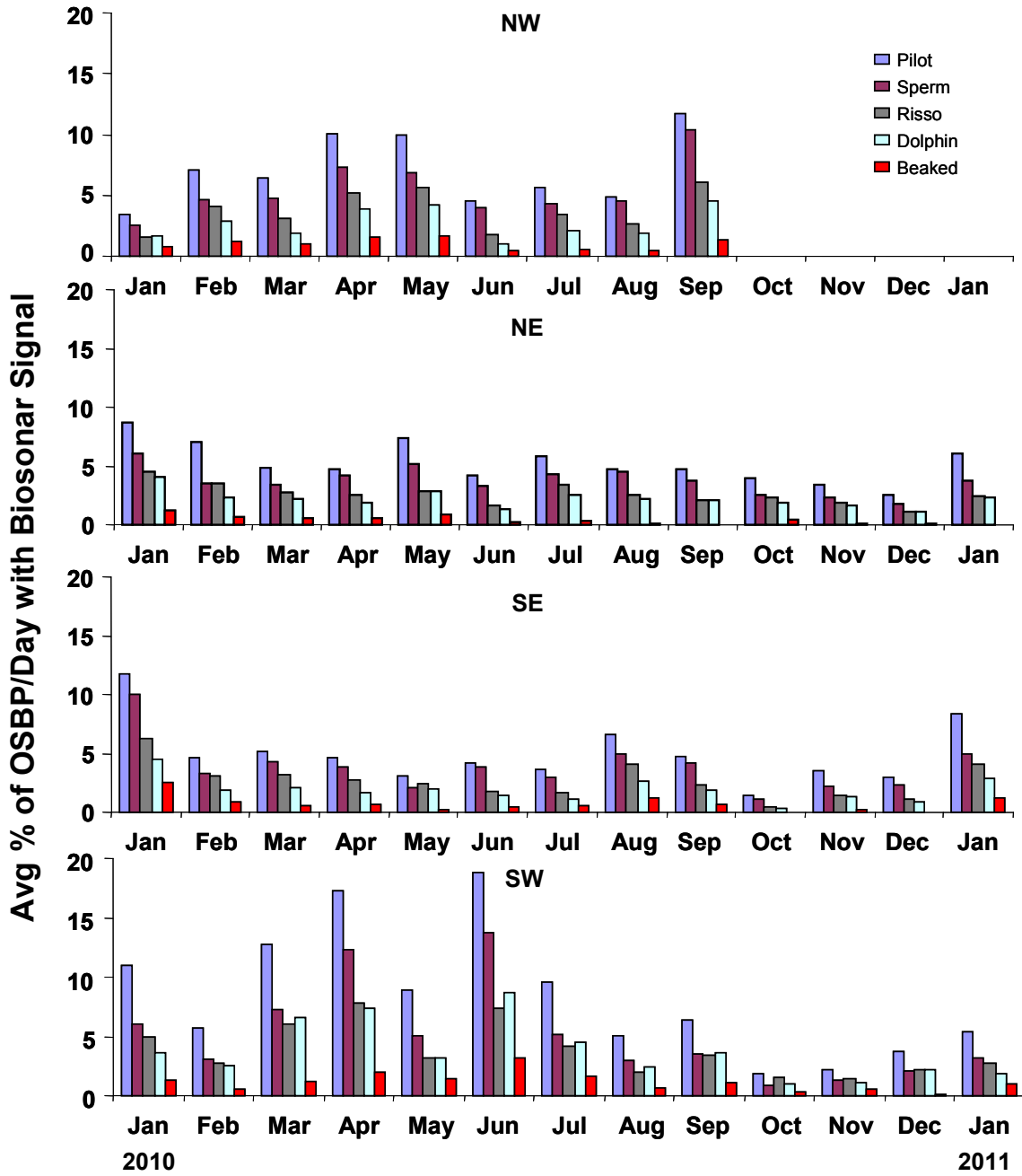


Figure 8. The per day average of OSBP with biosonar signals for each month at four locations around Kauai for the five species of odontocetes being considered.

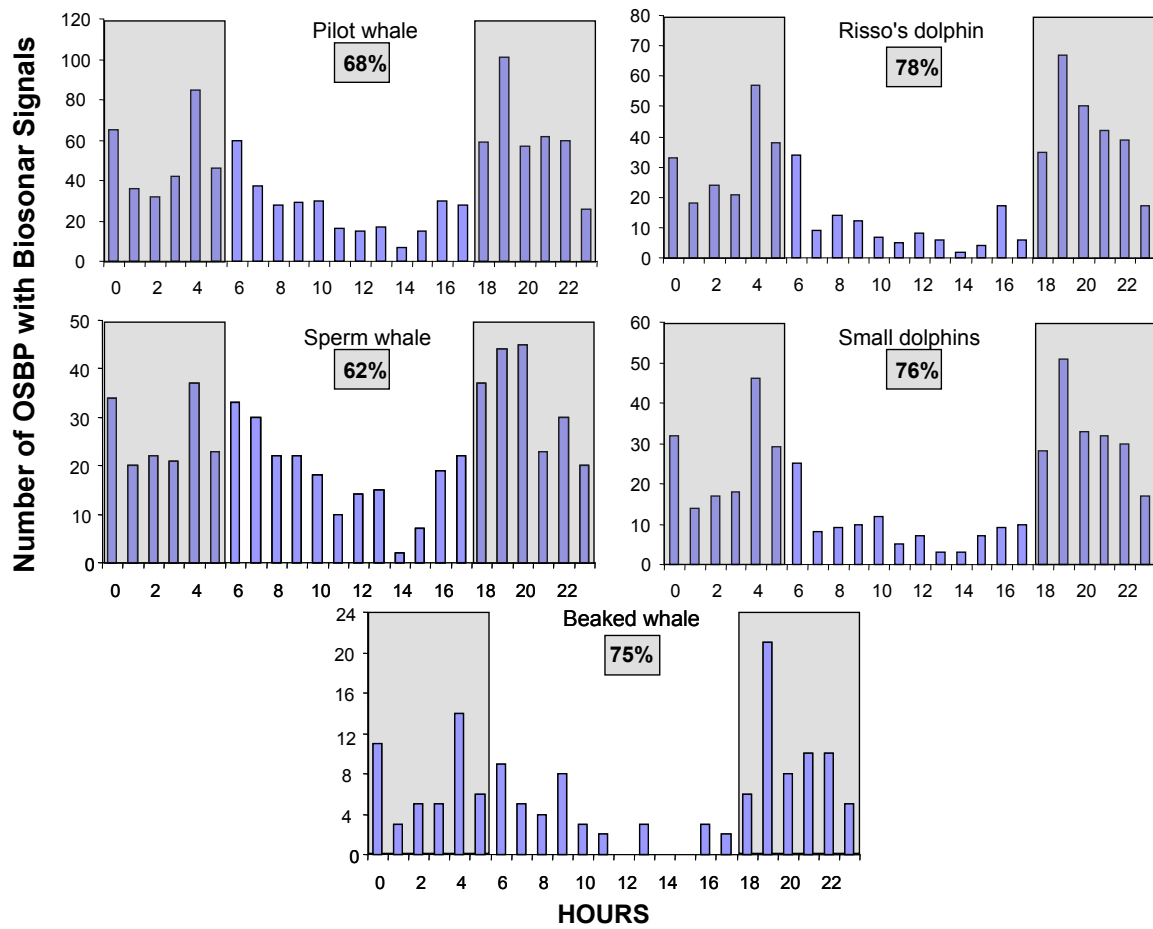


Figure 9. The diurnal variation of the number of files containing biosonar signals from the different species for the SW location. The shaded areas of each plot represent the dawn-dusk-night time hours. The percentage at the middle of each plot represents the number of clicks detected during the crepuscular and night hours.

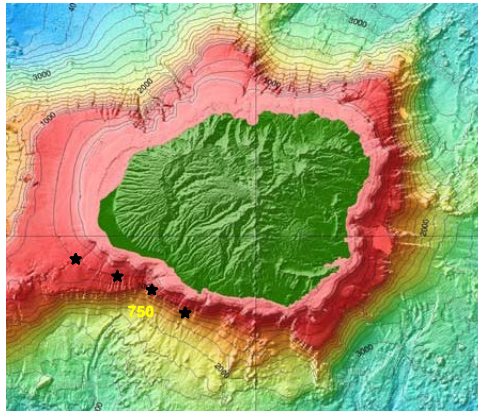


Figure 10. New EAR location along the south shore line of Kauai.

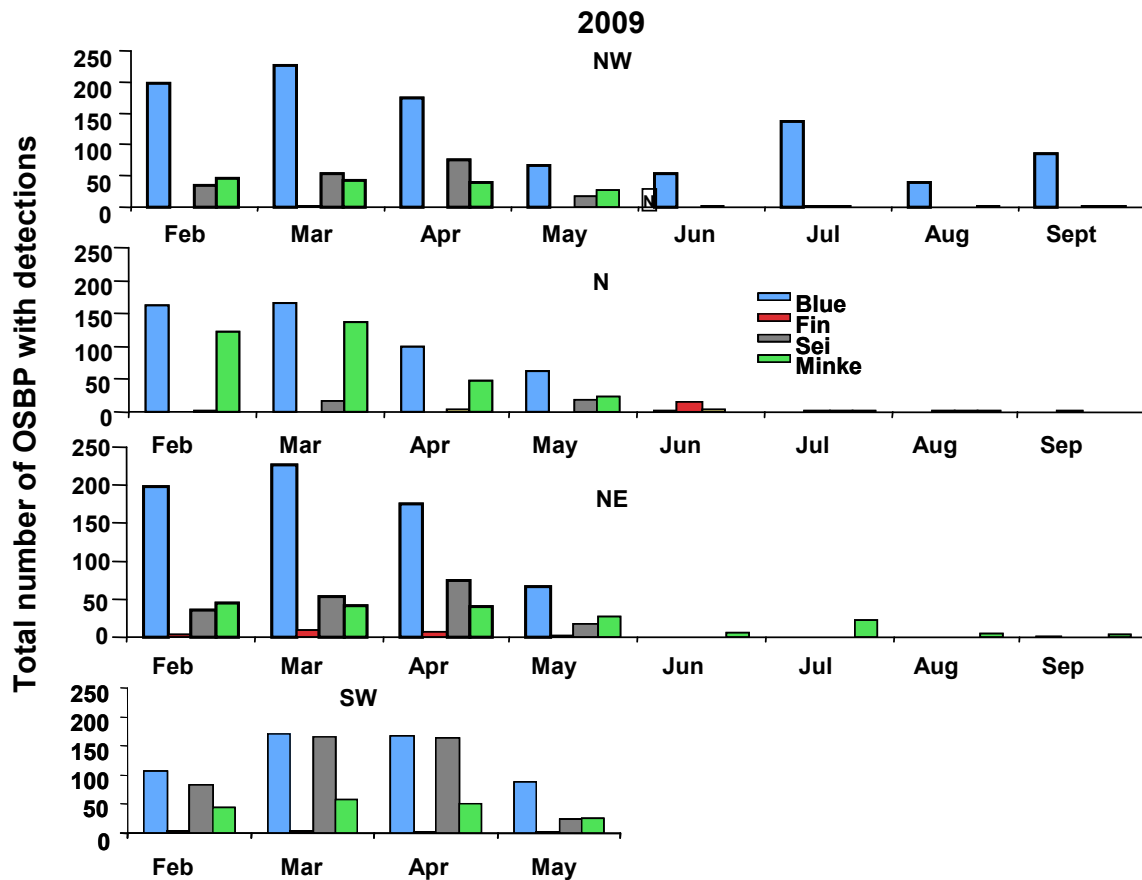


Figure 11. Preliminary baleen whale detections in 2009

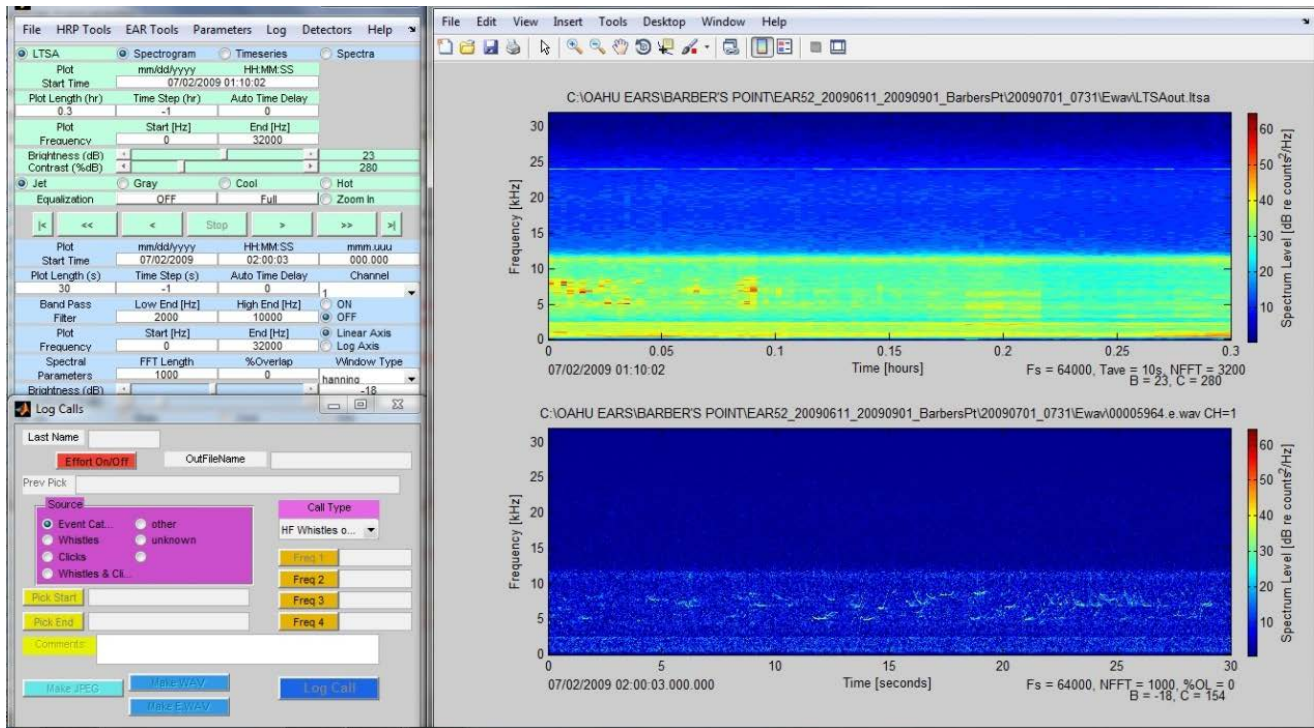


Figure 12. Screen shot of the Triton analysis window. The top window is the LTSA and the lower window is a 30-second recording showing the presence of dolphin whistles.

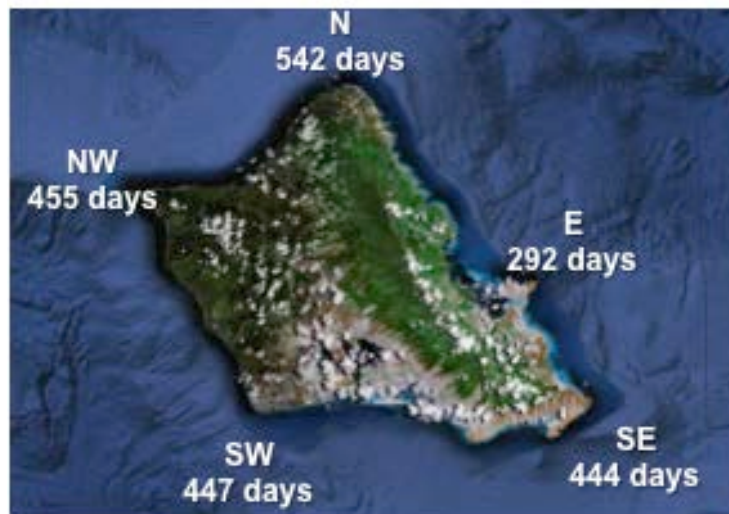


Figure 13. Number of recording day analyzed from each EAR deployment location.

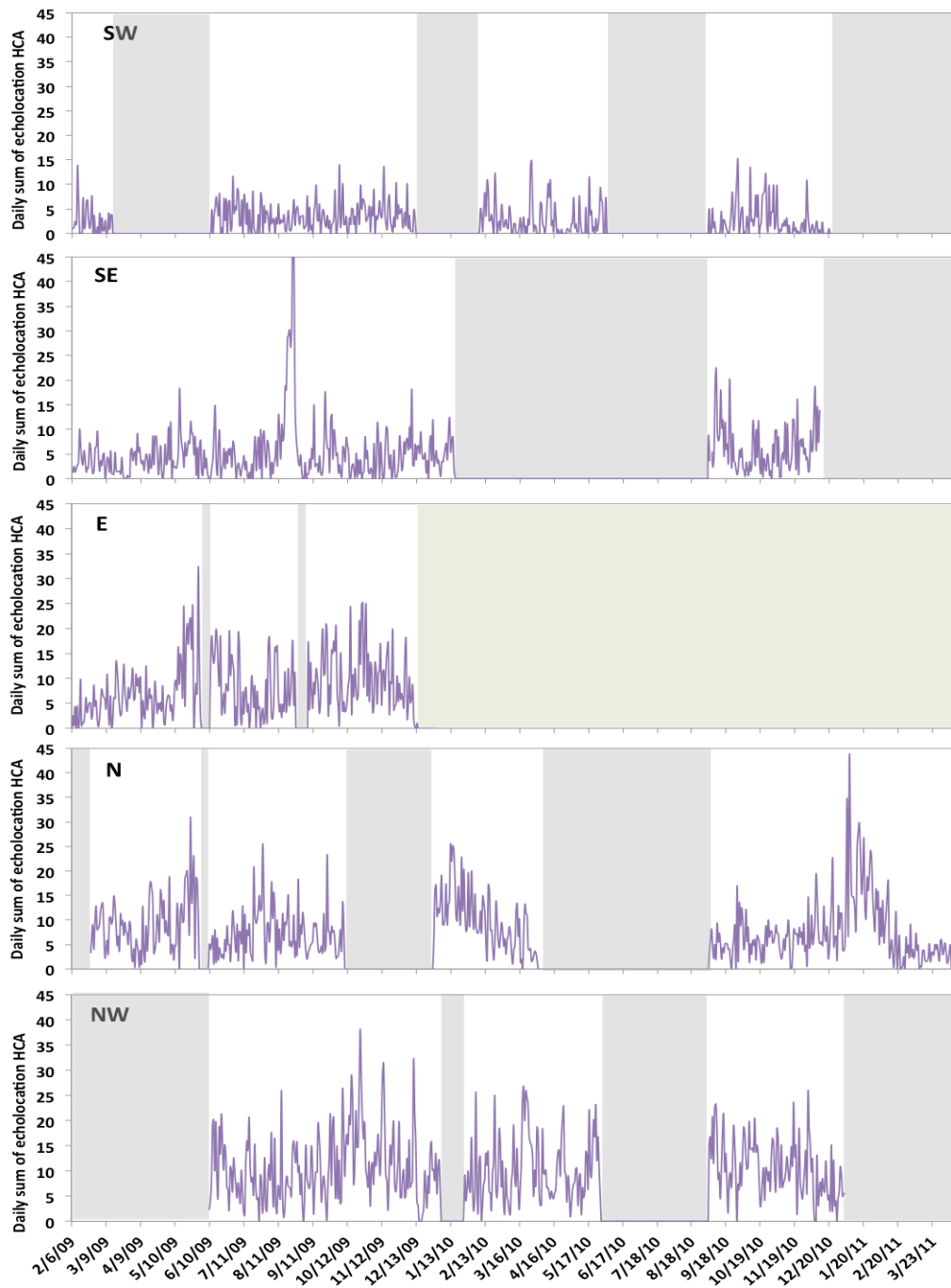


Figure 14. Occurrence of echolocation signals at the five deployment locations over the study period. Note: grey areas represent gaps in the data sets. The green area represents data periods that have not yet been analyzed.

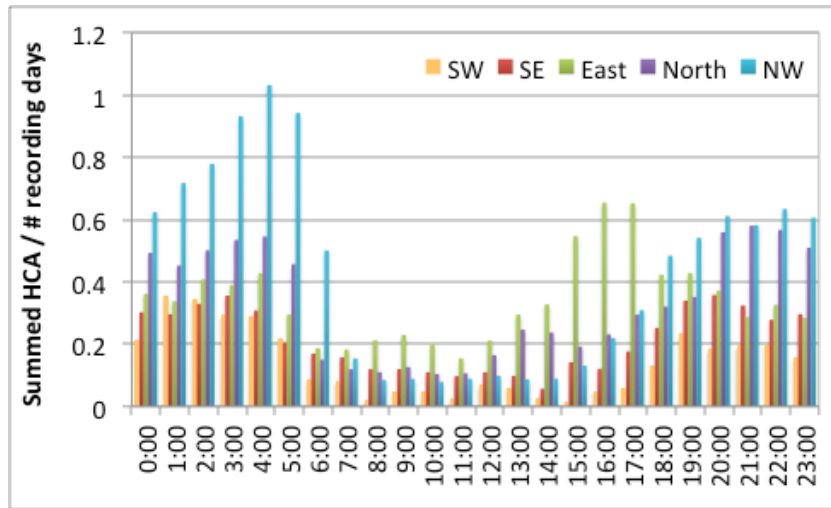


Figure 15. Hourly occurrence of echolocation at the five Oahu recording sites.

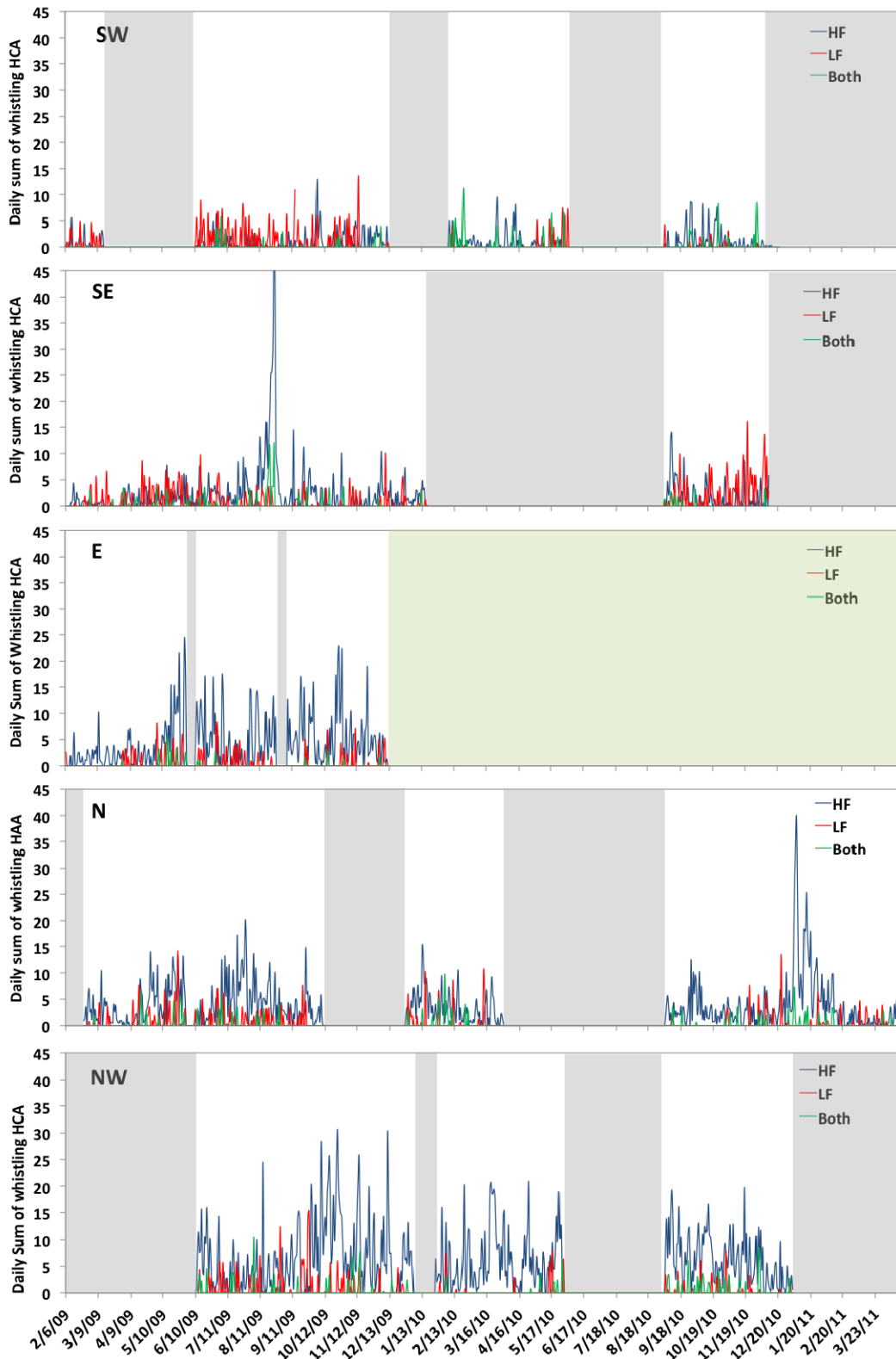


Figure 16 shows the daily summed HCA of whistling activity recorded at each site

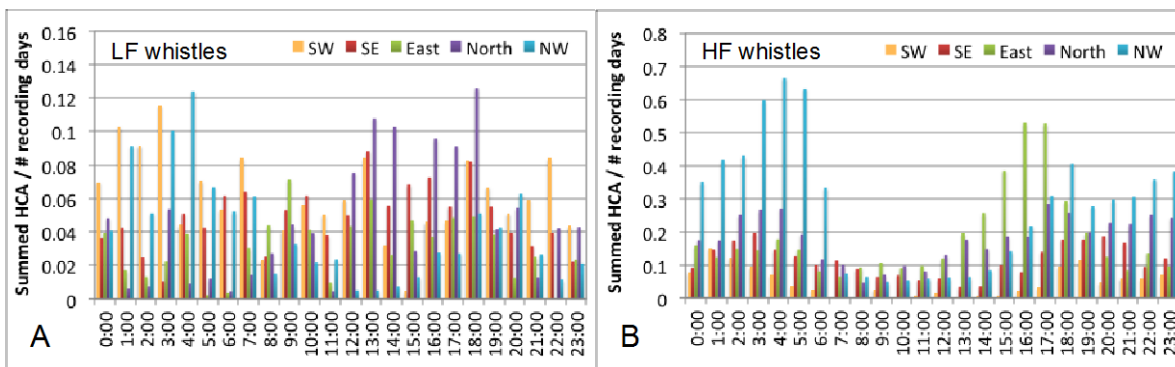


Figure 17. Hourly occurrence of LF (A) and HF (B) whistle activity at the five Oahu recording sites.