Final Report

Passive Acoustic Monitoring of Cetaceans in the Hawaii Range Complex Using Ecological Acoustic Recorders (EARs)

Prepared for: Commander, U.S. Pacific Fleet

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Prepared by

Marc O. Lammers[1,2], Lisa M. Munger[1], Julie N. Oswald[3], and Tina M. Yack[3]

[1] Oceanwide Science Institute
P.O. Box 61692
Honolulu, HI 96839

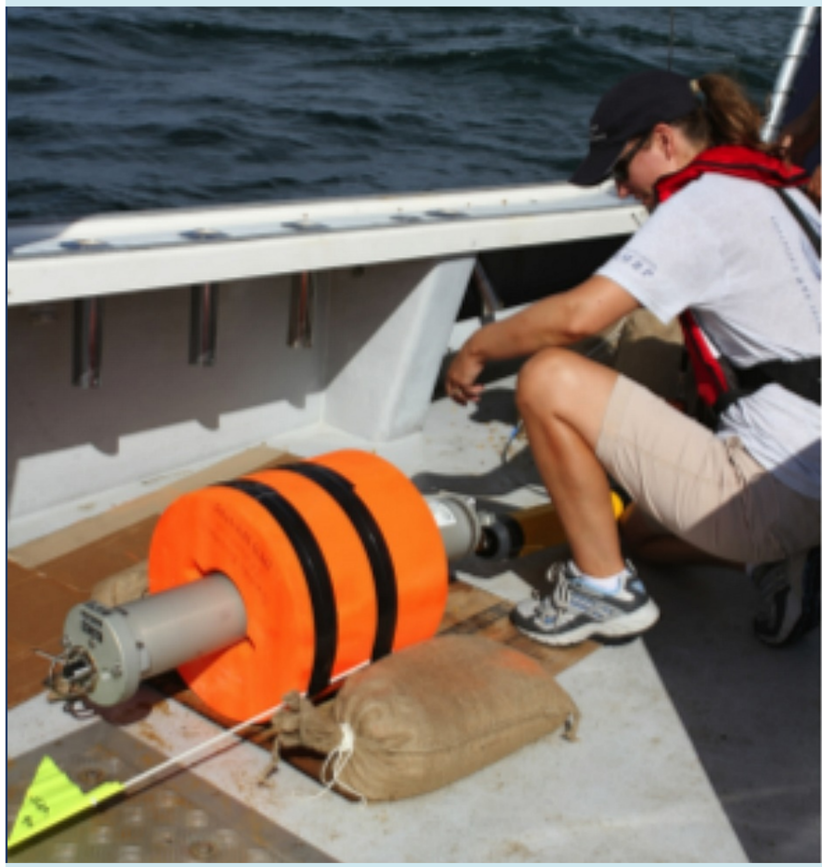
[2] Hawaii Institute of Marine Biology
46-007 Lilipuna Road
Kaneohe, HI 96744

[3] Bio-Waves, Inc.
364 2nd Street, Suite #3
Encinitas, CA 92024

Submitted by:

HDR

Honolulu, HI



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Ecological acoustic recorder (EAR) with float and acoustic release, on vessel deck prior to deployment. Photo taken by Dan Engelhaupt.

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Marc O. Lammers
Lisa M. Munger
Julie N. Oswald
Tina M. Yack

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Oceanwide Science Institute, P.O. Box 61692, Honolulu, HI
Hawaii Institute of Marine Biology, 46-007 Lilipuna Road, Kaneohe, HI
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14. ABSTRACT
A long-term passive acoustic monitoring program was initiated in 2011 by the United States Navy Pacific Fleet to investigate the occurrence of cetaceans in waters within the main Hawaiian Islands under the Hawaii Range Complex (HRC) monitoring plan. As a part of this monitoring plan, four ecological acoustic recorders (EARs) were deployed at locations around the islands of Niihau and Kaula, to the west of Kauai. These EARs recorded data over three deployment periods: July to December 2011, January to May 2012, and July 2012 to February 2013. They were programmed to record at a sampling rate of 80 kilohertz (kHz) with a duty cycle of 30 seconds 'on' either every 5 or 10 minutes, depending on the deployment.

Data were analyzed using several approaches to detect cetacean signals and mid-frequency active sonar (MFAS) events. The Marine Mammal Monitoring on Navy Ranges (M3R) Class-Specific Support Vector Machine (CS-SVM) automated detector, developed for the United States Navy, was implemented to detect clicks from beaked whales (Ziphius cavirostris and Mesoplodon spp.) and sperm whales (Physeter macrocephalus). 'Baleen5,' an automated detector algorithm for baleen whales developed at the Hawaii Institute of Marine Biology, was implemented to detect calls from four baleen whale species: blue whale (Balaenoptera musculus), fin whale (B. physalus), minke whale (B. acutorostrata) and humpback whale (Megaptera novaeangliae). The fifth species for which the detector was trained, sei whales (B. borealis), was excluded from this study due to uncertainty regarding North Pacific call types.
A ground-truth study was conducted to evaluate the performance of both detectors and determine the rate of true

positives, false positives, true negatives, and false negatives by manually examining individual detections (i.e., individual clicks or calls/song units) and searching periods without detections.

Manual analyses were conducted to detect mid-frequency active sonar (MFAS) pings throughout all three deployments, as well as baleen whale calls and sperm whale clicks within 2-week periods surrounding each MFAS event. In addition, a combined manual and automated approach was conducted for all three deployments to detect delphinid signals and classify them using the Real-time Odontocete Call Classification Algorithm (ROCCA). Finally, a thorough manual analysis of the third deployment was conducted to detect sperm whale and delphinid acoustic encounters, and classify the latter into one of four signal groups: "clicks only;" "low frequency" (containing whistles predominantly below 10 kHz); "high frequency and low frequency" (containing whistles with energy below and above 10 kHz); and "high frequency" (containing whistles predominantly above 10 kHz).

Six MFAS exposure periods, consisting of MFAS events occurring over 2 or more consecutive days, were selected for detailed statistical analyses of delphinid, baleen whale, and sperm whale occurrence within the surrounding 2-week period. Delphinid encounter rates and durations were statistically analyzed for pooled detections (all species) across all EAR sites and MFAS exposure periods, then stratified by site, exposure period, and by species/signal group. The low number of detections for most baleen whales (except humpback whales) and sperm whales around MFAS limited the quantitative analyses possible for their occurrence relative to MFAS.

To briefly summarize results with respect to the Navy's monitoring questions:
Q1a. What species of beaked whales (Ziphius/Mesoplodon) are in the region surrounding Niihau and Kaula Islands in the HRC?
A small number of Blainville's beaked whale (n = 12) and Cuvier's beaked whale (n = 4) detections were confirmed by analysts. One possible Longmans' beaked whale detection could not be confirmed with certainty. Beaked whales appear to be rare within the detection area of the EARs in this part of the HRC.
Q1b. Do beaked whale detection rates vary before, during, and after mid-frequency active sonar (MFAS) detections?
Sample sizes were inadequate to examine the question in this study.
Q2a. What is the seasonal occurrence of baleen whales near Niihau and Kaula Islands in HRC?
In order from most to least common, humpback whales, minke whales, and fin whales were confirmed to occur in winter and spring months in the HRC.
Q2b. Do baleen whale detection rates vary before, during, and after MFAS detections?
Either the metrics of occurrence were too coarse (humpback whale song) or sample sizes were inadequate (minke and fin whales) to answer the question presently.
Q3a. What is the occurrence of sperm whales near Niihau and Kaula Islands in the HRC?
Sperm whales occur sporadically throughout the year.
Q3b. Do sperm whale detection rates vary before, during, and after MFAS detections?
The sample sizes obtained were inadequate to answer the question
Q4a. What species of delphinids occur near Niihau and Kaula Islands in the HRC?
In order of most to least frequently detected/classified by ROCCA, species classes were: spinner/striped dolphin, bottlenose dolphin, rough-toothed dolphin, spotted dolphin, false killer whale, and pilot whale.
Q4b. Do delphinid detection rates vary before, during, and after MFAS detections?
Variations were observed for delphinids as a whole, but no consistent pattern was evident; statistically significant differences were observed for some species classes and for specific MFAS events, but sample sizes were limited and the direction of change was not consistent across different MFAS events.

15. SUBJECT TERMS
Monitoring, marine mammal, passive acoustic monitoring, sonar, vocal response, adaptive management review, Hawaii Range Complex

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Executive Summary

A long-term passive acoustic monitoring program was initiated in 2011 by the United States Navy Pacific Fleet to investigate the occurrence of cetaceans in waters within the main Hawaiian Islands under the Hawaii Range Complex (HRC) monitoring plan. As a part of this monitoring plan, four ecological acoustic recorders (EARs) were deployed at locations around the islands of Niihau and Kaula, to the west of Kauai. These EARs recorded data over three deployment periods: July to December 2011, January to May 2012, and July 2012 to February 2013. They were programmed to record at a sampling rate of 80 kilohertz (kHz) with a duty cycle of 30 seconds 'on' either every 5 or 10 minutes, depending on the deployment.

Data were analyzed using several approaches to detect cetacean signals and mid-frequency active sonar (MFAS) events. The Marine Mammal Monitoring on Navy Ranges (M3R) Class-Specific Support Vector Machine (CS-SVM) automated detector, developed for the United States Navy, was implemented to detect clicks from beaked whales (*Ziphius cavirostris* and *Mesoplodon* spp.) and sperm whales (*Physeter macrocephalus*). 'Baleen5,' an automated detector algorithm for baleen whales developed at the Hawaii Institute of Marine Biology, was implemented to detect calls from four baleen whale species: blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), minke whale (*B. acutorostrata*) and humpback whale (*Megaptera novaeangliae*). The fifth species for which the detector was trained, sei whales (*B. borealis*), was excluded from this study due to uncertainty regarding North Pacific call types.

A ground-truth study was conducted to evaluate the performance of both detectors and determine the rate of true positives, false positives, true negatives, and false negatives by manually examining individual detections (i.e., individual clicks or calls/song units) and searching periods without detections. When possible, these values were used to calculate precision (the ratio of true positives to the total number of automated detections), recall (the ratio of true positives to the total number of target signals present, including those missed by the detector), and specificity (the proportion of true negatives, or automated detections correctly classified as non-target signals). Questions resulting from the ground-truth process of the initial interpretation of the CS-SVM detector results led to discussions with the developers of the detector. Their input was used to formulate a re-evaluation of CS-SVM performance and a re-interpretation of the output based on additional contextual information on a per-recording basis rather than an individual detection basis.

Manual analyses were conducted to detect MFAS pings throughout all three deployments, as well as baleen whale calls and sperm whale clicks within 2-week periods surrounding each MFAS event. In addition, a combined manual and automated approach was conducted for all three deployments to detect delphinid signals and classify them using the Real-time Odontocete Call Classification Algorithm (ROCCA). Finally, a thorough manual analysis of the third deployment was conducted to detect sperm whale and delphinid acoustic encounters, and classify the latter into one of four signal groups: "clicks only;" "low frequency" (containing whistles predominantly below 10 kHz); "high frequency and low frequency" (containing whistles with energy below and above 10 kHz); and "high frequency" (containing whistles predominantly above 10 kHz).

Six MFAS exposure periods, consisting of MFAS events occurring over 2 or more consecutive days, were selected for detailed statistical analyses of delphinid, baleen whale, and sperm whale occurrence within the surrounding 2-week period. Delphinid encounter rates and durations were statistically analyzed for pooled detections (all species) across all EAR sites and MFAS exposure periods, then stratified by site, exposure period, and by species/signal group. The low number of detections for most baleen whales (except humpback whales) and sperm whales around MFAS limited the quantitative analyses possible for their occurrence relative to MFAS.

During the initial M3R CS-SVM detector ground-truth study, all of the beaked whale automated detections (in this case, individual clicks) checked by analysts were established to be false positives and found to be triggered primarily by unidentified odontocete (likely delphinid) signals. No missed beaked whale signals were found by additional manual examination of sound recordings ("files"). Based on the initial ground-truth analysis, precision and recall could not be calculated for the beaked whale detector, and beaked whale presence could not definitively be inferred in the dataset based on the detector's output. Specificity was calculated to be 0.97 for Blainville's beaked whale and 0.95 for Cuvier's beaked whale, indicating that ≥ 95 percent of individual click detections were correctly not attributed to either species.

During the re-evaluation of CS-SVM results, detector output was interpreted on a per-file basis rather than an individual-click basis, and the following criteria were adopted for files to be considered detections: at least five automated click detections (for sperm whales only) and at least 70 percent of click detections classified to the species class of interest (for sperm whales or beaked whales). Additional files were searched, and a small number of files containing beaked whale automated detections were found to be true positives (n = 15). One missed beaked whale signal was found by manual searching. Precision and recall of the CS-SVM detector when applying the revised criteria to a mixed beaked whale class (combined Cuvier's and Blainville's beaked whale detections) were 0.12 and 0.94, respectively, meaning that 88 percent of reviewed files with beaked whale auto-detections were false positives (signals not produced by the target species) and 94 percent of files with actual beaked whale signals present were correctly detected and classified. A specificity value of 0.91 was calculated for the CS-SVM beaked whale detector, meaning that under the revised interpretation criteria, 91 percent of files were correctly labeled as not containing any beaked whale clicks. Given that only 1,994 files (<1 percent of the total dataset) were classified as beaked whales by CS-SVM (based on revised criteria) and only 12 percent of those files are likely to contain true positives, this represents a very low percentage of data overall (239 of 277,220 files or < 0.1 percent) with potential beaked whale signals present. Combined with the high specificity of 0.91 (indicating low probability of misclassification), these results suggest that beaked whales are rare within the detection area of the EARs. Due to scarcity of confirmed beaked whale signals, no inference could be made about temporal or spatial patterns in beaked whale occurrence.

During the initial M3R CS-SVM ground-truth effort for sperm whales, precision and recall were calculated to be 0.20 and 0.03, respectively, meaning that 80 percent of automated individual click detections were false positives (triggered primarily by other unidentified odontocete signals) and 97 percent of the manually detected true sperm whale signals were missed by the detector. Specificity was high (0.93), meaning that 93 percent of clicks not classified as sperm whales were correctly rejected (true negatives). During the re-evaluation of CS-SVM results, precision and recall were re-assessed using the revised criteria and found to be 0.52 and 0.26, respectively; specificity was 0.94. Although the precision and recall values represent an improvement in performance (based on interpretation criteria, not changes in detector settings or implementation) and specificity remained high, the rates of false positives (48 percent) and false negatives (74 percent missed) again precluded any meaningful inference about sperm whale occurrence in the dataset based on automated detector output. As a side note, the baseline CS-SVM for sperm whales used in this analysis was prototypical and known to be suboptimal. An improved sperm whale CS-SVM classifier has since been developed and is deployed at the Pacific Missile Range Facility. Ground-truthing of the updated detector was beyond the scope of this effort.

The Baleen5 algorithm detected 2 blue whale signals and 21 fin whale signals in the EAR recordings from deployments 1 and 2; however, manual analysis showed that all of these detections were false positives. Precision and recall could not be calculated for either species, as no missed or true detections were identified during the manual analysis. Therefore, the Baleen5 detector results for blue and fin whales were not considered further because their reliability could not be independently established. Ground-truth analysis of the humpback whale detector results revealed a precision of 0.94 and a recall of 0.09, indicating a low (6 percent) false positive rate (i.e., most detections were true), but high (91 percent) false negative rate (i.e., most song units were missed). Ground-truth analysis of the minke whale detector resulted in a precision of 0.29 and recall of 0.5, indicating a 71 percent false positive rate and 50 percent missed minke whale calls.

The results of the Baleen5 detector analyses combined with the visual/manual analyses performed around periods of MFAS confirm that humpback, minke and fin whales are seasonally present near Niihau and Kaula Islands in winter and spring. Humpback whales were the predominant species in terms of acoustic presence. They occurred at all monitored sites and their song was nearly ubiquitous in recordings made during the winter/spring time period. Some spatial/temporal differences were seen in the occurrence of song. Pueo Point had the highest occurrence of detected song during the peak of the humpback whale season in March, while SW Niihau had significantly less detected song in April than either Pueo Point or NW Niihau. The second most commonly detected baleen whale species was the minke whale. The Baleen5 algorithm frequently detected their boing calls, especially at Pueo Point. However, given the poor precision and recall of the algorithm for minke boing calls, temporal and spatial differences could not be reliably established. The presence of fin whales was noted in the manual analyses conducted for baleen whale presence during periods associated with MFAS. Their calls only occurred in the winter/spring time frame and were rare, with only a total of 39 recordings containing fin whale calls out of more than 80,000 files manually examined. Therefore, while it can be concluded that fin whales do occur in this part of the HRC, their presence is likely sporadic.

The only two baleen whale species that occurred before, during and/or after the examined periods of MFAS exposure were humpback whales and fin whales. However, establishing whether or not MFAS had an effect on detection rates was not feasible for either species, for different reasons. In the case of humpback whales, nearly continuous singing by one or more individuals during the winter seasons precluded comparison based on the presence or absence of song in recordings. On the other hand, the occurrence of fin whale calls was too rare to make meaningful comparisons among calling rates relative to MFAS. The three MFAS exposure periods that coincided with fin whale calls did not provide any indication that fin whale signaling rates around Niihau and Kaula are influenced by the presence of MFAS. However, this was due primarily to the scarcity of fin whale calls in the area rather than the absence of any correlation.

The results of the combined M3R CS-SVM analysis of the three deployments and the visual/manual analysis of the third deployment data indicate that sperm whales are sporadically present year-round within the monitoring area, with no apparent seasonal or diel pattern of occurrence. The presence of sperm whale clicks in the data was examined using both automated and manual analysis methods. During the CS-SVM re-interpretation effort, a subset of automatically detected files from each of the three deployments were manually confirmed to contain sperm whale signals (67 files of 129 examined); a high rate of missed sperm whale files (0.74) was also identified. The occurrence of sperm whale clicks in EAR recordings was also established manually for the data from the three sites monitored during the third deployment (NW Niihau, Pueo Point and SW Niihau). Encounter rates were low within the third deployment data, ranging from 0.19 encounters/day at Pueo Point to 0.08 encounters/day at SW Niihau. Overall, sperm whales occurred only sporadically at the monitored sites, with multiple weeks often elapsing between encounters.

Sperm whale encounters occurred before and/or after four of the six MFAS exposure periods examined. No encounters occurred at any site during days of MFAS activity. Statistically, this was likely due to chance, given the infrequent overall occurrence of sperm whales in the area (< 20 percent of days). No trends were noted with respect to the occurrence of sperm whales before or after MFAS. Differences in the number of encounters/day and encounter duration during the 7 days before vs. 7 days after MFAS exposure were not significant.

Delphinid activity was highest at NW Niihau, followed by Pueo Point, SW Niihau, and Kaula Island. There were marked seasonal patterns, with greater encounter rates and longer mean encounter duration during the summer/fall deployment periods than during the winter/spring deployment. In order from most to least common, delphinid encounters within the three EAR deployments were classified by ROCCA as spinner/striped (*Stenella sp*), bottlenose dolphin (*Tursiops truncatus*), rough-toothed dolphin (*Steno bredanensis*), spotted dolphin (*Stenella attenuata*), false killer whale (*Pseudorca crassidens*), and pilot whale (*Globicephala macrorhynchus*).

For delphinids grouped as a whole, there were no statistically significant differences in encounter rate or duration for pooled time periods before, during, and after all MFAS exposure periods. When stratified by site and by MFAS exposure trial, there were variations in these metrics, but there was no consistent directional pattern (increase or decrease before, during or after MFAS). Thus, no broad-scale, consistent changes in overall delphinid occurrence near the monitored sites were found in relation to multi-day MFAS exposure periods. Some significant differences were found for rough-toothed dolphins and the low-frequency whistle signal group relative to pooled MFAS exposure periods, and for the spinner/striped dolphin class around specific MFAS exposure periods, but sample sizes were not large enough to establish consistent patterns or rule out contributing factors other than MFAS. Further examination of delphinid acoustic behavior over shorter/smaller time and spatial scales may be necessary to better understand any species-specific responses to MFAS.

To briefly summarize with respect to the Navy's monitoring questions:

Q1a. What species of beaked whales (*Ziphius/Mesoplodon*) are in the region surrounding Niihau and Kaula Islands in the HRC?

A small number of Blainville's beaked whale (n = 12) and Cuvier's beaked whale (n = 4) detections were confirmed by analysts. One possible Longmans' beaked whale detection could not be confirmed with certainty. Beaked whales appear to be rare within the detection area of the EARs in this part of the HRC.

Q1b. Do beaked whale detection rates vary before, during, and after mid-frequency active sonar (MFAS) detections?

Sample sizes were inadequate to examine the question in this study.

Q2a. What is the seasonal occurrence of baleen whales near Niihau and Kaula Islands in HRC?

In order from most to least common, humpback whales, minke whales, and fin whales were confirmed to occur in winter and spring months in the HRC.

Q2b. Do baleen whale detection rates vary before, during, and after MFAS detections?

Either the metrics of occurrence were too coarse (humpback whale song) or sample sizes were inadequate (minke and fin whales) to answer the question presently.

Q3a. What is the occurrence of sperm whales near Niihau and Kaula Islands in the HRC?

Sperm whales occur sporadically throughout the year.

Q3b. Do sperm whale detection rates vary before, during, and after MFAS detections?

The sample sizes obtained were inadequate to answer the question

Q4a. What species of delphinids occur near Niihau and Kaula Islands in the HRC?

In order of most to least frequently detected/classified by ROCCA, species classes were: spinner/striped dolphin, bottlenose dolphin, rough-toothed dolphin, spotted dolphin, false killer whale, and pilot whale.

Q4b. Do delphinid detection rates vary before, during, and after MFAS detections?

Variations were observed for delphinids as a whole, but no consistent pattern was evident; statistically significant differences were observed for some species classes and for specific MFAS events, but sample sizes were limited and the direction of change was not consistent across different MFAS events.

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Glossary of Acronyms and Terminology

CS-SVM	Class-Specific Support Vector Machine
EAR	ecological acoustic recorder
EEZ	exclusive economic zone
ESA	Endangered Species Act
HIMB	Hawaii Institute of Marine Biology
HF	high frequency
HRC	Hawaii Range Complex
kHz	kilohertz
km^2	square kilometer(s)
LF	low frequency
LTSA	long-term spectral average
M3R	Marine Mammal Monitoring on Navy Ranges
MHI	main Hawaiian Islands
MFAS	mid-frequency active sonar
MMPA	Marine Mammal Protection Act
NOAA	National Oceanic and Atmospheric Administration
NWHI	Northwest Hawaiian Islands
OSI	Oceanwide Science Institute
PAM	passive acoustic monitoring
ROCCA	real-time odontocete call classification algorithm
IUCN	International Union for Conservation of Nature & Natural Resources

encounter - sequence of one or more recordings containing delphinid or sperm whale signals separated by no more than 30 minutes.

MFAS event - sequence of one or more recordings containing MFAS pings separated by no more than 2 hours.

MFAS exposure period - occurrence of one or more MFAS events with total duration greater than 2 hours spanning at least 2 consecutive days and observed at one or more EAR sites.

MFAS exposure trial - individual MFAS exposure period at a single EAR site.

Signal group - categories used for manual classification of delphinid encounters from third deployment. Four possible signal groups: "clicks only", “low-frequency” (LF), containing whistles predominantly below 10 kilohertz (kHz); “high-frequency and low-frequency” (HF & LF), containing whistles with energy below and above 10 kHz; and “high-frequency” (HF), containing whistles predominantly above 10 kHz.

Pooled - data combined or considered as a whole; not stratified by category (e.g., 'pooled delphinids' = all delphinid data combined and not stratified by species class; 'pooled MFAS exposure periods' = data analyzed for combined MFAS exposure periods and not single exposure periods)

Boing - stereotyped call produced by minke whales in the North Pacific and targeted by automated detector used in this study

True Positive - automated detection correctly classified as target signal

False positive - automated detection incorrectly classified as target signal

True negative - automated detection correctly classified as non-target signal

False negative - automated detection incorrectly classified as non-target signal or a target signal missed by the detector

1. Introduction

The waters surrounding the main Hawaiian Islands (MHI) are habitat for 25 documented species of cetaceans, including 18 documented odontocete species and 7 mysticete species (Barlow 2006, Carretta et al. 2014). These waters are also important to the United States (U.S.) Navy, which conducts training and testing activities in areas offshore of the MHI that constitute the Hawaii Range Complex (HRC). These activities may include the use of mid-frequency active sonar (MFAS), among other sound sources, and range in scale from small, unit-level training to major multi-national exercises such as Rim of the Pacific exercises. As part of its efforts to monitor potential impacts of naval activities on marine mammals, the U.S. Navy supports several areas of marine mammal research in the HRC including sound exposure modeling, tagging and satellite telemetry, aerial and vessel surveys, and passive acoustic monitoring using various platforms (e.g., Klinck et al. 2012, Martin et al. 2013, Baird et al. 2014).

Vessel-based efforts in recent years have provided information on species occurrence and habitat use within the Hawaiian archipelago. Large-scale vessel-based line-transect surveys for cetaceans were conducted by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service in U.S. exclusive economic zone (EEZ) waters of the MHI and Northwest Hawaiian Islands (NWHI) in summer/fall 2002 and 2010 (Barlow 2006, Bradford et al. 2013, Carretta et al. 2014). These cruises included visual survey effort and towed hydrophone array and sonobuoy recordings, and provide the basis for the most recent and best available abundance estimates for many of the cetacean species occurring in Hawaii (Carretta et al. 2014). Since 2000, small-vessel based surveys have also been conducted in waters off the MHI, and have provided evidence for island-associated and pelagic populations of several odontocete species, have documented depth-related differences in distribution, and have contributed to knowledge of behavioral ecology of several species of current management/policy importance (e.g., beaked whales, false killer whales) (Baird et al. 2006, Baird et al. 2008a,b, Baird et al. 2009, Baird et al. 2011, Baird et al. 2013a,b,c).

The impact of anthropogenic noise on cetaceans is a topic of growing concern globally. Responses to noise sources such as commercial shipping, seismic airguns, and military sonars have been documented in numerous mysticete and odontocete species (see Nowacek et al. 2007, D'Amico et al. 2009 for review; more recent studies include Di Iorio and Clark 2010, McCarthy et al. 2011, Tyack et al. 2011, Castellote et al. 2012, Melcón et al. 2012, Goldbogen et al. 2013, DeRuiter et al. 2013a,b, Henderson et al. 2014, Miller et al. 2014). Of the cetacean species/taxa occurring in Hawaiian waters, several are of particular concern to the Navy because of potential susceptibility to sonar (particularly for deep-diving taxa such as beaked whales and sperm whales), data deficiency, frequency of occurrence within Navy operational areas, and/or other management and policy issues.

Beaked whales (family Ziphiidae) are a research priority for the U.S. Navy because of their potential susceptibility to sonar, which has been linked to behavioral disruption and/or injury/death in other areas (e.g., D'Amico et al. 2009, Tyack et al. 2011). Three species of beaked whale are documented to occur in the Hawaiian archipelago: Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), and Longman's beaked whale (*Indopacetus pacificus*). Abundance estimates for Blainville's and Cuvier's beaked whales within the Hawaiian Islands EEZ are 2,338 (CV = 1.13) and 1,941 (CV = 0.70), respectively (Bradford et al. 2013), with re-sighting and movement data from small-vessel work and satellite telemetry suggesting insular and pelagic populations of each species (McSweeney et al. 2007, Baird et al. 2013b). Longmans' beaked whale is one of the least known cetacean species; since the year 2000 only a few sightings during vessel-based surveys and one stranding have been reported (Barlow 2006, Bradford et al. 2013, West et al. 2012). The 2002 abundance estimate for Longman's beaked whales was 1,007 (CV = 1.25) (Barlow 2006), and the 2010 abundance estimate, currently the best available, is 4,571 (CV = 0.65) (Bradford et al 2013). For all three beaked whale species in Hawaii, there are insufficient data for trends in abundance, and none of the species are considered endangered under the Endangered Species Act (ESA), nor strategic, threatened, or depleted under the Marine Mammal Protection Act (MMPA). Two of the species, Blainville's and Longman's beaked whale, are considered 'data deficient' by the International Union for Conservation of Nature & Natural Resources (IUCN) red list (Taylor et al. 2008).

Baleen whales (suborder Mysticeti) are a research priority because, with the exception of humpback whales (*Megaptera novaeangliae*), they are rarely sighted and relatively poorly documented in Hawaii, and anthropogenic noise impacts are a concern. Seven species of baleen whale have been reported in Hawaii: humpback whales, blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), Bryde's whales (*B. edeni*), sei whales (*B. borealis*), minke whales (*B. acutorostrata*), and North Pacific right whales (*Eubalaena japonica*). Except for Bryde's whales (n = 798, CV = 0.28) and minke whales (no abundance estimate for Hawaii), all baleen whale species/stocks found in Hawaii are listed under the ESA as "endangered," and therefore are automatically considered to be "depleted" and "strategic" under the MMPA (Caretta et al. 2014). Bryde's whales are considered 'data deficient' by the IUCN. The majority of baleen whales (except possibly Bryde's) migrate seasonally and are found in Hawaiian waters in winter months, when weather and sea conditions are typically prohibitive for aerial and vessel surveys in offshore/pelagic waters (Smultea et al. 2010). The most recent abundance estimates for blue whales (n = 81, CV = 1.14), fin whales (n = 58, CV = 1.12), and sei whales (n = 178, CV = 0.9) are based on summer/fall line-transect surveys in 2002 and 2010, and as such do not represent the period when most baleen whales are present in Hawaii (Bradford et al. 2013). Minimum density estimates exist for fin whales (0.027 calling fin whales per 1,000 square kilometers [km^2] near a hydrophone at 800 [m] depth near Kaneohe, Oahu; McDonald and Fox 1999) and minke whales (2.15 "boing"-calling minke whales per 1,000 km^2 off Kauai; Martin et al. 2013; 2.77-3.64 minke whales within 3,780 km^2 off Kauai; Martin et al. 2015) based on passive acoustic data recorded on fixed hydrophones, but these are not absolute estimates of abundance for the region. Humpback whale population size in Hawaii is estimated to be >10,000 animals and increasing at 5.5-6 percent per year (Allen and Angliss 2013, Calambokidis et al. 2008), and the central Pacific stock is currently under consideration for delisting from the ESA. For all other baleen whale species in Hawaii, there are insufficient data to evaluate trends in abundance.

Sperm whales are deep divers, for which anthropogenic noise is a habitat concern. Sperm whales are commonly seen throughout the Hawaiian EEZ, frequently at depths > 3,000 m (Baird et al. 2013b) but also in nearshore waters of the MHI and NWHI (Barlow 2006, Bradford et al. 2013). In addition, sperm whale sounds have been recorded throughout the year off Oahu (Thompson and Friedl 1982). The best currently available abundance estimate for Hawaii sperm whales is 3,354 (CV = 0.34), and there are insufficient data to evaluate trends in abundance (Bradford et al. 2013). Sperm whales are formally listed as endangered under the ESA, and consequently the Hawaiian stock is automatically considered to be "depleted" and "strategic" under the MMPA.

Delphinidae is the most diverse cetacean family represented in Hawaii, with 12 documented species, and it comprises the most frequently encountered species in Navy operational areas. Most delphinid populations found in the MHI are not considered endangered, threatened, or depleted, with the exception of the insular MHI stock of false killer whales (*Pseudorca crassidens*), which shows evidence of decline in the past 2 decades (minimum abundance = 129) (Caretta et al. 2014). Abundance and trends are not known for the NWHI insular stock or pelagic stock of false killer whales. During small-vessel surveys in the MHI in 2000 through 2012, the most commonly encountered species in depths > 3,000 m were rough-toothed dolphins (*Steno bredanensis*), pantropical spotted dolphins (*Stenella attenuata*), and striped dolphins (*Stenella coeruleoalba*) (Baird et al. 2013b). In depths < 2,000 m, the most commonly sighted species were short-finned pilot whales (*Globicephala macrorhynchus*)(n = 12,422, CV = 0.43), pantropical spotted dolphins, common bottlenose dolphins (*Tursiops truncatus*) (minimum population estimate for this species around Kauai/Niihau = 168) (Carretta et al. 2014), and rough-toothed dolphins (Baird et al. 2013b). Spinner dolphins (*Stenella longirostris*) were also most frequently encountered in shallow water and in known resting habitats. Evidence exists for insular and pelagic stocks of spinner dolphins, bottlenose dolphins, and short-finned pilot whales (Caretta et al. 2014). Uncommon to rare species include Risso's dolphins (*Grampus griseus*), comprising < 1 percent of all odontocete sightings in leeward surveys of the MHI from 2000 to 2012, Fraser's dolphin (*Lagenodelphis hosei)*, pygmy killer whales (*Feresa attenuata*), and killer whales (*Orcinus orca*) (Baird et al. 2013b). Aside from those cited here, current abundance estimates or assessment of population trends are not available for most delphinid species in the Hawaiian islands region (Carretta et al. 2014).

Two additional odontocete species are found in Hawaii, pygmy sperm whales (*Kogia breviceps*) and dwarf sperm whales (*Kogia sima*) (both in the family Kogiidae). Pygmy sperm whales have been observed in nearshore waters off Oahu, Maui, Niihau, and Hawaii Island (Baird 2005, Baird et al. 2013b, Mobley et al. 2000, Shallenberger 1981). Small-vessel surveys within the MHI conducted since 2002 have documented dwarf sperm whales on 73 occasions, most commonly in water depths between 500 m and 1,000 m (Baird et al. 2013b). However, data are insufficient for estimating the abundance or population trends for these species.

Although vessel-based survey efforts in Hawaiian waters have provided a wealth of data on species occurrence, behavior, and movements, they are constrained by time, logistics, weather conditions, and other factors associated with vessel platforms. Large-scale line-transect surveys are infrequent and limited by logistics and weather; these have been conducted only twice since 2000 throughout the Hawaiian archipelago's U.S. EEZ, in 2002 and 2010, and took place in the summer/fall months. These surveys provide infrequent 'snapshots' and because of their seasonal timing, they preclude collection of reliable data for some species, such as baleen whales, which are present in Hawaiian waters primarily in winter and spring months. In addition, cryptic or deep-diving species may not be readily detectable or available at the surface, and may be considered rare or have insufficient data to estimate abundance/trends. Sightings may also be misidentified or rare due to predominantly rough weather and sea states offshore of the

Hawaii islands (Smultea et al. 2010). Small-vessel surveys conducted in the MHI since 2000 have focused more than 70 percent of survey efforts on waters off the island of Hawaii (Big Island), have been targeted mainly towards small cetaceans and odontocetes, and have generally been limited by weather to leeward and relatively nearshore waters. Consequently, results from visual surveys are likely not fully representative of species occurrence and habitat use in all regions within Hawaii, or of pelagic/migratory species such as large baleen whales.

In 2011, U.S. Pacific Fleet initiated a long-term passive acoustic monitoring (PAM) program to better understand the year-round occurrence of cetaceans and their potential response to MFAS in the HRC. HDR, Inc. subcontracted the Hawaii Institute of Marine Biology (HIMB), Oceanwide Science Institute (OSI), and Bio-waves, Inc. to collect and analyze data from four ecological acoustic recorders (EARs) deployed in portions of the HRC between July 2011 and February 2013. Manual analyses and automated algorithms were used to detect and classify cetacean signals and MFAS events. The results of these efforts are presented in this report in order to address the following eight monitoring questions that have been formulated by the U.S. Navy, in collaboration with the primary investigators:

Q1a. What species of beaked whales (*Ziphius/Mesoplodon*) are in the region surrounding Niihau and Kaula Islands in the HRC?

Q1b. Do beaked whale detection rates vary before, during, and after mid-frequency active sonar (MFAS) detections?

Q2a. What is the seasonal occurrence of baleen whales near Niihau and Kaula Islands in HRC?

Q2b. Do baleen whale detection rates vary before, during, and after MFAS detections?

Q3a. What is the occurrence of sperm whales near Niihau and Kaula Islands in the HRC?

Q3b. Do sperm whale detection rates vary before, during, and after MFAS detections?

Q4a. What species of delphinids occur near Niihau and Kaula Islands in the HRC?

Q4b. Do delphinid detection rates vary before, during, and after MFAS detections?

2. Methods

2.1 EAR Deployments

Acoustic data were obtained using bottom-moored EARs (**Figure 1**). The EAR is a microprocessor-based autonomous recorder that samples the ambient sound field on a programmable duty cycle (Lammers et al. 2008). Three deployments of four EARs were made during the data collection period, which spanned between 27 July 2011 and 15 February 2013. Three of the EARs were deployed in waters off the island of Niihau and labeled ‘NW Niihau’, ‘SW Niihau’ and ‘Pueo Point’ (**Figure 2**). One EAR was deployed near Kaula Island, approximately 19 nautical miles SW of Niihau, and was labeled ‘Kaula.’ The four EARs were deployed in water depths ranging between 526 m and 791 m (**Table 1**) using acoustic releases (ORE Edge Tech PORT LF) and approximately 80 kilograms of anchoring weight. During the first and second deployments, three of the four EARs were programmed to sample at a rate of 80 kilohertz (kHz) on a recording duty cycle of 30 seconds ‘on’ every 5 minutes, providing a Nyquist bandwidth of approximately 40 kHz (see **Table 1** for EAR programming and deployment specifics). The Kaula EAR and all EARs during the third deployment were programmed to record on a recording duty cycle of 30 seconds ‘on’ every 10 minutes in order to extend the deployment duration.

The first deployment of the four EARs was in July 2011 and the recording duration of instruments ranged from 96 to 183 days (**Table 1**). The second deployment of three of the four EARs took place in January 2012. The recording durations during this deployment varied between 95 and 100 days. No re-deployment was made at Kaula in January 2012 due to logistical constraints. The final deployment period began in April 2012 for the Kaula EAR and in late July 2012 for the other three EARs. The recording durations during this period varied between 20 and 208 days. Both the Kaula EAR and the SW Niihau EAR stopped recording prematurely due to a malfunction with the recorder’s hard disk drive. The final EAR deployment at Kaula is hereafter grouped into "deployment 2" due to temporal overlap with the second deployment of the other three EARs.

2.2 Analysis Methods

2.2.1 Automated Detection: Baleen5 and M3R CS-SVM

2.2.1.1 BALEEN WHALES

The 'Baleen5' program, developed by Dr. Helen Ou at HIMB, is a MATLAB (TM) algorithm containing automated call detectors for five species of baleen whales: minke, fin, blue, humpback and sei whales. Baleen5 was implemented in this study to detect and classify calls from minke, fin, blue and humpback whales within HRC deployments 1 and 2 (July–December 2011 and January–May 2012). Sei whale calls were not considered as part of this analysis because there is presently uncertainty regarding the characteristics of their calls in the north Pacific (Rankin and Barlow 2007) and therefore the performance of the detector, which was trained on sei whale calls from the Atlantic Ocean, was not considered reliable. Bio-Waves, Inc. performed a ground-truth analysis exercise of the Baleen5 output to independently evaluate the

Figure 1. Images of an EAR prior to deployment and while deployed.

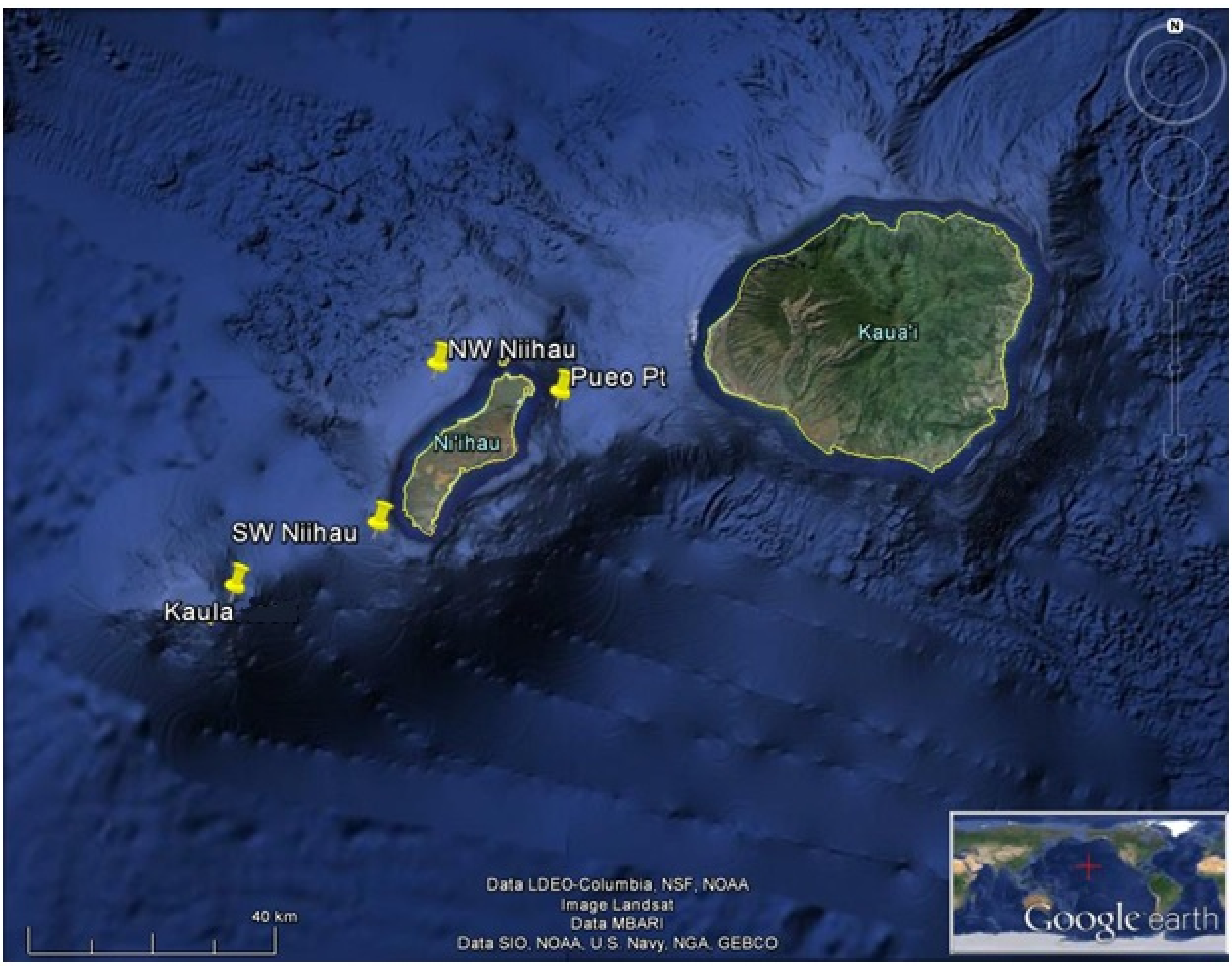


Figure 2. Map of EAR sites around the islands of Niihau and Kaula. Yellow pushpins denote EAR deployment sites.

Table 1. EAR deployment and recording information. Fs = sampling frequency, 'on time' = recording duration, 'interval' = time interval between scheduled recordings. Bold rows indicate deployments with different recording schedule.

Site	Lat/Lon	Depth (m)	Fs, on time, interval	Recording Dates	# of files	Hours Recorded
Pueo Point	21 57.315 N, 160 01.059 W	737	80 kHz, 30 s, 300 s	7/27/2011-11/2/2011	28330	236
Pueo Point	21 57.315 N, 160 01.059 W	740	80 kHz, 30 s, 300 s	1/27/2012-4/30/2012	27151	226
Pueo Point	**21 57.315 N, 160 01.068 W**	**736**	**80 kHz, 30 s, 600 s**	**7/22/2012-2/14/2013**	**29902**	**249**
NW Niihau	21 59.614 N, 160 12.171 W	526	80 kHz, 30 s, 300 s	7/27/2011-11/2/2011	28330	236
NW Niihau	21.59.614 N, 160.12.171 W	527	80 kHz, 30 s, 300 s	1/27/2012-5/5/2012	28575	238
NW Niihau	**21 59.611 N, 160 12.184 W**	**580**	**80 kHz, 30 s, 600 s**	**7/22/2012-2/7/2013**	**28873**	**240**
SW Niihau	21 46.176 N, 160 17.557 W	766	80 kHz, 30 s, 300 s	7/27/2011-11/1/2011	27824	232
SW Niihau	21.46.176 N, 160.17.557 W	791	80 kHz, 30 s, 300 s	1/27/2012-5/4/2012	28367	236
SW Niihau	**21 46.181 N, 160 17.570 W**	**790**	**80 kHz, 30 s, 600 s**	**7/22/2012-12/13/2012**	**20830**	**174**
Kaula	**21 40.827 N, 160 30.644 W**	**538**	**80 kHz, 30 s, 600 s**	**7/02/2011-12/31/2011**	**26144**	**218**
Kaula	**21 40.852 N, 160 30.626 W**	**577**	**80 kHz, 30 s, 600 s**	**4/26/2012-5/15/2012**	**2894**	**24**
TOTAL				1347 days	277220	2309

algorithm’s performance and to inform the interpretation of the results. The characteristics of the Baleen5 detectors as well as the methods and results of the ground-truth exercise are described in **Appendix A**.

2.2.2 Beaked whales and sperm whales

The Marine Mammals Monitoring on Navy Ranges (M3R) system's class-specific support vector machine (CS-SVM) was implemented to detect and classify clicks in recordings from the EAR deployments in the HRC. The characteristics of the M3R system are described in Jarvis et al. (2014). Bio-Waves, Inc. performed a ground-truth analysis exercise of the CS-SVM output for deployments 1 and 2 for sperm whales, Cuvier’s and Blainville’s beaked whales, to independently evaluate the detector’s performance and to inform the interpretation of the results. The methods and results of this ground-truth exercise are described in detail in **Appendix A**.

2.2.3 Re-interpretation of M3R-SVM results

The initial interpretations of the M3R CS-SVM outputs for the first two deployment periods were based on a click-by-click interpretation of the results. In other words, if the algorithm classified individual clicks as belonging to a particular species, that species was interpreted as being present in the recording. However, the ground-truth analysis performed by Bio-Waves, Inc. for beaked and sperm whales using this click-by-click approach (i.e., examining each individual click detection to label it as true or false) showed that all beaked whale detections made using the approach were false and that there were no missed detections; in addition, performance of the detector was unexpectedly poor for sperm whales (**Appendix A**). Following the original ground-truth analysis by Bio-Waves, Inc. discussions were held with the developer of the M3R CS-SVM detector (S. Jarvis) about the proper approach for interpreting the detector's output. It was noted that when CS-SVM is operated during real-time cetacean monitoring efforts on naval ranges, output is continuous and detections are interpreted in the context of surrounding detections and classifications. For example, when a click train produced by beaked or sperm whales is present, there should be numerous detections of that species in the recording and the classifier should predominantly attribute clicks to that species when plotted versus time (e.g., **Figure 3a**). When the CS-SVM detector is confronted with an unknown class, it will produce detections that are scattered/distributed among several classes without a clear preponderance of one class (**Figure 3b**). If there are only a few clicks classified as a species, or if clicks in a file are classified as many different species, this is likely a sign of misclassification (**Figure 4**). It was concluded that interpreting the results for EAR data on a click-by-click basis is problematic and classification results should instead be viewed in the context of the surrounding history of classifications for a given time period.

Bio-Waves, Inc. conducted a re-evaluation of the M3R CS-SVM results for all three deployments using a two-stage method. First, the classifications for each 30-second recording were compiled into a table that shows the percentage of clicks assigned to each species in that recording (**Table 2**). Next, an iterative approach was used to determine the thresholds for the minimum number of clicks required per file and percentage of single-species CS-SVM classifications per file in order to maximize precision and recall. Precision and recall are metrics used to evaluate a detector's performance in terms of exactness and completeness, respectively (described further in **Appendix A**).

Recordings (or acoustic 'files') to review were chosen for sperm whales, Cuvier's beaked whales, Blainville's beaked whales, and 'mixed beaked whales' (combined detections for both Cuvier's and Blainville's beaked whales). Initially, only files with five or more M3R CS-SVM click detections and at least 70 percent of clicks attributed to the species/group of interest were selected to be ground-truthed during this effort. Due to the limited sample size of files with greater than five clicks for beaked whales this criterion was eliminated for beaked whales but retained for sperm whales. Bio-Waves manually examined at least 50 files per species/group that met these criteria for a total of 249 additional files examined during this effort. In addition, during the OSI manual analysis of the third deployment, 96 of the files with CS-SVM detections were examined for sperm whale signals and included in the re-evaluation of the CS-SVM sperm whale detector. Analysts logged whether the file contained true positives or false positives; for false positives, the actual source of the signals was determined when possible. Missed signals (false negatives) produced by target species were noted opportunistically within the entire subset of files that were manually examined, including those that were examined during the original ground-truth analysis (**Appendix A**). The true positives, false positives, and missed detection values were then used to calculate precision (a measure of exactness, or the proportion of detections that were true detections) and recall (a measure of completeness, or the proportion of signals that were detected) values for the species of interest.

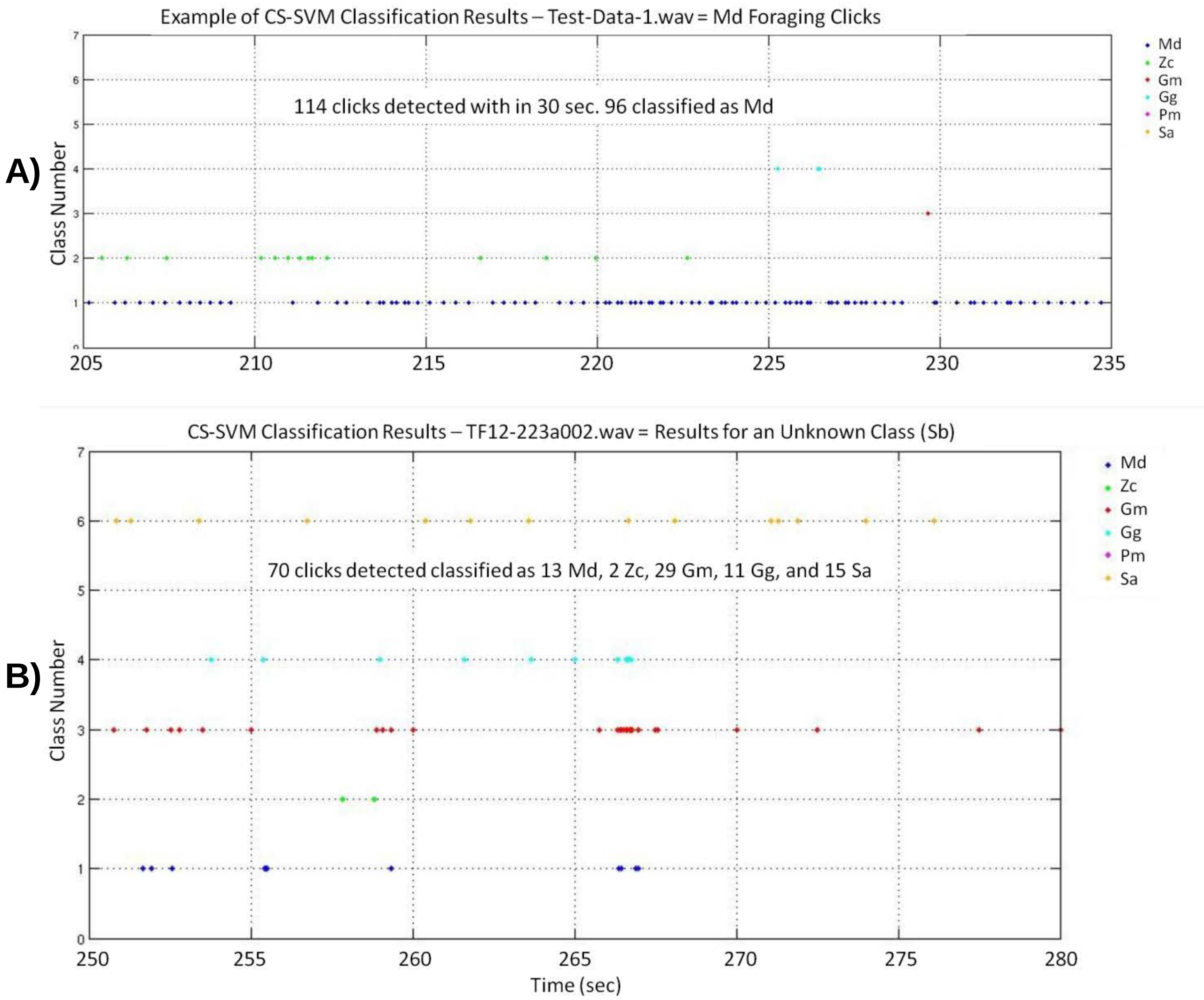
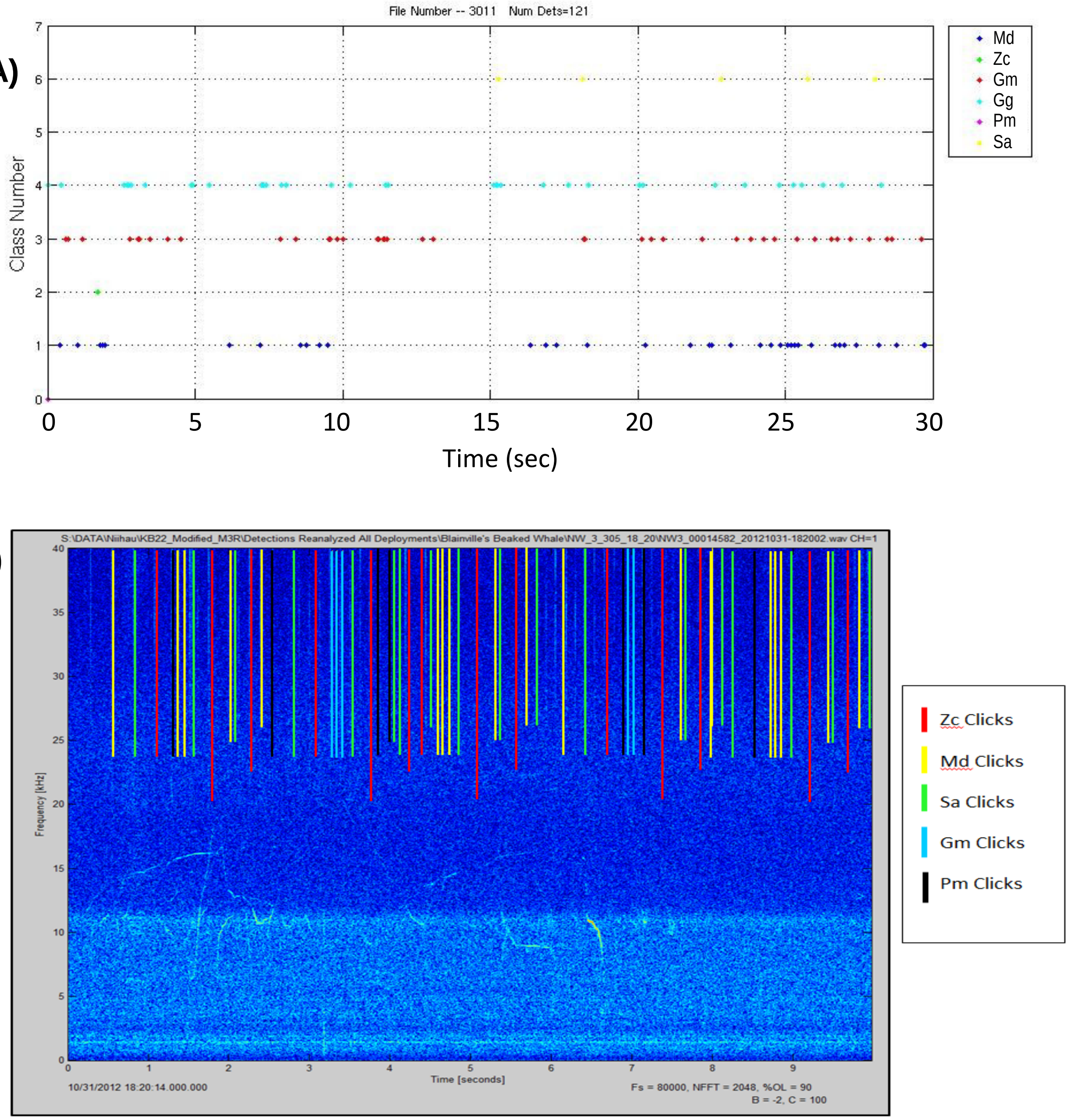


Figure 3. A) Example M3R CS-SVM classification results from a Naval range hydrophone (not from EARs described in this study) showing the presence of Blainville's beaked whales within a 30-second segment. Each dot represents an individual automated click detection. Clicks classified as different species are represented by different class numbers (y-axis) and colors. B) 30-second segment of classifier output for a recording of rough-toothed dolphin (an unknown to the CS-SVM) provided by Aran Mooney of Woods Hole Oceanographic Institute. The 70 clicks automatically detected within the 30-second window are assigned to 5 of the CS-SVM's 6 classes with no definitive click train evident for any species. Figures provided by S. Jarvis.

A)



B)

Figure 4. Examples of CS-SVM classifier output for two different EAR files, this study, with A) detections within each class plotted with time and B) a spectrogram showing clicks color-coded by CS-SVM classification. In these two files, detections are distributed among several classes. Tonal contours between 5 kHz and 20 kHz are delphinid whistles and are not relevant to the CS-SVM classifier.

Table 2. Example subset of files with M3R CS-SVM detections, showing the percentage of automatically detected clicks classified as each species by the CS-SVM classifier and the total number of automatically detected clicks in each file. File ID is the file name assigned by Bio-Waves for individual 30 second sound files recorded by the EAR. Gg = Risso's dolphin (*Grampus griseus*), Gm = short-finned pilot whale (*Globicephala macrorynchus*), Md = Blainville's beaked whale (*Mesoplodon densirostris*), Pm = sperm whale (*Physeter macrocephalus*), Zc = Cuvier's beaked whale (*Ziphius cavirostris*).

File ID	Gg	Gm	Md	Pm	Sa	Zc	Number of Clicks
184_18_40		84%		7%		9%	68
184_20_10	3%	90%	1%	4%		3%	134
185_6_40	22%	67%				11%	54
186_9_0		76%	1%			23%	71
186_9_50		76%	4%	9%		11%	55
186_10_0	3%	87%	2%	2%		5%	230
186_10_10		87%			8%	5%	79
186_22_40	24%	59%		10%		8%	51
189_19_30	6%	72%	6%		8%	8%	71

True negatives (files that were correctly labeled by the automated detector as not being produced by the target species, e.g., less than 70 percent of clicks attributed to target species and/or no detection of the target species) were also tabulated during this analysis to provide a measure of specificity, where specificity provides a measure of correct rejection (True Negative/(True Negative + False Positive). A specificity value of 1.00 indicates that the detector correctly rejects all signals not produced by the target species.

To examine the relationship between the percentage of clicks classified as a particular species and correct classification of files, Bio-Waves plotted true and false detections (in this case, "detection" = file containing the signal(s) in question) for each species/group for files that met the 70 percent classification threshold, with the number of automated click detections within the file on the x-axis and the percentage of clicks classified as that species/group on the y-axis. Examination of the plots and experimentation with different threshold criteria revealed that increasing the number of clicks or required percentage of classified clicks resulted in inadequate sample sizes, and decreasing the required percentage of clicks classified as the species of interest did not significantly improve the results. Therefore, the 70 percent classification threshold (for beaked and sperm whales) and five-click minimum (for sperm whales only) was used to calculate precision and recall and to evaluate performance of the sperm whale and beaked whale classifiers.

2.2.4 ROCCA

All data from the three deployments were analyzed visually/manually (see **Section 2.2.7**, Manual Analysis: deployment 3) to detect delphinid acoustic encounters (hereafter referred to as "encounters"). Files containing delphinid signals that occurred within 30 minutes of one another were considered to be part of the same encounter. An encounter could consist of a single file if no additional files containing delphinid signals were found within 30 minutes before or 30 minutes after the file.

Delphinid encounter logs and acoustic recordings were sent to Bio-Waves for whistle measurement and classification analysis. Only encounters that contained at least two files and at least 10 whistles with a minimum of 3 decibels of signal-to-noise ratio were included in the analyses. If an encounter contained more than 50 whistles, a custom algorithm in R software (Version 2.15; The R Foundation for Statistical Computing 2012) was used to randomly select 50 whistles for analysis. Whistle contours were then extracted, measured and classified using the Real-time Call Classification Algorithm (ROCCA), a whistle classification module in the acoustic data processing software platform, PAMGuard (Gillespie et al. 2008, Oswald et al. 2013). Time-frequency contours were extracted from whistles by using a computer touch-pad to trace contours on ROCCA's spectrographic display. ROCCA was used to automatically measure 50 variables from each extracted contour. These variables included duration, frequency measurements (e.g., minimum, maximum, beginning, ending, and at various points along the whistle), slopes, and variables describing shape of the whistles (e.g., number of inflection points and steps; see Barkley et al. 2011 for a complete list and description of variables measured).

When whistle contours had been extracted and measured, ROCCA's random-forest classifier was used to automatically identify individual whistles and delphinid acoustic encounters to species. A random forest is a predictive model containing a collection of decision trees grown using binary partitioning of the data. Each binary partition of the data is based on the value of one feature (in this case, a whistle feature; Breiman 2001). The goal for each split is to divide the data into two nodes, each as homogeneous as possible (i.e., containing whistles from the smallest number of species possible). Randomness is introduced into the tree-growing process by examining a random subsample of all of the features at each node. The feature that produces the most homogeneous split is chosen at each partition. When whistle features are analyzed using a random forest, each of the trees in the forest produces a species classification. Classifications are then tallied over all trees and the whistle is classified as the species that received the highest proportion of classifications. In addition to classifying individual whistles, delphinid acoustic encounters were classified based on the number of tree classifications for each species, summed over all of the whistles that were analyzed for that encounter.

The random forest classifier used to analyze the EAR data was a two-stage model that was trained using whistles recorded in the tropical Pacific Ocean. All recordings included in the training dataset were recorded from single-species schools that had visual confirmation of species identity and were at least 3 nautical miles from any other visual or acoustic detection of whistling species. Seven species were included in the model: short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), pantropical spotted dolphins (*Stenella attenuata*), bottlenose dolphins (*Tursiops truncatus*), rough-toothed dolphins (*Steno bredanensis*), striped dolphins (*Stenella coeruleoalba*), and spinner dolphins (*Stenella longirostris*). The first stage of the model classified whistles to one of two categories: 'large delphinids-Steno' (including false killer whales, pilot whales and rough-toothed dolphins) and '*Stenella-Tursiops*' (including spinner, spotted, striped and bottlenose dolphins). In stage two of the model, whistles within each category were classified to species or species-group (**Figure 5)**.

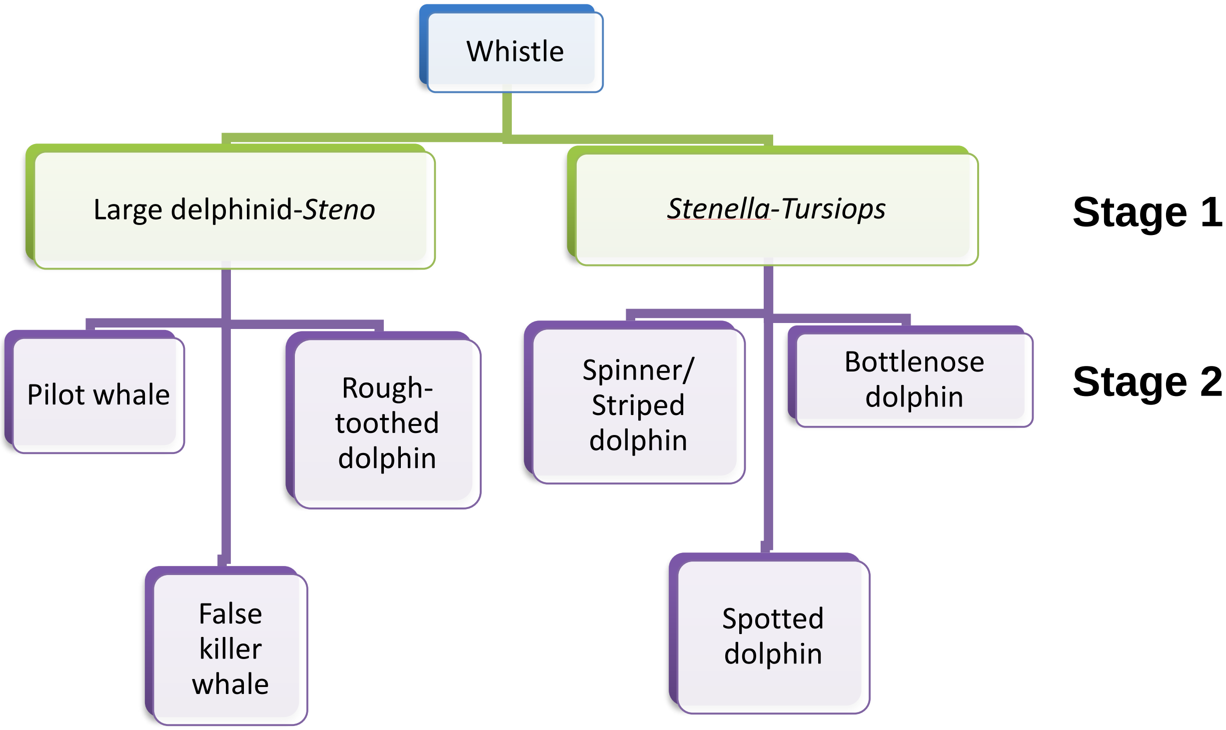


Figure 5. Schematic diagram of the two-stage random forest classifier. In stage one, whistles are classified to one of two broad categories ('large delphinid-'*Steno*' or '*Stenella-Tursiops*'). In stage two, whistles within each category are classified to individual species or species-group.

Striped and spinner dolphins were combined into one species-group due to low correct classification scores in the training dataset when these species were considered separately.

To create the random forest classifier, data were first sub-sampled so that there were equal sample sizes for each species or species-group. This prevented whistle measurements from any one species from dominating the data and skewing the classification results. Two-fold cross-validation was used to test the performance of the model. To accomplish this, the test dataset was randomly divided into two subsets of data, with whistles from the same encounter kept together in the same dataset. One dataset was used to train the model, while the other was used to test the model. The datasets were then swapped so that each was used as both a training and a testing set. This procedure was repeated 10 times. Classification success was evaluated by examining the average percent of encounters that were correctly classified for each species and comparing that to the classification score that would be expected by chance alone (17 percent; **Table 3**). Overall 61 percent (standard deviation = 10 percent) of encounters were correctly classified in the training dataset. All correct classification scores were significantly greater than expected by chance (Fisher's exact test, $\alpha = 0.05$).

Table 3. Confusion matrix for the two-stage classifier used to classify whistles recorded with the Niihau EARs. The percent of encounters correctly classified for each species is in bold, with standard deviations in parentheses. The number of encounters and total number of whistles in the testing and training dataset are given for each species.

Actual species	Percent classified as						n encounters	n whistles
	Pilot whale	False killer whale	Spotted dolphin	Rough-toothed dolphin	Spinner/ striped dolphin	Bottlenose dolphin		
Pilot whale	**44** (16)	35 (14)	5 (8)	7 (8)	7 (9)	2 (5)	12	109
False killer whale	11 (11)	**88** (24)	0 (0)	1 (5)	0 (0)	0 (0)	9	309
Spotted dolphin	0(0)	5 (6)	**50** (15)	0 (0)	24 (10)	21 (8)	18	204
Rough-toothed dolphin	1 (5)	11 (11)	0 (0)	**71** (13)	17 (5)	0 (0)	12	145
Spinner/striped dolphin	0 (0)	1 (2)	8 (4)	11 (4)	**68** (8)	12 (4)	51	204
Bottlenose dolphin	0 (0)	0 (0)	9 (12)	23 (14)	22 (11)	**46** (15)	8	155

When acoustic encounters had been identified to species or species-group, the number of acoustic encounters per day was calculated overall and by species for each EAR and deployment. For species with sufficient sample sizes, the average number of acoustic encounters was calculated for each hour of the day.

2.2.5 Triton (manual) Analysis

2.2.5.1 DEPLOYMENTS 1 AND 2 (MFAS, SPERM WHALES AND BALEEN WHALES)

OSI visually/manually searched all data from deployments 1 and 2 for MFAS occurrence using the MATLAB^{TM} software package, Triton, developed at Scripps Institution of Oceanography (Wiggins 2007) and adapted for use with EAR data. Triton was used to create long-term spectral averages (LTSAs) of the recordings. An LTSA is a composite spectrogram made up of Fourier transforms averaged over user-defined frequency and time bins. It provides a coarse-resolution visual representation of the acoustic energy distribution in frequency and time, and its compressed nature allows an analyst to rapidly scan the dataset and to identify periods of possible signals of interest. For this analysis, an LTSA was produced for each EAR dataset with 20-Hertz frequency bins and 10-second time bins. Analysts searched for MFAS by browsing the LTSA and verifying MFAS pings aurally and visually in the raw spectrogram (**Figure 6**). Duration of MFAS events was calculated by considering files with pings no more than 2 hours apart part of the same event; these events were summed on a daily basis to give the duration of MFAS per day.

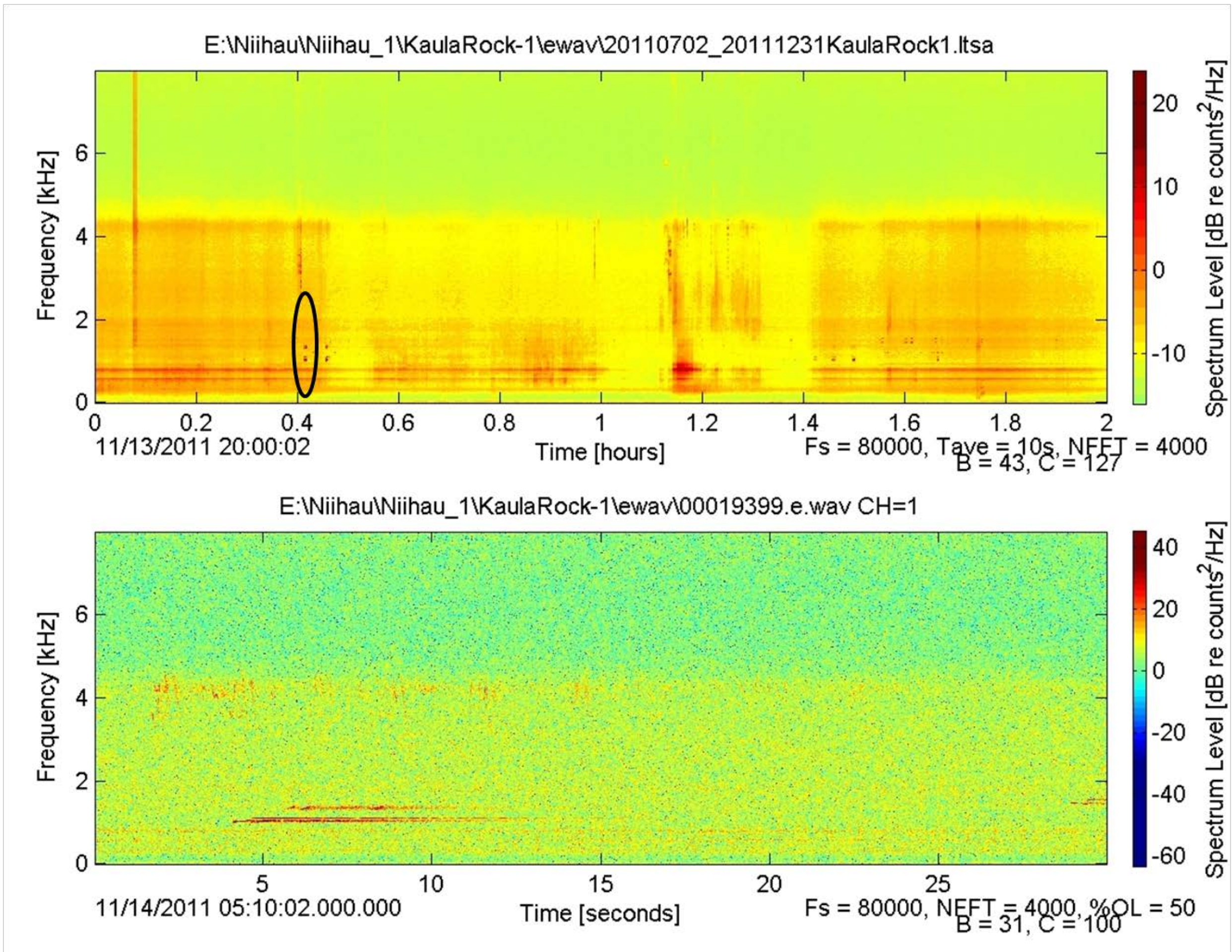


Figure 6. Example LTSA and expanded spectrogram of MFAS ping

OSI manually searched around all MFAS events within deployments 1 and 2 for sperm whale clicks and baleen whale calls for one week before, during (i.e., the day[s] of MFAS), and one week after each event. An analyst visually browsed spectrograms of each file and confirmed potential sperm whale clicks or baleen whale calls. Sperm whale clicks are distinctive because of their low frequency relative to other odontocete clicks (Madsen et al. 2002; Møhl et al. 2003). For baleen whale detection, data were filtered and downsampled using the 'decimate' function in MATLAB (TM) to an effective bandwidth of 5 kHz prior to searching. Available baleen whale call types for logging were blue whale, fin whale, humpback whale, minke whale boing (Rankin and Barlow 2005), sei whale, and fin/sei. The latter category was used for signals that where intermediary between fin and sei whale downsweep calls. Each logged call was rated either "definite" or "possible" based on the certainty of the analyst; possible and questionable detections (including all fin/sei detections and any detections outside of typical baleen whale occurrence months) were reviewed by an experienced baleen whale acoustician (L. Munger) and re-rated or re-classified if confident. See **Appendix A** for further description of sperm whale clicks and baleen whale calls.

2.2.5.2 DEPLOYMENT 3 (MFAS, SPERM WHALES, BALEEN WHALES & DELPHINIDS)

Within the third deployment, OSI performed a thorough manual analysis of the entire dataset for delphinid and sperm whale signals, as well as MFAS and baleen whale calls before, during and after MFAS events as described in previous section. Signals (delphinid whistles/clicks, sperm whale clicks, or MFAS pings) were detected by visually examining the full-bandwidth LTSA for the presence of transient occurrences of tonal and broadband acoustic energy that are potentially indicative of whistles (or MFAS) and clicks, respectively. Signals identified in the LTSA display were then verified by examining the corresponding high-resolution spectrogram of the original 30-second recording (1,000–1,400 point Fast Fourier Transform, Hanning window, 50-75 percent overlap, depending on time segment and frequency band being examined). A spectrogram displays the frequency content of a signal (vertical axis) as a function of time (horizontal axis) with a gray or color scale to designate the intensity of the time-varying features of frequency.

As in the first two deployments, files containing delphinid signals that occurred within 30 minutes of one another were considered to be part of the same encounter (see **2.2.4**, first paragraph). Four categories of delphinid encounters were logged. One category was for encounters with clicks (broadband pulses) only, and the remaining three categories were for encounters containing whistles: low-frequency (LF) whistles with most energy below 10 kHz, high-frequency (HF) whistles with most energy greater than 10 kHz, and HF & LF, which indicates both types of whistles within a single 30-second recording and/or whistles with equal energy spanning above and below 10 kHz. Research on delphinid whistle characteristics has shown that these frequency bands loosely correspond to body size of animals, with smaller species producing higher frequencies and larger species producing lower frequency sounds (Wang et al. 1995; Azzolin et al. 2014). Logged encounters were passed on to Bio-Waves for classification of whistles using ROCCA.

In addition, the third deployment was decimated and searched for baleen whale calls one week before, during (days of), and one week after MFAS events as described in **Section 2.2.5.1**.

2.3 Analysis: Before and After MFAS

2.3.1 Selection of MFAS Exposure Periods

MFAS exposure periods were selected for statistical analyses based on the following criteria: 1) a baseline occurrence period of at least 10 days with no other sonar detections prior to MFAS onset, and 2) MFAS detected for multiple hours over at least 2 consecutive days at the EAR site. These criteria were adopted in order to (a) ensure a proper baseline representation of species occurrence prior to MFAS exposure and (b) to avoid grouping short MFAS events with longer ones and thereby potentially confounding the results. Six multi-day MFAS periods met these criteria, four of which were detected at two EARs concurrently, for a total of 10 MFAS exposure ‘trials’ that could be analyzed. We considered detection on each instrument an independent 'trial' because odontocete signals could only be detected on one instrument at a time (i.e., EARs were not spaced closely enough to have overlapping detections of odontocetes).

2.3.2 Delphinids and MFAS

For all three deployments, the encounter rate (encounters/site-day) and mean encounter duration were determined for pooled data, then for data stratified by ROCCA species class (all deployments) or manually-classified signal group (deployment 3 only). The potential influence of

MFAS on delphinid acoustic occurrence was investigated by examining these metrics within the periods of 3 days before, during, and 3 days after each MFAS exposure period. The ‘during’ period was defined to include an entire 24-hour day within which MFAS was detected (e.g., if MFAS was detected from 1130 to 1500, the entire calendar day from 0000 to 2359 was defined as "during"). This approach was chosen to account for the fact that the EARs recorded on a duty cycle, so it was not possible to establish the exact start and stop times of MFAS occurrence in the area. The ‘before’ and ‘after’ periods were defined as starting the calendar day before or after the first/last day with MFAS, respectively (e.g., the ‘3 days before’ period would contain 11/11/2011 00:00 through 11/13/2011 23:59 for a ‘during’ period beginning on 11/14/2011 00:00). Periods longer than 3 days were not initially considered because it was assumed that any differences tied to MFAS would be greatest shortly before and after the exposure period.

Analyses were conducted first for pooled delphinid encounters (including unidentified delphinid encounters) across MFAS exposure trials. Mean encounter rates and mean encounter durations within the 3 days before, during, and 3 days after periods were compared using ANOVA and considering each MFAS trial (i.e., each individual exposure period on an individual EAR) a sampling unit. Subsequent analyses were conducted for each ROCCA or manually-identified species/signal group with sufficient sample sizes, pooled across MFAS exposure periods. Encounter rates were analyzed for the 3 days before, during, and 3 days after periods associated with MFAS using the Chi-square statistic. The "expected" values in the Chi-squared table were calculated assuming an equal probability of detection within each time period, i.e., by dividing the total number of encounters across the three time periods by total number of site-days of recording. This average detection rate was applied to each of the three time periods (3 days before, during, and 3 days after) to obtain the expected number of encounters within a given time period. Encounter durations within the 3 days before, during, and 3 days after periods were compared using ANOVA. Encounter rates for each species were also analyzed per MFAS exposure period if sufficient sample size was available for a given exposure period.

2.3.3 Sperm whales and Baleen whales relative to MFAS

For all three deployments, the occurrence of sperm whale clicks and baleen whale calls was quantified for the period 7 days before, during, and 7 days after MFAS exposure periods. The 7-day period was used because of low detection rates for these taxa. For sperm whales, the daily number of encounters (as defined above) was established and the sum of the encounter durations for each day was calculated. These were then compared among periods. For baleen whales, the percentage of daily recordings containing the calls of detected species was calculated and compared among periods.

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3. Results

3.1 MFAS Occurrence

MFAS was detected on all sites and in all deployments. The EAR site with the greatest total duration of detected MFAS events was Pueo Point (216 hours), followed by NW Niihau (174 hours), Kaula (39 hours), then SW Niihau (30 hours) (**Table 4**) despite the longer recording/deployment period at SW Niihau compared to Kaula (see **Table 1**). By month, the most days with MFAS were detected in July and August of both 2011 and 2012; however, only one of these MFAS events in mid-August 2012 was preceded by a sufficient 10-day baseline period to be included in the detailed analysis of MFAS exposure periods (**Figure 7**). Selected MFAS exposure periods occurred concurrently at NW Niihau and Pueo Point on four occasions (with no or few detections on the other sites totaling less than 1 hour); two other independent MFAS exposure periods were selected for analysis, one at Kaula and one at SW Niihau (**Table 5**). The majority of MFAS exposure periods (four of six temporally separate occasions) took place during the summer-fall timeframe, with two occurrences during the winter-spring timeframe (**Figure 7**).

Table 4. List of all MFAS events detected. Highlighted dates/sites were selected as exposure periods for detailed analyses of cetacean occurrence before, during, and after MFAS events.

Date	Sum of MFAS Duration (minutes)			
	Kaula	NW Niihau	Pueo Point	SW Niihau
7/24/2011	310.5			
7/29/2011			55.5	
7/30/2011	40.5		110.5	35.5
7/31/2011	10.5		25.5	25.5
8/1/2011			80.5	
8/2/2011	0.5	55.5	361	
8/10/2011		666.5	676.5	
8/11/2011	42	751.5	746.5	
8/12/2011	0.5	441.5	461.5	
9/23/2011			5.5	
10/5/2011	10.5	256	336.5	60.5
10/6/2011		85.5	85.5	
10/16/2011			20.5	
10/22/2011			5.5	
11/14/2011	311			
11/15/2011	1111			
11/16/2011	20.5			
12/6/2011	100.5			
2/15/2012		421	426	
2/16/2012		737	752	
2/17/2012		247.5	232.5	
4/6/2012		5.5		365.5
4/7/2012				560.5
5/10/2012	410.5			
7/23/2012		391	410.5	
7/25/2012			810.5	
7/26/2012		981	540.5	580.5
7/28/2012		781	1070.5	
7/29/2012		111	610.5	100.5

Date	Sum of MFAS Duration (minutes)			
	Kaula	**NW Niihau**	**Pueo Point**	**SW Niihau**
7/30/2012			30.5	50.5
8/2/2012		551	560.5	
8/4/2012			40.5	
8/15/2012		971	721	
8/16/2012		1371	1430.5	
8/17/2012		221	920.5	
8/28/2012			20.5	
10/17/2012		941	940.5	40.5
10/18/2012		461	360.5	
1/11/2013		1	50.5	
1/23/2013			40.5	
2/13/2013			10.5	
Total	**2368.5**	**10448.5**	**12951**	**1819.5**

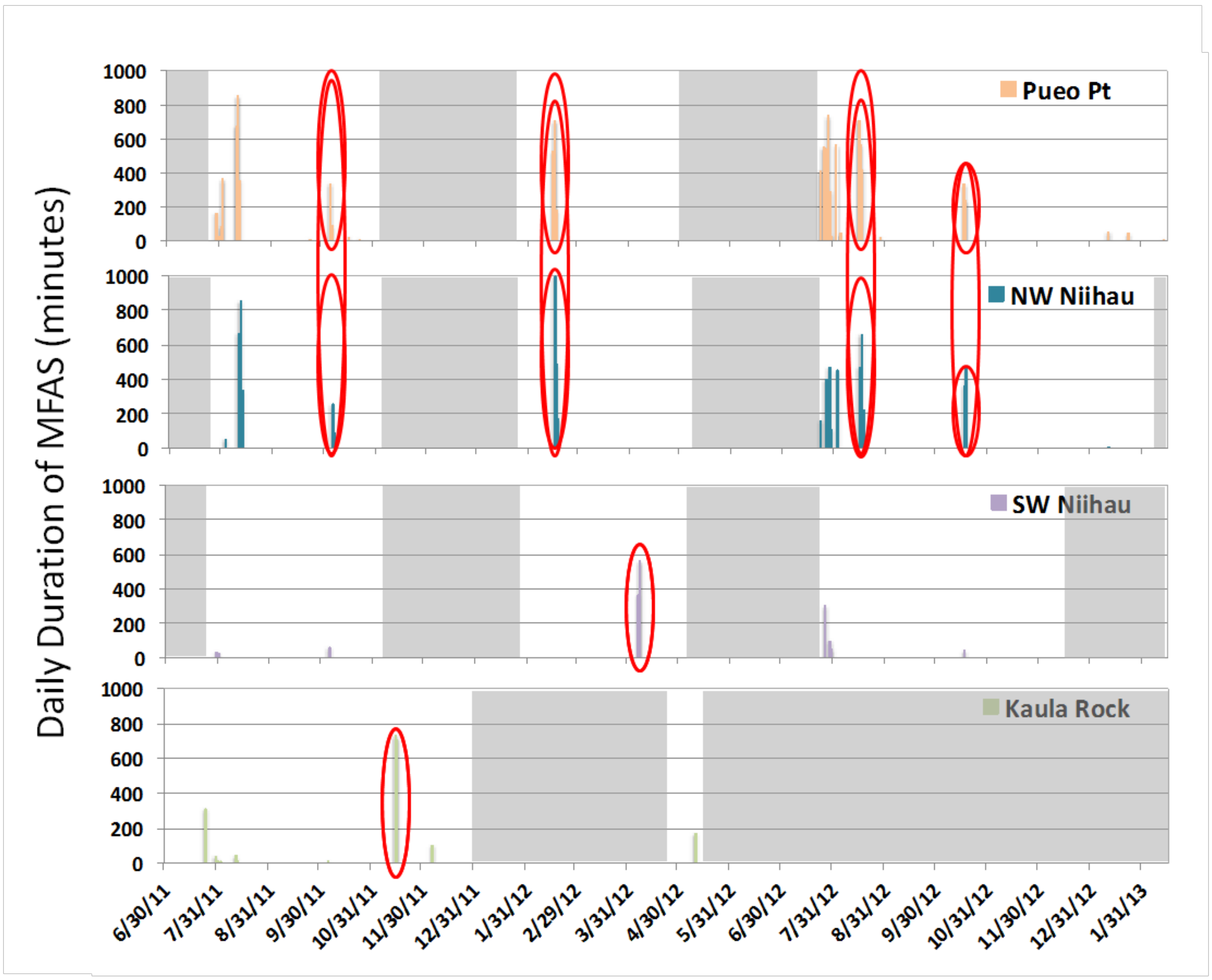


Figure 7. Timeline of MFAS occurrence, showing daily summed duration of MFAS by date. MFAS exposure periods that were selected for detailed analysis are circled in red. Note that some short-duration MFAS events are not visible at the scale of this plot. Grayed areas indicated times the EAR(s) was/were not recording or deployed.

Table 5. List of MFAS Exposure Periods and EAR sites included in analyses

MFAS event #	Dates	Sites
1	10/5/2011-10/6/2011	NWN, Pueo Pt
2	11/14/2011-11/16/2011	Kaula
3	2/15/2012-2/17/2012	NWN, Pueo Pt
4	4/6/2012-4/7/2012	SWN
5	8/15/2012-8/17/2012	NWN, Pueo Pt
6	10/17/2012-10/18/2012	NWN, Pueo Pt

3.2 Automated Detection and Validation of Beaked and Sperm Whale Clicks

M3R CS-SVM software produced odontocete detections (all species for which detector was trained; see **Appendix A**) within 9 percent of the files in the dataset (25,639 of 277,220 files total for all deployments). Of these, 15,902 contained at least one detection (i.e., a single click) classified as a beaked whale and 6,389 files contained at least one detection classified as a sperm whale. The performance of the detector was evaluated by Bio-Waves in a ground-truth study, presented in **Appendix A**. During this ground-truth study, a total of 1,013 files with beaked or sperm whale automated detections (within deployments 1 and 2 only) were checked manually, 1,662 files were searched to determine if missed signals were present in the two-hour periods around selected automated detections, and an additional 500 "blank" files (with no automated detections) were also searched for missed signals. Detections were individually examined using a click-by-click approach and showed that all beaked whale automated detections were false positives. There were no missed detections in the files examined. As a result, it was not possible to calculate precision or recall for either species of beaked whale. However, it was possible to calculate specificity by determining the number of true negatives for each species. A total of 30,665 true negative Blainville's beaked whale detections were identified, resulting in a specificity of 0.97 and a total of 23,554 true negative Cuvier's beaked whale detections were identified, resulting in a specificity of 0.95. Of the sperm whale detections that were reviewed manually during the original ground-truth analysis, 152 were found to be true positives, resulting in a precision of 0.2. A total of 4,537 missed sperm whale clicks were found, resulting in a recall of 0.03. A total of 42,716 true negatives were identified, resulting in a specificity of 0.93 (**Appendix A**).

Re-evaluation of CS-SVM results was conducted using per-file based criteria of at least five automatically detected clicks (sperm whales only) and at least 70 percent of clicks classified as the species class of interest (sperm whales and beaked whales). During this re-evaluation effort, an additional 249 files that met these revised interpretation criteria were examined manually, yielding 15 beaked whale detections that were true positives and 1 missed beaked whale detection (**Table 6**). Precision and recall of the CS-SVM beaked whale detector when applying the 70 percent classification criteria were 0.12 and 0.94, respectively (**Table 6**), meaning that 88 percent of reviewed files with automated detections were false positives and 94 percent of files containing beaked whale signals were detected and correctly classified. A total of 1,135 true negative files were identified, resulting in a specificity of 0.91, meaning that 91 percent of manually examined files without beaked whales were correctly classified as not containing beaked whale signals. When the five-click, 70 percent classification thresholds were applied, sperm whale precision and recall changed to 0.52 and 0.26, respectively (**Table 6**), indicating a true positive rate of 52 percent of automated detections (files) that were reviewed, and a missed detection rate of 74 percent. A total of 1,038 files were identified as true negatives, resulting in a specificity of 0.94. Different interpretation thresholds were evaluated; increasing the required percentage of clicks classified as the target species resulted in inadequate sample sizes and decreasing the required percentage of clicks did not significantly improve the results, and as such the more conservative value of 70 percent was used.

Table 6. Manually examined wav files that had ≥ 70 percent of clicks classified as the species of interest by the M3R CS-SVM classifier and contained 5 or more automatically detected clicks (sperm whales only). True Neg. = true negative.

M3R CS-SVM Species Classification	Ground-Truthed Files				Results		
	True	False	Missed	True Neg.	Precision	Recall	Specificity
Blainville's Beaked Whale	5	45	7	1208	**0.10**	**0.42**	**0.96**
Cuvier's Beaked Whale	3	66	1	1197	**0.04**	**0.75**	**0.95**
Beaked Whale (Mixed)	15	111	1	1135	**0.12**	**0.94**	**0.91**
Sperm Whale	67	62	191	1038	**0.52**	**0.26**	**0.94**

Due to the low number of beaked whale automated detections (1994 files that met the ≥70 percent classification criteria) and low precision of the detector (0.12 when applying the revised interpretation criteria), it is probable that only a very low percentage of the overall dataset (12 percent of 1,994 = 239 files of 277,222 files, totaling < 0.1 percent) contains potential beaked whale signals. This assertion would require additional manual review of automated detections to verify. Based on the automated detector output alone, it was not possible to draw meaningful inference about temporal or spatial patterns in beaked whale occurrence, nor to examine potential effects of MFAS on beaked whale detection rates.

The poor performance of the CS-SVM sperm whale detector was surprising given the distinctive time/frequency characteristics of sperm whale clicks compared to other odontocete signals. Improvements to the detector have been made since this study was begun, and in combination with some parameter adjustments, it is probable that the most recent version of CS-CVM would perform better and produce more useful results for sperm whales in EAR data.

3.3 Occurrence of manually verified sperm whale and beaked whale clicks

A total of 274 of the manually examined files contained clicks produced by sperm whales (258) and beaked whales (16). Of these, the highest number of sperm whale encounters occurred at NW Niihau (144), followed by Pueo Point (53), SW Niihau (44) and Kaula Island (17) (**Table 7; Figure 8**). Blainville’s beaked whales encounters occurred at predominantly at SW Niihau (7), followed by Kaula Island (3), NW Niihau (1) and Pueo Point (1) (**Table 7; Figure 8**). No diel or seasonal patterns were evident, possibly due to the small sample size of manually verified files with sperm whale and beaked whale encounters present.

Table 7. Manually verified sperm whale and beaked whale click occurrence by EAR site

Species	# Files by Site			
	NW Niihau	Pueo Point	SW Niihau	Kaula Island
Sperm whale	144	53	44	17
Blainville's beaked whale	1	1	7	3
Cuvier's beaked whale	2	1	0	1

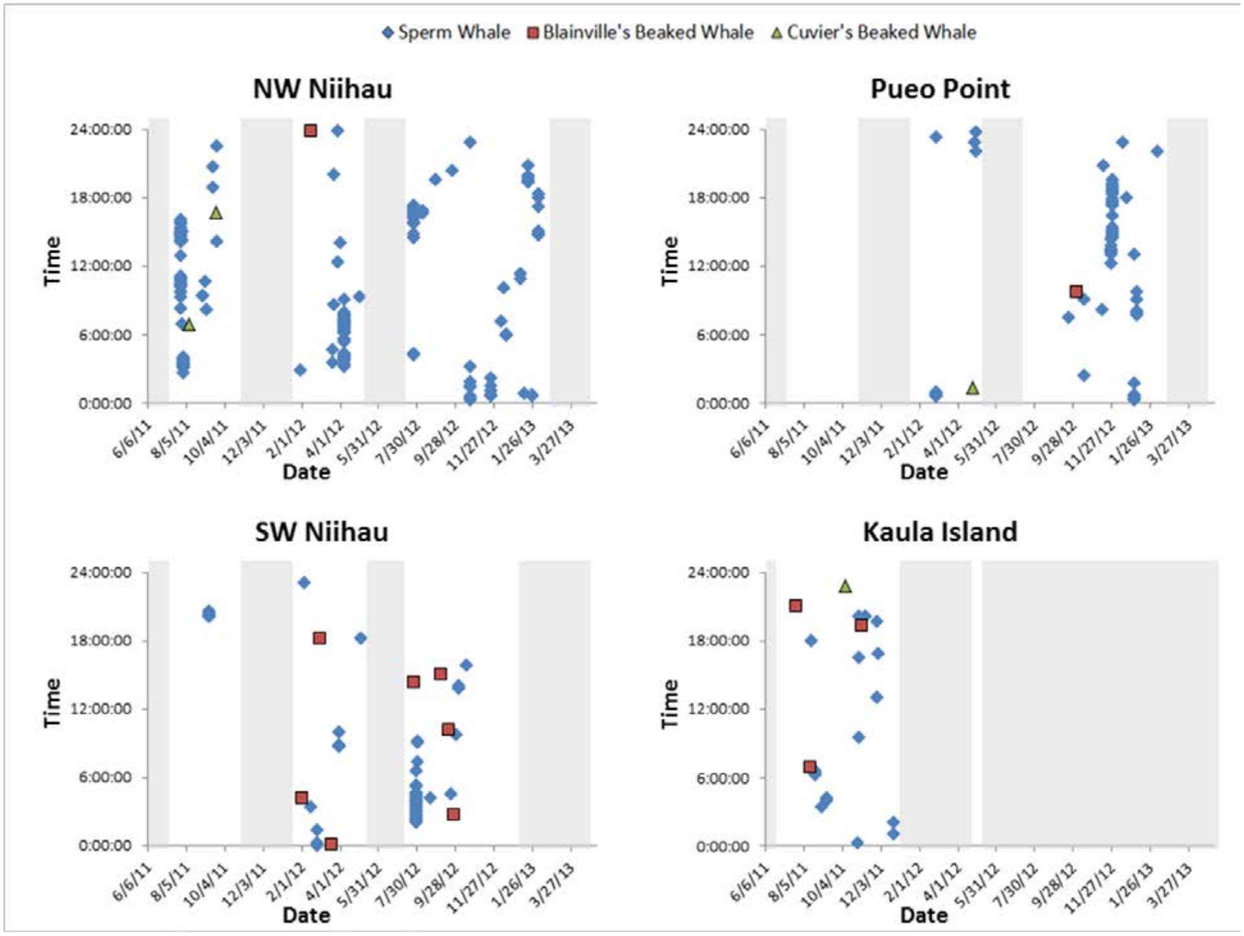


Figure 8. The presence of manually verified sperm whale (blue diamonds), Cuvier's (green triangles) and Blainville's (red squares) beaked whales are plotted for each EAR site with the date along the x-axis and the time of day along the y-axis. Grayed areas indicated times the EAR(s) was/were not recording or deployed.

3.4 Delphinids

3.4.1 Spatial and seasonal patterns – pooled

Delphinid encounters were manually detected at all sites throughout all deployments. Overall, the EAR site with the greatest amount of delphinid activity (as indicated by overall encounter rates, total duration/day, and mean encounter duration) was NW Niihau, followed by Pueo Point, then SW Niihau and lastly Kaula (**Table 8**). Dolphin activity (as indicated by mean total duration/day) was greatest for each site during either deployment 1 or 3, which encompassed mostly summer/fall months, compared to Deployment 2, which covered only winter/spring months. Pooled encounter rates (encounters/day) were 1.25-1.5 times greater during the summer/fall deployments than during winter/spring deployments at NW Niihau, Pueo Point, and Kaula (**Table 8**). Mean total duration per day was 2 to 5.5 times greater in summer/fall deployments than during winter/spring deployments across all sites.

Table 8. Overall delphinid encounter rates and durations by EAR site and deployment. Deployment 1 = summer/fall 2011; Deployment 2 = winter/spring 2012; Deployment 3 = primarily summer/fall 2012 (some winter recording into early 2013).

	Deployment	NW Niihau	Pueo Point	SW Niihau	Kaula
# dolphin encounters	1	538	348	366	397
	2	386	244	339	51
	3	776	800	347	NA
	Total	**1700**	**1392**	**1052**	**448**
Sum encounter duration (minutes)	1	16369	12064	22378	17448.5
	2	6133	3797	4689.5	365.5
	3	55838	44470	16233.5	NA
	Total	**78340**	**60331**	**43301**	**17814**
Total recording days	1	99	99	98	183
	2	100	95	99	20
	3	201	208	145	NA
	Total	**400**	**402**	**342**	**203**
Mean total duration/day	1	165	122	228	95.3
	2	61.3	40.0	47.4	18.3
	3	278	214	112	NA
	Overall	**196**	**150**	**127**	**87.8**
Mean encounter rate (enc/day)	1	5.4	3.5	3.7	2.2
	2	3.9	2.6	3.4	2.6
	3	3.9	3.8	2.4	NA
	Overall	**4.3**	**3.5**	**3.1**	**2.2**
Mean encounter duration (minutes)	1	30.4	34.7	61.1	44.0
	2	15.9	15.6	13.8	7.2
	3	72.0	55.6	46.8	NA
	Overall	**46.1**	**43.3**	**41.2**	**39.8**

The peak in delphinid activity, as indicated by the total amount of time delphinids were present (summed duration) by month at each site, was from August to November, with a minimum from February to March (**Figure 9a**). Although the mean encounter rate (encounters/day) each month did not decrease dramatically in winter/spring months (**Figure 9b**), this was compensated by longer encounter durations in summer/fall and shorter durations in winter/spring (**Figure 9c**), resulting in the overall strong seasonal pattern in the monthly summed duration of dolphin presence. Delphinid activity also varied inter-annually. At NW Niihau and Pueo Point, monthly summed duration of dolphin presence increased in summer/fall 2012 (deployment 3) relative to summer/fall 2011 (Deployment 1). However, at SW Niihau encounter rates and durations decreased in 2012 compared to 2011.

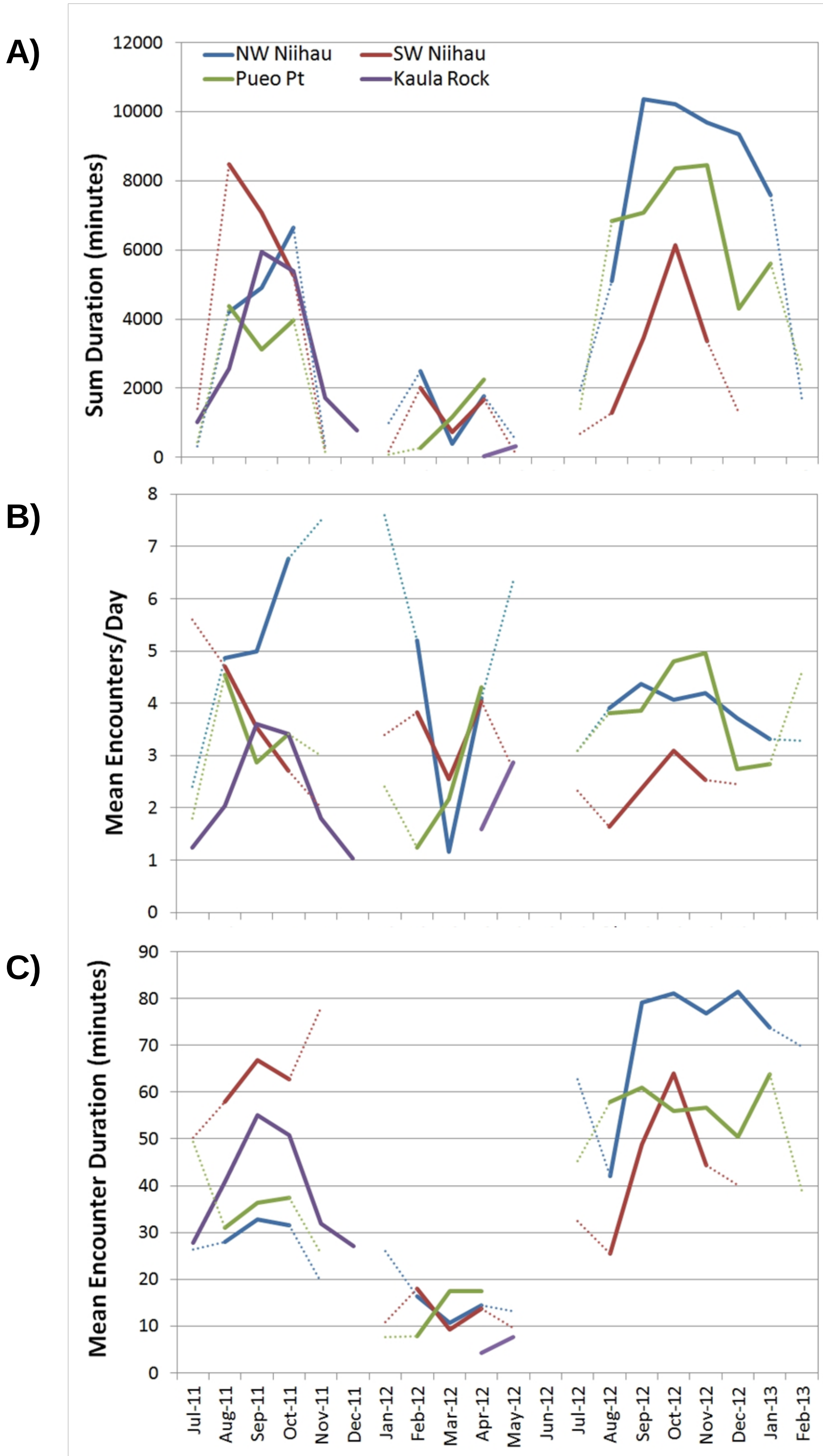


Figure 9. A) Monthly summed duration of all delphinid encounters, B) Mean number of encounters/day by month and C) Mean encounter duration by month for the three HRC deployments. Dotted lines indicate recording for less than half the month (≤ 14 days). Gaps in lines indicate periods with no recording.

3.4.2 Spatial and seasonal patterns – by species

The ROCCA algorithm classified 47 percent, 19 percent, and 32 percent of encounters within EAR deployments 1, 2, and 3, respectively (**Figure 10**). The greatest number of ROCCA classifications were spinner/striped dolphin, followed by bottlenose dolphin and rough-toothed dolphin (**Table 9**; **Figures 11 through 13**). A small number were classified as spotted dolphin, false killer whale, and pilot whale. All species were detected during deployments 1 and 3, but pilot whales and false killer whales were not detected during deployment 2 (**Figures 11 through 13**). Trends in species occurrence were similar within deployments, although some differences did occur among EAR sites.

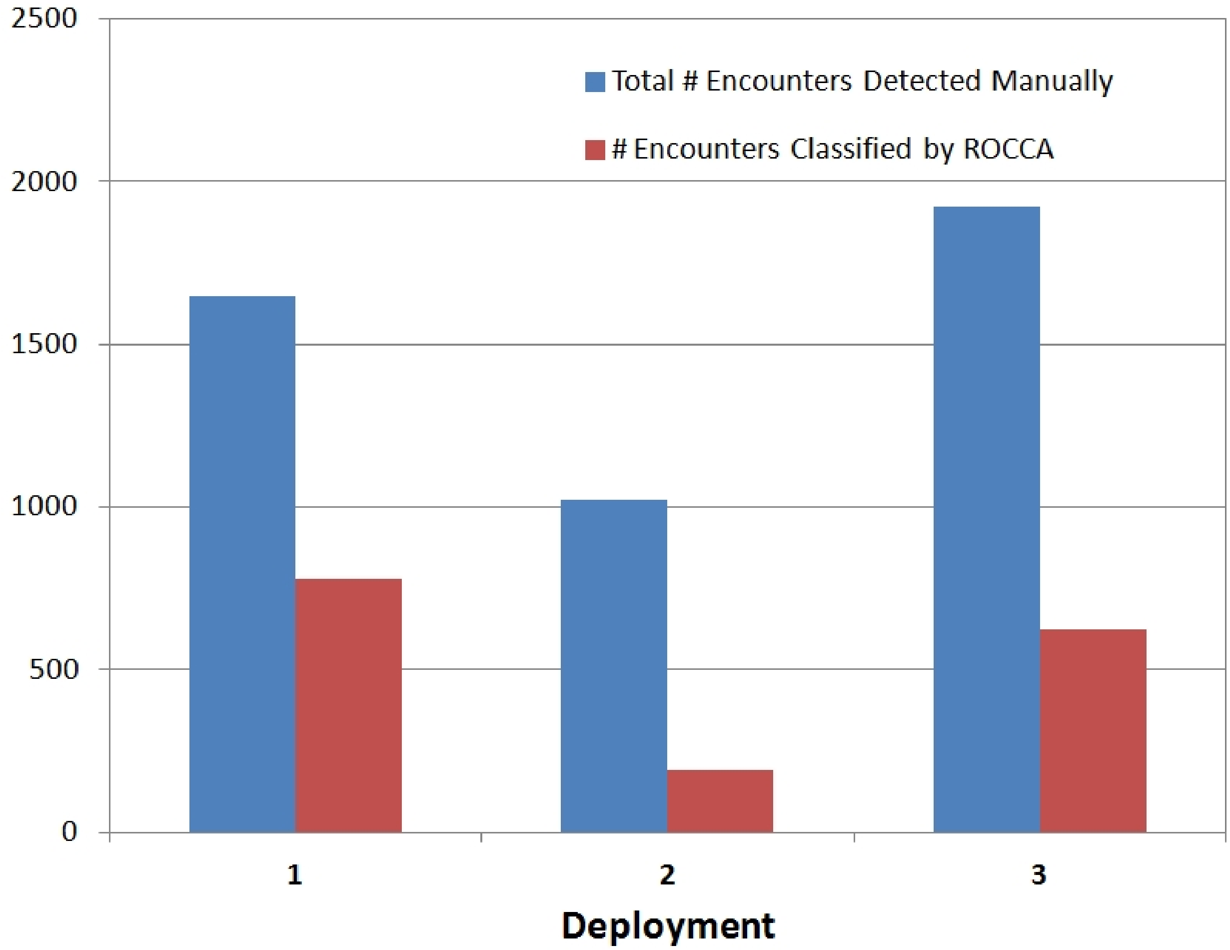


Figure 10. Total number of encounters detected manually (blue) within each deployment, and number encounters classified to species by ROCCA (red).

Table 9. Number of ROCCA-classified encounters per day by species, deployment and EAR site.

		NW Niihau	SW Niihau	Pueo Point	Kaula
Deployment 1	**Pilot whale**	0.02	0.05	0.00	0.01
	False killer whale	0.22	0.05	0.01	0.04
	Spotted dolphin	0.01	0.02	0.01	0.08
	Rough-toothed dolphin	0.54	0.06	0.07	0.13
	Spinner/striped dolphin	1.76	1.18	1.13	0.61
	Bottlenose dolphin	0.59	0.22	0.08	0.15
Deployment 2	**Pilot whale**	0.00	0.00	0.00	0.00
	False killer whale	0.00	0.00	0.00	0.00
	Spotted dolphin	0.00	0.01	0.01	0.00
	Rough-toothed dolphin	0.02	0.09	0.12	0.00
	Spinner/striped dolphin	0.73	0.45	0.24	0.10
	Bottlenose dolphin	0.07	0.12	0.04	0.00
Deployment 3	**Pilot whale**	0.01	0.12	0.02	n/a
	False killer whale	0.09	0.11	0.10	n/a
	Spotted dolphin	0.01	0.02	0.01	n/a
	Rough-toothed dolphin	0.09	0.19	0.13	n/a
	Spinner/striped dolphin	0.61	0.49	0.67	n/a
	Bottlenose dolphin	0.20	0.06	0.06	n/a

3.4.2.1 DEPLOYMENT 1

Spinner/striped dolphins made up well over half of the ROCCA-classified acoustic encounters (56 percent% at NW Niihau to 87 percent at Pueo Point) at every EAR and the average number of acoustic encounters per day was greater than one at every EAR except for Kaula Island. The next most common ROCCA-classified species were bottlenose dolphins and rough-toothed dolphins, although the percentage of acoustic encounters was much lower for those species at every EAR. Bottlenose dolphins made up 6–19 percent of encounters (Pueo Point and NW Niihau, respectively) and rough-toothed dolphins made up 4–17 percent of encounters (Niihau SW and NW Niihau, respectively). The number of acoustic encounters per day ranged from 0.59 to 0.08 for bottlenose dolphins and from 0.06 to 0.54 for rough-toothed dolphins. Spotted dolphins were most commonly detected at Kaula Island (14 percent of encounters, 0.08 acoustic encounters per day) and were rare at the other EAR sites (less than 1.5 percent of encounters, 0.01–0.02 acoustic encounters per day). False killer whales were most common at NW Niihau (7 percent of encounters, 0.22 acoustic encounters per day) and were rare at the other EAR sites (less than 4 percent of encounters, 0.01–0.05 acoustic encounters per day). Pilot whales were rare at all EAR sites (less than 3.5 percent of encounters, 0.01–0.05 acoustic encounters per day) and were not detected at all at Pueo Point (**Table 9, Figure 11**).

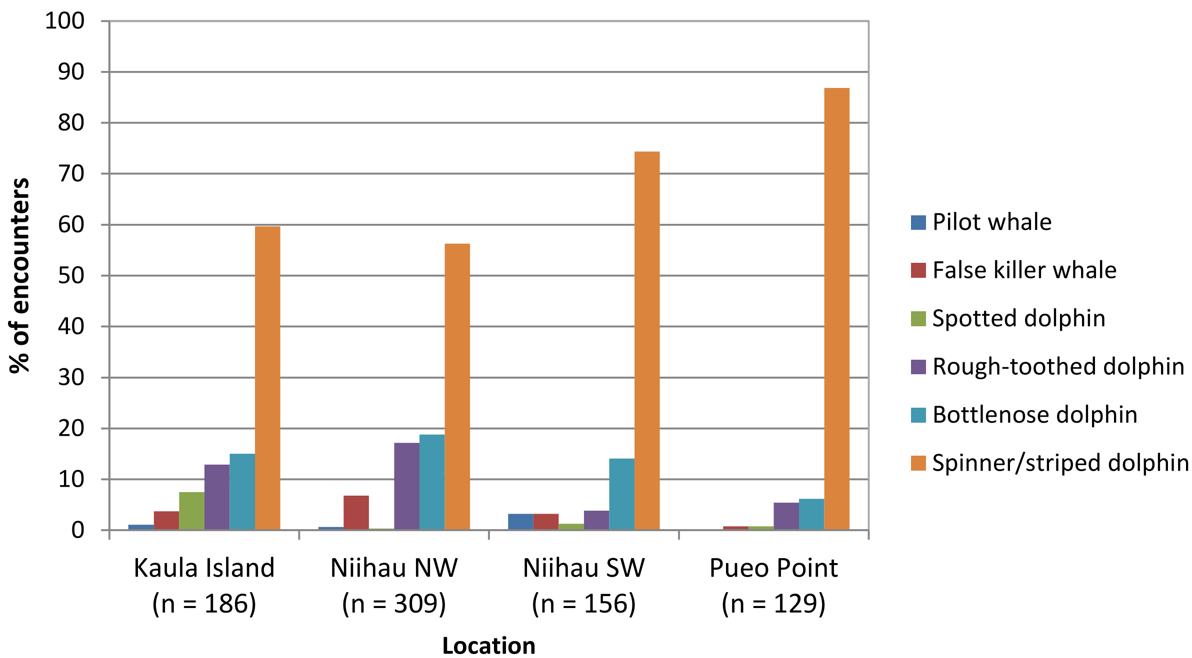


Figure 11. Percent of ROCCA-classified encounters comprised by each species for each EAR site in deployment 1. N = total number of ROCCA-classified encounters at each site.

3.4.2.2 DEPLOYMENT 2

Spinner/striped dolphins were the only species detected and classified by ROCCA at Kaula Island, and there were only two ROCCA-classified encounters during this 21-day deployment. Spinner/striped dolphins made up the majority of ROCCA-classified acoustic encounters at the other EAR sites, comprising 89 percent of encounters at NW Niihau and over half of encounters at SW Niihau and Pueo Point (67 percent and 59 percent, respectively). The number of acoustic encounters per day was relatively high for spinner/striped dolphins, ranging from 0.24 to 0.73 encounters per day. Bottlenose dolphins and rough-toothed dolphins were both most common at SW Niihau and Pueo Point, although they each comprised fewer than 30 percent of encounters at both sites. The number of acoustic encounters per day for bottlenose and rough-toothed dolphins was much lower than it was for spinner/striped dolphins, ranging from 0.04 to 0.12 for bottlenose dolphins and from 0.02 to 0.12 for rough-toothed dolphins. Spotted dolphins were not detected at NW Niihau or Kaula Island and were only detected once at both SW Niihau and Pueo Point. Pilot whales and false killer whales were not detected at any of the EAR sites during deployment 2 (**Table 9, Figure 12**).

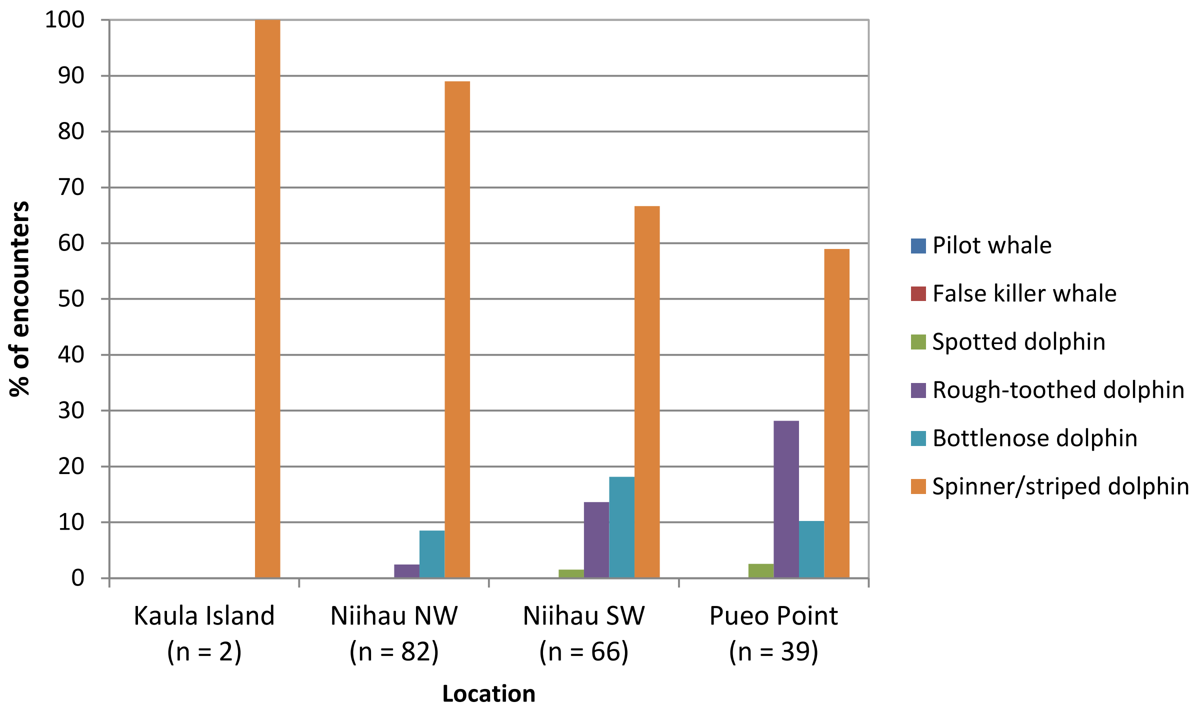


Figure 12. Percent of ROCCA-classified encounters comprised by each species for each EAR site in deployment 2. N = total number of ROCCA-classified encounters at each site.

3.4.2.3 DEPLOYMENT 3

Spinner/striped dolphins made up over 60 percent of ROCCA-classified encounters at NW Niihau and Pueo Point and almost 50 percent of encounters at SW Niihau. The number of acoustic encounters per day for spinner/striped dolphins was highest at Pueo Point (0.67) and lowest at SW Niihau (0.49). Rough-toothed dolphins were the second-most commonly detected species at SW Niihau (0.19 acoustic encounters per day) and Pueo Point (0.13 acoustic encounters per day) and bottlenose dolphins were the second-most commonly detected species at NW Niihau (0.2 acoustic encounters per day). False killer whales made up approximately 10 percent of acoustic encounters (0.09 – 0.11 acoustic encounters per day) at all three EAR sites. Pilot whales were most common at SW Niihau, making up 12 percent of encounters (0.12 acoustic encounters per day). Pilot whales were rare at NW Niihau and Pueo Point (0.01 and 0.02 acoustic encounters per day, respectively). Spotted dolphins made up approximately 1 percent of encounters at all three EAR sites and the number of acoustic encounters per day ranged from 0.01 to 0.02 (**Table 9, Figure 13**).

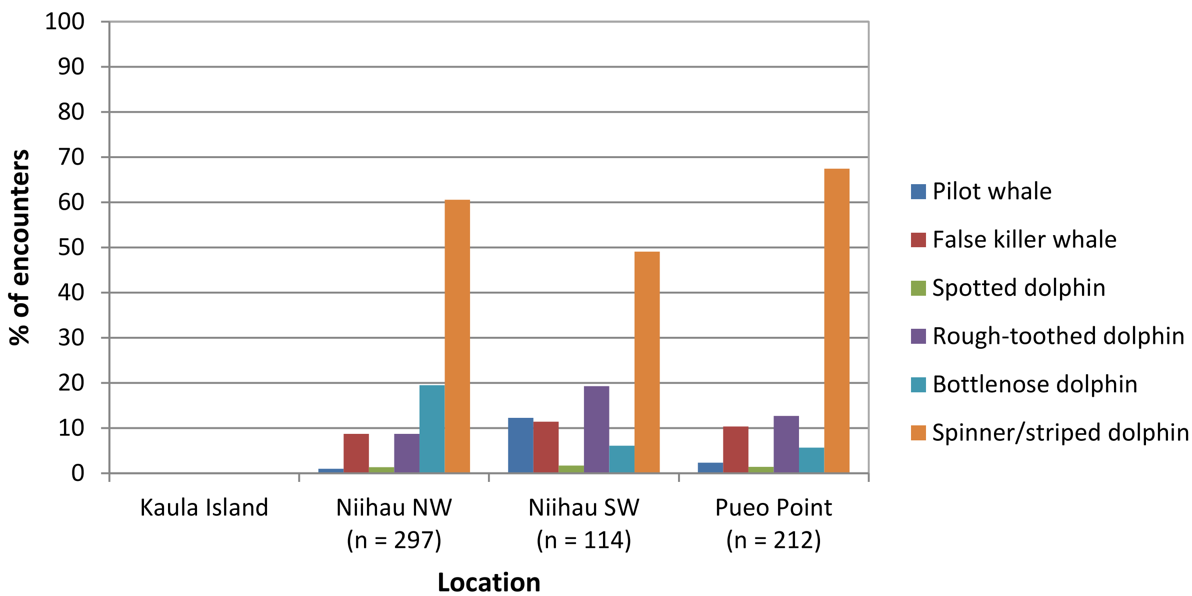
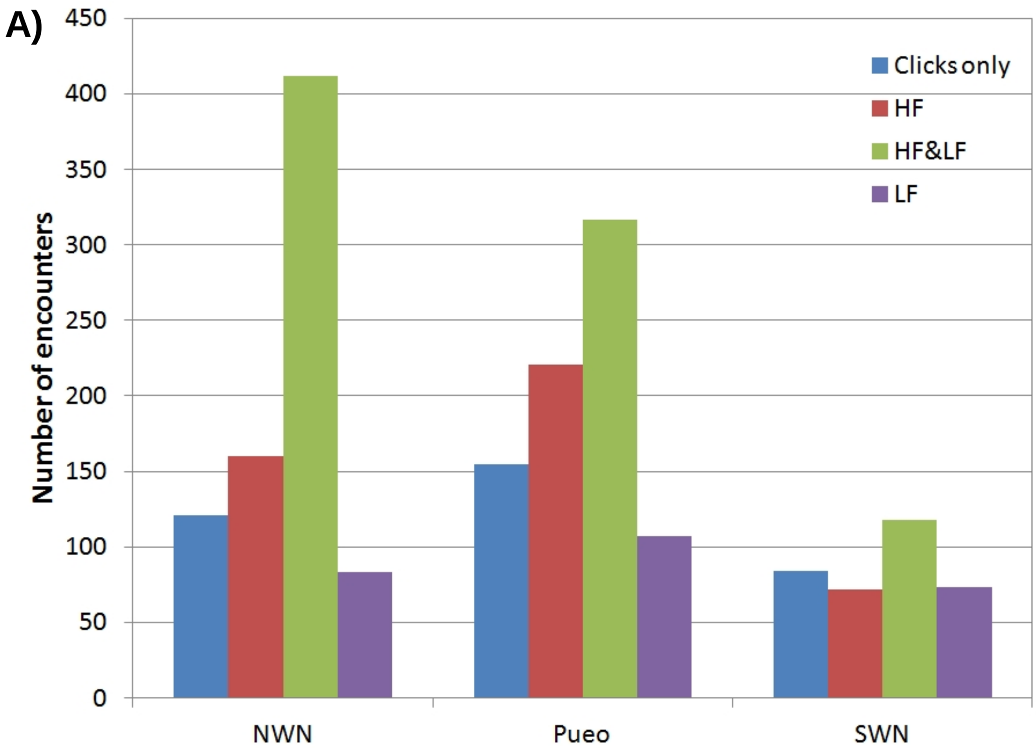


Figure 13. Percent of ROCCA-classified encounters comprised by each species for each EAR site in deployment 3. N = total number of ROCCA-classified encounters at each site.

From the OSI manual analysis of deployment 3, the most commonly classified encounter type at all sites was HF & LF whistles (including encounters with both clicks and whistles, as well as whistles only) (**Figure 14a**). The pattern in number of encounters was similar at NW Niihau and Pueo Point, where HF & LF encounters were the most common, followed by HF whistles, then Clicks Only and LF whistles (**Figure 14a**). The pattern in mean duration of encounters at NW Niihau and Pueo Point was also similar; HF & LF whistle encounters were longest in duration on average, followed by LF whistles, HF whistles, and lastly Clicks Only (**Figure 14b**). The pattern at SW Niihau was slightly different; HF & LF whistle encounters were still the most common, but the other three categories were only slightly lower in number of encounters and comparable to one another (between 72 and 85 encounters detected of each) (**Figure 14a**). At SW Niihau, the LF whistle encounters were slightly longer on average than HF & LF whistles, with HF whistle encounters somewhat shorter in duration and clicks only much shorter in duration (**Figure 14b**). Also of note are the short encounter durations for HF whistles and LF whistles at Pueo Point compared to the other two sites (**Figure 14b**).



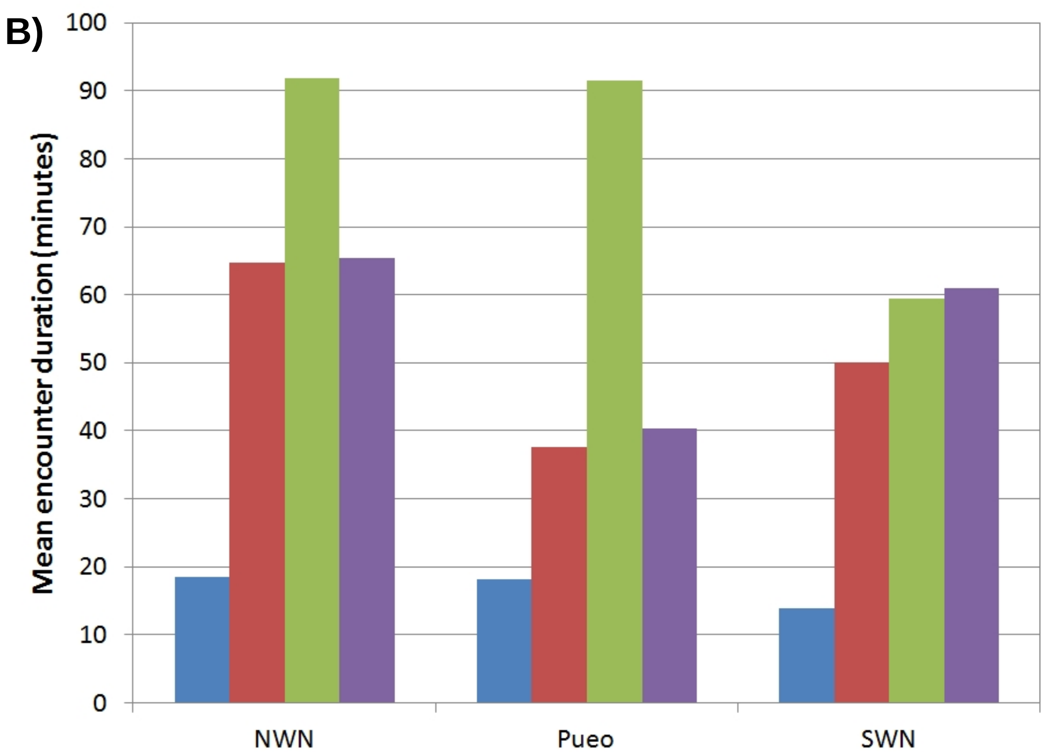


Figure 14. A) Number of encounters in each manually-classified signal group and B) mean encounter duration for encounters manually classified into clicks/whistle signal groups for deployment 3.

3.4.3 Diel patterns

Overall, there was a strong diel pattern in the number of pooled delphinid encounters (excluding those within 7 days following MFAS to rule out the potential effects of MFAS), with the greatest number of encounters occurring from 1700 to 0500, and fewest during the daytime hours 0600–1600 (**Figure 15**). Peak detection hours were between 0100 and 0400 and 1800-2100 depending on site. The higher encounter rates at night matches the pattern for encounters classified by ROCCA as spinner/striped dolphins (**Figure 16**), which were the majority of ROCCA-identified encounters.

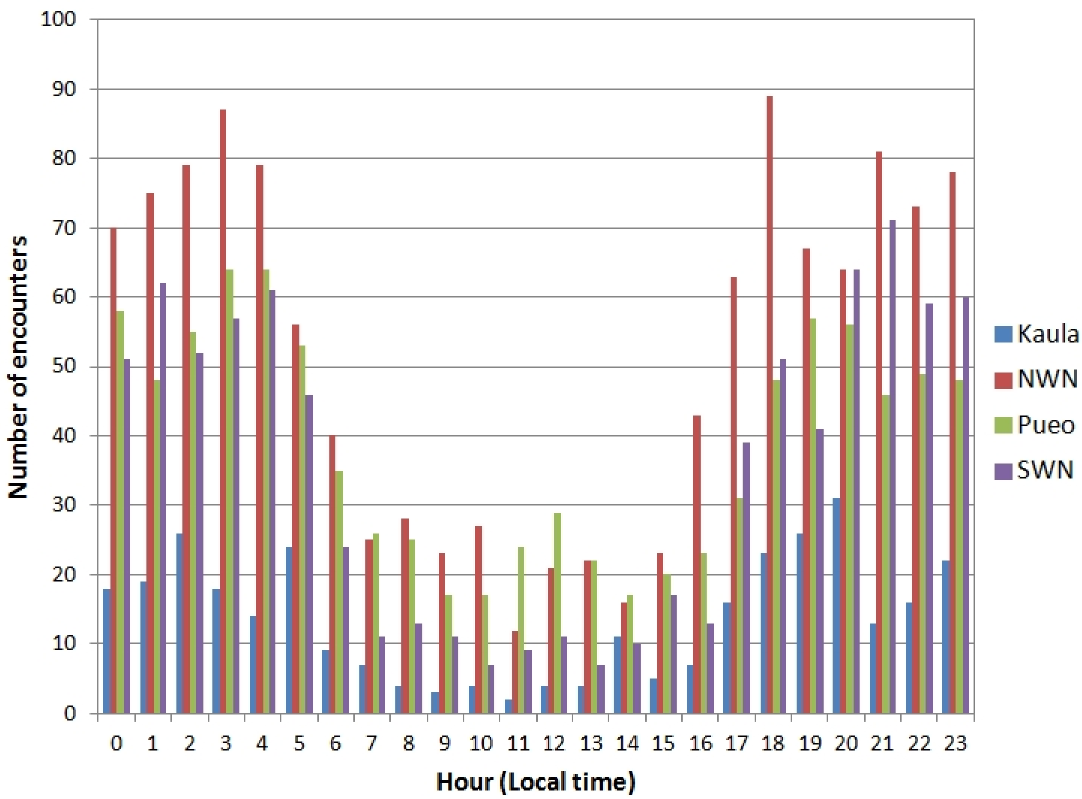


Figure 15. Number of delphinid encounters excluding those within 7 days after MFAS, by hour of day, for all deployments.

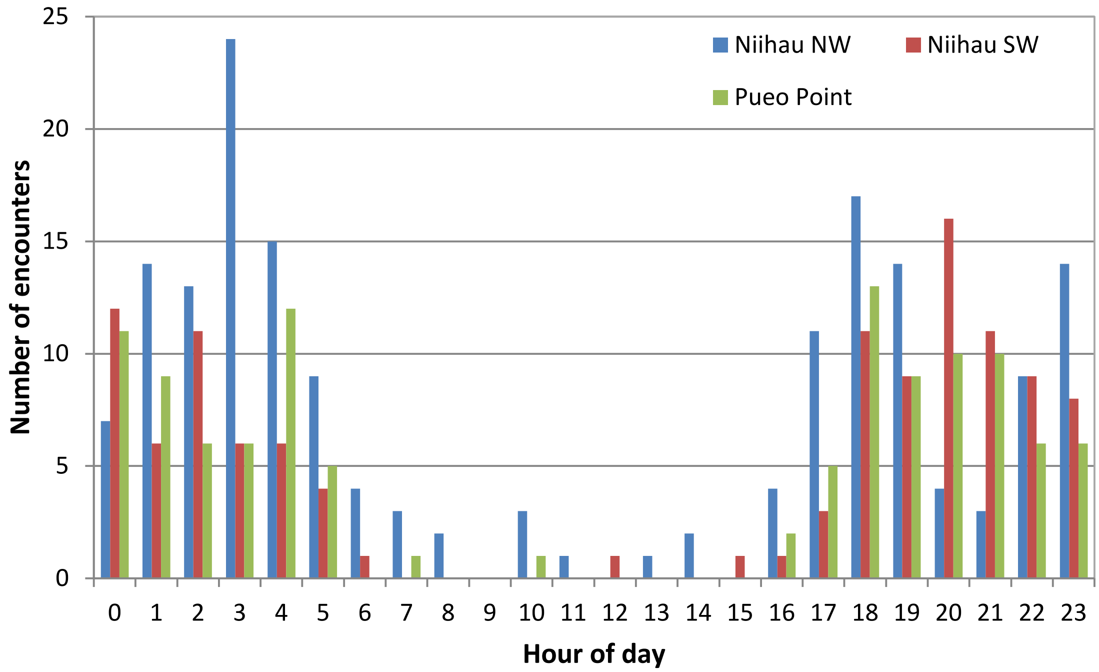


Figure 16. Number of encounters by hour of the day for spinner/striped dolphins at NW Niihau (blue, n = 174 encounters), SW Niihau (red, n = 116 encounters) and Pueo Point (green, n = 112 encounters). Because patterns were similar among deployments, only deployment 1 is shown here.

To examine diel patterns in the occurrence of ROCCA-classified species, the number of encounters per hour was plotted by hour of the day for each EAR and deployment. This analysis was only possible for spinner/striped dolphins, bottlenose dolphins and rough-toothed dolphins because of insufficient sample sizes for the other species. Spinner/striped dolphins showed a distinct diel pattern during all three deployments at NW Niihau, SW Niihau and Pueo Point (**Figure 16**). At these sites, there were very few acoustic encounters during the day. The number of encounters started to increase to a peak after sunset at all three EAR sites, with another peak evident before sunrise at NW Niihau and Pueo Point. This pattern was quite different at Kaula. At this site, acoustic encounters occurred in the early morning until about mid-day, with no encounters during the afternoon and evening (**Figure 17**). Acoustic encounters of bottlenose dolphins did not exhibit any defined diel pattern at NW Niihau during deployments 1 and 3, the only datasets with sufficient sample size for analysis (**Figure 18**). Acoustic encounters of rough-toothed dolphins were relatively constant during the day and night, with a slight peak in the early morning hours (**Figure 19**). Due to limited sample sizes, it was only possible to examine SW Niihau, deployment 1 for rough-toothed dolphins.

Within the signal group categories manually assigned during deployment 3, the 'clicks only', 'HF and LF whistles', and 'HF whistle' category all followed the predominant spinner/striped-like diel pattern, whereas in the 'LF whistles' category detections were spread more evenly throughout the 24-hour day and did not show any distinct diel pattern (**Figure 20**).

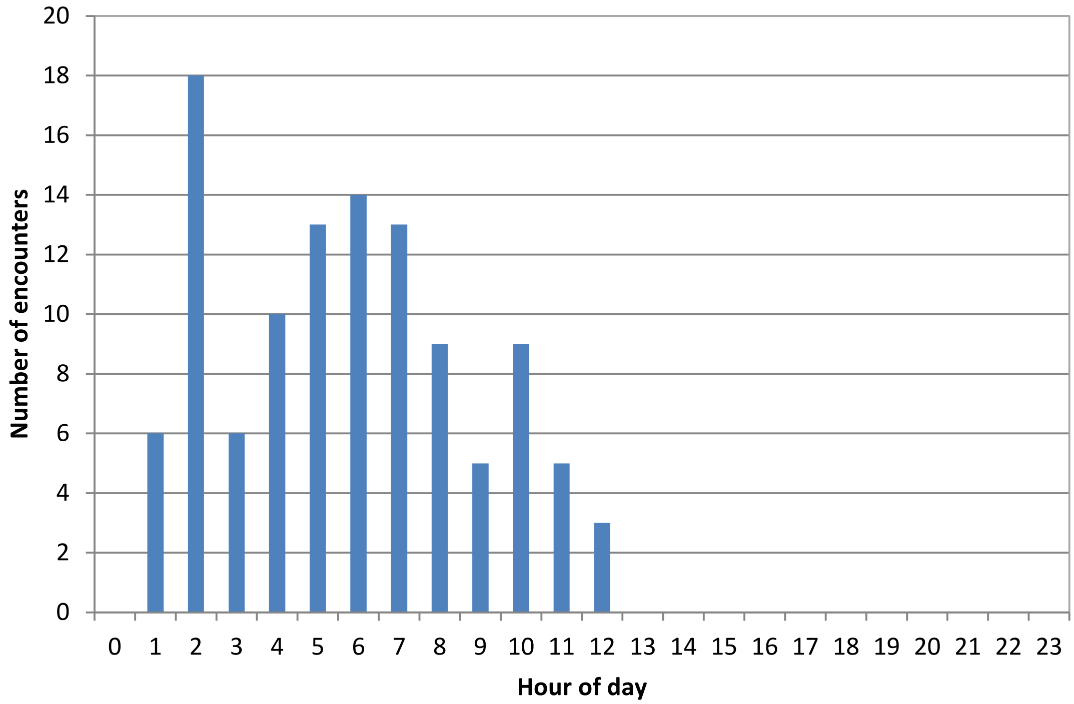


Figure 17. Number of encounters per hour by hour of the day for spinner/striped dolphins at Kaula (n = 111 encounters). Only deployment 1 is shown, due to insufficient sample sizes for deployments 2 and 3.

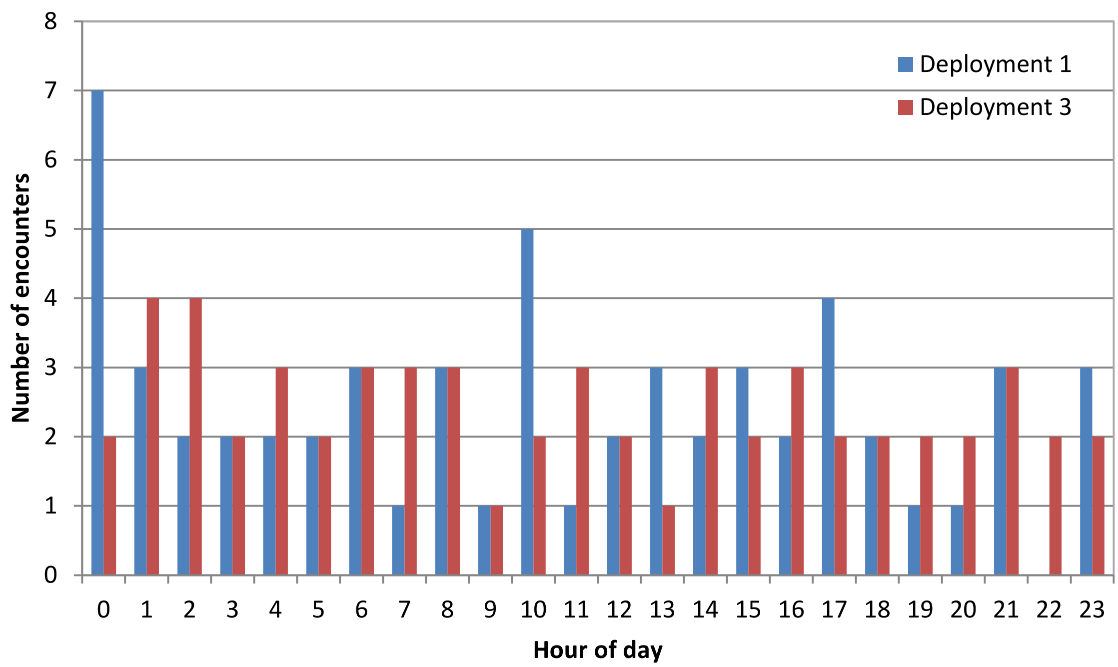


Figure 18. Number of encounters per hour by hour of the day for bottlenose dolphins at NW Niihau, deployment 1 (blue, n = 58 encounters) and deployment 3 (red, n = 58 encounters). No other EARs or deployments were examined for bottlenose dolphins due to insufficient sample sizes.

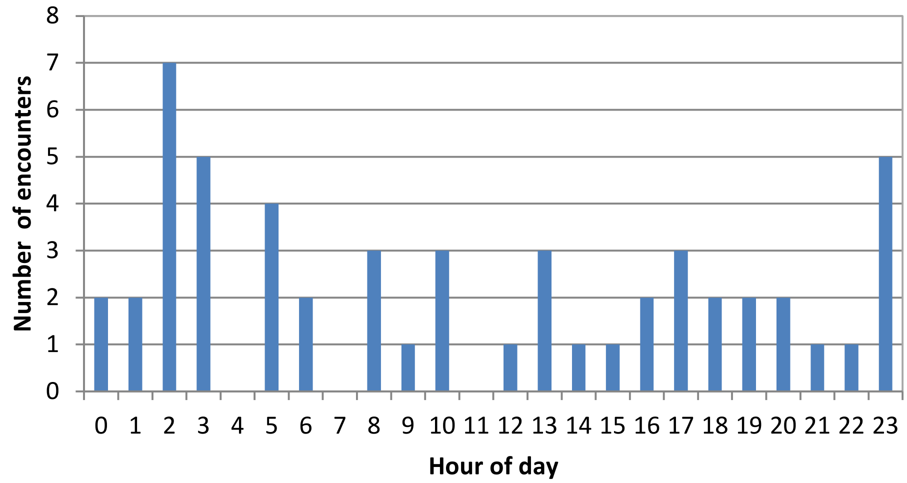


Figure 19. Number of encounters per hour by hour of the day for rough-toothed dolphins at NW Niihau, deployment 1 (n = 53 encounters). No other EARs or deployments were examined for rough-toothed dolphins due to insufficient sample size.

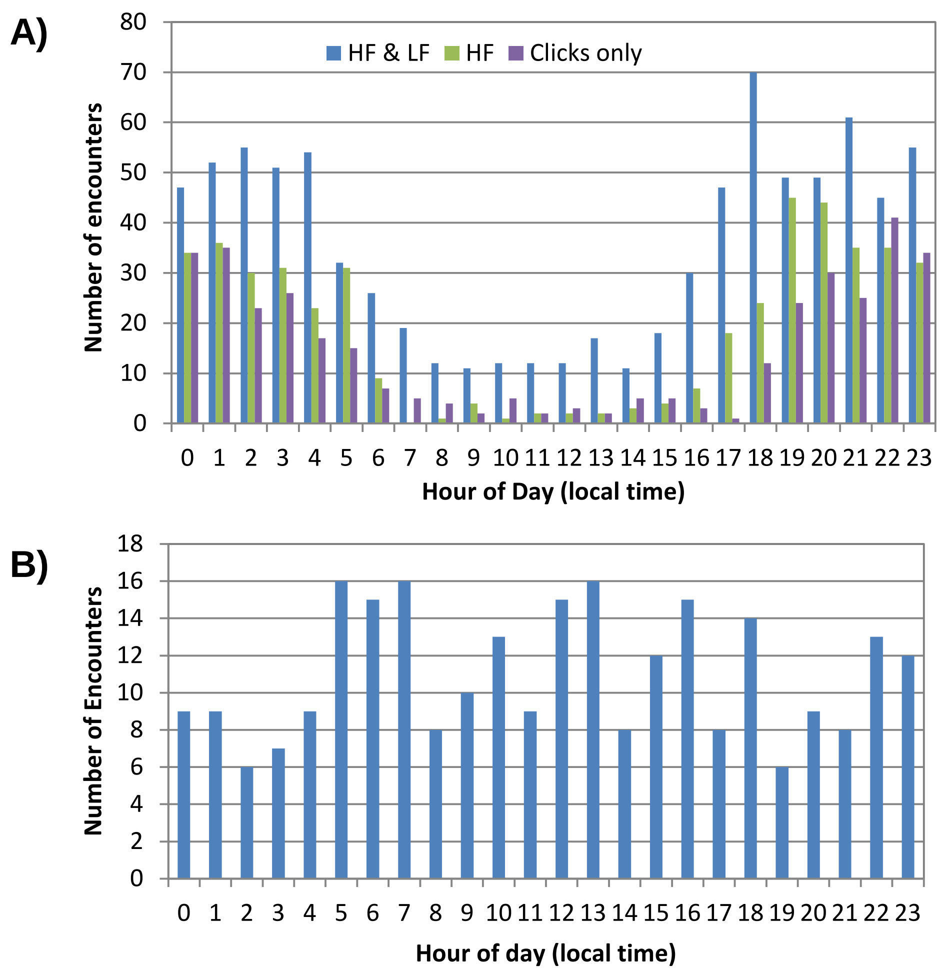


Figure 20. Number of encounters by hour of day for A) Deployment 3 encounters classified as clicks only, HF & LF whistles, and HF whistles, and B) Deployment 3 encounters classified as LF whistles.

3.4.4 III.C.4. Delphinids (pooled) and MFAS

For pooled delphinid (i.e., all species/signal groups combined) encounters, there was no significant difference between mean encounter rates or mean encounter duration from 3 days before, during, or 3 days after MFAS trials (**Figures 20 and 21**, ANOVA, $p = 0.81$ and $p = 0.85$, respectively). There was no consistent pattern in changes in encounter rates or durations when examined by each MFAS exposure trial (**Figure 22**). In five of the MFAS exposure trials, the '3 days after' encounter rate was lower than '3 days before.' In four of the MFAS exposure trials, the opposite was true, and in one trial they were the same (**Figure 22a**). There were four MFAS exposure trials where the 'during' encounter rate was lower than either before or after, three when it was intermediate between the two, and three where it exceeded both the 'before' and 'after' encounter rates (**Figure 22a**). A similarly scattered distribution of outcomes was observed in mean encounter durations analyzed 3 days before, during, and 3 days after each MFAS exposure trial (**Figure 22b**).

A)

B)

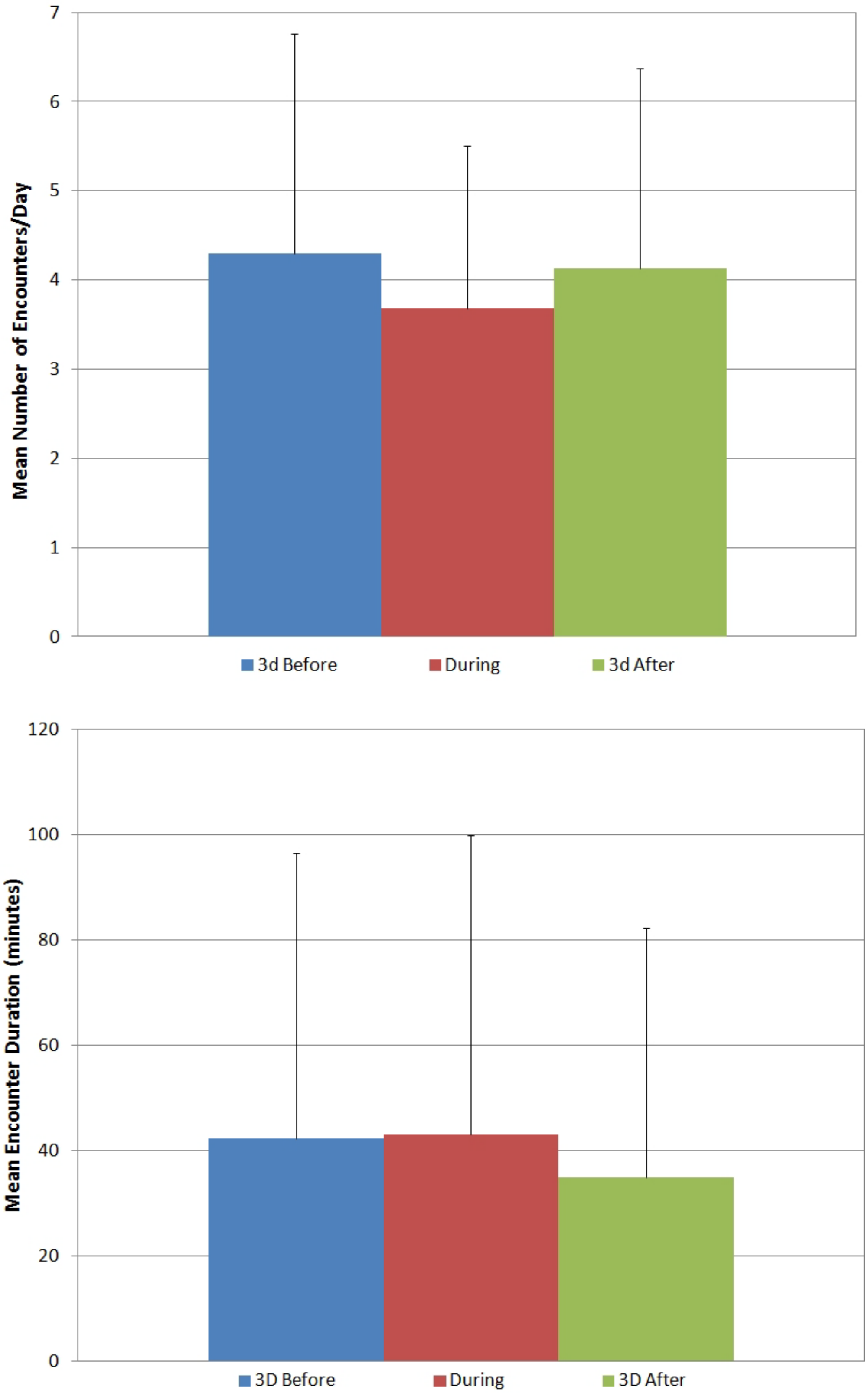


Figure 21. A) Mean number of pooled delphinid encounters per day and B) mean encounter duration for the periods of 3 days before, during (days of), and 3 days after MFAS, averaged across the 10 MFAS exposure periods analyzed.

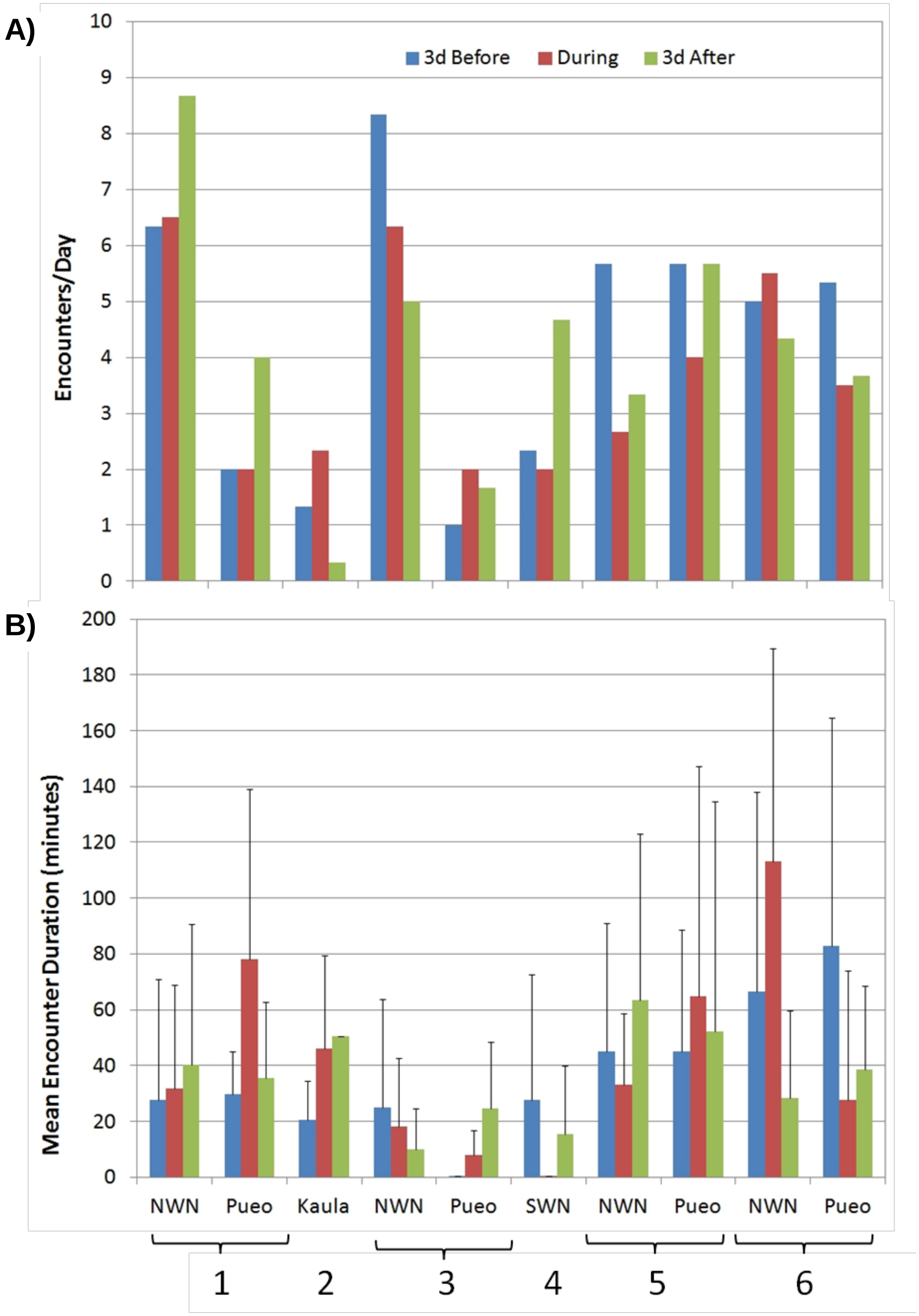


Figure 22. A) Mean number of pooled delphinid encounters per day and B) mean encounter duration for the periods of 3 days before, during (days of), and 3 days after MFAS, for each of the MFAS exposure trials analyzed, by site. MFAS exposure period indicated at bottom of plot (refer to Table 5 for MFAS dates).

3.4.5 Delphinids (species-stratified) and MFAS

Encounter rates for each species varied considerably within timeframes surrounding MFAS exposure periods and the total sample sizes of encounters around each MFAS exposure period were generally small (**Figures 23 through 26**). Two of the species classified by ROCCA did not have a sufficient number of encounters in the time periods around MFAS to analyze: pilot whales (0 encounters within MFAS trial periods) and spotted dolphins (1 encounter).

For the remaining species/signal groups, statistical hypothesis tests were conducted to determine if any significant differences were present between the 3 days before, during, and 3 days after MFAS exposure time frames. MFAS exposure periods were pooled in order to provide sufficient sample sizes for each species.

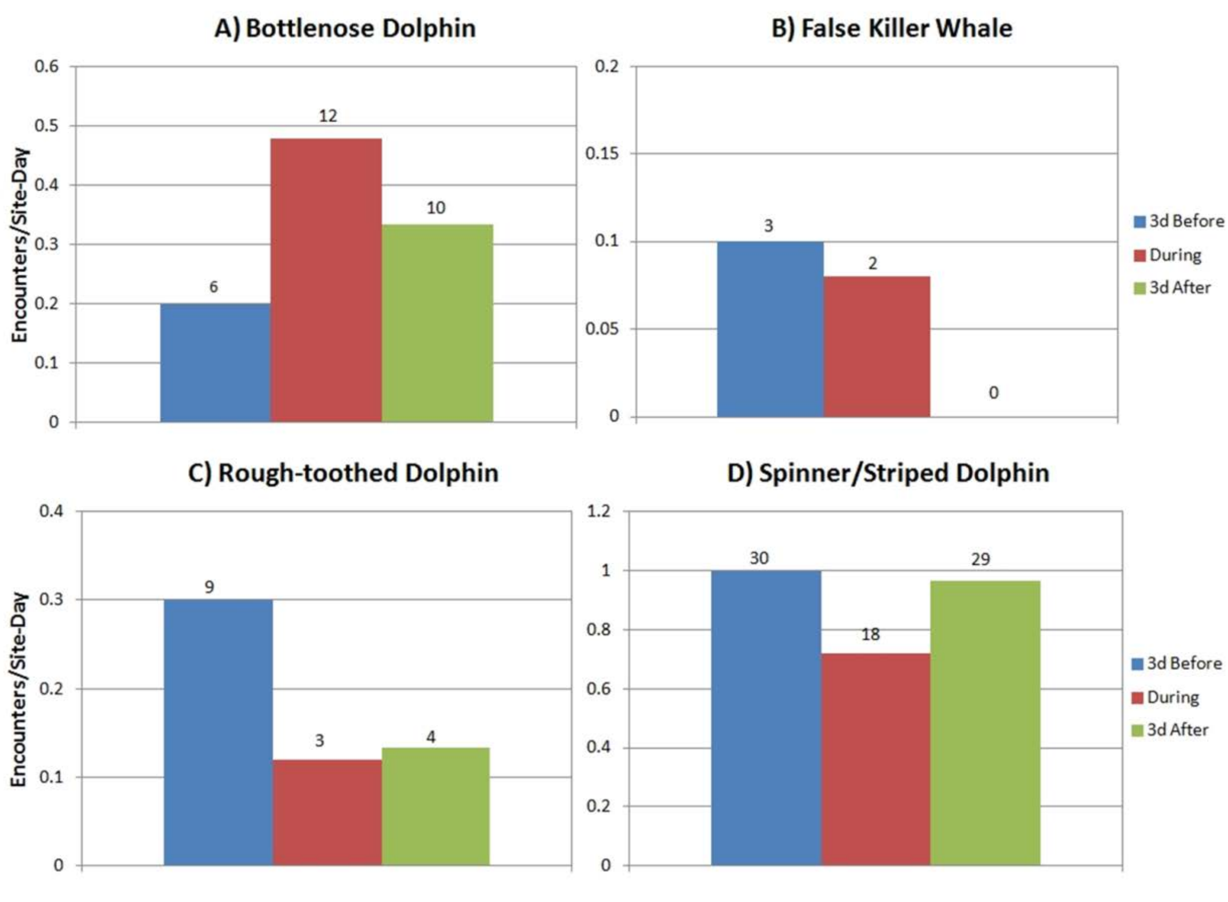


Figure 23. Encounters per site-day for each ROCCA-classified species, pooled across all MFAS exposure trials. Numbers above each bar represent number of encounters within time frame (blue = 3 days before MFAS, red = during MFAS, and green = 3 days after MFAS).

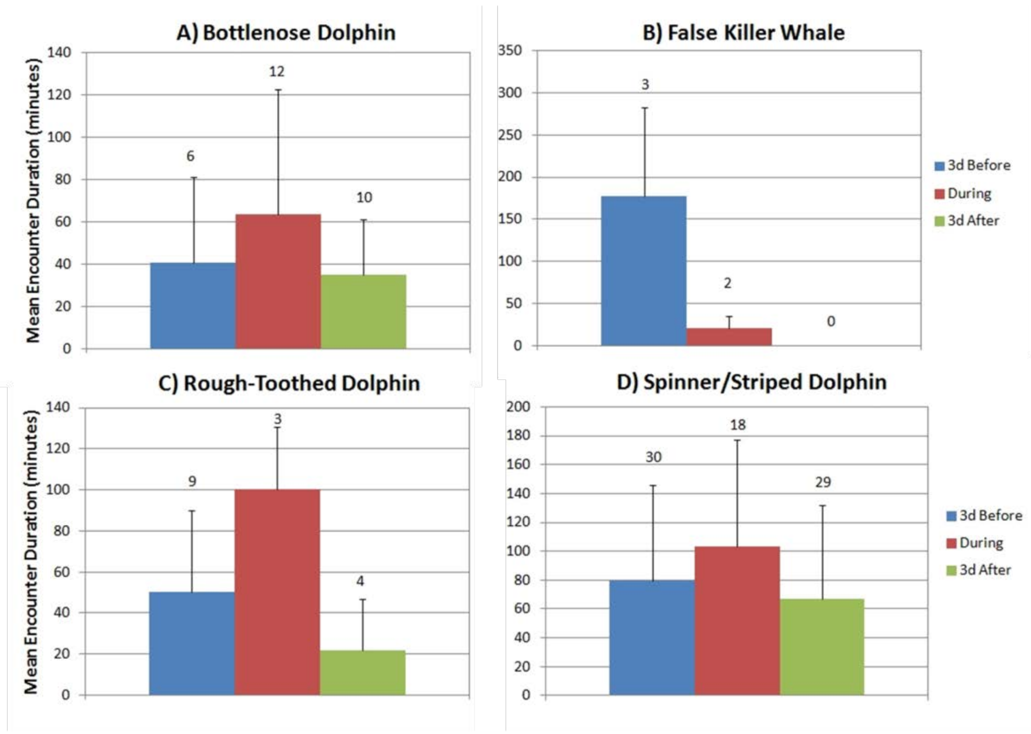


Figure 24. Mean encounter duration for each ROCCA-classified species, pooled across all MFAS exposure trials. Numbers above each bar represent number of encounters within time frame (blue = 3 days before MFAS, red = during MFAS, and green = 3 days after MFAS). Asterisk at C) indicates statistical significance (ANOVA, $p < 0.05$) for rough-toothed dolphin.

Figure 25. Encounters per site-day for each OSI manually classified signal group, pooled across MFAS exposure trials within deployment 3. Numbers above each bar represent number of encounters within time frame (blue = 3 days before MFAS, red = during MFAS, and green = 3 days after MFAS).

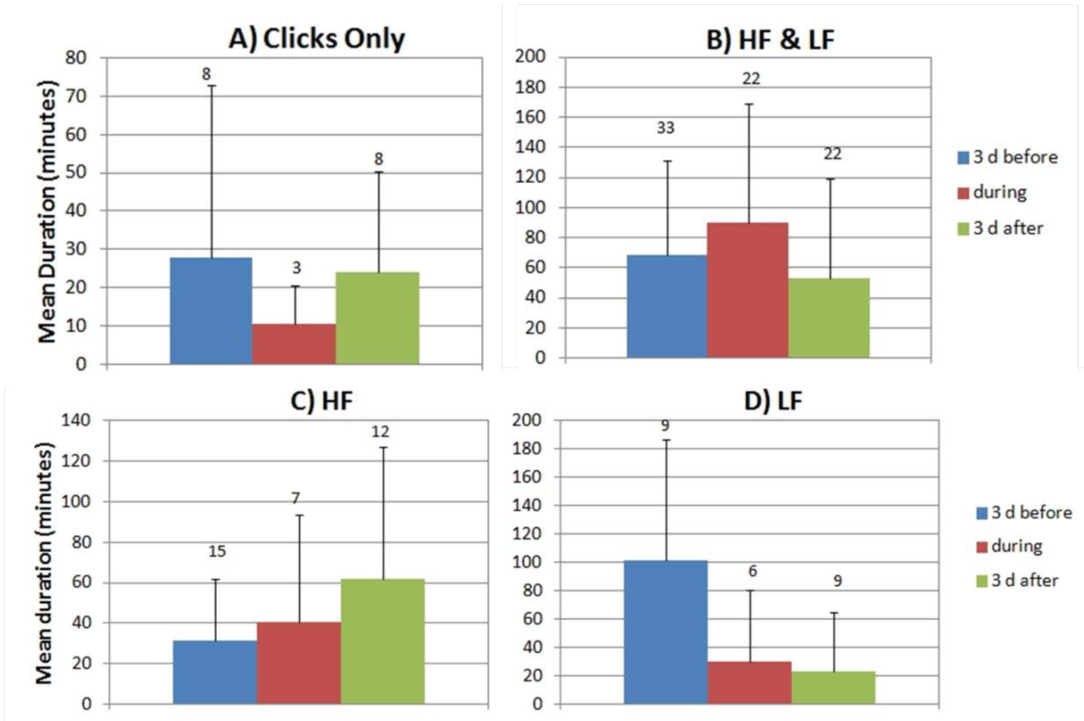


Figure 26. Mean encounter duration for each OSI manually classified signal group, pooled across MFAS exposure trial within deployment 3. Numbers above each bar represent number of encounters within time frame (blue = 3 days before MFAS, red = during MFAS, and green = 3 days after MFAS). Asterisk at D) indicates statistical significance (ANOVA, p < 0.05) for LF whistle signal group.

There were no significant differences in encounter rates for any species or signal group within the 3 days before, during, or 3 days after periods pooled across MFAS exposure periods (**Figures 23, 25; Table 10**). There were significant differences in mean encounter duration for rough-toothed dolphins (**Figure 24**; ANOVA; $p < 0.05$) and for the LF signal group (**Figure 26**; ANOVA, $p < 0.05$) between the 3 days before, during, and 3 days after periods but not for any of the other species or signal groups' mean duration when pooled across MFAS exposure periods.

Table 10. Chi-square contingency table for number of encounters for each species or signal group within 3 days before, during and 3 days after pooled MFAS exposure trials. Note that in rough-toothed, clicks only, and LF species/groups the sum of observed ≠sum of expected due to rounding error; however, no change in significance if exact values used.

Species/Group	Observed			Expected			χ^2	p
	3 d Before	During	3 d After	3 d Before	During	3 d After		
Bottlenose	6	12	10	10	8	10	3.6	NS
False Killer Whale	3	2	0	2	1	2	3.5	NS
Rough-Toothed	9	3	4	6	5	6	3.0	NS
Spinner/Striped	30	18	29	27	23	27	1.6	NS
Clicks only (dep 3)	8	3	8	7	6	7	1.7	NS
HF & LF (dep 3)	33	22	22	27	23	27	2.3	NS
HF (dep 3)	15	7	12	12	10	12	1.7	NS
LF (dep 3)	9	6	9	8	7	8	0.23	NS

Encounter rates and mean encounter duration for spinner/striped dolphins were examined for each MFAS exposure period individually. Spinner/striped dolphin was the only species class with sufficient numbers of encounters to analyze individual MFAS exposure periods. MFAS exposure periods 2 and 4 only contained three encounters each and were not analyzed. Encounter rates for spinner/striped dolphins were significantly different between the 3 days before, during, and 3 days after periods around MFAS exposure periods #1, #3 and #5 (**Table 11A**, χ^2 test, $p < 0.05$). However, the pattern was not consistent; the encounter rate increased 3 days after MFAS #1 but decreased during and after MFAS #3 and #5. A significant difference in mean encounter duration was observed for MFAS exposure period #5 (**Table 11B**; ANOVA; $p<0.05$).

Table 11. Data tables and statistical test results for spinner/striped dolphin for each MFAS exposure period with ≥ 10 encounters. A) Encounter rates and χ^2 statistic for 3 days before, during, and 3 days after periods. Expected values were calculated assuming consistent rate of encounters per site-day in each time period (number of site-days for each MFAS exposure period given previously in Table 5). Bold values indicate statistical significance at p < 0.05. Note that in MFAS exposure period #5 and #6 the sum of observed ≠sum of expected due to rounding error; no change in significance if exact values used. B) Mean encounter duration 3 days before, during, and 3 days after each MFAS exposure period, analyzed using ANOVA. Bold yellow-highlighted values indicate statistical significance at p < 0.05.

MFAS exp. pd	A) Number of Encounters						χ^2	p
	Observed			Expected				
	3 d Before	During	3 d After	3 d Before	During	3 d After		
1	**5**	**5**	**19**	**11**	**7**	**11**	**9.66**	**<0.05**
3	**10**	**1**	**1**	**4**	**4**	**4**	**13.5**	**<0.05**
5	**9**	**3**	**1**	**4**	**4**	**4**	**8.75**	**<0.05**
6	4	8	5	6	4	6	4.83	NS

MFAS exp. pd	B) Mean Encounter Duration (SD)			p
	3 d Before	During	3 d After	
1	64.5 (75.0)	85.5 (50.6)	62.6 (50.0)	NS
3	55.0 (47.3)	50.5 (NA)	20.5 (NA)	NS
5	**81.6 (41.1)**	**160.5 (85.4)**	**320.5 (NA)**	**<0.05**
6	156 (111)	108 (83.3)	54.5 (24.1)	NS

3.5 Sperm Whales

3.5.1 Seasonality

3.5.1.1 M3R RESULTS

Across all sites and the three deployment periods, an analysis of the M3R-CSVM output yielded 1,149 recordings that met the criteria of containing at least five clicks, of which 70 percent or more were classified as belonging to sperm whales (**Figure 27A**). Of the 129 files reviewed, 67 recordings were manually confirmed as being true positive detections and 62 were found to be false positives (**Figure 27B**). The remaining 1,020 recordings were not checked. It should be noted that many more recordings (n = 97) contained one or more clicks that M3R-CSVM classified as belonging to sperm whale, but these were not considered in the analysis since they did not meet the five-click, ≥ 70 percent sperm whale criteria.

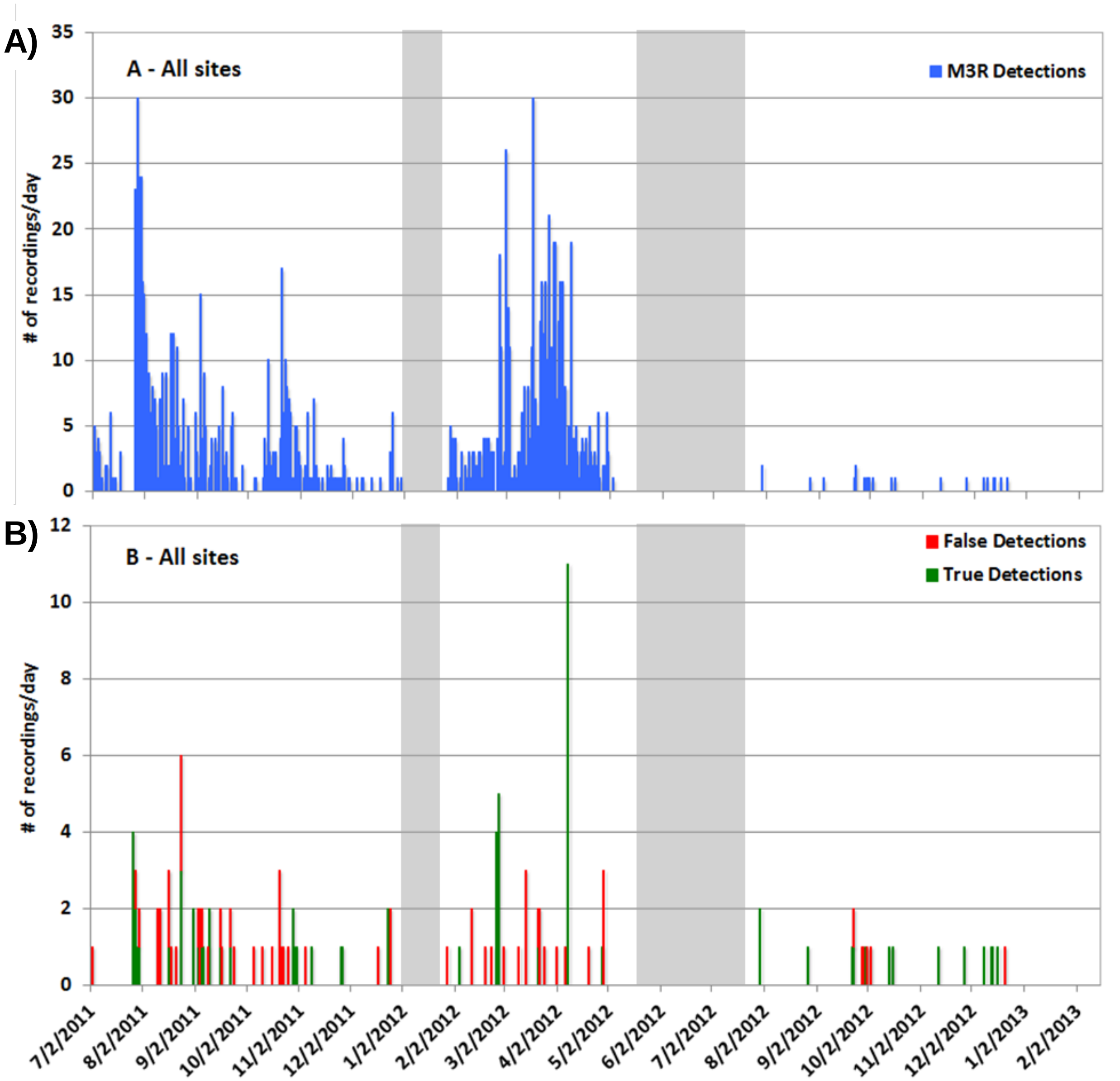


Figure 27. A) The number of recordings per day across all sites and deployments classified by M3R-CSVM as containing sperm whale clicks based on the adopted threshold criteria (see text), and B) the number of visually verified true and false positive M3R detections during the same period. Grayed times indicate periods when no EARs were recording.

At NW Niihau, the M3R-CSVM output produced 613 recordings that met the five-click, ≥ 70 percent sperm whale criteria, nearly all occurring during the second deployment period (**Figure 28A**). Of these, 31 recordings were manually confirmed as being true positive detections and 27 were found to be false positives (**Figure 28B**). The remaining 555 recordings were not checked.

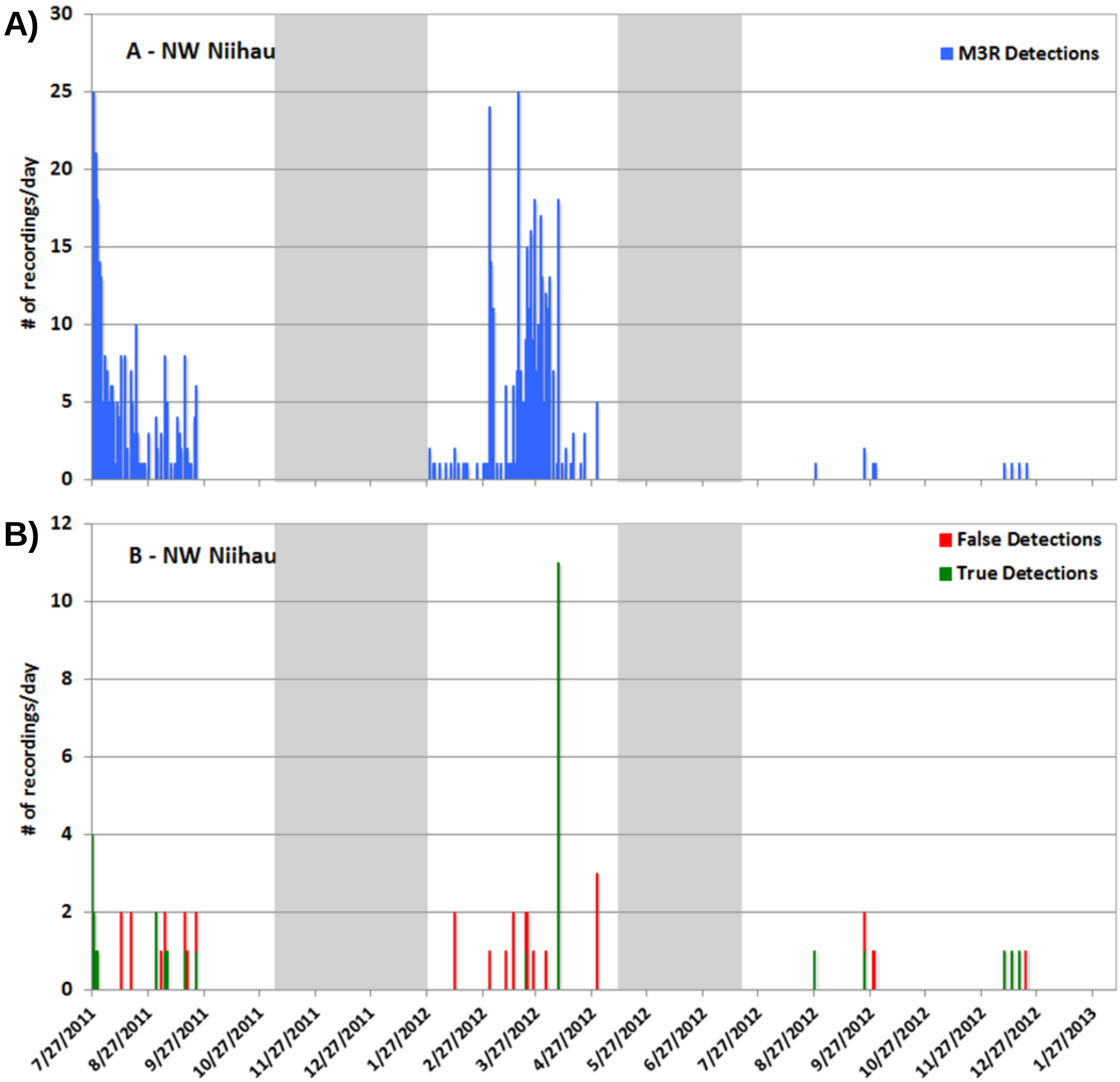


Figure 28. A) The number of recordings per day at NW Niihau classified by M3R-CSVM as containing sperm whale clicks based on the adopted threshold criteria (see text), and B) the number of visually verified true and false positive M3R-CSVM detections during the same period. Grayed times indicate periods when the EAR was not recording or deployed. Note that the y-axes have different scales in (A) and (B).

At Pueo Point, the M3R-CSVM output produced 184 recordings that met the five-click, ≥ 70 percent sperm whale criteria, the majority occurring during the second deployment period (**Figure 29A**). Of these, 12 recordings were manually confirmed as being true positive detections and 10 were found to be false positives (**Figure 29B**). The remaining 162 recordings were not checked.

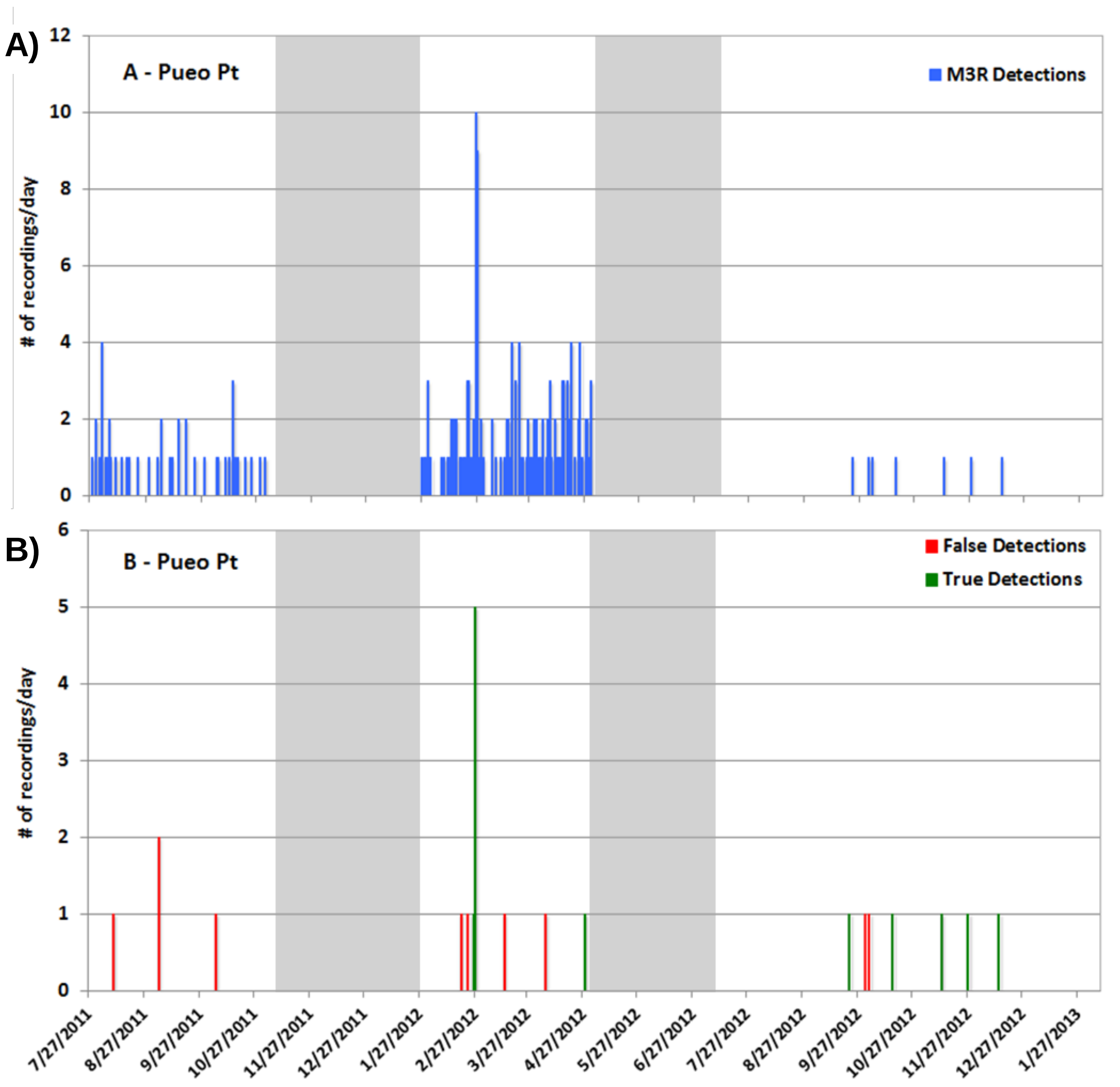


Figure 29. A) The number of recordings per day at Pueo Pt classified by M3R-CSVM as containing sperm whale clicks based on the adopted threshold criteria (see text), and B) the number of visually verified true and false positive M3R-CSVM detections during the same period. Grayed times indicate periods when the EAR was not recording or deployed. Note that the y-axes have different scales in (A) and (B).

At SW Niihau, the M3R-CSVM output produced 137 recordings that met the five-click, ≥ 70 percent sperm whale criteria (**Figure 30A**). Of these, eight recordings were manually confirmed as being true positive detections and seven were found to be false positives (**Figure 30B**). The remaining 122 recordings were not checked.

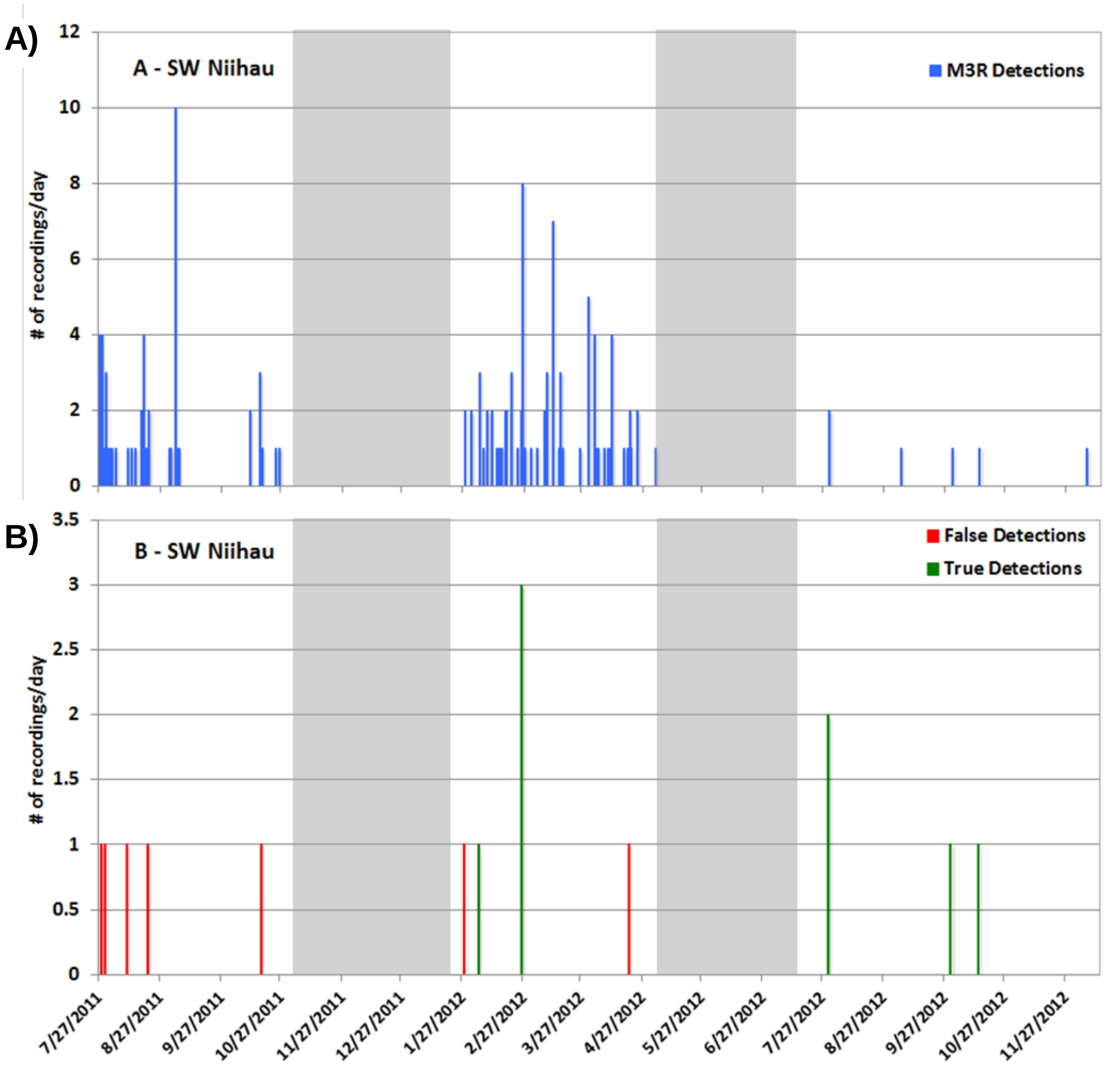


Figure 30. A) The number of recordings per day at SW Niihau classified by M3R-CSVM as containing sperm whale clicks based on the adopted threshold criteria (see text), and B) the number of visually verified true and false positive M3R-CSVM detections during the same period. Grayed times indicate periods when the EAR was not recording or deployed. Note that the y-axes have different scales in (A) and (B).

At Kaula, the M3R-CSVM output produced 215 recordings that met the five-click, ≥ 70 percent sperm whale criteria, all of them occurring during the first and second deployment periods (**Figure 31A**). Of these, only 16 recordings were manually confirmed as being true positive detections and 18 were found to be false positives (**Figure 31B**). The remaining 181 recordings were not checked.

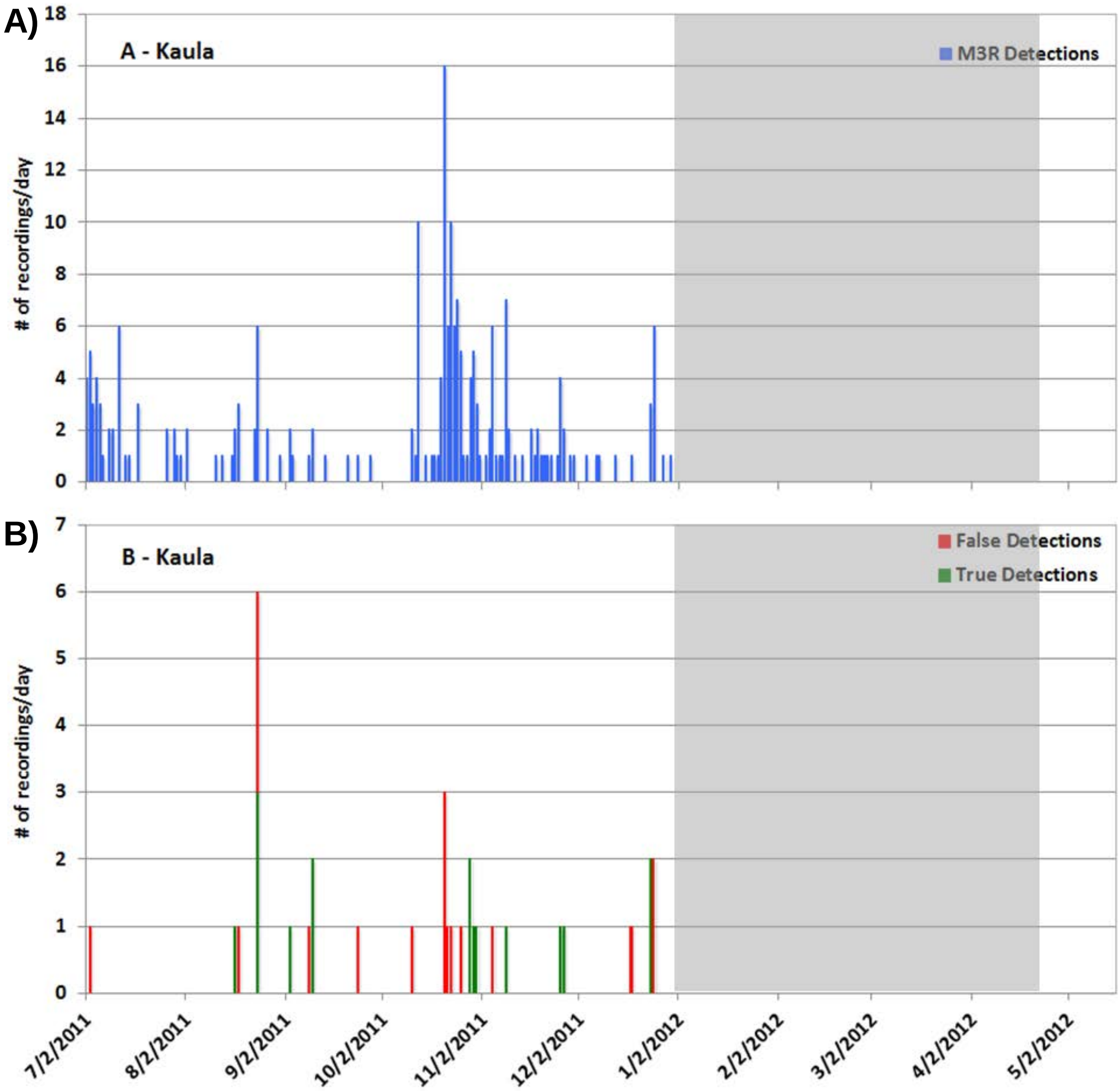


Figure 31. A) The number of recordings per day at Kaula classified by M3R-CSVM as containing sperm whale clicks based on the adopted threshold criteria (see text), and B) the number of visually verified true and false positive M3R-CSVM detections during the same period. Grayed times indicate periods when the EAR was not recording or deployed. Note that the y-axes have different scales in (A) and (B).

3.5.1.2 MANUAL SPERM WHALE DETECTIONS ON THIRD DEPLOYMENT

The occurrence of sperm whale clicks in EAR recordings was also established manually for the data from the three sites monitored during the third deployment (NW Niihau, Pueo Point and SW Niihau). Across the three sites, 79 sperm whale encounters (defined in the methods) were logged resulting in an overall mean encounter rate of 0.37 encounters/day (S.D. = 0.95) and a mean encounter duration of 82.5 minutes (S.D. = 79.5) for the monitored area as a whole (**Figure 32**). Sperm whales were detected at one or more sites on 40 days out of the 209 days of the deployment, or approximately 19 percent of monitored days. The greatest number of detections (six) occurred on 19 December and the longest period without encounters at any site (17 days) occurred between 27 October and 12 November. The longest single encounter occurred at Pueo Point on 27 November and lasted 510.5 minutes.

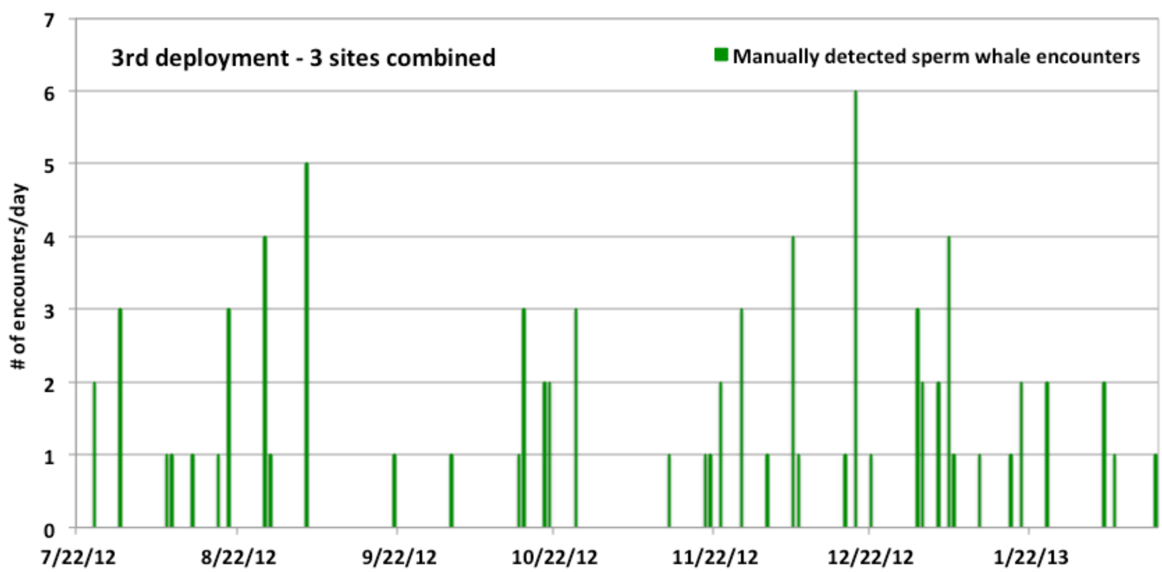


Figure 32. The number of encounters per day across all sites (NW Niihau, Pueo Pt and SW Niihau) containing sperm whale clicks detected through manual analysis of the third deployment period.

Grouped seasonally, there were an average of 0.36 (S.D. = 1.0) encounters/day during summer (22 July–20 September), 0.37 (S.D. = 0.98) encounters/day during fall (21 September–20 December) and 0.40 (S.D. = 0.86) encounters/day in winter (21 December–15 February). The differences among seasons were not statistically significant (Kruskall-Wallis test, H = 0.33, D.F. = 2, p = 0.85). Similarly, the median duration of encounters also did not differ significantly among seasons (Kruskall-Wallis test, H = 1.45, D.F. = 2, p = 0.49). In addition, no diel trends were observed in the occurrence of sperm whale encounters.

The majority of sperm whale encounters and also the greatest number of encounters/day occurred at Pueo Point (n = 40, mean = 0.19 encounters/day, S.D. = 0.39), followed by NW Niihau (n = 22, mean = 0.11 encounters/day, S.D. = 0.77) and SW Niihau (n = 17, mean = 0.08 encounters/day, S.D. = 0.36) (**Figure 33**). The median duration of encounters was greatest at NW Niihau (60.5 minutes), followed by SW Niihau (40.5 minutes) and Pueo Point (20.5 minutes). The differences among sites in encounters/day and encounter duration, however, were not statistically significant (encounters/day: Kruskall-Wallis test, H = 0.18, D.F. = 2, p = 0.92; duration: Kruskall-Wallis test, H = 3.94, D.F. = 2, p = 0.14). Sperm whale encounters occurred at NW Niihau and Pueo Point during all three season of the third deployment (summer, fall, and winter). At SW Niihau, sperm whale encounters occurred during summer and fall, but not during winter (**Figure 33**).

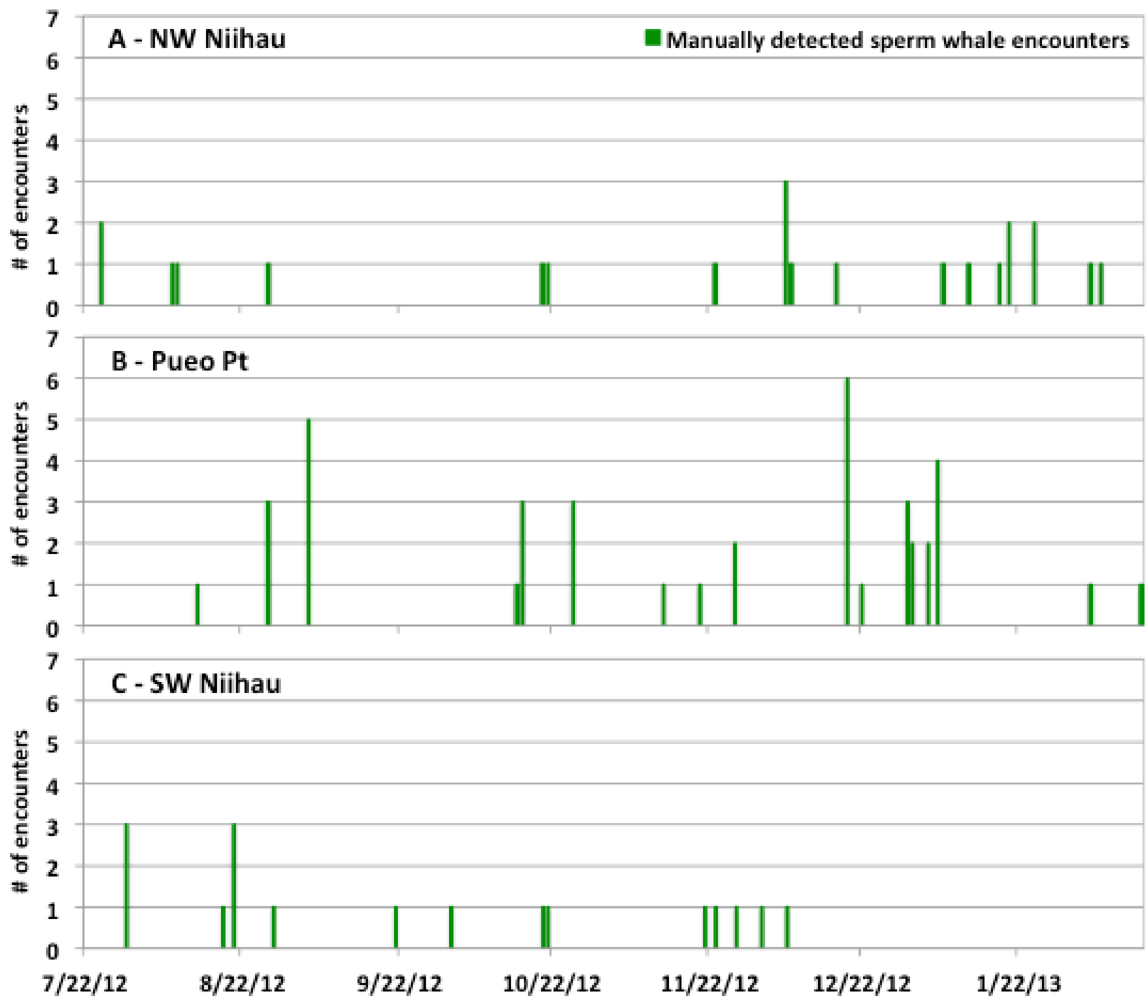


Figure 33. The number of sperm whale encounters per day detected through manual analysis at the three sites monitored during the third deployment period.

3.5.2 Sperm Whale Presence Relative to MFAS

The occurrence of sperm whales was manually established for the six periods of MFAS exposure selected for in-depth analysis (see **Section 3.1** above). Sperm whale presence was compared for the period 7 days prior to, during, and 7 days following an MFAS exposure period. Examining sperm whale occurrence over shorter periods (e.g., 3 days) was not considered useful due to the small sample size of encounters obtained. Sperm whale clicks were not detected in any recordings associated with MFAS periods 2 and 3 (see **Table 5**), but were detected around the remaining four MFAS periods (**Figure 34**). For MFAS period #1 (5–6 October 2011), no sperm whale encounters occurred at any sites during the 7 days prior to the MFAS event and only one encounter lasting a single 30-second recording occurred at SW Niihau 2 days after the event. For MFAS period #4 (5–6 April 2012) no sperm whale encounters occurred at any sites during the 7 days prior to the MFAS event, but encounters did occur 2 and 5 days after the event at NW Niihau and SW Niihau, respectively. For MFAS period #4

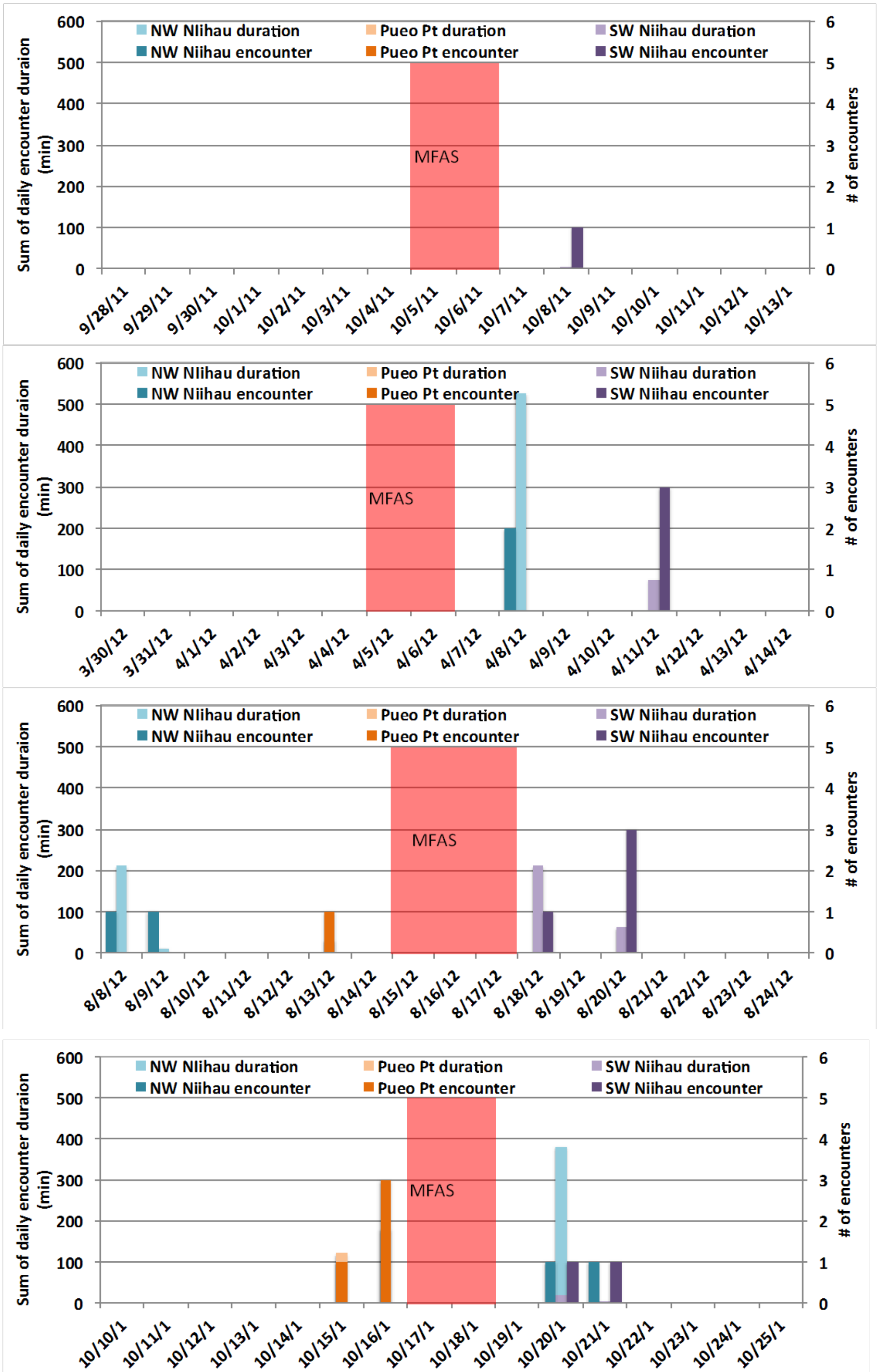


Figure 34. The occurrence of sperm whales 7 days before, during and 7 days after the MFAS exposure periods of 5–6 August 2011, 5–6 April 2012, 15–17 August 2012, and 17–18 October 2012.

(15–17 August 2012), sperm whale encounters occurred 6 and 7 days prior to the event at NW Niihau and 2 days before at Pueo Point. They also occurred 1 and 3 days after the event at SW Niihau. For MFAS period #5 (17–18 October 2012), sperm whale encounters occurred 1 and 2 days prior to the MFAS event at Pueo Point and 2 and 3 days after the event at both NW Niihau and SW Niihau. Finally, it should be noted that there were no sperm whale encounters during any of the days of the six MFAS events themselves. However, a comparison of the proportions of days with observed sperm whale encounters during days with MFAS (0/14) and expected (2/14) (based on 12 encounters occurring during 84 non-MFAS days) did not reveal a significant difference (Chi-square test, $\chi^2 = 1.875$, D.F. = 1, $p > 0.05$).

Combined across the three monitored sites and six MFAS exposure periods, the mean sperm whale encounter rate and encounter duration were both lower during the 7 days before an MFAS exposure period than during the 7 days following the period (**Figure 35**). However, these differences were not statistically significant (encounter rate: Mann-Whitney U test, n = 18, U = 134, p = 0.38; encounter duration: Mann-Whitney U test, n = 9, U = 27, p = 0.23). Sample sizes were too small to attempt statistical inferences based on site-by-site or event-by-event comparisons.

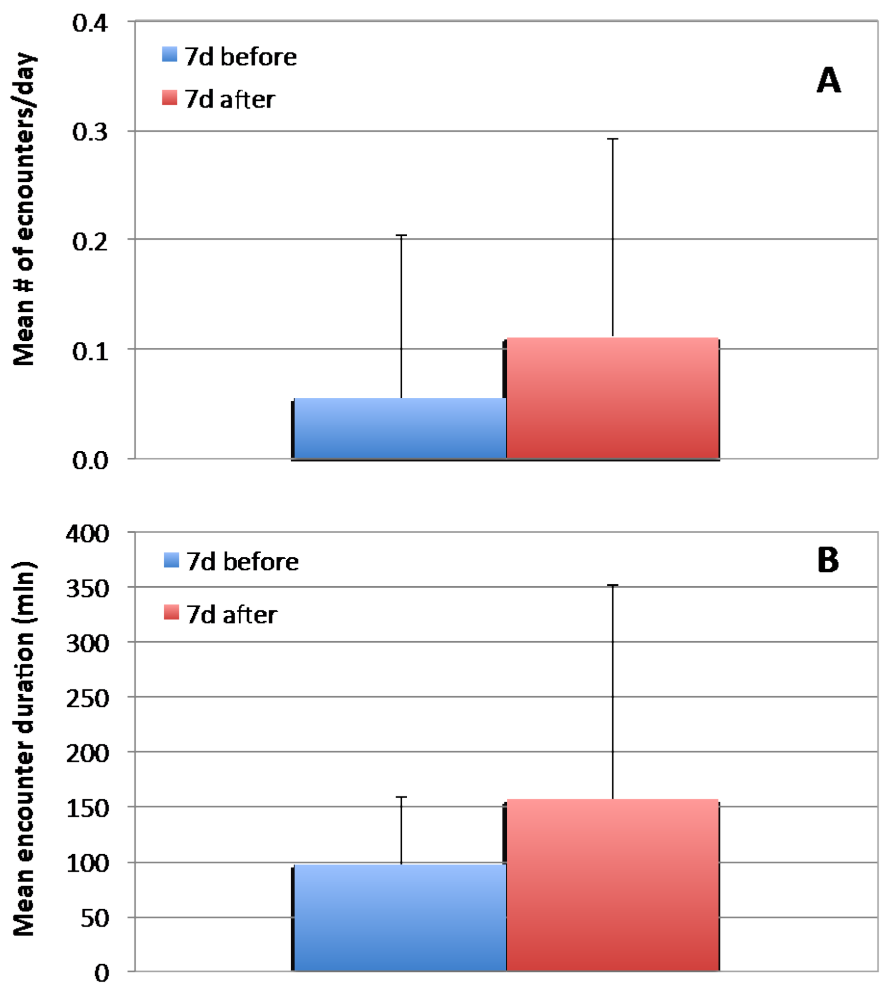


Figure 35. The mean rate of occurrence (A) and encounter duration (B) of sperm whales 7 days before and 7 days after MFAS exposure periods.

3.6 Baleen whales

3.6.1 Detector Results/Ground-truth

The results of the ground-truth exercise conducted by Bio-Waves, Inc. revealed that the performance of the Baleen5 detector varies widely by species (see **Appendix A**). All blue and fin whale automated detections were found to be false during the visual validation performed by Bio-Waves, Inc. so performance (precision and recall) metrics could not be calculated for these two species. Therefore, the Baleen5 detector results for blue and fin whales are not presented here because their reliability could not be independently established.

The ground-truth exercise revealed that the Baleen5 detector has a precision rate of 0.94 and a recall rate of 0.06 for humpback whale calls. This translates to a low false positive rate, but a very high false negative rate. In other words, the detections made were generally true positives, but the detector missed the vast majority of humpback whale signals present in the data. The exercise also revealed that the detector has a precision rate of 0.29 and a recall rate of 0.48 for minke whale calls. This indicates that the detector misclassified 71 percent signals from other species/sources as minke whale calls ('boings') and missed approximately half of all minke whale calls that were present in the data. Below are the Baleen5 detector results for humpback whale and minke whale calls at each EAR site.

3.6.1.1 HUMPBACK WHALES

Figure 36 shows the number of recordings/day containing Baleen5 humpback whale detections across the four monitored sites and the two deployment periods. Less than 0.2 percent of all detections occurred during the first deployment at NW Niihau, Pueo Point, and SW Niihau. This deployment spanned from late July through October and therefore did not coincide with the known humpback whale season in Hawaii. Consequently, these detections are presumably all false positives. At Kaula, the first credible detections occurred in early December 2011. However, evidence of a consistent humpback whale presence did not occur until the end of December, which coincided with the end of the deployment.

The second deployment at NW Niihau, Pueo Point, and SW Niihau began in late January 2012. Consistently high rates of detection occurred at all three sites through the end of March. During the month of February, no statistically significant differences were found among the three sites in the mean number of recordings/day with detections (One-way ANOVA, $n = 29$, $df = 2$, $F = 1.5$, $p = 0.228$). In the month of March, the number of recordings/day with humpback whale detections was significantly higher at Pueo Point than at the other two sites (one-way ANOVA, $n = 31$, $df = 2$, $F = 7.5$, $p < 0.001$). In the month of April, the number of encounters/day with detections remained high at NW Niihau and Pueo Point, but decreased significantly at SW Niihau (one-way ANOVA, $n = 30$, $df = 2$, $F = 50.6$, $p < 0.001$). At Kaula, deployment 2 began in late April 2012 and only lasted until mid-May. A decreasing number of recordings/day with detections was noted during the approximately 3-week deployment period.

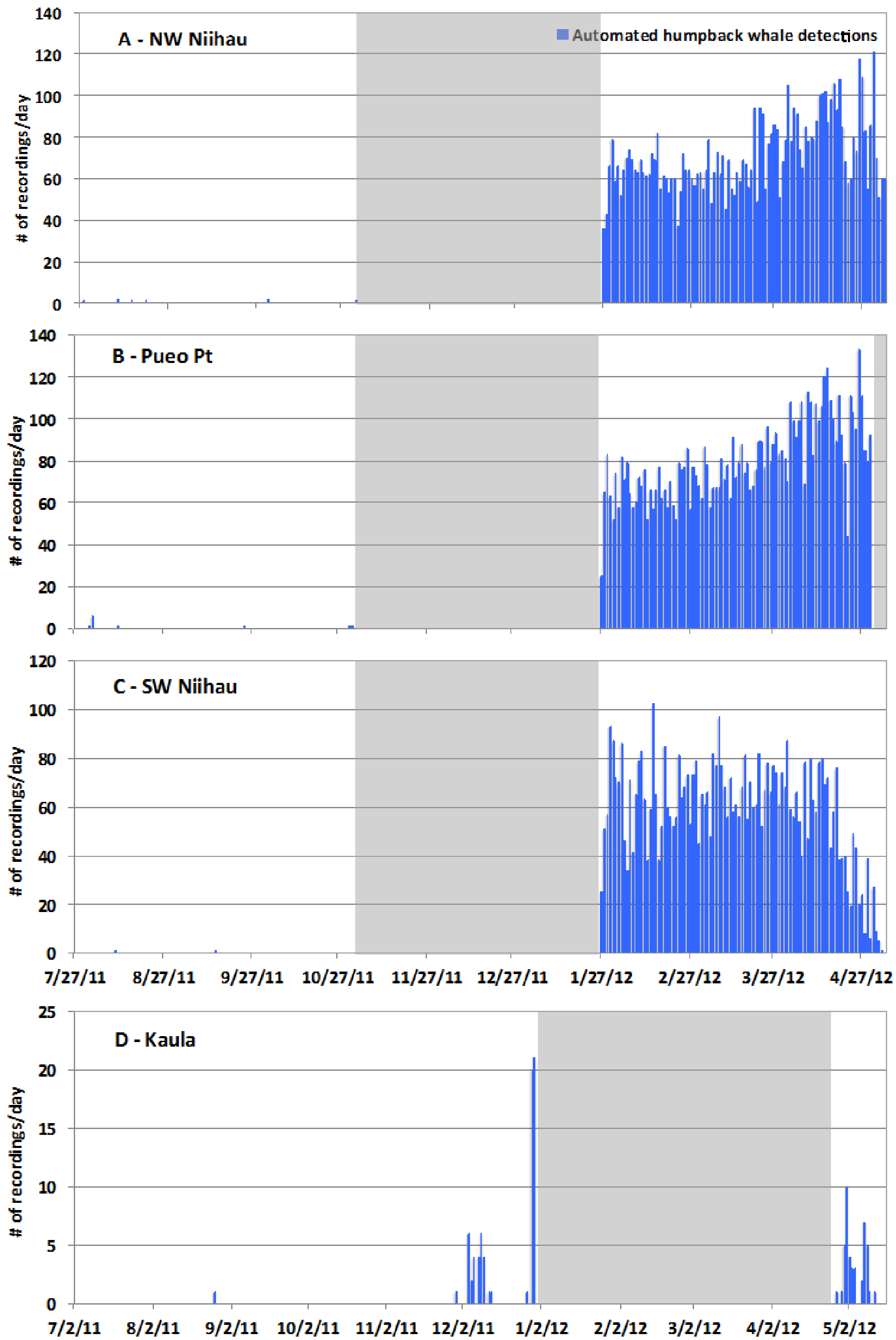


Figure 36. The number of recordings per day classified by the Baleen5 algorithm as containing humpback whale song units at (A) NW Niihau, (B) Pueo Pt, (C) SW Niihau and (D) Kaula for the first two deployment periods (the Baleen5 detector was not run on the deployment 3 recordings). Grayed periods indicate when the EAR was not recording or deployed.

3.6.1.2 MINKE WHALES

Figure 37 shows the number of recordings/day containing Baleen5 minke whale detections across the four monitored sites and the two deployment periods. No minke whale detections occurred at Kaula during either deployment period. Only three detections occurred during the first deployment at the other three sites, all three of which were manually established to be false positives. During the second deployment period, the greatest number of minke whale detections occurred at Pueo Point, followed by SW Niihau and NW Niihau. However, due to the low precision rate associated with minke whale detections, it was decided that statistical inference to examine spatial and temporal differences was not warranted due to the high likelihood of call misclassification.

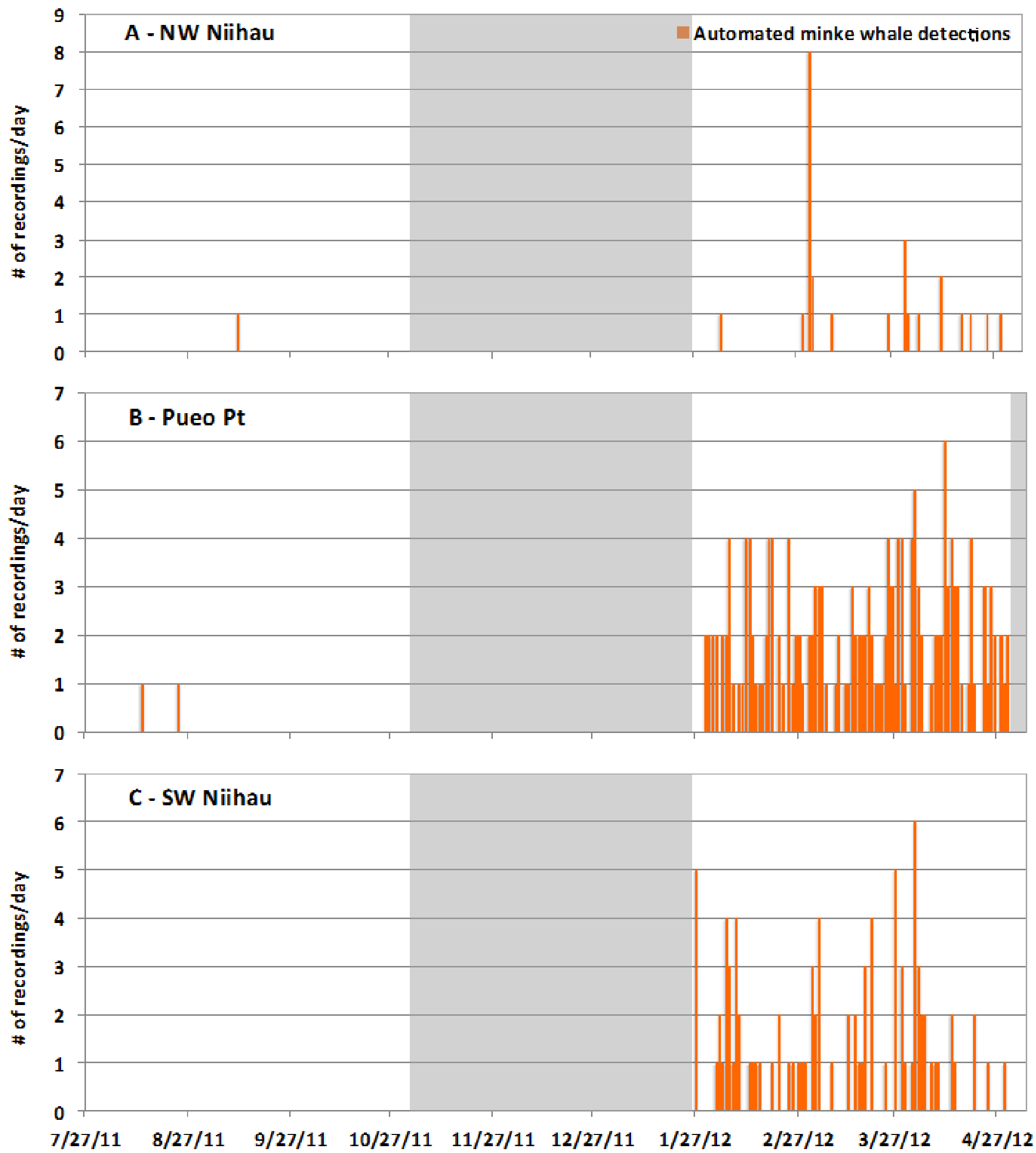


Figure 37. The number of recordings per day classified by the Baleen5 algorithm as containing minke whale calls at (A) NW Niihau, (B) Pueo Pt, (C) SW Niihau and (D) Kaula for the first two deployment periods (the baleen5 detector was not run on the deployment 3 recordings). Grayed periods indicate when the EAR was not recording or deployed.

3.6.2 Baleen Whales and MFAS

The occurrence of baleen whale calls was manually established for the 7-day period before an MFAS exposure period, during the exposure period, and 7 days after the exposure period. Of the six MFAS exposure periods examined in detail for cetacean occurrence (**Table 5**), two (events 2 and 3) took place during the winter/spring seasons. Baleen whale calls were only found associated with these two periods and only humpback whale song units and fin whale calls occurred at the sites where MFAS signals were detected (**Figure 38**). No minke or blue whale calls were noted during these periods. Humpback whale song was present nearly continuously during each of the before, during and after MFAS exposure periods examined. It was therefore not possible to draw quantitative distinctions among periods using the presence/absence of song metric employed in the manual analysis. Fin whale calls, on the other hand, occurred very sparsely. No fin whale calls were observed during the 7 days before MFAS exposure for exposure period #2 and only three recordings at both NW Niihau and Pueo Point contained calls during this exposure period. During the 7 days following this MFAS exposure period, 1 recording at NW Niihau and 30 recordings at Pueo Point contained fin whale calls. During MFAS exposure period #3, only one recording with fin whale calls occurred during the 7 days before MFAS at SW Niihau, no calls were noted during the exposure period, and only one recording with calls was found during the 7 days after exposure at SW Niihau. The low sample size and the small number of recordings with fin whale calls precluded any statistical inference.

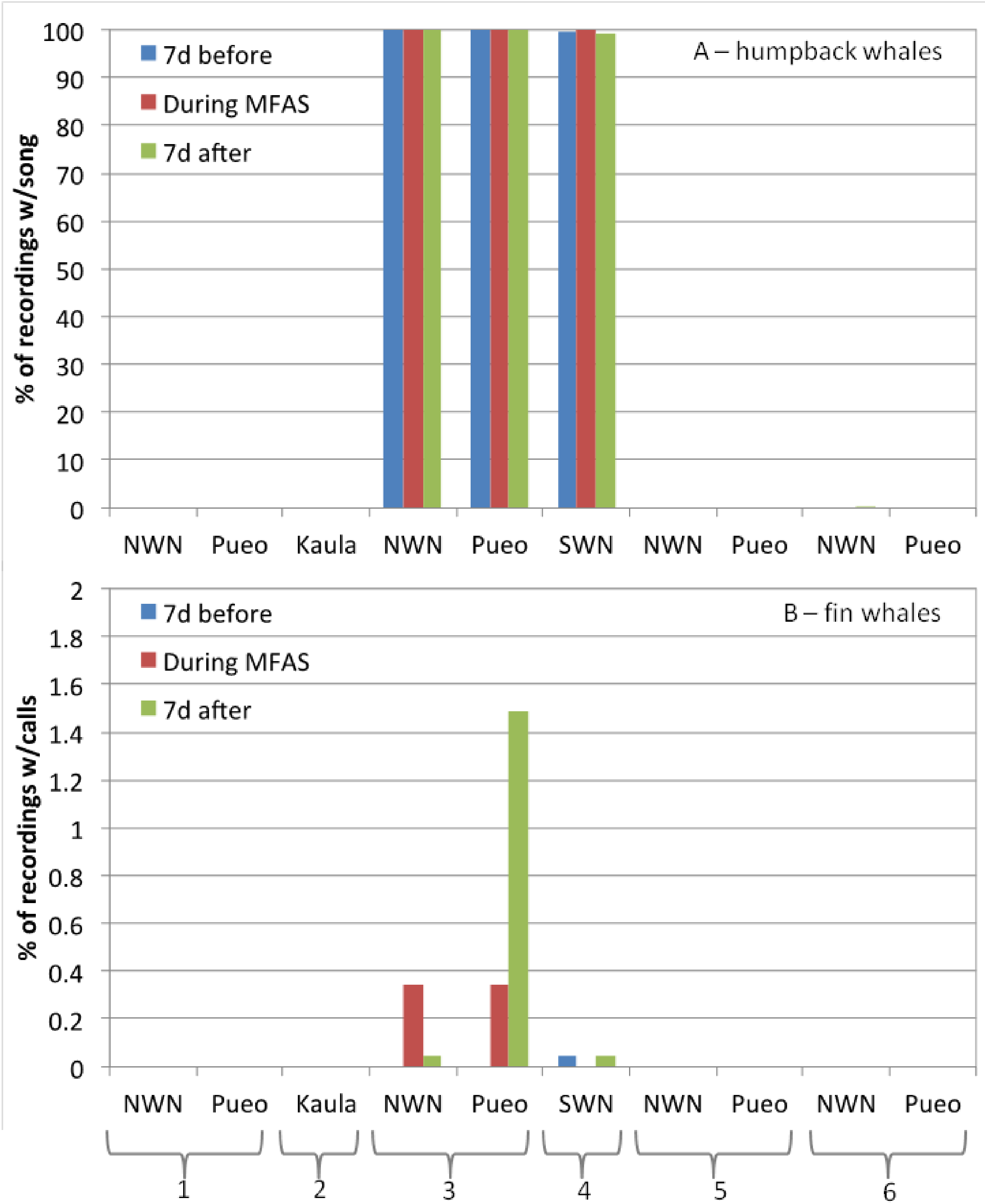


Figure 38. The percentage of recordings containing (A) humpback whale song units and (B) fin whale calls during the period 7 days before an MFAS exposure period, during the exposure period, and 7 days after the exposure period.

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4. Discussion

4.1 Beaked whales

Q1a. What species of beaked whales (Ziphius/Mesoplodon) are in the region surrounding Niihau and Kaula Islands in the HRC?

The M3R CS-SVM detector produced a low number of possible beaked whale detections compared to the size of the dataset (15,902 of 277,222 files, ~6 percent). Upon initial review in the Bio-Waves ground-truth study (**Appendix A**), none of the clicks examined were true positive detections of beaked whales; most of the false positives were found to be unidentified odontocetes. No additional missed beaked whale clicks were found by manual searching during this original ground-truthing effort. However, during a second effort to re-evaluate and re-interpret the detector output based on revised criteria, **a low number (16) of beaked whale automated detections were manually verified to be true positive detections of Blainville's (n = 12) or Cuvier's beaked whale (n = 4).** Other species of beaked whales are known to exist in Hawaiian waters, but they were not included in the M3R CS-SVM classifier. During manual ground-truth review, **Bio-Waves noted clicks in one file that could be attributed to Longman's beaked whale, but the classification could not be confirmed with 100 percent confidence** (see **Appendix A**).

Thus, there is acoustic evidence that at least two (Blainville's, Cuvier's) and possibly a third beaked whale species (Longman's) are present in the HRC region monitored in this study, but likely in low numbers near the sites where EARs were located. The low precision (0.12) and high recall (0.94) of the detector (using re-interpretation criteria) indicates a high rate of false positives, but a low rate of missed detections. In addition, the high specificity (Blainville's = 0.96, Cuvier's = 0.95, mixed beaked whale class = 0.91), means that a large proportion of files that did not contain clicks produced by beaked whales were correctly rejected. The low number of true positives and high specificity suggests that these species are rare in the study area.

Q1b. Do beaked whale detection rates vary before, during, and after mid-frequency active sonar (MFAS) detections?

Due to the low precision of the detector and the rarity of true positive detections, we could not reliably infer when the M3R CS-SVM positively detected beaked whales within the dataset, nor quantify detection rates around MFAS events. However, the high recall of the detector (using the revised criteria) indicates that few beaked whale signals were likely to be missed and the high specificity indicates that few non-target signals were likely to be misclassified as beaked whales. **Therefore, the low number of auto-detections overall (<1 percent of data files that meet the revised interpretation criteria) indicates that the likelihood of detecting beaked whales may be low overall within the detection area of EARs deployed in the HRC**. This contrasts with results of beaked whale detection in the Pacific Missile Range Facility prior to a naval training event in 2012, during which an average of 1.7 beaked whale dives per hour were detected using data from 31 hydrophones in a fixed array, deployed at depths from 650 to 4,700 m (Manzano-Roth et al. 2013). The EARs deployed around Niihau and Kaula in this project were located at depths shallower than 800 m, and thus may not have been in a high-use area for beaked whales, which routinely dive to depths > 800 m around the MHI (Baird et al. 2006). Consequently, sparsely located, fixed passive acoustic sensors alone may not be the optimal method for studying beaked whale responses to MFAS in areas of low animal density. Successful approaches to this research question have incorporated fixed hydrophone arrays to detect and localize beaked whales initially, combined with small vessels to deploy archival and/or satellite telemetry tags on animals (e.g., Baird et al. 2014, Southall et al. 2012). In addition, longer duty cycle (>50 percent) or continuous recording at higher bandwidth by fixed hydrophones would be desirable to investigate acoustic occurrence at finer temporal resolution and provide more complete information about the frequency content of potential beaked whale clicks.

4.2 Baleen Whales

Q2a. What is the seasonal occurrence of baleen whales near Niihau and Kaula Islands in HRC?

Combined, the results of the Baleen5 detector analyses and the visual/manual analyses performed around periods of MFAS confirm that humpback, minke and fin whales are seasonally present near Niihau and Kaula Islands in winter and spring. No confirmed blue whale detections were made using either analysis method. The occurrence of sei whale calls was ambiguous and therefore not considered, as their call characteristics in the North Pacific are still poorly understood and potentially confused with fin whale calls (Rankin and Barlow 2007).

Of the baleen whale species detected, humpback whales were clearly the predominant species in terms of acoustic presence. They occurred at all four monitored sites and their song was nearly ubiquitous in recordings made during the winter/spring time period. Interestingly, some spatial and temporal differences were seen in the occurrence of song detected using the Baleen5 algorithm. Pueo Point had the highest occurrence of detected song during the peak of the humpback whale season in March. SW Niihau saw a significantly greater decrease in song detected in April than either Pueo Point or NW Niihau, suggesting perhaps an earlier departure of whales from this area than the latter two sites. However, these results must be interpreted with caution, given the poor recall performance of the Baleen5 detector for humpback whale signals. Assuming that the detector likely missed the majority of song units, any noted decrease or absence of detections may not be indicative of a true change. Rather, the differences observed are likely only true if the detector's performance was consistent across sites and throughout the deployment period, an assumption that was not expressly tested during the ground-truth exercise.

The second most commonly detected baleen whale species was the minke whale. The Baleen5 algorithm frequently detected their boing calls, especially at Pueo Point. **However, given the poor precision and recall of the algorithm for minke boings (approximately 71 percent were false positives and 52 percent of minke boings were missed), no reliable conclusions can be drawn about any spatial or temporal differences.** Humpback whale song units were the primary source of confusion for the algorithm, so any observed differences in minke whale detections between sites could in reality be tied to differences in humpback whale activity.

Fin whale calls were detected infrequently in the data sets. The presence of fin whales was noted in the manual analyses conducted for baleen whale presence during periods associated with MFAS, and none of the fin whale calls found manually were detected by the Baleen5 algorithm. **Their calls only occurred in the winter/spring time frame, but were rare, with only a total of 39 recordings containing fin whale calls out of more than 80,000 files manually examined. Of these, 30 recordings of fin whales occurred over only two days in February 2012 (8 on 22 February and 22 on 24 February).** These occurred at NW Niihau, Pueo Point and SW Niihau. Therefore, it can reasonably be concluded that, while fin whales do occur in this part of the HRC, their presence is only sporadic, suggesting potential use of the area for migration and traveling but no residence for extended periods.

Q2b. Do baleen whale detection rates vary before, during, and after MFAS detections?

The only two baleen whale species that occurred before, during and/or after the six examined periods of MFAS exposure were humpback whales and fin whales. However, establishing whether MFAS had an effect on detection rates was not feasible for either species, for different reasons. In the case of humpback whales, nearly continuous singing by one or more individuals during the winter seasons made it ineffective to compare periods based on simply the presence or absence of song. There is no evidence to indicate that MFAS is tied to a cessation of singing by all animals in an area with MFAS exposure. However, the analysis conducted cannot exclude the possibility that singing patterns changed during and after MFAS exposure. To examine this possibility, potential analyses could include examining the occurrence of individual units or measuring changes in chorusing levels (e.g., Au et al 2000).

The occurrence of fin whale calls was too rare to make meaningful comparisons among calling rates relative to MFAS. The three MFAS exposure trials that coincided with fin whale calls did not provide any indication that fin whale signaling rates around Niihau and Kaula islands are influenced by the presence of MFAS. However, this was due primarily to the scarcity of fin whale calls in the area rather than because of an absence of any correlation. The strongest indication of fin whale presence occurred at Pueo Point following the February 2012 MFAS event when 30 recordings over two non-consecutive days contained fin whale calls. However, these calls occurred five or more days following the MFAS exposure period, so it is unlikely that they represented a behavioral response to the MFAS event.

The effect, if any, of MFAS on the calling behavior of other baleen whale species could not be established due to a lack of detected signals.

4.3 Sperm Whales

Q3a. What is the occurrence of sperm whales near Niihau and Kaula Islands in the HRC?

The results of the M3R CS-SVM analysis of the three deployments and the visual/manual analysis of the third deployment data indicate that sperm whales are present year-round near Niihau and Kaula Islands. The low recall rate of the M3R CS-SVM detector for sperm whale clicks (0.26) did not warrant using those results for establishing rates of occurrence because of the high likelihood that missed detections would confound the estimate. However, the manual analysis of the third deployment did produce occurrence estimates that ranged from 0.19 encounters/day at Pueo Point to 0.08 encounters/day at SW Niihau. **Therefore, although present year-round, sperm whales occurred only sporadically at the monitored sites, with multiple weeks sometimes elapsing between encounters**. Differences in the number of encounters/day and encounter duration among sites were not statistically significant, so it does not appear that sperm whales consistently use some areas around Niihau more than others.

Q3b. Do sperm whale detection rates vary before, during, and after MFAS detections?

Sperm whale encounters occurred before and/or after four of the six MFAS exposure periods examined. No encounters occurred at any EAR site during days of MFAS activity, but statistically this was likely due to chance, given the infrequent overall occurrence of sperm whales in the area (< 20 percent of days). **No statistically significant trends were noted with respect to the occurrence of sperm whales before or after MFAS.** Differences in the number of encounters/day and encounter duration during the 7 days before vs. 7 days after MFAS exposure were not significant. Therefore, based on these particular data, the answer to monitoring question Q3b appears to be no. However, this answer must be qualified by the fact that **the occurrence of sperm whales relative to MFAS events was low, so it cannot be known whether any sperm whales were actually exposed to MFAS**. Moreover, the high amplitude of sperm whale clicks likely results in detection ranges on the order of kilometers, so the location of sperm whales (even had they been detected during MFAS) and therefore the exposure to MFAS could not have been reliably inferred.

4.4 Delphinids

Q4a. What species of delphinids occur near Niihau and Kaula Islands in the HRC?

The EAR sites ordered from highest to lowest levels of delphinid activity were NW Niihau, Pueo Point, SW Niihau, and Kaula Island. There were also marked seasonal patterns, with greater encounter rates and mean encounter duration during the summer/fall deployment periods (deployments 1 and 3) than during the winter/spring deployment (deployment 2).

In order from most to least common, delphinid encounters throughout the 3 EAR deployments were classified by ROCCA as spinner/striped dolphin, bottlenose dolphin, rough-toothed dolphin, spotted dolphin, false killer whale, and pilot whale. Within deployment 3, manually classified encounters from most to least common signal group type were: HF & LF whistles, HF whistles, LF whistles, and clicks only. Within the HF & LF and HF whistle groups, the majority of ROCCA classifications were attributed to spinner/striped dolphins (**Table 12**). Within the LF whistle group, ROCCA classifications were divided among false killer whales, rough-toothed dolphins, and pilot whales. These results are corroborated by mean whistle characteristics reported in Oswald et al. (2003) and Oswald et al. (2007), wherein delphinid species in the HRC would typically be categorized as follows: bottlenose dolphins, striped dolphins and pantropical spotted dolphins into HF & LF whistles (all exhibit average minimum frequency < 10 kHz and maximum > 10 kHz); spinner dolphins into HF whistles (average minimum and maximum frequency 9.99 kHz and 15.09 kHz, respectively); and false killer whale, short-finned pilot whale, and rough-toothed dolphins into the LF whistle category, with average minimum and maximum frequencies ranging from 3.73–6.46 kHz to 6.39–9.53

kHz, respectively (Oswald et al. 2007). These are not infallible rules, and there is likely some overlap, especially for the HF & LF and HF categories, i.e., *Stenella* spp. and bottlenose dolphins. There was good correspondence in diel patterns observed for the HF & LF, HF, and 'clicks only' group and the ROCCA spinner/striped dolphin class, and these correspond well with what is known about spinner dolphin nocturnal foraging and daytime resting behavior (**Figures 16 and 20**; see next paragraph). There was no strong diel pattern observed within the LF signal group, suggesting that species within this group ('blackfish' and rough-toothed dolphins) do not show the same strong shift in behavior from day to night.

Table 12 Delphinid encounters within deployment 3 only, as classified by OSI and ROCCA. Not every encounter was classified by ROCCA because only encounters made up of two or more wav files and containing at least 10 whistles were included in the ROCCA analysis.

			ROCCA species class						
OSI species class		**# enc.**	**% classif. by ROCCA**	**bottle-nose**	**false killer whale**	**pilot whale**	**rough-toothed**	**spinner/ striped**	**spotted**
	HF&LF	847	50%	16%	4%	1%	10%	69%	1%
	HF	453	22%	9%	0%	0%	1%	86%	4%
	LF	263	37%	1%	46%	19%	33%	1%	0%
	Clicks only	360	0%	NA	NA	NA	NA	NA	NA

The overlap in time-frequency characteristics of whistles produced by spinner and striped dolphins (Oswald et al. 2007) make them particularly difficult to distinguish from one another. Because of this, spinner and striped dolphins were grouped together into one class (spinner/striped) for the ROCCA classification analysis. Most or all of the acoustic encounters identified as spinner/striped dolphins are likely spinner dolphins, as striped dolphins are relatively rare in Hawaiian waters and are usually encountered in water depths greater than 3,500m (Baird et al. 2013b), well beyond the depth of the Niihau EAR deployments (all < 800 m). Spinner dolphins are one of the most commonly encountered whistling species in Hawaiian waters, especially close to shore (Mobley et al. 2000, Baird et al. 2013b). Examination of the number of acoustic encounters per hour of the day for the spinner/striped class (**Figure 16**) also suggests that most or all of the encounters were spinner dolphins. The diel temporal pattern observed on EARs deployed at NW Niihau, SW Niihau and Pueo Point corresponds with what is known about the general behavior of Hawaiian spinner dolphins. The number of acoustic encounters was low during the day and increased to a peak after sunset, with another peak just before sunrise at NW Niihau and Pueo Point (**Figure 16**). Based on previous visual and acoustic studies, Hawaiian spinner dolphins are known to rest quietly in shallow wind-protected areas along leeward coasts during the morning and mid-day (Norris et al. 1994). These periods of rest are characterized by an almost total lack of whistling (Lammers 2004). Spinner dolphins become acoustically active in the late afternoon/early evening, as they join other groups and move offshore to forage (Norris et al. 1994, Lammers 2004). Whistling activity has been shown to peak during travel and stay high during the night while animals are foraging (Brownlee 1983). While the number of acoustic encounters per hour of the day at NW Niihau, SW Niihau and

Pueo Point mirrored this pattern, the number of acoustic encounters per hour of the day observed at Kaula Island did not. At Kaula Island, acoustic encounters only occurred in the very early morning hours until about mid-day (**Figure 17**). Kaula Island is a small remnant of the rim of a tuft crater, with steep slopes and fewer suitable spinner dolphin resting areas compared to other islands (Palmer 1936). It may be that the spinner/striped dolphin acoustic encounters recorded at Kaula Island were spinner dolphins primarily engaged in night-time foraging, who then moved to other areas to rest during the afternoon, possibly including areas around Kaula that were acoustically shielded or outside the detection distance of the EAR.

Keawanui Bay, not far from where the NW Niihau EAR was deployed, is a shallow protected bay on the leeward side of Niihau, which makes it a potential resting location for spinner dolphins. This may explain why the NW Niihau EAR had the highest number of acoustic encounters per day during all three deployments. The number of acoustic encounters per day was largely driven by spinner/striped dolphins for all EARs, as this species-group consistently made up over 50 percent of acoustic encounters. Locations with more potential spinner dolphin resting habitat (such as the EAR sites at NW Niihau and Pueo Point) had a higher number of acoustic detections per day than locations that may have relatively fewer available resting areas, such as Kaula Island, which had the lowest number of spinner/striped dolphin acoustic detections per day during deployments 1 and 2 (**Table 9**). There was no EAR deployed at Kaula Island during deployment 3 and the lowest number of acoustic encounters per day occurred at SW Niihau during this deployment.

After spinner/striped dolphins, bottlenose and rough-toothed dolphins were the most commonly detected and ROCCA-classified species. Both species were detected at every EAR site and during every deployment with the exception of Kaula Island, deployment 2. The Kaula Island EAR only recorded for 20 days during deployment 2, so it is difficult to draw any meaningful conclusions about the presence of rough-toothed dolphins for that deployment period and location. The fact that bottlenose and rough-toothed dolphins were commonly detected on most EARs was expected based on previous visual surveys, photo-identification, tagging and genetic sampling that have occurred around Niihau and Kauai (for a summary, see Baird et al. 2013b). Four demographically isolated insular bottlenose dolphin populations have been reported in the Hawaiian Islands, with a resident, island-associated population occurring off Niihau and Kauai (Baird et al. 2009, Martien et al. 2012). Rough-toothed dolphins were the most commonly encountered species during 310 hours of visual survey effort off Niihau and Kauai in 2011 and 2012 (Baird et al. 2013b) and the fifth most commonly encountered odontocete species during 369 hours of visual survey effort around the Hawaiian Islands from 2000 to 2006 (Baird et al. 2008b).

An examination of temporal trends indicates that every species had the highest number of encounters per day at all EARs during deployment 1, with the exception of pilot whales and false killer whales at SW Niihau and Pueo Point (**Table 9**). These results suggest the waters around Niihau were more favorable to delphinids during the summer/fall months comprised by deployment 1 than they were during the winter/spring months comprised by deployment 2. Rough-toothed dolphins also exhibited a slight diel pattern, with a peak in the number of acoustic encounters at midnight and another peak at 0300 (**Figure 19**). These peaks suggests that rough-toothed dolphins may have been foraging at night similar to spinner dolphins; however the limited sample size in this study makes it difficult to assess the significance and consistency of this temporal pattern. A diel pattern in the number of acoustic encounters per hour was not evident for bottlenose dolphins. The number of acoustic encounters per hour of the day was relatively constant for this species (**Figure 18**).

False killer whales, pilot whales and spotted dolphins were the least common species identified by ROCCA in the EAR recordings. Pilot whales and false killer whales were not detected at all during deployment 2 and daily acoustic encounter rates were low for these species during deployments 1 and 3 ($\leq$0.12 for most EARs, **Table 9**). The only exception was an acoustic encounter rate of 0.22 encounters per day for false killer whales at Niihau NW. Spotted dolphins were detected during all three deployments, but with very low daily encounter rates ($\leq$0.02, **Table 9**). False killer whales, pilot whales and spotted dolphins have all been reported to be common in Hawaiian waters (Carretta et al. 2009), but these species spend more time in deeper waters over the slope and beyond (Baird et al. 2013b) than in the relatively nearshore habitats where the EARs were deployed. In addition, the relative abundance of several species around Kauai and Niihau has been reported to be different than would be expected based on their abundance in other areas of the Hawaiian Islands. For example, during visual and photo-identification surveys in Hawaiian waters between 2000 and 2012, spotted dolphins were the most abundant species around Oahu and the Big Island of Hawaii, but only represented 3.9% of sightings off Kauai and Niihau (Baird et al. 2013b). In contrast, rough-toothed dolphins were sighted more frequently off Kauai and Niihau than was expected given their sighting rates off the other Hawaiian Islands (Baird et al. 2013b). These differences may be due to oceanographic differences among the islands that affect the presence of prey for these species (Baird et al. 2013b). Baird et al. (2013b) also speculated that differences in the distribution of species could be caused by differences in anthropogenic activities around the different islands.

The classifier used to identify species in the Niihau EAR recordings contained seven species commonly encountered in Hawaiian waters. However, several whistling species that have been documented in Hawaiian waters are not represented in the classifier due to a lack of single species recordings, which are necessary for training and testing the classifier. These species include melon-headed whales, pygmy killer whales, killer whales, and Fraser's dolphin. Based on five years of visual survey effort by Baird et al. (2013b), all four of these species are rare or absent around Niihau and so their omission is not likely to have significantly affected the results presented here. Efforts are currently underway to add more species to ROCCA's tropical Pacific classifier so that future classifiers will be more complete and accurate.

The results of this analysis provide insight to spatial and temporal patterns in delphinid species occurrence in an area that is regularly used in Navy training exercises. However, when examining the results of this analysis, it is important to be aware of the assumptions that were made during the classification process. First, whistles were grouped into acoustic encounters, with a new acoustic encounter defined as a period in which 30 or more minutes elapsed between whistles. Acoustic encounters were used as a proxy for individual schools. Because there were no visual observations associated with the acoustic recordings and we were not able to localize whistles (and therefore track schools), it is not possible to ensure that a new encounter signified that one school had left the area and a new school had entered. In some instances, the animals may have been quiet for 30 or more minutes but remained in the area and then started to whistle again. In other instances, a new school may have moved into an area after fewer than 30 minutes of silence. Because of this, the absolute number of acoustic encounters may be an over- or under-estimate for individual species, but because the same assumption was made for all species, we believe that the relative number of encounters compared among species or EAR sites is likely representative of the true patterns of species occurrence. The addition of localization capabilities to deployments of moored acoustic recorders would make it possible to track schools and more accurately identify independent groups of dolphins.

Another assumption that was made during this analysis was that all classifications made by ROCCA were correct. The ROCCA classifier used to identify species performed well on test data, with correct classification scores that were significantly greater than chance for all species; however, it was not 100 percent accurate (**Table 3**). For pilot whales, most misclassified schools were identified as false killer whales, and vice versa. This suggests that for the Niihau EAR data, any school classified as one of those species was very likely a 'blackfish' species. For spotted, bottlenose and spinner/striped dolphins, classification errors were generally evenly spread among species but the percent of schools correctly classified was significantly greater than the percent of schools classified as any other individual species. As a result of the even distribution of misclassifications during testing, the absolute numbers of encounters may be slightly inaccurate, but relative patterns of occurrence should be representative of true occurrence patterns. For rough-toothed dolphins, classification errors were split between spinner/striped dolphins and false killer whales, but again the percentage of schools correctly classified was high enough to allow relative occurrence patterns to be represented relatively accurately.

Another possible source of error in species identification is the presence of mixed species schools. ROCCA currently cannot identify mixed species schools, so if multiple species were simultaneously present and whistling, the classification results would not reflect this. This may have resulted in under-representation for some species and over-representation for others. The identification of mixed species schools is a substantial challenge and the ability to overcome this challenge would be a significant step forward in the field of passive acoustic monitoring.

Q4b. Do delphinid detection rates vary before, during, and after MFAS detections?

For delphinids grouped as a whole, there were no statistically significant differences in encounter rate or duration within the periods of 3 days before, during, and 3 days after all MFAS exposure periods. When stratified by EAR site and by MFAS exposure period, there were variations in these metrics, but there was no consistent directional pattern (increase or decrease before, during or after MFAS). Thus, no broad-scale, consistent changes in overall delphinid occurrence near the monitored locations were found in relation to multi-day MFAS events.

There was, however, some evidence for potential species-specific responses to MFAS. No statistically significant differences in the encounter rate of any species or signaling group were observed among the 3 days before, during, and 3 days after periods around MFAS exposure periods. However, **the encounter duration was significantly different for rough-toothed dolphins (greatest during MFAS and lowest 3 days after; Figure 24) and the LF whistle signal group (significantly lower duration in the 'during' and '3 d after' period than**

before; Figure 26) for pooled MFAS exposure periods. In addition, encounter rates for spinner/striped dolphins varied significantly in three of four individual MFAS exposure periods tested (but the pattern was not the same in each MFAS period), and encounter duration was significantly different in one of the four examined MFAS exposure periods. These results suggest that response to MFAS may be species and/or event-specific, and responses could include either increased or decreased acoustic presence (indicated by encounter rate and/or duration). Changes in acoustic occurrence could be linked to many possible behavioral changes and/or stress responses; a decrease in detected encounter rates or duration could indicate avoidance behavior or decreased vocalization rates, whereas an increase could indicate heightened alertness or a response to masking.

Several caveats should be noted when interpreting these results. The first relates to the small sample sizes and high variability in encounter duration. For example, the increased mean duration of rough-toothed dolphin encounters during MFAS is based on only three encounters total in that time bin, and the duration of each of these individual encounters was within the range observed for rough-toothed dolphin encounters in general. The observed differences in encounter duration for some species in the 'during' or 'after' MFAS periods could be a chance result of this high natural variability rather than a response to MFAS. Data were pooled for most species in order to provide sufficient sample size for quantitative analysis, but pooling in this fashion does not allow for investigation of specific responses to a given MFAS event or other stimulus. If responses are present, but inconsistent (for example, sometimes moving toward an area and sometimes moving away), these effects would not be detectable in pooled data. For some species, such as false killer whales, acoustic encounters were only detected around one MFAS event. Anecdotally, the presence of false killer whales before and during the onset of MFAS, but absence during the 3-day period that followed, suggests some evidence of an effect, but statistically this was not significant.

Another issue is that there were far more unidentified delphinid encounters than ROCCA-classified encounters; sample sizes for species-specific analyses would increase and stronger patterns may emerge if all encounters could be classified and included. Classification using ROCCA required at least 10 whistles with a 3-decibel signal-to-noise ratio and two or more consecutive EAR recording files. If animals change their acoustic behavior in response to sonar, the probability of classifying signals may not be the same during periods with MFAS versus periods without MFAS. Further analysis would be required to investigate whether signaling rates and characteristics of individual whistles or clicks differed around MFAS events, but such analysis would be limited for duty-cycled data.

Finally, the duty cycle of the EARs varied -- most instruments in deployments 1 and 2 recorded 30 seconds on every 5 minutes, but Kaula (deployments 1 and 2) and the third deployment EARs recorded 30 seconds on every 10 minutes, possibly influencing the ability to detect and classify signals as well as assess encounter duration on the same scale as the other EAR sites. Another factor influencing the ability to detect signals was the location of the EARs. Although modeling sound propagation characteristics at each EAR site was outside the scope of this study, the variation in bathymetry and placement around islands could be expected to result in differences in detection range at each EAR, which would also vary depending on species-specific call characteristics (e.g., source level, frequency). In addition, cetacean species that occur in Hawaiian waters are known to have different depth preferences (see discussion of depth preferences in **Section 4.4, Q4a**; Baird et al. 2013b), so the EAR depths of 500–800 m likely influenced which species were detected and their relative representation in the data set.

Results from this and other studies point to the difficulty in collecting and interpreting behavioral data, particularly for highly mobile and social animals with variable behavior such as dolphins. Changes in vocal behavior in response to anthropogenic noise have been studied in several species of marine mammals. For example, beluga whales (*Delphinapterus leucas*), killer whales (*Orcinus orca*) and Pacific humpback dolphins (*Sousa chinensis*) have been documented to change call rates and time-frequency characteristics of their calls in response to vessel noise (Au et al. 1985, Van Parijs and Corkeron 2001, Foote et al. 2004; Lesage et al. 1999). Much less is known about the behavioral responses of odontocetes to MFAS. Rendell and Gordon (1999) reported that long-finned pilot whales (*Globicephala melas*) increased whistling rates during and after exposure to military sonar signals. DeRuiter et al. (2013a) found that false killer whales (*Pseudorca crassidens*) and melon-headed whales (*Peponocephala electra*) increased whistling rates and appeared to mimic played-back MFAS signals after exposures. Other studies have documented acoustic and behavioral responses in delphinids exposed to MFAS, but responses were not consistent and were not always observed (Henderson et al. 2014).

It is difficult to discern whether variation around MFAS is due to MFAS or to normal variability, and there are many factors that could play a role in the magnitude of a response (if any), including prior behavioral state, depth, proximity to sound source, sound exposure level, environmental conditions, characteristics of the MFAS signals, and others. Finer-scale metrics may be needed to quantify acoustic response (if any) to MFAS, including changes in the characteristics of vocalizations themselves in addition to changes in the occurrence of vocalizations. These may require continuous recording before, during, and after MFAS, as well as substantial recording sessions spanning several lunar and seasonal cycles to establish baseline occurrence and temporal variability.

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