Submitted in support of the 2012 Annual Marine Species Monitoring report for the U.S. Navy's Hawaii Range Complex

# Results of EAR Deployment in Waters off Ni'ihau During Rim of the Pacific (RIMPAC) - 2010

July 2012

Whitlow W. L. Au
HIMB

HDR

# Table of Contents



# Figures



# Tables

## Suggested Citation

Au, W.W.L. 2012. Results of EAR deployment in the waters off Ni'ihau during RIMPAC 2010. Final report submitted by HDR to U.S. Navy NAVFAC Pacific. 14 pp.

# Abbreviations and Acronyms

| | |
|---|---|
| dB | decibel(s) |
| EAR | ecological acoustic recorder |
| ERMA | energy ratio mapping algorithm |
| GB | GigaByte(s) |
| kHz | kilohertz |
| km | kilometer(s) |
| LTSA | long-term spectral averages |
| m | meter(s) |
| M3R | Marine Mammal Monitoring on Navy Range |
| MFAS | Mid-frequency active sonar |
| min | minute(s) |
| PAR | passive acoustic recorder |
| RIMPAC | Rim of the Pacific |
| sec | second(s) |
| TOTO | Tongue of the Ocean |

# Results of EAR Deployment in Waters of Ni'ihau During RIMPAC-2010

Two ecological acoustic recorders (EARs) were deployed on July 17, 2010, one at a depth of 800 meters (m) off the northwest coast (21° 59.613' N, 160° 12.167' W), and the other at a depth of 16 m off the southeast coast of Ni'ihau (21° 47.306' N, 160° 11.964' W). These two sites were selected by personnel from the Naval Facilities Engineering Command, Pacific to provide acoustic data during the 2010 Rim of the Pacific (RIMPAC) exercise in the Hawaii Range Complex. A map of the deployment sites is shown in **Figure 1**. The sampling rate for data acquisition was 80 kilohertz (kHz), and the duty cycle for turn-on and sleep was 30 seconds of sampling every 5 minutes. Each EAR consisted of a single hydrophone with a -193 decibel (dB) sensitivity, 47 dB of electronic gain, an anti-aliasing filter set at 80% of the sample rate and a 16 bit analog-to-digital converter. The electronics were controlled by a Persistor CF2 microcontroller. The deep EAR was recovered on December 21, 2010 and the shallow EAR was recovered two months later, although both stopped recording on October 22, each with a full disk (128 GigaByte [GB]) containing 28,329 files of data.

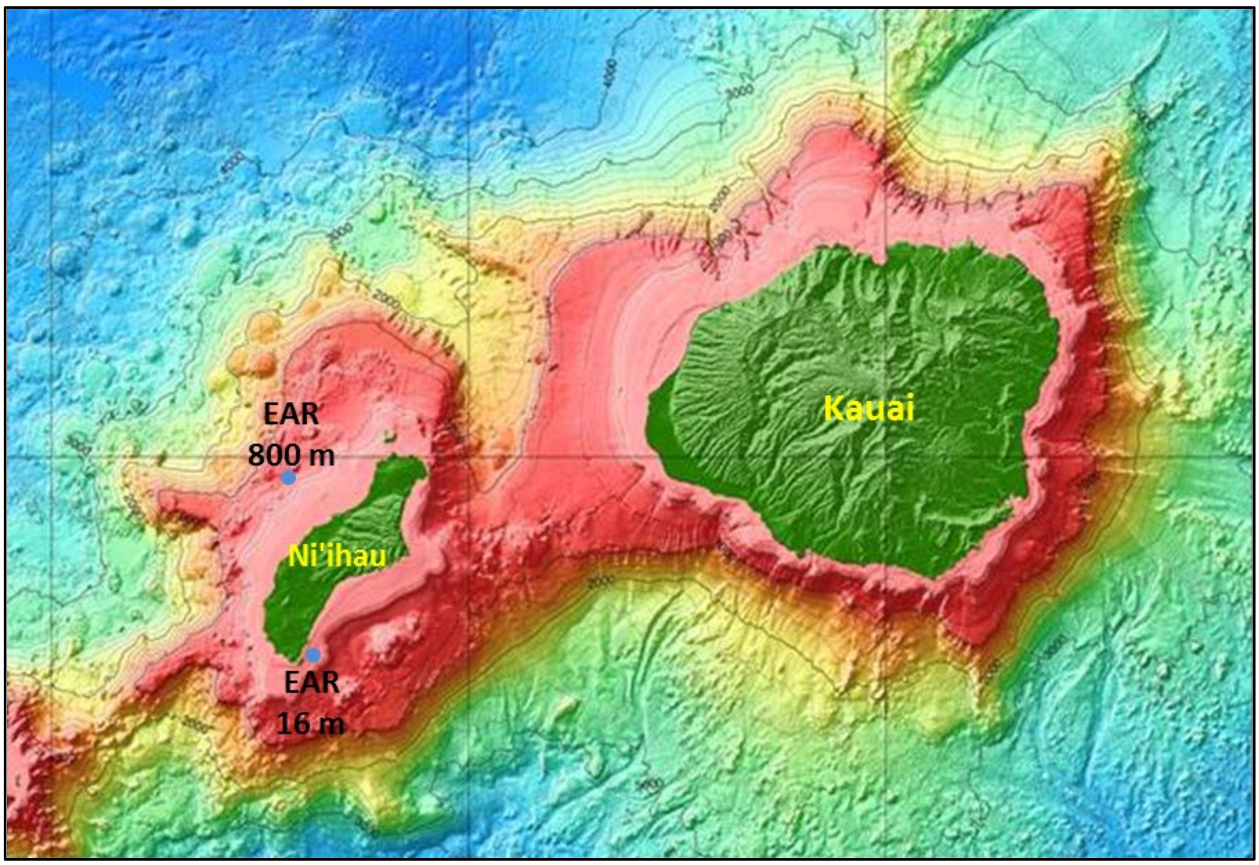



**Figure 1. Approximate location of the EARs deployed in waters off Ni'ihau during RIMPAC-2010.**

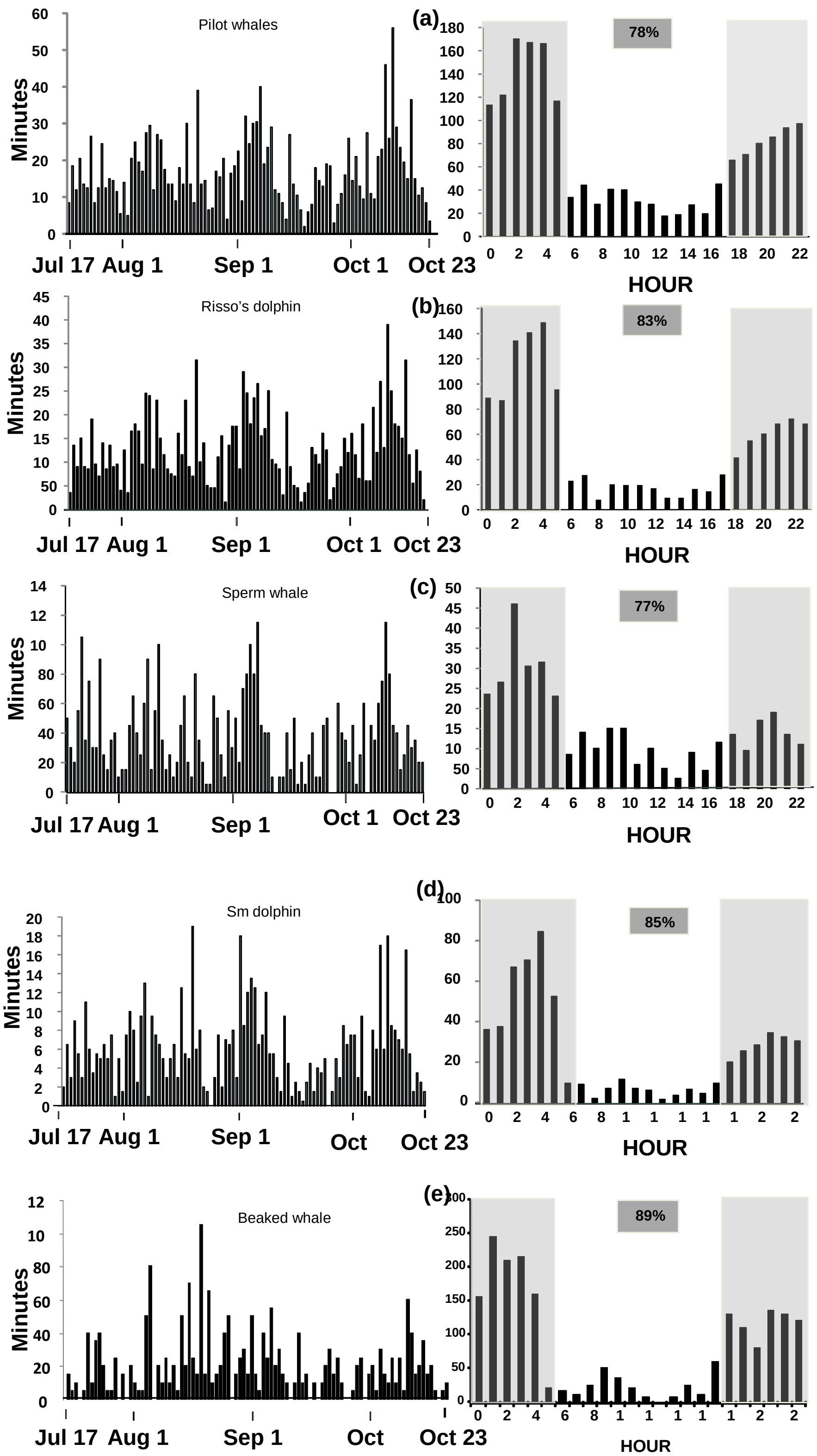
Data analysis for the deep EAR focused on deep-diving odontocetes that forage at depths greater than several hundred meters and emit biosonar clicks to detect, classify and locate their prey. Data analysis for the shallow EAR focused on small dolphins that emit whistles. The deep EAR was deployed to capture signals of deep-foraging animals using their biosonar. At deep depths it would be difficult to reliably capture whistles from animals close to the surface. The shallow EAR would not be ideal to capture biosonar signals emitted at deep depth.

# I. Deep EAR

Three detection algorithms were used to determine the presence of beaked whales: the energy ratio mapping algorithm (ERMA) developed by Holger Klinck (Klinck and Mellinger 2011); the support vector machine algorithms incorporated within the M3R (Marine Mammal Monitoring on Navy Range) developed by Susan Jarvis (Jarvis et al. 2008), and a custom MATLAB algorithm developed for this project. M3R detected six species of deep-diving odontocetes based on the characteristics of their biosonar signals: short-finned pilot whales (*Globicephala macrorhynchus*), sperm whales (*Physeter macrocephalus*), Risso's dolphins (*Grampus griseus*), small (unidentified) dolphins, Cuvier's beaked whales (*Ziphius cavirostris*), and Blainville's beaked whales (*Mesoplodon densirostris*). The energy ratio mapping algorithm is only designed to detect beaked whales. Both the ERMA and the M3R algorithms operate semi-automatically and provide a preliminary summary of acoustic data. The beaked whale detections obtained by ERMA and the M3R were matched against each other (individual detection performance can be found in Jarvis et al. [2008] and Klinck and Mellinger [2011]), and if both detectors indicated a beaked whale present in a particular file, then it was accepted. If only one detector indicated a beaked whale presence, then the file was further examined by a custom MATLAB algorithm which examined the waveform, spectrum and time-frequency distribution by visually examining the Wigner-Ville distribution analysis of the signals in the file. Approximately 40% of the beaked whale detections were matched by the ERMA and M3R detectors, meaning that 60% (approximately 1,200 files) of possible beaked whale detections had to be examined visually with the semi-automatic custom MATLAB program. The M3R algorithm also has templates of biosonar clicks produced by pilot whales, Risso's dolphin, sperm whales, and small dolphins. M3R detected biosonar clicks and then matched the detected clicks with templates for the six species in the library. Small dolphins such as spinner (*Stenella longirostris*), pan-tropical spotted (*Stenella attenuata*), rough-toothed (*Steno bredanensis*) and bottlenose dolphins (*Tursiops truncatus*) cannot be differentiated based on their biosonar clicks. These unidentifiable clicks were placed in the small dolphin category.

The results from the deep EAR are shown in **Figure 2 a-e** with the graphs on the left indicating the number of minutes of detection of the different species each day. Since the EAR was turned on for 30 seconds every five minutes, a total of five minutes was assigned to a specific species if a file contained clicks from that species. The number of files that contain biosonar clicks from the different species provides a gross indicator of the relative abundance of the different species. Short-finned pilot whales had the highest number of detections, and beaked whales the lowest number of detections. Therefore, it is reasonable to assume that more short-finned pilot whales frequented the EAR locations than beaked whales. No assumptions are made about the general abundance of these species, since the relationship between number of files of detected biosonar signals and abundance is not known, and may not be validated independent of other measures such as visual sightings. The graphs on the left indicate that the five categories of odontocetes were present at this location almost every day, with the duration of stay being highly variable. Occasions when fewer than five species were present were rare. Pilot whales, Risso's dolphins, sperm whales and small dolphins were present almost every day of the recording period (there was a single day when sperm whales were not detected). Beaked whales were also detected at this location on 89 of 99 days (90% of the time), but like other species there was high variability in the number of detections each day.

The graphs on the right side of **Figure 2 a-e** are histograms of the total number of detection minutes for each hour of a day for the duration of the recording period. The shaded areas represent 12 hours of dawn-dusk-night periods. The relative percentage of detections made during this period is shown by the percentage value shown in the shaded boxes at the top of each graph. These graphs clearly indicate that most deep-diving biosonar activity occurred at dawn, dusk, and night, ranging from 75% for sperm whales to 87% for beaked whales. Since odontocetes use biosonar to locate and discriminate prey, these




Note: Dawn, dusk and night hours are shaded, and vertical axis scales differ among graphs.

**Figure 2. Odontocete detections by date and time of day from the deep EAR deployed in waters off northwestern Ni'ihau during RIMPAC-2010.**

findings imply that foraging activity peaks at these times. However, this pattern may not be typical in other parts of the world. Our analysis of EAR data obtained during the Sirena-10 cruise conducted in the summer of 2010 by the North Atlantic Treaty Organization's Undersea Research Centre indicated that beaked whales in the location of the Josephine Seamount off the coast of Portugal occurred mainly during the day with only 37% of foraging occurring at night (Giorli and Au, 2011). Hazen et al. (2011) found no significant effect of time on beaked whale relative foraging effort in the Tongue of the Ocean (TOTO), Bahamas. These three examples appear to suggest that beaked whale foraging behaviors vary regionally, and that beaked whales may forage primarily at night in Hawaiian waters. TOTO is a deep-water basin approximately 204 x 36 kilometers (km) in dimension with steep walls rising from the bottom. This contrasts considerably with the Hawaiian Islands in which each island rises from the bottom of the ocean. Therefore, the night-time foraging behavior of deep-diving odontocetes may be a property peculiar to foraging around islands with steep bottom slopes or foraging in tropical waters.

The percentages of biosonar clicks that the EAR detected per species are shown in **Figure 3**. This figure provides a rough estimate of the percentage of deep-diving, foraging odontocete species in the waters of northwest Ni'ihau. It is difficult to obtain precise estimates of the species composition of deep-diving odontocetes from acoustic data collected from a single autonomous acoustic recorder. The relative number of animals in a typical pod would be a factor influencing the number of clicks emitted and the area of water that a pod may cover. For example, the best available information indicates that beaked whales tend to be in very small pods, whereas pilot whales may be in larger pods (Baird et al. 2003, 2005). The larger a pod size, the greater the probability of detecting biosonar foraging signals, since larger pods cover a larger area and emit more signals. More research needs to be done in order to obtain more quantitative species composition data from a single sensor.

No Navy sonar signals were recorded on the deep EARs. The daily number of detections is highly variable from the sampled period of July through October as seen in **Figure 2**. Therefore, there was insufficient data to determine if the number of call detections had changed during or after the period when there may have been sonar in the area.

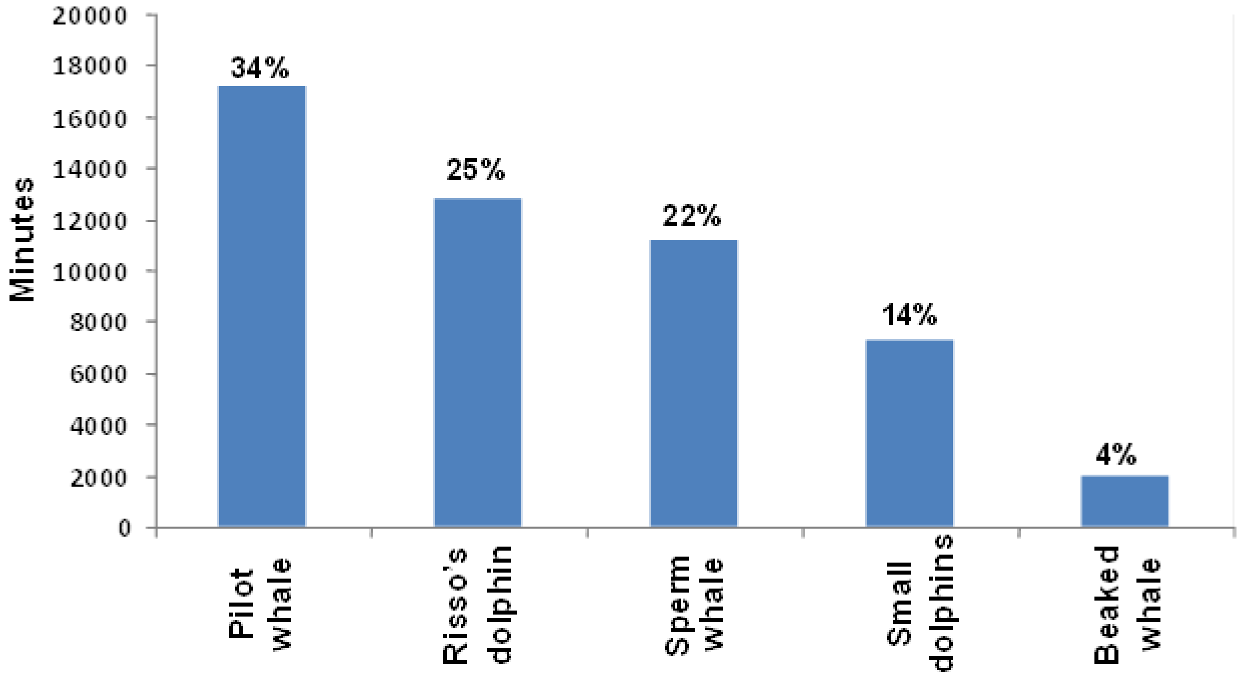



**Figure 3. Total minutes and percentages of files containing the different species of odontocetes detected by the M3R system for pilot whales, Risso's dolphins, beaked whales, sperm whales, and small dolphins.**

# II. Shallow EAR

The shallow EAR data was analyzed by visually inspecting long-term spectrogram representations of the data. The software package Triton was used for the analysis. This software incorporates a long-term spectral averages (LTSA) program developed at Scripps Oceanographic Institution by Dr. Sean Wiggins. The spectrograms of all 30-second files recorded during a month were displayed side by side (mathematically) to produce a large spectrogram covering a one-month period. The composite spectrogram was then visually examined at hourly intervals, and the date and time of any signals detected were recorded. The compressed nature of the LTSA allows a rapid visual scan of hours of data and identifies periods of possible cetacean presence. Three basic types of signals were typically present: dolphin whistles, dolphin clicks, and mid-frequency sonar pings. Other sporadic non-cetacean signals were not considered for further analysis (i.e., wave action, thunder and lightning striking the surface of the water). The dolphin whistles were "high frequency", having energy above 10 kHz. Two examples of dolphin whistles are shown in **Figure 4**. These are typical of whistles emitted by spinner dolphins (Bazua-Duran and Au, 2002). **Table 1** contains the dates and times (in one-hour intervals) when dolphin whistles were detected. Most of the whistle events occurred in the mornings between 0600 and 0900, although they were occasionally detected in the afternoon and at night. Dolphins were present on 3 out of 15 days in July, 12 days in August, 16 days in September and 1 out of 23 days in October.

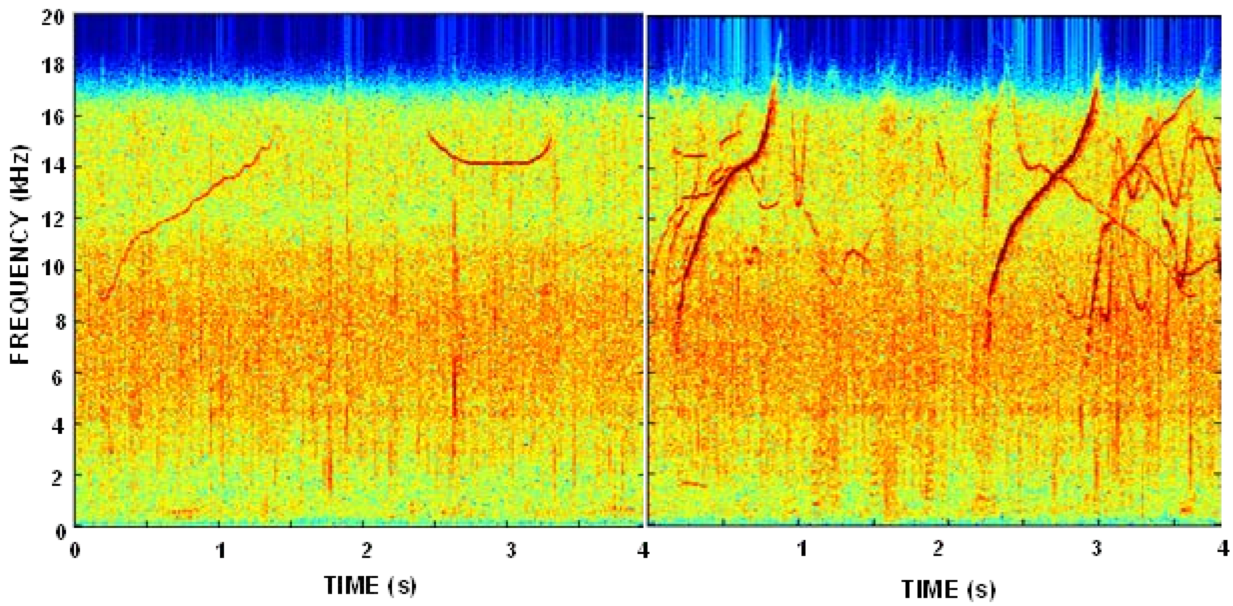



**Figure 4. Two spectrograms of high-frequency dolphin whistles recorded by the shallow EAR. These fit within the typical spectrograms of dolphin whistles reported by Bazua-Duran and Au (2002).**

During the month of July, mid-frequency FM sonar signals were detected on five different days. An example spectrogram is shown in **Figure 5**. In this figure, the frequency of the sonar ping started at approximately 2.5 kHz and increased linearly to 2.7 kHz over a 2-second duration. The sonar ping resembles the mid-frequency sonar ping used by the United States Navy in anti-submarine warfare. The dates, times and durations of detected mid-frequency sonar pings are shown in **Table 2**. Signal levels greater than 151 dB re 1 µPa on a root-mean-square scale or 160 dB re 1 µPa on a peak-to-peak scale cause the EAR to saturate. It was clear that some of the sonar pings had this effect on the EAR, distorting the signal and creating a multitude of harmonics. The shape of saturated signals typically approaches that of square waves which by their nature have a multitude of harmonics. An example of a saturated signal is shown in **Figure 6,** amid dolphin whistles. On July 28, mid-frequency sonar signals were detected for approximately 11 minutes (min) 29 seconds (sec) and on July 29, for 7 min 30 sec. The sonograms of many sonar signals appear to be very complex with various frequency components. This is because many sonar signals were intense enough to cause the EAR to clip the signal. Clipping of any signal causes artifacts to appear on the spectrogram, making the spectrogram unusable.

There were only a few sonar detections between 20 and 29 July recorded on the shallow EAR (Table 2) and only one marine mammal vocalization detected during a sonar event (**Figure 6**). The spectrogram in **Figure 6** shows no change in the vocalizations of the dolphin during or after the sonar signal.

**Table 1. Dates and times of dolphin detections by month for the shallow EAR.**

| Month | Day | Time |
|---|---|---|
| July | 23 | 06:00–10:00 |
| July | 25 | 08:00–09:00 |
| July | 30 | 07:00–11:00 |
| August | 5 | 07:00–09:00 |
| August | 12 | 22:00–23:00 |
| August | 13 | 06:00–07:00 |
| August | 15 | 07:00–08:00 |
| August | 17 | 06:00–11:00 |
| August | 22 | 07:00–08:00 |
| August | 24 | 08:00–09:00 |
| August | 26 | 06:00–07:00 |
| August | 28 | 07:00–08:00 |
| August | 29 | 08:00–10:00 |
| August | 30 | 08:00–09:00 |
| August | 30 | 15:00–17:00 |
| August | 31 | 08:00–09:00 |
| September | 2 | 07:00–08:00 |
| September | 2 | 10:00–12:00 |
| September | 2 | 13:00–14:00 |
| September | 3 | 07:00–08:00 |
| September | 8 | 08:00–10:00 |
| September | 11 | 02:00–03:00 |
| September | 11 | 08:00–09:00 |
| September | 13 | 07:00–08:00 |
| September | 14 | 08:00–09:00 |
| September | 17 | 07:00–08:00 |
| September | 18 | 07:00–09:00 |
| September | 20 | 07:00–09:00 |
| September | 20 | 13:00–15:00 |
| September | 21 | 08:00–09:00 |
| September | 24 | 08:00–09:00 |
| September | 25 | 07:00–08:00 |
| September | 25 | 10:00–11:00 |
| September | 26 | 07:00–08:00 |
| September | 27 | 08:00–09:00 |
| September | 29 | 02:00–03:00 |
| September | 29 | 08:00–09:00 |
| September | 29 | 10:00–13:00 |
| September | 30 | 07:00–09:00 |
| October | 8 | 02:00–03:00 |

Note: Dolphin detections are presented in hourly intervals.

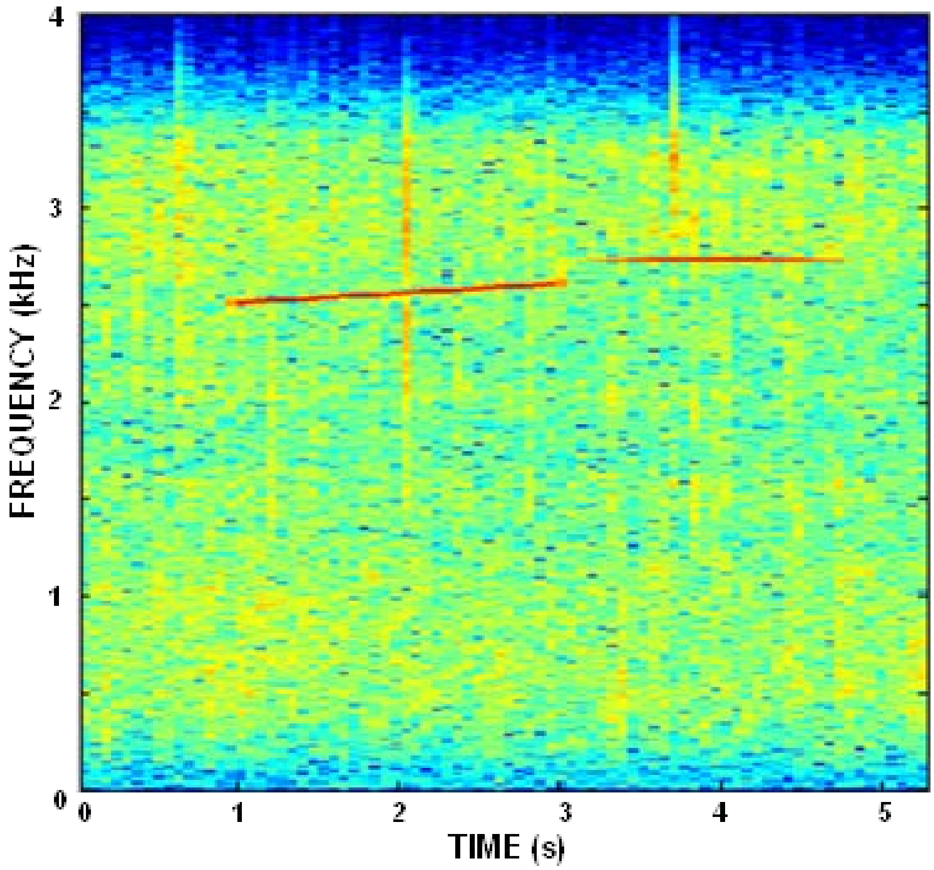



**Figure 5. A spectrogram of a mid-frequency sonar ping at time between 1 and 3 seconds. The second shorter signal may be a reflection from the surface.**

**Table 2. Dates, times and durations of sonar ping detections.**

| Date of Detection | Time of Detection | Duration of Contact (min:sec) |
|---|---|---|
| 20 July 2010 | 13:50 | 0:10 |
| 20 July 2010 | 14:55 | 0:50 |
| 20 July 2010 | 23:05 | 1:30 |
| 23 July 2010 | 02:35 | 1:15 |
| 23 July 2010 | 07:55 | 2:54 |
| 27 July 2010 | 22:35 | 0:30 |
| 27 July 2010 | 23:30 | 0:19 |
| 28 July 2010 | 13:50 | 7:04 |
| 28 July 2010 | 16:55 | 2:00 |
| 28 July 2010 | 20:05 | 2:25 |
| 29 July 2010 | 07:00 | 7:30 |

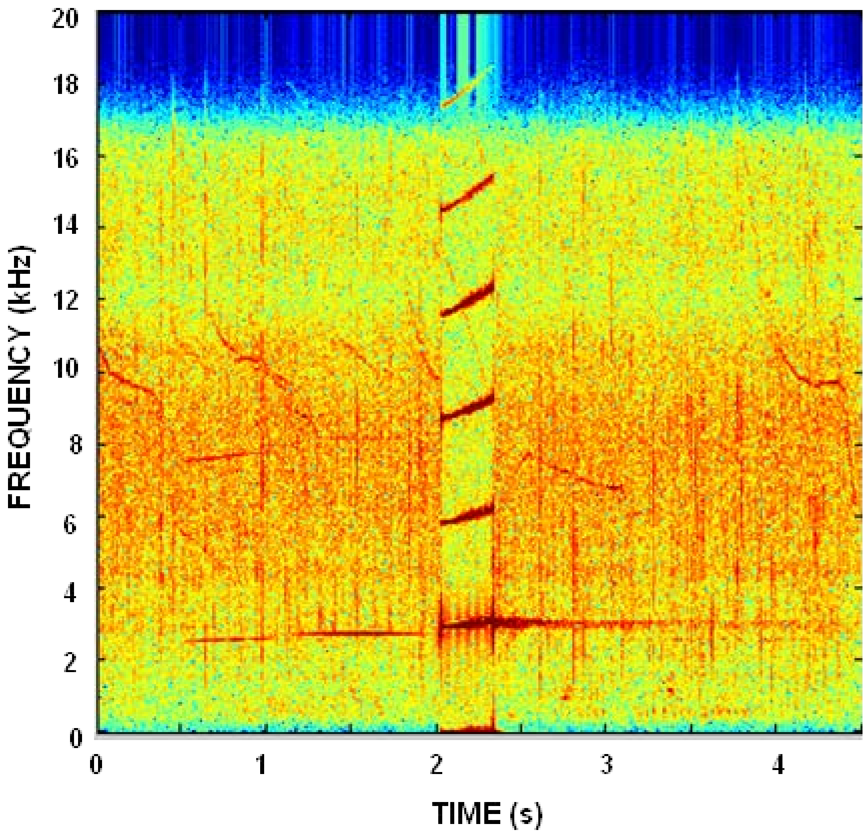



**Figure 6. A sonar signal that saturated the EAR, producing many harmonics. Dolphin whistles can also be seen in the spectrogram. The peak-to-peak sound pressure level that causes EAR saturation is approximately 160 dB re 1 μPa.**

# Discussion and Summary

Passive acoustic recorders (PARs) are useful tools for detecting the presence of sound-producing marine mammals, as well as for assessing temporal and seasonal patterns in their habitat use. PARs have the advantage that their detection ability is not affected by time of day, sea state conditions, and bad weather. However, PARs also have several limitations, namely the inability to estimate the number of sound-producing animals at a given location and time, and the inability to estimate the relative abundance of sound producing animals without making certain broad assumptions. One cannot infer how far an animal is from a single sensor by the amplitude of the acquired signal, nor is it possible to obtain the location of the animal with respect to a single sensor.

This report summarizes the number of acoustic data files containing biosonar signals from various cetacean species. The use of this parameter is more conservative than other approaches, such as the number of biosonar signals detected, or the rate at which the signals were detected. The number of biosonar signals detected can be affected by the distance of an animal from the sensor, the orientation of the animal with respect to the sensor, and the point in the duty cycle of the recorder at which the animal signals were acquired. The same line of caveats would also apply to the rate of detection. A large number of biosonar clicks detected in a file does not necessarily mean that more animals were present than for a file which contained fewer biosonar signals.

The use of PARs to monitor marine mammal presence during a naval exercise has limited value for several reasons. The locations of the marine mammals, with respect to a Navy ship emitting mid-frequency sonar signals, cannot be ascertained with a single sensor or with a multitude of sensors unless they are synchronized in time so that localization of animals and the sonar source can be achieved. Unfortunately, no PARs exist that can perform such a localization process on the same large spatial scale as a naval exercise. Even if the precise location of a naval vessel emitting a sonar signal is known relative to a PAR device, the location and movement of animals by a PAR cannot be estimated.

The information obtained by the two EARs deployed off Ni'ihau is summarized below:

1. Biosonar signals of deep-diving odontocetes, with the exception of beaked whales, were detected every day, except there was one day in which no sperm whale signals were detected. Beaked whales were not detected on 10 out of 99 days of acoustic data.
2. A combined 59% of all clicks detected were from pilot whales and Risso's dolphins. Only 4% of all clicks were produced by beaked whales.
3. Most biosonar clicks were detected at dawn, dusk and at night. Eighty-nine percent of the beaked whale signals were detected during these periods. The high level of night-time activity for beaked whales in Hawaii seems to differ from results collected in higher latitudes.
4. Often, more than one species of odontocete were detected during a single 30-second recording period for both the shallow and deep EARs.
5. Dolphins were detected on only 32 out of 99 days (32% of the time) by the EAR in the shallow water off southeastern Ni'ihau. They were most likely spinner dolphins. The majority of dolphin detections recorded by the shallow EAR occurred between 0600 and 0900.
6. Mid-frequency FM sonar signals were detected on five days in July. There were two days in which the sonar signals were detected over a seven-minute period but there were insufficient data to determine if mid-frequency FM sonar had an effect on marine mammal vocalizations.

# References

Baird, R.W., McSweeney, D.J., Webster, D.L., Gorgone, A.M., and Ligon, A.D. 2003. Studies of odontocete population structure in Hawaiian Waters: results of a survey through the Main Hawaiian Islands in May and June 2003. Report prepared under Contract No. AB133F-02-CN-0106 to Cascadia Research from the National Oceanic and Atmospheric Administration, Western Administrative Support Center, 7600 Sand Point Way N.E., Seattle, WA 98115. 26 pp.

Baird, R.W., Webster, D.L., McSweeney, D.J., Ligon, A.D., and Schorr, G.S. 2005. Diving behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's beaked whales (*Mesoplodon densirostris*) in Hawai'i. Report prepared under Order No. AB133F-04-RQ-0928 to Cascadia Research Collective, Olympia, WA from the Southwest Fisheries Science Center, National Marine Fisheries Service La Jolla, CA 92037. 24 pp.

Bazua-Duran, C. and Au, W.W.L. 2002. The whistles of Hawaiian spinner dolphins. J. Acoust. Soc. Am. 112, 3064-3072.

Giorli, G. and Au. W.W.L. 2011. Sirena-10 Ecological Acoustic Recorder (EAR) Buoys Acoustic Analysis. HIMB Technical Report, TR-HIMB8152011.

Hazen, E.L., Nowacek, D.P., St. Laurent, L., Halpin, P.N., and Moretti, D.J. 2011. The relationship among oceanography, prey fields, and beaked whale foraging habitat in the Tongue of the Ocean. PLoS ONE 6(4), e19269. doi:10.1371/journal.pone.0019269.

Jarvis, S., DiMarzio, N., Morrissey, R., and Moretti, D. 2008. A novel multi-class support vector machine classifier for automated classification of beaked whales and other small odontocetes. Canadian Acoustics 36, 34-40.

Klinck, H., and Mellinger, D.K. 2011. The energy ratio mapping algorithm: a tool to improve the energy-based detection of odontocete echolocation clicks. J. Acoust. Soc. Am. 129, 1807-1812.