

# Nighttime foraging by deep diving echolocating odontocetes off the Hawaiian islands of Kauai and Ni'ihau as determined by passive acoustic monitors

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Remote autonomous ecological acoustic recorders (EARs) were deployed in deep waters at five locations around the island of Kauai and one in waters off Ni'ihau in the main Hawaiian island chain. The EARs were moored to the bottom at depths between 400 and 800 m. The data acquisition sampling rate was 80 kHz and acoustic signals were recorded for 30 s every 5 min to conserve battery power and disk space. The acoustic data were analyzed with the M3R (Marine Mammal Monitoring on Navy Ranges) software, an energy-ratio-mapping algorithm developed at Oregon State University and custom MATLAB programs. A variety of deep diving odontocetes, including pilot whales, Risso's dolphins, sperm whales, spinner and pan-tropical spotted dolphins, and beaked whales were detected at all sites. Foraging activity typically began to increase after dusk, peaked in the middle of the night and began to decrease toward dawn. Between 70% and 84% of biosonar clicks were detected at night. At present it is not clear why some of the known deep diving species, such as sperm whales and beaked whales, concentrate their foraging efforts at night.

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## I. INTRODUCTION

One of the best ways of studying marine animals living in an inaccessible environment is to use autonomous remote devices that can acoustically sense the presence of animals, their movements, activities, and daily pattern. If information is desired on a 24 h basis then the best type of sensor would be an acoustic recorder that can be programmed to turn on at specified intervals for a specified duration and not be on continuously in order to conserve battery power and storage space. The process of turning a device on at a specified interval is commonly referred to as the duty cycle. Various types of autonomous passive acoustic monitors (PAMs) have been developed to study both marine and terrestrial animals although in truth these devices are really recorders not strictly monitors. In this manuscript, the presence of deep diving odontocetes around the island of Kauai and at one location off the island of Ni'ihau will be examined with a number of autonomous remote PAM devices operating nearly simultaneously.

Our knowledge of the behavior of deep diving odontocetes has expanded many fold with the introduction of the D-tag (digital acoustic recording tag) developed at Woods Hole

Oceanographic Institute (Johnson and Tyack, 2003). DTAGs have been placed via suction cups to a number of deep diving odontocetes such as Blainville's beaked whales, *Mesoplodon densirostris*, and Cuvier beaked whales, *Ziphius cavorostris* (Johnson and Tyack, 2003; Madsen *et al.*, 2005), sperm whales, *Physeter macrocephalus* (Miller *et al.*, 2004), short-finned pilot whales, *Globicephala macrorhynchus* (Aguilar de Soto, 2006; Aguilar Soto *et al.*, 2008).

Beaked whales, sperm whales, and short finned pilot whale are some odontocete species that forage in a depth regime between several hundred meters up to slightly over 1000 m using their biosonar to hunt for prey (Johnson *et al.*, 2004; Aguilar de Soto, 2006). Johnson *et al.* (2004) reported that beaked whales can dive to depths on the order of 1200 m but do not emit biosonar signals until they descend below approximately 200 m below the surface. Madsen *et al.* (2005) showed that Blainville's beaked whale biosonar foraging process is similar to foraging bats with a search, approach, and terminal phase. During the search phase the interclick intervals vary between 300 and 400 ms and decrease to about 10 ms during the terminal/buzz phase. Watkins *et al.* (1993) reported that sperm whales can dive down to depths approaching 2000 m while foraging for prey. DTAG data collected by Miller *et al.* (2004) showed the steady use of regular biosonar clicks with creaks produced during the deepest part of dives by sperm whales. Aguilar Soto *et al.* (2008) reported foraging

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depths of short-finned pilot whale between 250 and 1000 m while using their biosonar to detect prey.

Another device that has contributed to our expanding knowledge of deep diving foraging odontocete is a remote autonomous high-frequency acoustic recording package (HARP) developed at the Scripps Institute of Oceanography (Wiggins and Hildebrand, 2007). Use of the HARP was also accompanied by research to identify odontocetes by their biosonar signals. The use of a HARP off the Cross Seamount (Johnston *et al.*, 2008; McDonald *et al.*, 2009) and another in the waters of Palmyra Atoll (Baumann-Pickering *et al.*, 2010) have successfully confirmed the presence of foraging beaked whales in both locations. Soldevilla *et al.* (2010) reported on the presence and behavior of Risso's dolphin (*Grampus griesus*) and Pacific whitesided dolphin (*Lagenorhynchus obliquidens*) in the Southern California Bight. These studies have demonstrated that some species of echolocating odontocetes can be identified by characteristics of their biosonar signals and autonomous remote recorders can collect data to study the long-term behavior of deep diving odontocetes in a single location.

There are approximately 18 species of odontocetes and six species of baleen whales that can be found in Hawaiian waters (R. Baird, 2012, personal communication). Except for spinner dolphins (*Stenella longirostris*) and humpback whales (*Megaptera novaeangliae*) the locations and time of occurrence of these cetaceans cannot be predicted with any degree of certainty. Knowing what animals are present in a given body of water at any given time is important in order to understand the overall cetacean population dynamics. Where and when animals might be present may provide insights as to how different species utilize a given habitat. For example, spinner dolphins typically rest during the day in several different known locations along a coast. In the late afternoon and at night they may travel along the entire coastline at varying distances from shore foraging for food. They move with the

mesopelagic boundary community throughout the night to optimize their foraging effort (Benoit-Bird *et al.*, 2001).

DTAG research in other parts of the world on several deep diving odontocete species also found in Hawaiian waters such as beaked whales, sperm whales, and short-finned pilot whales have shown that these animals forage at depths exceeding several hundred meters to just over 1000 m. In this manuscript the diurnal foraging behavior of deep diving foraging odontocetes around the island of Kauai and at one location off the island of Ni'ihau in the main Hawaiian island chain will be discussed using data collected by the ecological acoustic recorder (EAR) developed jointly at the Hawaii Institute of Marine Biology and the Coral Reef Ecosystem Division of National Marine Fisheries Service (Lammers *et al.*, 2008).

## II. APPROACH

### A. Acoustic recordings

The EAR is a recording system that is controlled by a Persistor CF2 microcontroller with the acquired digital data stored on a laptop hard drive (Lammers *et al.*, 2008). Each EAR was contained in an aluminum housing that had a depth rating of 900 m. The EAR was programmed for a duty cycle of 30 s of data collection every 5 min. Running the EAR on a duty cycle was done to conserve both battery power and disk storage space. The system has 48 dB of gain, an anti-aliasing filters set at 90% of the Nyquist rate and a Sensor Technology SQ26-01 hydrophone with a response sensitivity of  $-195.5$  dB that is relatively flat ( $\pm 3$  dB) to slightly over 40 kHz. The overall sensitivity of the EAR is approximately 150 v/dB re  $1 \mu\text{Pa}$ .

Initially five EARs were deployed at different depths off the island of Kauai. The approximate locations and depth of deployment are shown in Fig. 1. A data acquisition rate of 64 kHz were used in the first two deployments and the rate was increased to 80 kHz for the third, fourth, and fifth deployments. The results from the third to fifth deployment

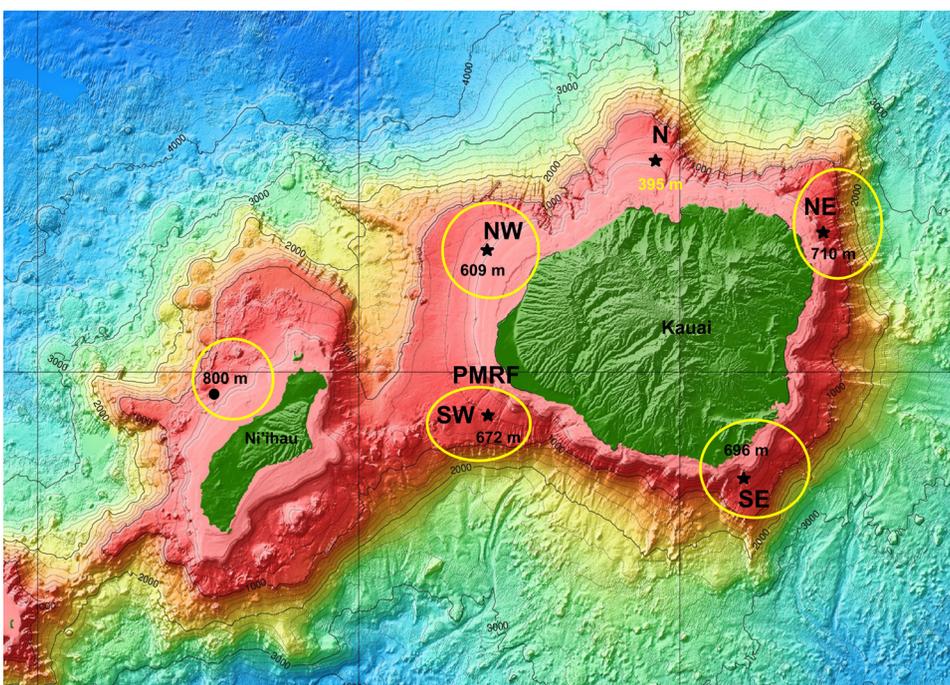


FIG. 1. (Color online) Location of EARs around the islands of Kauai and Ni'ihau. The depth of each EAR is shown next to the symbol marking its location.

covering the time period between January 2010 and January 2011 will be discussed. An EAR having a data acquisition sampling rate of 80 kHz was also deployed off the island of Ni'ihau (Fig. 1) between July and December 2010. Each EAR had a syntactic foam floatation collar and was connected to an acoustic release (Edgtech ORE Offshore CART) which was in turn connected to a wire rope that attached to an anchored consisting of a cement block (garage block) and with three small sand bags each weighing about 30 lbs.

## B. Data analysis

The acoustic data were analyzed with the support vector machine (SVM) portion of the Marine Mammal Monitoring on Navy Ranges (M3R) software (Jarvis *et al.*, 2008; Jarvis, 2012) and an energy-ratio-mapping algorithm (ERMA) for detecting beaked whales (Klinck and Mellinger, 2011) and a custom MATLAB program. The M3R (Jarvis *et al.*, 2008; Jarvis, 2012) is the primary Navy software to detect and discriminate deep foraging odontocetes at the following U.S. Navy ranges, Atlantic Undersea Test and Evaluation Center (AUTECE), Southern California Offshore Range (SCORE), and Pacific Missile Range Facility (PMRF). The SVM portion of the M3R software uses nine dimensional feature vectors formed by computing the time between 6 zero crossings about the peak and three normalized envelope amplitude peaks. The M3R software contain templates of biosonar signals from the short-finned pilot whale, Risso's dolphin, sperm whales, Cuvier and Blainville beaked whales and spinner dolphins (*Stenella longirostris*). A preliminary performance check can be found in Jarvis *et al.* (2008) and a more detailed performance evaluation can be found in Jarvis (2012). The classification precision of the M3R on test data sets for all the species are high, 85% or higher depending on the species (Jarvis, 2012). We combined the Cuvier and Blainville beaked whales together under the beaked whale category. We also combined all dolphins biosonar signals except those of Risso's dolphin as small dolphin, which would include a number of in shore species that typically do not dive to deep depths but their biosonar clicks can occasionally be detected by a deep-moored PAM. It is important to note that SVM has been used successfully by Yovel *et al.* (2008) to study discrimination of plants and bushes using bat biosonar signals and the discrimination of fish species using dolphin biosonar signals (Yovel and Au, 2010).

ERMA was also used to detect echolocation clicks of beaked whales in the recorded data sets. In a first step, ERMA calculates the energy ratio between two frequency bands (26.0–28.0 kHz and 19.5–21.5 kHz) for consecutive data snippets of 10 ms duration. In a second step, a Teager-Kaiser energy operator (Kandia and Stylianou, 2006) is applied to the series of energy ratios to pronounce peaks in the detection function. In the final step, a noise-adaptive threshold based on the energy levels in the 19.5–21.5 kHz frequency band is applied to the detection function to identify echolocation clicks in the data sets. The number of false alarms is further reduced by applying several checks to the detector output: Click bouts consisting of less than 5 clicks are discarded from further analysis. Click bouts consisting of more than 5 clicks are evaluated

for inter-click-intervals (ICIs); if more than 33% of the ICIs within the click bout fall into the ICI range 0.2–0.5 s, the click bout is considered to originate from beaked whales. In a test of different automatic click detection algorithms Yack *et al.* (2010) found that ERMA had a correct detection rate for beaked whales of 63% and a low false alarm rate of 3%.

Extra emphasis in the data analysis was spent in the detecting of beaked whales by using the ERMA results as a check to the M3R results. This focus was motivated by the many beaked whale stranding events that are associated with anthropogenic sounds, especially the use of mid-frequency sonar transmission of the U.S. and other Navies. Beaked whale signals that were detected by both M3R and ERMA were accepted as a true detection. A test set of over 100 files were examined comparing M3R and ERMA detection results. Any files in which either M3R or ERMA but not both detected beaked whales were further examined by a custom MATLAB program. This program sequentially detected each click in the file and displayed on the computer monitor the waveform and the Wigner-Ville time-frequency distribution for a 64 point segment covering 800  $\mu$ s. The display similar to Fig. 2 would remain for a second and then the display for the next click would be shown, and so on until the operator pressed a key on the keyboard to indicate clicks from a beaked whale were detected or until the whole file was read. The duration of beaked whale clicks tend to be much longer (about 250 and 450  $\mu$ s) than clicks from other odontocetes with the exception of sperm whales. Beaked whales also possess a frequency modulation (FM) component (Zimmer *et al.*, 2005) which can be seen in the Wigner-Ville plot. If an FM component was detected, the operator pressed a key indicating a beaked whale. If the file did not contain beaked whale signals, the next file would be examined, etc. ERMA was more conservative in detecting beaked whale signals and missed approximately 30% of the detection made by M3R. Since M3R had a low detection rate the results from M3R were used in this project.

## III. RESULTS

An example of the daily detection of the five different species from the M3R algorithm is shown in Fig. 3 for the SW Kauai location (closest to PMRF) for the period between

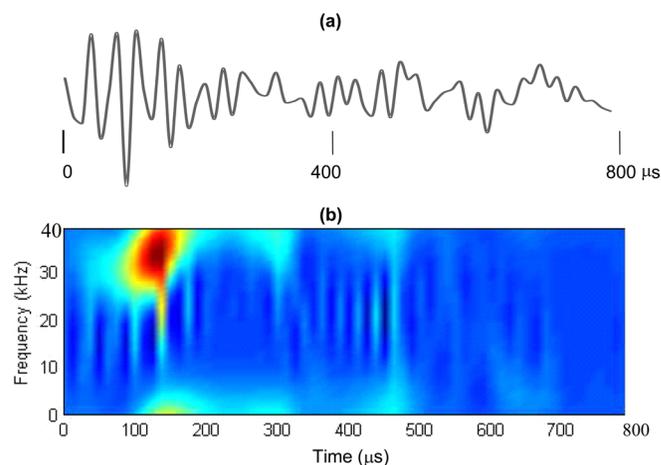


FIG. 2. (Color online) A beaked whale (a) time waveform and (b) time-frequency properties of the signal computed as a Wigner-Ville distribution.

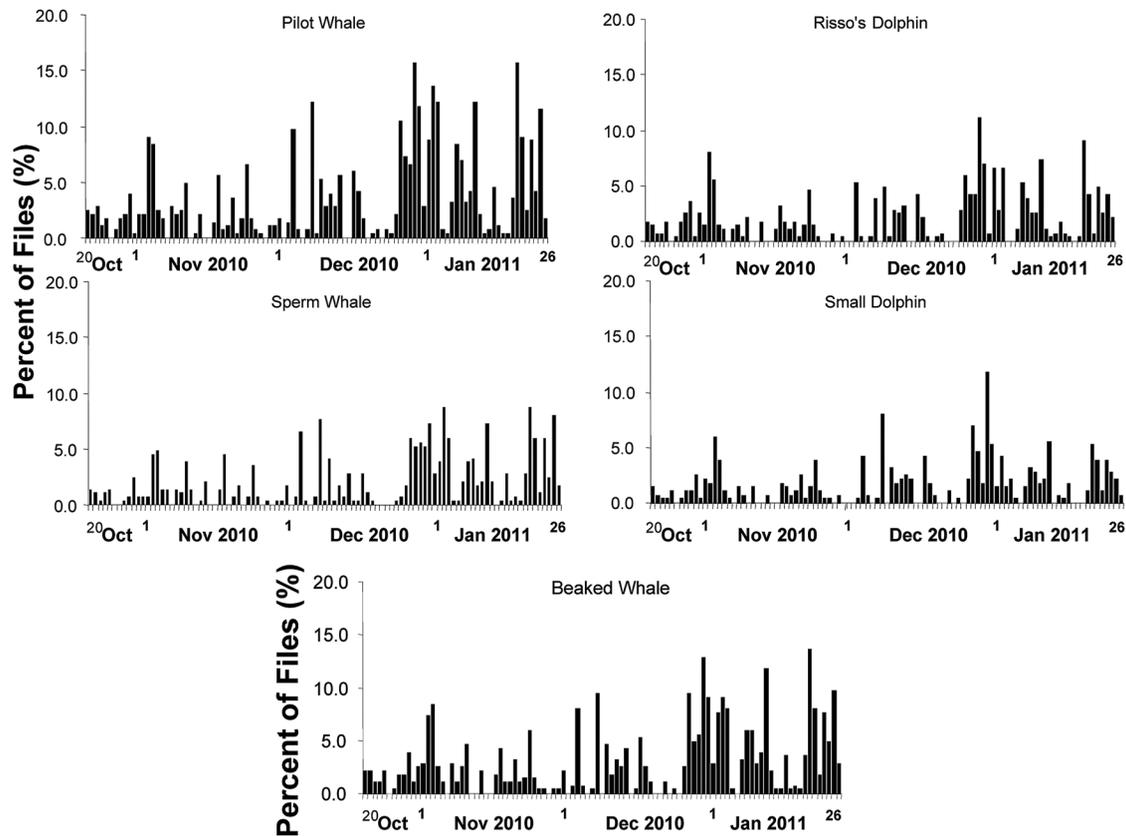


FIG. 3. An example of the percentage of the maximum number of files per day that contain biosonar signals for each species in the period from 20 October 2010 until 26 January 2011 at the SW location of Kauai.

20 October 2010 and 11 January 2011. A maximum of 288 files of data are recorded per day and the vertical axis of Fig. 3 is the percentage of the maximum number of files that contain biosonar signals. If the histograms for each species are overlaid on each other, one will see that at least one species of deep diving echolocating odontocetes would be detected on each day of the recording period. The maximum value of the vertical axis was the same for each histogram to provide an indication of the relative number of detection for the different species. The results in Fig. 3 clearly indicated that pilot whales were detected most often; however, the daily detection rate for any species is extremely variable. An extreme example can be seen for 3 consecutive days on the detection of pilot whales. On 18 January, only 0.3% of the files contained pilot whale biosonar signal, compared to 3.5% the next day and on 20 January, the maximum 15.6% of the files had biosonar signals. There were also consecutive days in which biosonar signals for a particular species were not detected. The histograms provide a rough idea of how much foraging is being done by each species within range of the EAR. However, it should not be interpreted as the amount of time per day the different species spent foraging for prey. They could easily move in and out of range of the EAR. The detection range of an EAR cannot be accurately predicted or measured because of the narrow beam pattern of biosonar signals. More on this issue will be elaborated on in Sec. IV.

The diurnal behavior of foraging by deep diving odontocetes was examined by dividing the 24 h in a day into two 12-h periods. The dawn-dusk-night or twilight-night period

was defined from 6:00 p.m. until 6:00 a.m. and the day period between 6:00 a.m. and 6:00 p.m. At the latitude of the main Hawaiian Islands ( $19^{\circ}$ – $22^{\circ}$ N) the time difference between sunrise on the longest day and the shortest day is only about 1 h. An example of average number of files in which signals from the various species were detected is shown in Fig. 4 for the same data set shown in Fig. 3 for the time period between 20 October 2010 and 11 January 2011 at the SW Kauai location. The shaded areas on each histogram plot represent the twilight-night time period. The twilight period is often referred to the crepuscular period where many animals display increased activity. The shaded block with a percentage value attached to each histogram is the percentage of time that files with biosonar signals were detected during the twilight-night time period. The percent of files with biosonar clicks detected during the twilight-night period at the different EAR locations and for different deployment periods are summarized in Table I for the locations around Kauai and one at Ni'ihau. The results in Table I are consistent with the results of Fig. 4 in that most of the foraging clicks were detected at night, although there was a fair amount of variability depending on location, time period, and species and without any other obvious trends. For example, the smallest percentage of foraging clicks detected during the twilight-night time period was 57% for sperm whale at the SW location during the 13 June to 19 September 2010 period. Yet at the NE location for this same time period, the highest percentage of night time foraging clicks of 86% for sperm whale was recorded. During the

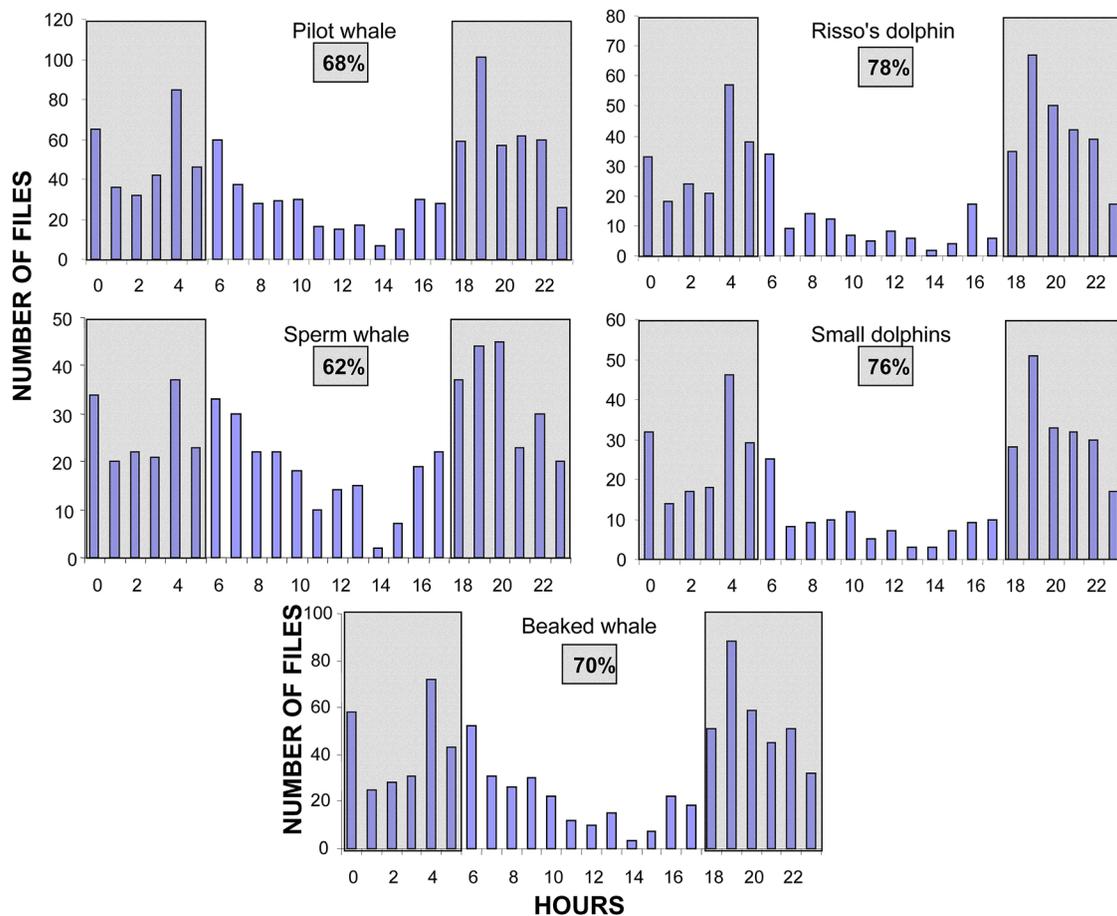


FIG. 4. (Color online) An example of the average number of files in which foraging clicks from the different species were detected on an hourly basis for the time period between 20 October 2010 and 26 January 2011 at the SW location of Kauai. The percentage of twilight-night detection is shown in the shaded block of each histogram.

20 October 2010 to 26 January 2011 time period, the smallest percentage of night time foraging clicks for short-finned pilot whale was 62% at the SE location while during this same time period the highest percentage was 80% occurred at the NE location. Beaked whales also had a strong tendency to forage at night with foraging.

In order to obtain a broad and general appreciation of the amount foraging during the twilight-night time period around Kauai and Ni'ihau, the total number of files detected for each day and for all time periods and locations were summed for each species. The corresponding number of files that pertained to the twilight-night period was summed and the percent of detection of foraging clicks during twilight-night period is summarized in Table II. The results clearly show a definite preference for twilight-night time foraging by the different species.

#### IV. DISCUSSION

The histograms are plot in terms of the number of files containing biosonar signals for each species. This is the most conservative interpretation of the data. The number of clicks and the number of bouts of click trains in a file will depend on the number and size of the pods in the vicinity of the EAR, and the location and orientation of the pod in relationship to the EAR in three dimensional space. Consider the biosonar beam pattern of an Atlantic bottlenose dolphin in the vertical

and horizontal planes in Fig. 5 (Au *et al.*, 2012). The front-to-back intensity ratio of biosonar signals can be as high as 50–60 dB so that if most the animals in the pod are searching for prey and moving away from the EAR, the signals arriving at the EAR will be very weak. This phenomenon makes it impossible to determine the detection range of a PAM device or provide information of any biosonar activity index. If an animal is pointing directly at the PAM, the detection range would be maximum with the best possible signal-to-noise ratio and if it was pointed greater than  $\pm 60^\circ$  in the horizontal plane the signal level would 40 dB or more below the on-axis level reducing the signal-to-noise ratio and the detectability of the signal. At this time, this beam pattern is the only one available for any odontocete that encompass angles almost entirely around an animal and should be consider as a proxy (until others are measured) for other echolocating odontocetes. Zimmer *et al.* (2005) presented the apparent source level of a Cuvier's beaked whales from DTAG data involving two tagged whales and obtained a rough and high variable estimate of a beam pattern that is generally consistent with the beam pattern in Fig. 5. However they specifically stated that "data available are not sufficient to describe a complete three dimensional beam pattern of the transmitted sound energy." Shaffer *et al.* (2013) recently estimated the biosonar beam pattern of Blainville's beaked whales and obtained results that were also consistent with Fig. 5.

TABLE I. The percentage of files with biosonar clicks detected during the twilight-night time period from the different species and different locations around Kauai and one location off Ni'ihau.

<b>Jan 25 – May 3, 2010</b>					
<b>Location</b>	<b>Pilot Whale</b>	<b>Sperm Whale</b>	<b>Risso's Dolphin</b>	<b>Small Dolphin</b>	<b>Beaked Whale</b>
<b>NW</b>	<b>72%</b>	<b>69%</b>	<b>80%</b>	<b>72%</b>	<b>72%</b>
<b>NE</b>	<b>79%</b>	<b>79%</b>	<b>90%</b>	<b>88%</b>	<b>83%</b>
<b>SE</b>	<b>80%</b>	<b>80%</b>	<b>90%</b>	<b>88%</b>	<b>83%</b>
<b>SW</b>	<b>70%</b>	<b>68%</b>	<b>84%</b>	<b>78%</b>	<b>73%</b>
<b>Jun 13 – Sep 19, 2010</b>					
<b>NW</b>	<b>68%</b>	<b>71%</b>	<b>72%</b>	<b>71%</b>	<b>67%</b>
<b>NE</b>	<b>80%</b>	<b>86%</b>	<b>92%</b>	<b>83%</b>	<b>79%</b>
<b>SE</b>	<b>72%</b>	<b>68%</b>	<b>86%</b>	<b>80%</b>	<b>72%</b>
<b>SW</b>	<b>68%</b>	<b>57%</b>	<b>81%</b>	<b>71%</b>	<b>72%</b>
<b>Oct 20, 2010 – Jan 26, 2011</b>					
<b>NE</b>	<b>80%</b>	<b>80%</b>	<b>89%</b>	<b>85%</b>	<b>86%</b>
<b>SE</b>	<b>62%</b>	<b>62%</b>	<b>80%</b>	<b>74%</b>	<b>70%</b>
<b>SW</b>	<b>68%</b>	<b>62%</b>	<b>78%</b>	<b>76%</b>	<b>70%</b>
<b>Jul 17 – Dec 17, 2010</b>					
<b>Ni'ihau</b>	<b>78%</b>	<b>77%</b>	<b>83%</b>	<b>85%</b>	<b>89%</b>

There are other reasons for the high variability of the daily detection of animals with a PAM device besides the effects of a relatively narrow biosonar beam. The daily movement of a pod of animals may bring the pod within the detection range of the EAR on some days and out of range on other days but yet it may be in the general area of the EAR but just out of range. The daily movement of a species could also move animals totally out of the area of the EAR. The range and pattern of movement of these deep diving species are not well known.

The results of this study showed a strong inclination of different deep diving echolocating odontocetes to foraging mainly at night. Johnston *et al.* (2008) using a HARP

reported that beaked whales at the Cross Seamount foraged mainly at night. Soldevilla *et al.* (2010) using recording from six HARPs moored between 300 and 1300 m found that Risso's dolphins in the southern California Bight forage mainly at night. However, data from tagged beaked whales have shown no difference between day and night in the foraging patterns of beaked whale in the Tongue of the ocean, Bahama (Hazen *et al.*, 2011) and off El Hierro, in the Canary Islands (Arranz *et al.*, 2011). Baird *et al.* (2008) using time-depth recorders on six Blainville and two Cuvier's beaked whale off the Hawaii Island also found that deep foraging dives occurred at the same rate during the day and night. It should be recognized that different type of information on odontocete foraging behavior is being gathered by PAM devices and time-depth recording and acoustic tags. Tags can obtain detailed temporal and spatial information on a few subjects for a short period of time whereas PAM devices sample a population for an extended period of several months. The Seaglider experiment off the Kona coast of Hawaii Island indicated that Cuvier's beaked whales and

TABLE II. The overall percentage of twilight-night time detection for all the locations and time period.

	<b>Pilot Whale</b>	<b>Sperm Whale</b>	<b>Risso's Dolphin</b>	<b>Small Dolphin</b>	<b>Beaked Whale</b>
<b>Overall</b>	<b>73%</b>	<b>70%</b>	<b>84%</b>	<b>79%</b>	<b>76%</b>

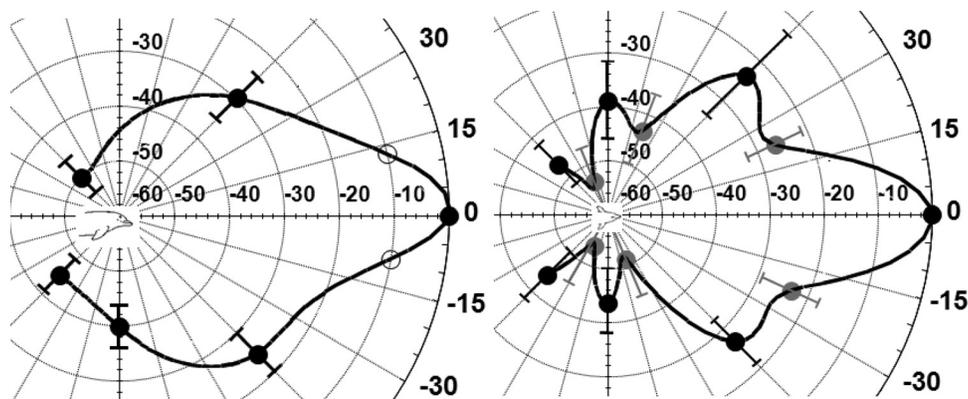


FIG. 5. Biosonar beam pattern of an Atlantic bottlenose dolphin (from Au *et al.*, 2012).

sperm whale did not display any difference between day and night foraging patterns (Klinck *et al.*, 2012). The differences between PAMs, tags and acoustic gliders can lead to different results and conclusions.

The foraging pattern of any animal is dependent on the dynamic behavior of the prey and in order to obtain an appreciation of the foraging process, an understanding of the prey field is required. Research in the Hawaiian islands have shown that the dynamic behavior of the mesopelagic boundary community (MBC) consisting of myctophid, shrimp, and small squid has an overriding influence on the natural history of spinner dolphins (Benoit-Bird *et al.*, 2001; Benoit-Bird and Au, 2003a,b). The MBC migrate from deeper waters toward the surface and toward shore beginning at dusk reaching its closest approach to shore at about mid-night and then back toward deeper waters before dawn. Spinner dolphins forage mainly at night as the MBC migrate horizontally toward shore and vertically toward the surface at dusk with a corresponding increase in the prey density as the organisms “pile up” in shallow waters (Benoit-Bird and Au, 2003a).

The prey field essentially dictates where on the coast spinner dolphin rest, where they forage, how they forage, and when they forage. A similar type of relationship would not be surprising between deep diving foraging odontocetes and the prey they depend on for their survival. Unfortunately there is a poor understanding of the dynamic behavior of the prey fields of these deep diving odontocetes and the rationale for night time foraging is much more difficult to understand. Short-finned pilot whales, sperm whales, Risso’s dolphins, and beaked whales all feed mainly on squids and occasionally of some unspecified species of fish. Seagars and Henderson (1985) reported that short-finned pilot whales in the Pacific west coast feed primarily on neritic squid *Loligo sp.* Mintzer *et al.* (2008) found that oceanic squid *Brachioteuthis riisei*, was the main prey of short-finned pilot whales in the Atlantic; however, *Taonius pavo* and *Histioteuthis reversa* were also a part of their diet. Sperm whales feed mainly on mesopelagic and benthic habitats on squids of different species and occasionally fish. Giant squid (*Archaeoteuthys sp.*) and jumbo squid (*Dosidicus sp.*) and Antarctic colossal squid (*Mesonychoteuthis hamiltoni*) (Clarke *et al.*, 1985; Whitehead, 2003) are some prey species of sperm whales. Risso’s dolphin feed mainly on squid and other cephalopods (Clarke *et al.*, 1985). Off the California coast the jumbo squid (*Dosidius gigas*) and the California market squid (*Loligo*

*opalescens*) are common prey (Orr, 1966; Kruse, 1989). Beaked whales tend to prefer deep water squid but there exist sufficient data to suggest that the prey specimens also include a variety of demersal and mesopelagic fishes (Mead, 2002; Pitman, 2002; Ohizumi and Kishiro, 2003).

Although the habitat of the deep diving odontocetes consist of the mesopelagic and upper bathypelagic zones of the ocean, it would not be surprising if some sort of habitat partitioning occurs as a function of depth. We can assume that sperm whales must forage for larger prey than the smaller odontocetes. Short-finned pilot whales and beaked whales are of similar size, and it is conceivable that the prey species may be similar. Risso’s dolphins weigh approximately  $\frac{1}{2}$  that of short-finned pilot whales, and it would be reasonable that they would forage for smaller prey. It would not be surprising that there are niches mediated by bottom depth for the different species of squids. Yet the various prey species behave in such a manner as to make it advantageous for the different species of deep diving odontocetes to forage at night.

At the current level of understanding, we can only speculate on the advantages of night time foraging. It is well known that the deep scattering layer (DSL) and other mesopelagic layer of organisms migrate vertically toward the surface at dusk and back to deeper depths at dawn. The question is how does this migration affect the squid species. If the squid prey also migrate from deep waters to forage on the organisms the DSL, the squids would rise into depth strata that would be more beneficial for deep diving odontocetes to forage on them. Arranz *et al.* (2011) have found that Blainville’s beaked whales spend most of their foraging time in the lower part of the DSL or near the bottom in the Canary Islands. From a biosonar perspective, the DSL represents a volume reverberation environment and finding prey within such a layer of scatterers would represent a difficult sonar task. To detect and localize targets below the DSL or even off the bottom may be a simpler task than attempting to do so in the DSL.

The role of the bottom topography is a factor that should be considered in future studies. The bottom off the Hawaiian Islands is volcanic and rises steeply from the deep into the air as can be seen in Fig. 1. This type of topography is rather different than a seamount which basically represent submerged isolated bathymetric feature on the abyssal plane. Canyons, like the one at the AUTECH range have steep walls that rises to an underwater plateau on both sides. The oceanographic

conditions for these bottom types can be expected to be very different and these differences will affect the dynamic behavior of squid and fish prey. There are also many other factors that affect prey behavior that we can only speculate on without any detailed measurements. Furthermore, the geographic locations, atmospheric and oceanic patterns will all be contributing factors in a complex interactive web of variables that affect squid and fish prey behavior. In the end, the general prey field behavior around Kauai and at one location of Ni'ihau is such that deep-diving odontocetes must have a distinct advantage foraging at night rather than during the day.

The data collected by a stationary PAM device such as the EAR make it possible to study the diurnal foraging behavior of deep-diving odontocetes over a long-time period. Other instruments such as acoustic and time-depth recording tags and acoustic gliders have not uncovered the twilight-night foraging behavior of deep-diving odontocetes. The Seaglider experiment found a twilight-night sound emission for delphinids but these were probably from spinner dolphins which are known to forage mainly at night in shallow waters. The Seaglider experiment was also performed off the Kona coast of Hawaii Island instead of Kauai and geographic differences may have been a factor in not detecting a strong twilight-night time foraging tendencies in sperm and beaked whales. Nevertheless, from the results of this study indicate a strong tendency for twilight-nighttime foraging by deep diving odontocetes around Kauai and Ni'ihau. The reasons for this foraging behavior are not known and will continue to be an area of interesting research.

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