APPENDIX B

PASSIVE ACOUSTIC MONITORING FOR CETACEANS WITHIN THE MARIANAS ISLANDS RANGE COMPLEX (MIRC)

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14. ABSTRACT
A long-term passive acoustic monitoring program was initiated in 2011 by the United States (U.S.) Navy Pacific Fleet in waters off Guam and the Commonwealth of the Northern Marianas Islands to investigate the occurrence of cetaceans and mid-frequency active sonar (MFAS). Four ecological acoustic recorders (EARs) were deployed at two sites off Guam, one at Saipan, and one at Tinian on September 2011. The four EARs wereretrievedand redeployed at the same sites in April 2012.Three of the four EARs wereretrieved in January 2013. The second EAR deployed at Guam S 11 mi was unable to be recovered due to presumed loss of battery power. Manual analyses were conducted to detect and classify delphinid signals based on whistle frequency bands categorized as “low-frequency” (LF), comprising whistles predominantly below 10 kilohertz (kHz); “low-frequency and high-frequency” (HF&LF), comprising whistles with energy below and above 10 kHz; and “high-frequency” (HF), comprising whistles predominantly above 10 kHz. The Marine Mammal Monitoring On Navy Ranges (M3R) Support Vector Machine automated detector, developed for the U.S. Navy, was implemented to detect clicks from beaked whales (Ziphiuscavirostrisand Mesoplodon spp.) and sperm whales (Physetermacrocephalus), and an automated detector for baleen whales developed at the Hawaii Institute of Marine Biology was employed to detect calls from five baleen whale species: blue whale (Balaenopteramusculus), fin whale (B. physalus),sei whale (B. borealis), minke whale (B. acutorostrata), and humpback whale (Megapteranovaeangliae). Manual data analyses have been completed for Guam S 11 mi, Saipan N, and Tinian W—three of the four sites from the first round of EAR deployment—and indicate potential differences in abundance, species assemblages, and temporal patterns. The greatest delphinid encounter rates overall were at Saipan, moderate encounter rates occurred at Tinian, and lowest encounter rates were at the southwest Guam site, potentially indicating high, medium, and low relative

abundance of delphinids, respectively. Analysis of the first deployment of Guam N is pending. Within the whistle groupings, LF whistling species were more frequently encountered at Guam than the HF&LF and HF categories, whereas at Saipan and Tinian mixed HF&LF whistles were the most commonly encountered of the three groups. Sperm whale encounters were logged manually as well and occurred sporadically throughout the three deployments analyzed to date, with periods of 1 to 3 days with encounters separated by periods of several days up to four weeks with no sperm whale detections. Three MFAS events were detected at southwest Guam and one at Saipan. The duration of these events ranged from a single 3-second ping to 28 hours of near-continuous pinging across more than 2 days of exercises. The reduction or absence of delphinid detections after the longer sonar exercises, which extended hours to days in duration, suggests a possible relationship between sonar duration and dolphin acoustic behavioral response. More data and investigations are needed to quantitatively support this anecdotal observation.

Beaked whale and sperm whale signals were detected by M3R-support vector machine software on approximately 80% of the recording days on average within each data set except for the southwest Guam site, which had a very low beaked whale detection rate. Detection rates varied widely from day to day, but showed a strong diel pattern, with higher detection rates during nighttime hours between 1800 and 0600. Temporal patterns in daily and hourly detection rates were nearly identical for the two groups, suggesting either identical behavior patterns in the two different groups, or detector inaccuracy and the need for further validation of automated results.

The automated baleen whale detector detected only a few files with minke whale (Balaenopteraacutorostrata) and humpback whale(Megapteranovaeangliae) vocalizations during the first deployment at northern Guam and Saipan, respectively, and only 2 days with 39 humpback whale detections at Saipan during the second deployment. The lack of baleen whale detections may be related to a lack of recording during most of winter (i.e., January–April), which is when baleen whales are known to occur in other tropical habitats in the northern hemisphere, or it may reflect very little use of these areas by baleen whales.Further confirmation and detection efforts may be needed to corroborate and/or augment the automated detector results.

15. SUBJECT TERMS

Marine mammal, passive acoustic monitoring, Guam, Commonweath of the Northern Mariana Islands

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PASSIVE ACOUSTIC MONITORING FOR CETACEANS WITHIN THE MARIANAS ISLANDS RANGE COMPLEX (MIRC)

Contract No. N62470-10-D-3011, Task Orders KB17 and KB14

PRELIMINARY REPORT

Prepared for:

Commander, U.S. Pacific Fleet

Submitted to:

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Prepared by:

Lisa M. Munger, Marc O. Lammers, and Whitlow W.L. Au

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Executive Summary

A long-term passive acoustic monitoring program was initiated in 2011 by the United States (U.S.) Navy Pacific Fleet in waters off Guam and the Commonwealth of the Northern Marianas Islands to investigate the occurrence of cetaceans under the Mariana Islands Range Complex (MIRC) monitoring plan. Four ecological acoustic recorders (EARs) were deployed at two sites off Guam, one at Saipan, and one at Tinian on September 2011. The four EARs were retrieved and redeployed at the same sites in April 2012. Three of the four EARs were retrieved in January 2013. The second EAR deployed to the southwest of Guam ("Guam S 11 mi") was unable to be recovered due to presumed loss of battery power. Manual analyses were conducted to detect and classify delphinid signals based on whistle frequency bands categorized as "low-frequency" (LF), comprising whistles predominantly below 10 kilohertz (kHz); "low-frequency and high-frequency" (HF&LF), comprising whistles with energy below and above 10 kHz; and "high-frequency" (HF), comprising whistles predominantly above 10 kHz. The Marine Mammal Monitoring On Navy Ranges (M3R) Support Vector Machine automated detector, developed for the U.S. Navy, was implemented to detect clicks from beaked whales (*Ziphius cavirostris* and *Mesoplodon* spp.) and sperm whales (*Physeter macrocephalus*), and an automated detector for baleen whales developed at the Hawaii Institute of Marine Biology was employed to detect calls from five baleen whale species: blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*),sei whale (*B. borealis*), minke whale (*B. acutorostrata*) and humpback whale (*Megaptera novaeangliae*).

Manual data analyses have been completed for Guam S 11 mi, Saipan N, and Tinian W—three of the four sites from the first round of EAR deployment—and indicate potential differences in abundance, species assemblages, and temporal patterns. The greatest delphinid encounter rates overall were at Saipan, moderate encounter rates occurred at Tinian, and lowest encounter rates were at the southwest Guam site, potentially indicating high, medium, and low relative abundance of delphinids, respectively. Analysis of the first deployment of Guam N is pending. Within the whistle groupings, LF whistling species were more frequently encountered at Guam than the HF&LF and HF categories, whereas at Saipan and Tinian mixed HF&LF whistles were the most commonly encountered of the three groups. Sperm whale encounters were logged manually as well and occurred sporadically throughout the three deployments analyzed to date, with periods of 1 to 3 days with encounters separated by periods of several days and up to four weeks with no sperm whale detections. Three MFAS events were detected at southwest Guam and one at Saipan. The duration of these events ranged from a single 3-second ping to 28 hours of near-continuous pinging across more than 2 days. The reduction or absence of delphinid detections after the longer sonar events, which extended hours to days in duration, suggests a possible relationship between sonar duration and dolphin acoustic behavioral response. More data and investigations are needed to quantitatively support this anecdotal observation.

Beaked whale and sperm whale signals were detected by M3R-support vector machine software on approximately 80% of the recording days on average within each data set except for the southwest Guam site, which had a very low beaked whale detection rate. Detection rates varied widely from day to day, but showed a strong diel pattern, with higher detection rates during nighttime hours between 1800 and 0600. Temporal patterns in daily and hourly detection rates

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The automated baleen whale detector detected only a few files with minke whale (*Balaenoptera acutorostrata*) and humpback whale (*Megaptera novaeangliae*) vocalizations during the first deployment at northern Guam and Saipan, respectively, and only 2 days with 39 humpback whale detections at Saipan during the second deployment. The lack of baleen whale detections may be related to a lack of recording during most of winter (i.e., January–April), which is when baleen whales are known to occur in other tropical habitats in the northern hemisphere, or it may reflect very little use of these areas by baleen whales. Further confirmation and detection efforts may be needed to corroborate and/or augment the automated detector results.

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Acronyms and Abbreviations

AI	Acoustic Index
CNMI	Commonwealth of the Northern Marianas Islands
CRP	Cetacean Research Program
DAA	Daily Acoustic Abundance (*delphinids*)
dB re 1 μPa	decibels referenced to one microPascal
EAA	Encounter Acoustic Abundance
EARs	Ecological Acoustic Recorders
HF	high frequency
HIMB	Hawaii Institute of Marine Biology
h	hour(s)
kHz	kilohertz
LF	low frequency
HF&LW	high and low frequency mixed
HF	high frequency
LTSA	long-term spectral average
MFAS	mid-frequency active sonar
MIRC	Marianas Island Range Complex
M3R	Marine Mammal Monitoring On Navy Ranges
PACFLT	U.S. Navy Pacific Fleet
PAM	passive acoustic monitoring
PIFSC	Pacific Islands Fisheries Science Center
ROCCA	Real-time Odontocete Call Classification Algorithm
SVM	support vector machine
U.S.	United States

I. Introduction

Prior to the 21st century, cetacean occurrence in waters of the Commonwealth of the Northern Marianas Islands (CNMI) and Guam was not well documented due to little dedicated survey effort in this region. This region is of special interest to the United States (U.S.) Navy, which operates installations on the island of Guam and conducts exercises and other activities in the operational area known as the Marianas Islands Range Complex (MIRC). In January-April 2007, the Mariana Islands Sea Turtle and Cetacean Survey (MISTCS) was the first systematic line-transect survey for sea turtles and cetaceans in waters around Guam and the Northern Mariana Islands (DoN 2007). MISTCS included visual survey effort, towed hydrophone array and sonobuoy recordings. Beginning in 2010, smaller-scale cetacean visual surveys with opportunistic acoustic recordings around Guam and the CNMI aboard small boats have been conducted annually by the National Oceanic and Atmospheric Administration Pacific Islands Fisheries Science Center's (PIFSC) Cetacean Research Program (CRP) in partnership with the Commander, U.S. Navy Pacific Fleet (PACFLT) (Hill et al. 2013a,b). These surveys have documented the occurrence of several cetacean species. During the 2007 MISTCS survey, the most frequently seen species were sperm whales (*Physeter macrocephalus*), followed by Bryde's (*Balaenoptera edenii*) and sei whales (*Balaenoptera borealis*). The pantropical spotted dolphin (*Stenella attenuata*) was the most frequently encountered delphinid species, followed by the false killer whale (*Pseudorca crassidens*) and the striped dolphin (*Stenella coeruleoalba*). There were also three sightings of beaked whales (two *Mesoplodon* spp. and one ziphiid whale). Species sighted during small-boat surveys in 2010 through 2012 were, in order of most frequently encountered: spinner dolphins (*Stenella longirostris*), pantropical spotted dolphins ,short-finned pilot whales (*Globicephala macrorhynchus*), bottlenose dolphins (*Tursiops truncatus*), sperm whales*)*, beaked whales (*Mesoplodon* spp, unidentified beaked whale), and one sighting each of a pygmy killer whale (*Feresa attenuata*) and dwarf sperm whale (*Kogia sima*) (Hill et al. 2013a). In 2013, these species were all seen again, as well as false killer whales and rough-toothed dolphins (*Steno bredanensis*) (Hill et al. 2013b). Some of these sightings consisted of mixed species groups including the following group compositions: pilot whales and bottlenose dolphins; false killer whales and bottlenose dolphins; and rough-toothed dolphins, bottlenose dolphins, and spinner dolphins (Hill et al. 2013b).

The vessel-based survey efforts conducted in 2007-2013 provide valuable new information on species occurrence and distribution in waters of Guam and CNMI, but are limited by time, logistics, weather conditions, and other factors associated with vessel platforms. Small-boat surveys conducted by PIFSCCRP/PACFLT in 2010 through 2013 did not detect any baleen whales, probably because effort was biased by the time of year (most effort was in summer, little effort in winter), because survey efforts were constrained by weather conditions and because the small boats used as a research platform could not survey over large distances offshore (Hill et al. 2013a,b). During the MISTCS effort in 2007, although survey effort was conducted offshore and in winter months, two-thirds (66%) of the effort took place in a Beaufort sea state of 5 or above, which limited visual detectability of animals. In 2011, PACFLT initiated a long-term passive acoustic monitoring (PAM) program to better understand the year-round occurrence of baleen whales, beaked whales and other odontocete species in the MIRC. HDR, Inc., subcontracted the Hawaii Institute of Marine Biology (HIMB), Oceanwide Science Institute, and Bio-waves, Inc. to collect and analyze data from four Ecological Acoustic Recorders (EARs) deployed in the

MIRC between September 2011 and January 2012 and three EARs deployed between April and September 2012, and report on the findings. In this report, the preliminary results of this effort are presented to provide answers to the following questions, numbered according to the subcontracted task orders from which they originate (KB14 and KB17).

KB14 monitoring questions:

Q1. What species of beaked whales (*Ziphius/Mesoplodon*) are in offshore areas of the MIRC adjacent to Guam and Saipan?

Q2. What is the seasonal occurrence of baleen whales in offshore areas of the MIRC adjacent to Guam and Saipan?

Q3. What is the seasonal occurrence of sperm whales in offshore areas of the MIRC adjacent to Guam and Saipan?

KB 17 monitoring questions:

Q4. What species of delphinids occur in offshore areas of the MIRC adjacent to Guam and Saipan?

Q5. Is mid-frequency active sonar (MFAS) present in the EAR data sets?

Q6. Were high-frequency sei whale (*Balaenoptera borealis*) calls detected on any EARs?

II. Methods

A. 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). During the first deployment, four EARs sampled at 80 kilohertz (kHz), providing a Nyquist bandwidth of approximately 40 kHz (anti-aliasing = 90%), with a recording duty cycle of 30 seconds 'on' every 6 minutes (8.3%). See **Table 1** for EAR programming specifics. During the second deployment, the recording duty cycle interval was changed to 30 seconds 'on' every 10 minutes (5%).

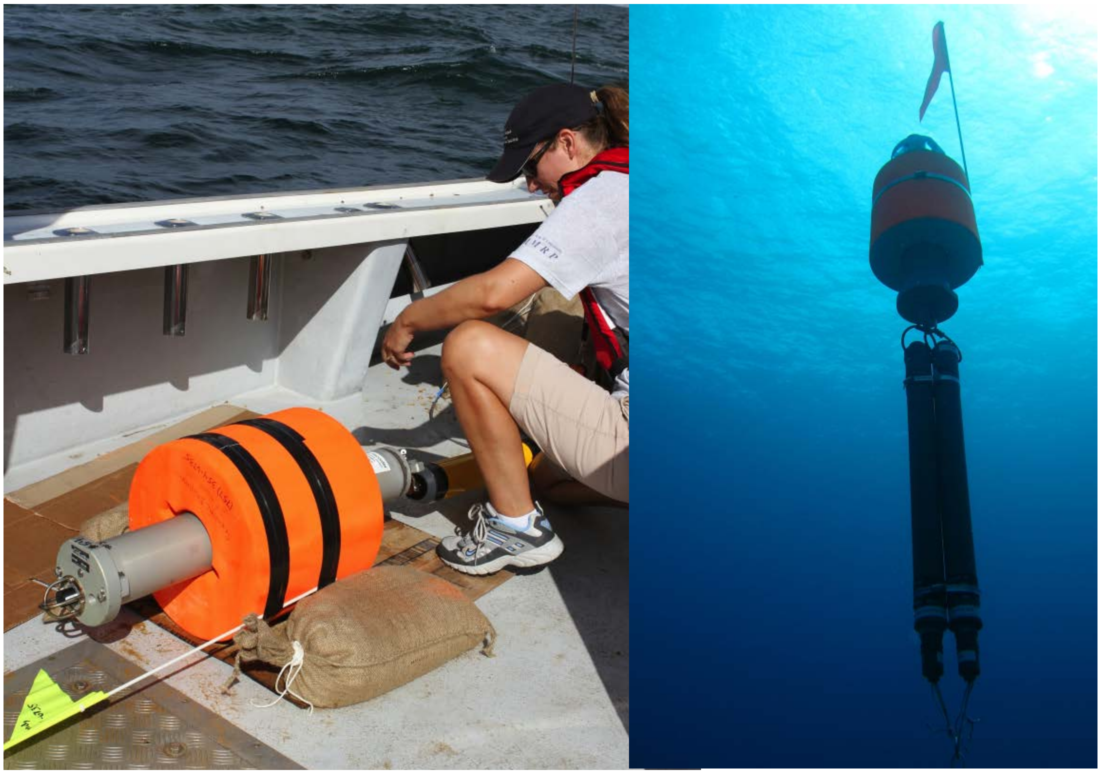


Figure 1. Images of an EAR prior to deployment and while deployed

Table 1.Recording parameters of MIRC EARs.

Sampling Rate	80 kHz
Recording Time (duration)	30 s
Recording Period (how often)	Dep. 1: 360 s (6 min) Dep. 2: 600 s (10 min)
Anti-Aliasing Filter	90%
Hydrophone Sensitivity	Approx. -193 dB re 1µPa
Clock	Local Time
Disk Space	320 GB maximum
Energy Detection	Disabled

dB re 1µPa = decibels referenced at 1 microPascal; Dep. = deployment; GB = gigabyte; kHz = kilohertz; s = second(s); % = percent; min = minute(s)

Two of the EARs were deployed in waters off Guam, labeled Guam S 11 mi and Guam N; one EAR was deployed west of Tinian (Tinian W); and one north of Saipan (Saipan N) (**Figure 2**), all in water depths between 778 and 944 meters (**Table 2**). All EARs were deployed with acoustic releases (ORE Edge Tech PORT LF). The first deployment of the four EARs was in September 2011 and the recording duration ranged between instruments from 62 days to 118 days (**Table 2**). These recording durations were shorter than anticipated (~180 days) and this was likely due to one of two reasons: a magnetic switch malfunction on the EAR and/or a faulty disk drive* (see Note). These EARs were refurbished and redeployed in April 2012 and three of the four units were recovered in January 2013 with recording durations up to 167 days. Logistical constraints delayed the recovery of these units until the limit of the expected battery life of the acoustic releases. As a result, the EAR at the Guam S 11 mi location was not recovered, most likely due to a battery failure on the release.

* Note: A defect with the magnetic switch component of several EARs manufactured after 2009 was identified in 2012 that causes the affected unit to power off unexpectedly and/or drain current from the batteries. The manufacturer of the switches has acknowledged this problem and as a result magnetic switches are no longer used on EARs. It is also possible that one or more EAR hard drives may have developed bad sectors during shipping/deployment due to jarring, which can cause an error during data transfer from the memory buffer to the disk resulting in a software crash. This issue has since been resolved on EARs via a software update.

Table 2. EAR deployment sites and recording summary.

Deployment 1 Site	Lat/Lon	Depth (m)	Recording Period	# of 30-s Recordings	Total Recording Hours
Deployment 1 Site					
Guam North	13° 41.781′ N 144° 45.186′ E	820	9/10/2011-1/06/2012	28320	236
Guam South 11 mile	13° 13.392′ N 144° 28.303′ E	952	9/16/2011-11/17/2011	14839	124
Tinian West	15° 04.602′ N 145° 26.676′ E	869	9/12/2011-11/28/2011	18478	154
Saipan North	15° 27.292′ N 145° 50.938′ E	850	9/12/2011-12/29/2011	25279	211
Deployment 2 Site					
Guam North	13° 41.789′ N 144° 45.209′ E	778	4/06/2012-9/05/2012	21818	182
Guam South 11 mile	13° 13.388′ N 144° 28.277′ E	944	NA	NA	NA
Tinian West	15° 04.605′ N 145° 26.667′ E	860	4/08/2012-4/23/2012	2141	18
Saipan North	15° 27.283′ N 145° 50.931′ E	840	4/8/2012-9/22/2012	23981	200

Lat = Latitude; Lon= Longitude; m = meters; s = seconds; # = number

B. Analysis methods

1. Manual analysis protocols

Odontocete whistles and clicks (excluding beaked whale clicks) were detected using the MATLAB script, Triton, developed at Scripps Institution of Oceanography (Wiggins 2003) 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.

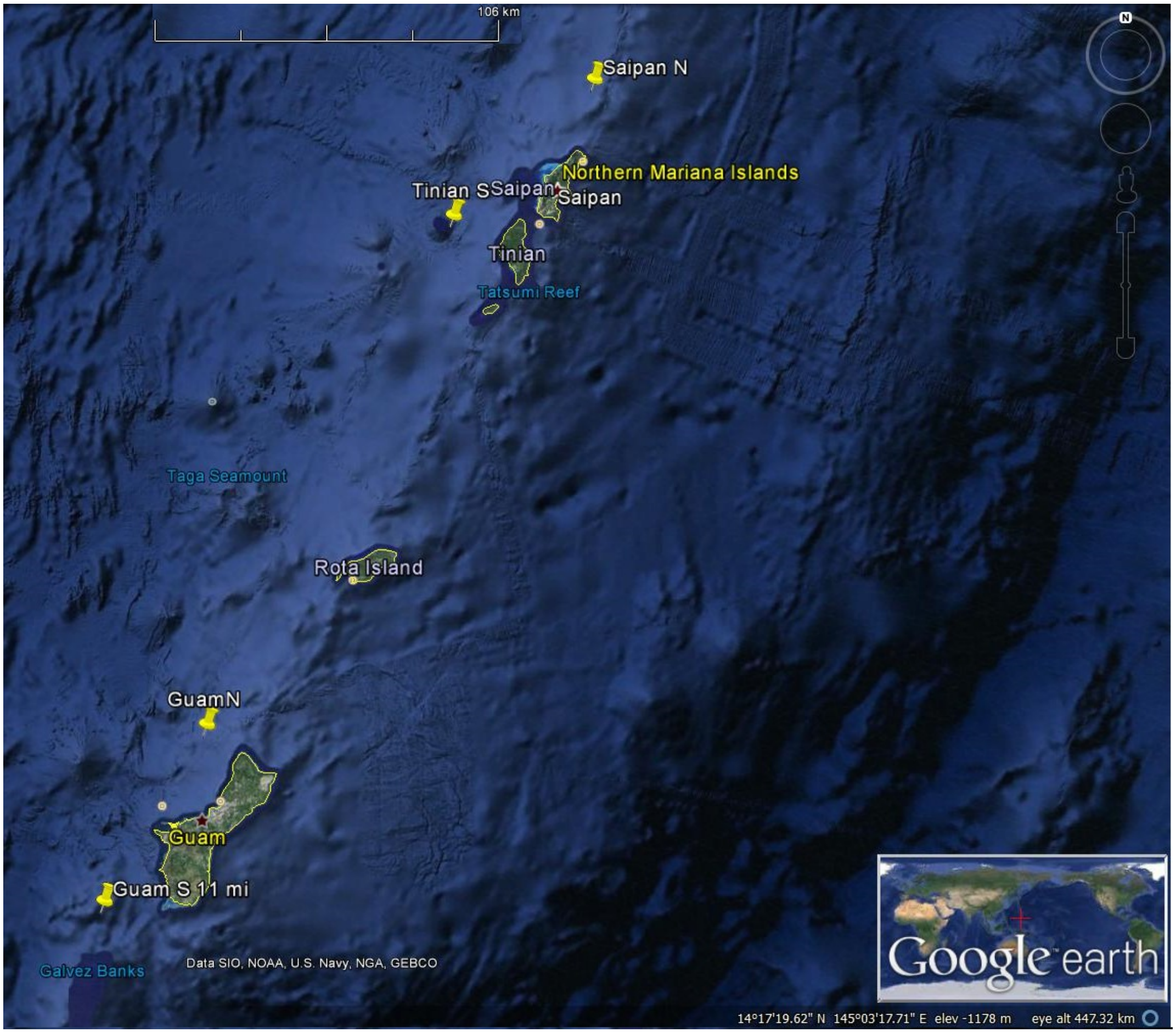


Figure 2.Map of MIRC EAR deployments. Yellow pushpins indicate EAR deployments.

Odontocete whistles and clicks 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 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.

An example LTSA and spectrogram display from the Guam S 11 mi site is shown in **Figure 3**. In addition, a preliminary scan of the frequency band from 0–2kHz was performed on the LTSA to search for high-frequency sei whale calls, similar to those recorded during MISTCS 2007 (Norris et al, 2012)

Four categories of odontocete sounds were logged: three whistle categories based on frequency, and one category for clicks. Whistle categories were delineated as follows: low-frequency ("LF") whistles with most energy below 10 kHz, high-frequency ("HF") whistles with most energy greater than 10 kHz, and "LF&HF", 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 odontocete 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). Dolphin species identification based on whistle characteristics (e.g., Oswald et al. 2003, 2007) was not performed as part of this study.

Broadband pulses produced by odontocetes were classified as echolocation clicks. **Figure 3** shows an LTSA window with a zoomed-in spectrogram below of a recording containing whistles and some echolocation clicks. Sperm whale clicks were logged separately; the clicks of this species are distinctive because of their low frequency relative to other odontocete clicks (see section II.B.2; Madsen et al. 2002; Mohl et al. 2003). The occurrence of MFAS was also noted.

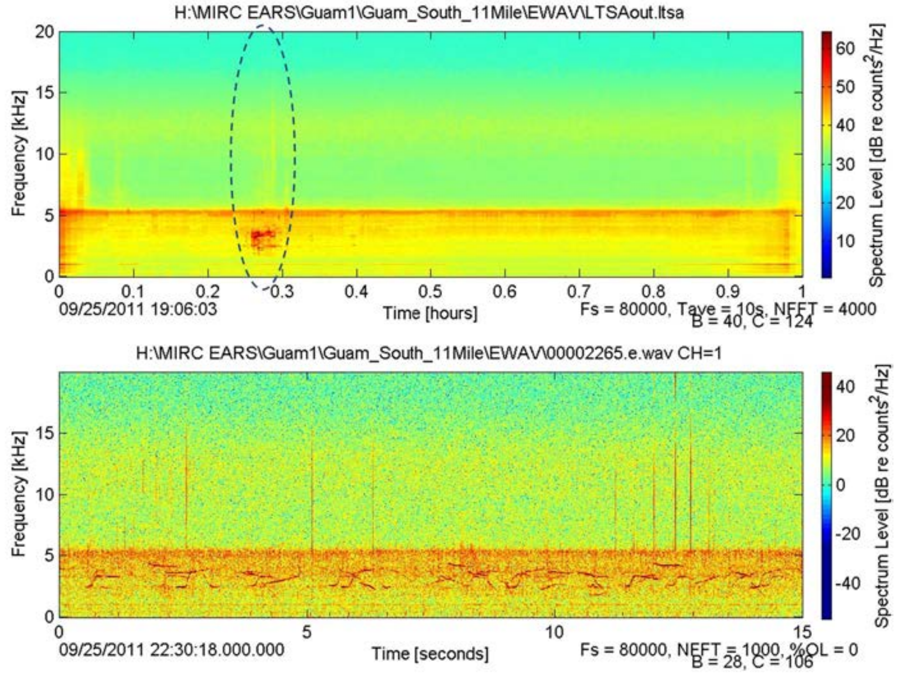


Figure 3. Figure window from Triton showing LTSA (top), with circled region of high energy in whistle frequency band, and expanded spectrogram (bottom) verifying presence of whistles and clicks.

Odontocete signals were grouped into encounters for further analysis. An encounter was defined as a time period consisting of one or more recording containing signals (whistles and/or clicks) occurring within 30 minutes of the next recording with signals. Therefore, the start and end of each encounter was separated from the next encounter by more than 30 minutes. Within each encounter, the five recordings with the greatest intensity/rate of signaling were assigned an Acoustic Index (AI) value based on the number and type of signals present (**Table 3**). For encounters with less than five recordings containing dolphin signals, zeroes were scored for the remainder of the five detections. The five AI scores within an encounter were then averaged to produce a measure of the amount of signaling for each encounter, and the result is the Encounter Acoustic Abundance (EAA). EAA was weighted by the encounter duration by multiplying the EAA by the duration of the encounter as a fraction of one day. For example, the EAA for a 1-hour encounter would be weighted by a factor of 1/24, or 0.0417. To show the amount of daily dolphin acoustic activity, the sum of the day's weighted EAA values, designated Daily Acoustic Abundance (DAA), was calculated and plotted. The start and end times of sperm whale encounters were also logged, but no abundance scores were assigned.

In order to summarize and examine patterns of occurrence by different signal types, odontocete encounters were stratified into four groups: clicks (including burst pulses), HF whistles, LF whistles, and HF&LF whistles. Clicks and whistles were not mutually exclusive; for example an HF whistle encounter would contain whistles above 10 kHz but could also contain some echolocation clicks and/or burst pulses. This recording would count as a 'Clicks' encounter as well. Therefore, the sum of the encounters reported across these four categories may exceed the

Table 3.Acoustic Abundance scores used to calculate Encounter Acoustic Abundance using the abundance of dolphin whistles, burst pulses and echolocation clicks (Sonar).

Signal Type & Rate	Acoustic Index
Whistles 1 - 5	1
BP only <5	1
Sonar only <1/2 rec	1
Whistles 6 - 10	1.5
Sonar only >1/2 rec	1.5
Sonar & BP <5	1.5
1-5 whistles & sonar or BP	2
Whistles >10	2.5
Sonar & BP >5	2.5
1-5 whistles Sonar & BP	3
6-10 whistles & sonar or BP	3
6-10 whistles Sonar & BP	3.5
>10 whistles & sonar or BP	3.5
>10 whistles Sonar & BP	4

BP = burst pulse;< = less than; > = greater than

total number of encounters overall on each EAR. Summary data (number of encounters, mean encounter duration, and sum of DAA) were normalized by the number of instrument effort-days (i.e., the number of days from the first to last day of recording at each site), in order to compare across sites.

2. Description of M3R analysis algorithms

Automated detection methods were implemented to investigate potential occurrence of beaked whale and sperm whale clicks in EAR data from the MIRC. Analyses were conducted using the Support Vector Machine (SVM) portion of the M3R software (Jarvis et al. 2008; Jarvis 2012) and custom MATLAB programs. The SVM portion of the M3R software uses nine dimensional feature vectors formed by computing the time between 6 zero crossings about the peak and 3 normalized envelope amplitude peaks. M3R is the primary Navy software used to detect and identify deep-diving odontocetes at the following U. S. Navy ranges: Atlantic Undersea Test and Evaluation Center, Southern California Offshore Range and Pacific Missile Range Facility. The M3R software contains templates of biosonar signals recorded in the aforementioned regions from the short-finned pilot whale, Risso's dolphin (*Grampus griseus*), sperm whales, Cuvier's (*Ziphius cavirostris*) and Blainville's beaked (*Mesoplodon densirostris*) whales, and spinner dolphins. A validation test of the M3R detector was performed in the study of Au et al. (2014a) using data collected by an EAR deployed off Kauai, Hawaii. A second validation test is presently being conducted by BioWaves, Inc. also using EAR data from Hawaii. Those validation results are not yet available. No validation test has been made for EAR data collected in the MIRC.

For this report, the focus is on M3R detector results for beaked whales (including Cuvier's and Blainville's) and sperm whales, which have unique click characteristics among the odontocetes. Beaked whales are the only odontocetes known to consistently produce biosonar signals that are frequency modulated (Johnson et al. 2004; Madsen et al. 2005; Zimmer et al. 2005). Sperm whales produce distinctive clicks with peak frequencies between approximately 5 and 15 kHz (Madsen et al. 2002; Mohl et al. 2003). Detection rates for beaked whales and sperm whales are reported on a per file basis. During the first deployment, a 30-second file was recorded every 6 minutes, resulting in 240 files per day. The duty cycle was increased to 10 minutes for the second deployment, resulting in 144 files per day.

3. Description of automated baleen whale call analysis algorithms

An automated baleen whale detector was developed by Dr. Helen Ou (HIMB) to identify the presence of calls from five species of baleen whales: blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), sei whale (downswept calls other than "high-frequency calls"), minke whale ("boings"), and humpback whale. The automated detector processed the data in multiple stages. Data were first decimated to obtain a lower effective sample rate. Detectors searching for blue, fin and sei whale calls decimated the data by a factor of 80 in two steps to provide an effective sample rate of 1 kHz. The humpback whale detector decimated the original data by a factor of 40, providing an effective sample rate of 2 kHz. The detector searching for minke whale calls decimated the original data by a factor of 20, providing an effective sample rate of 4 kHz.

Sounds from baleen whales were detected based on their frequency range and duration. The acoustic data were first passed through a frequency bandpass filter to obtain signals in the appropriate frequency range. Potential baleen whale signals in the desired frequency range were extracted using an envelope detector and applying a threshold level. The final step validated the time and frequency characteristics of the sounds and classified them as different baleen whale species. Results are reported based on the number of EAR files with positive detections for each day of the deployment.

III. Results

A. Manual analyses completed to date

Manual analyses of odontocete encounters were completed for 3 of the 4 EARs in the first deployment: Guam S 11 mi, Tinian W, and Saipan N. Analyses of the fourth EAR (Guam N) and the second deployment series are in progress. On Guam S 11 mi, the fewest number of odontocete (excluding sperm whales) encounters were detected overall (n=42), as well as the lowest encounter rate of the three sites (0.677 encounters/effort-day). Tinian W had intermediate values of 145 encounters and 1.88 encounters/effort-day. Saipan N had the greatest encounter rate, with 382 encounters and 3.54 encounters/effort-day (**Table 4**). However, the mean EAA was greatest at Guam S 11 mi, with a value of 1.34, as compared to 0.87 and 0.92 at Tinian W and Saipan N, respectively. In addition, the mean and median encounter duration were greatest at Guam S 11 mi (approximately 44 minutes and approximately 30 minutes), whereas at Tinian W and Saipan N the mean encounter duration was 35–36 minutes and the median duration was 18 minutes (**Table 4**). The maximum encounter duration of approximately 12.5 hours was recorded at Saipan N, and the other two sites did not have any encounters lasting more than approximately 4 hours (**Table 4**).

Table 4. Triton odontocete (not including sperm whale) detection summary for the MIRC EAR deployments analyzed to date (Deployment 1).

Site	#of Effort-days	#of Encounters	Encounters/ Effort-day	Mean Encounter Acoustic Abundance	Mean Encounter Duration	Median Encounter Duration	Max Encounter duration
Guam N	TBD	TBD	TBD	TBD	TBD	TBD	TBD
GuamS11mi	62	42	0.677	1.34	0:44:30	0:30:30	4:00:30
Tinian W	77	145	1.88	0.87	0:35:08	0:18:30	4:12:30
Saipan N	108	382	3.54	0.92	0:36:22	0:18:30	12:24:30

max = maximum; TBD = to be determined; # = number

Sperm whale encounters were also noted on Guam S 11 mi, Tinian W, and Saipan N (**Table 5**). Tinian W had the greatest sperm whale encounter rate of 0.43 encounters/effort-day, followed by 0.32 encounters/effort-day at Guam S 11 mi, and 0.22 encounters/effort-day at Saipan N. Sperm whale encounter duration was greatest on average at Saipan N, with mean and median values slightly over 3 h, and a maximum duration reported of approximately 14 hours (h). Tinian W sperm whale encounters were slightly over 2 h in duration on average, with a maximum of 7 h, and at Guam S 11 mi the mean and median duration were approximately 1 and 0.5 h, respectively, and a maximum of 10 h (**Table 5**). Sperm whales were detected irregularly at each site, with encounters usually within 1–3 days of each other; between mid-October and mid-November sperm whales were detected less frequently compared to the other time periods of recording (**Figure 4**).

Table 5. Triton sperm whale detection summary for the MIRC EAR deployments analyzed to date (Deployment 1).

Site	# of SW Encounters	SW Encounters per effort-day	Mean SW Encounter Duration	Median SW Encounter Duration	Max SW encounter duration
Guam N	TBD	TBD	TBD	TBD	TBD
GuamS11mi	20	0.32	1:16:53	0:29:41	10:12:19
Tinian W	33	0.43	2:27:45	2:23:59	7:17:40
Saipan N	24	0.22	3:07:34	3:20:59	14:17:50

max = maximum; SW = sperm whale; TBD = to be determined; # = number

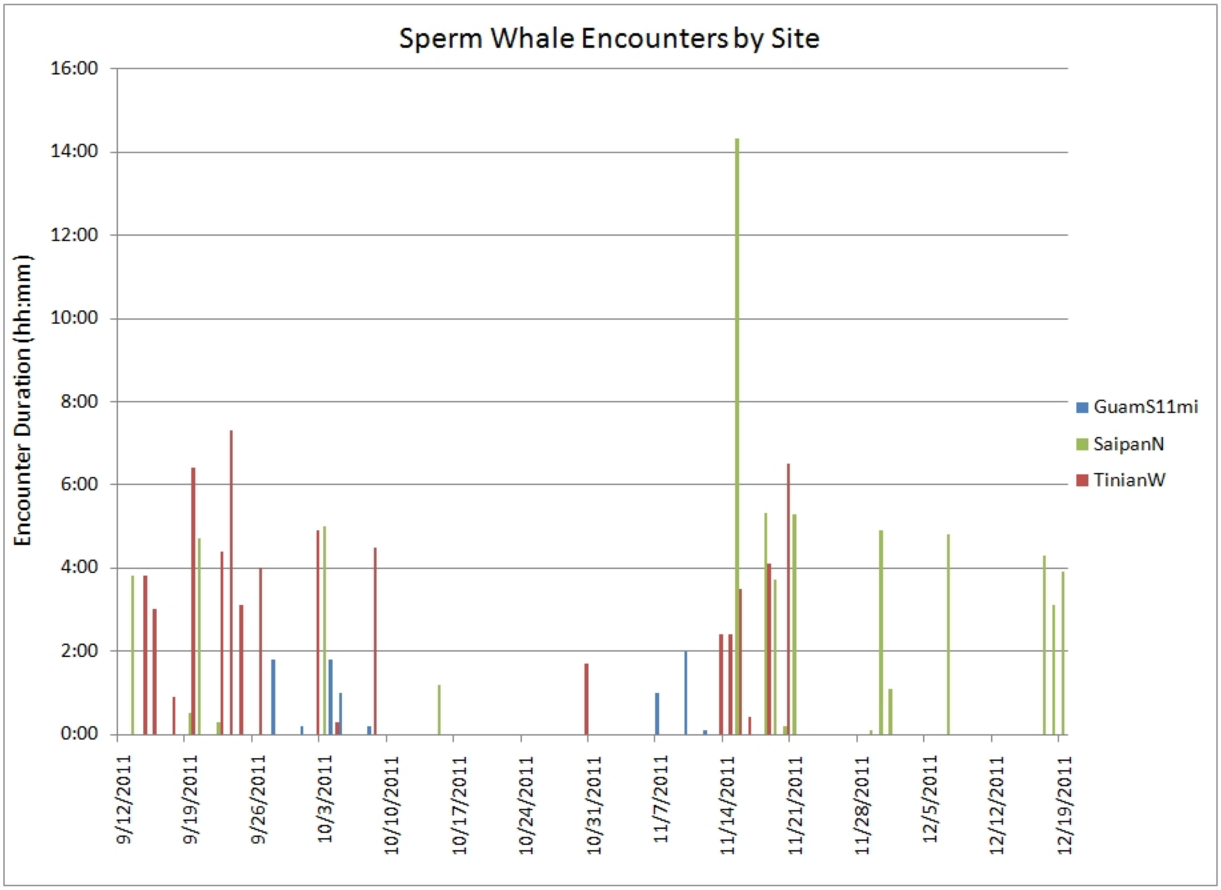


Figure 4. Maximum sperm whale encounter duration per day at the 3 EAR sites analyzed, Deployment 1.

No high-frequency sei whale calls (Norris et al, 2012) were detected by manually browsing LTSA data from Guam S 11 mi or Saipan N. Analysis of the remaining EAR data sets for these calls is pending.

The occurrence of different signal categories (e.g., HF or LF whistles, clicks) varied between sites. At Guam S 11 mi, where encounter rates were low overall compared to the other two sites analyzed, clicks and LF whistles were the two categories with greatest encounter rates (0.516 and 0.258 encounters/effort-day, respectively), greatest mean encounter duration (approximately 1h in each category), and greatest normalized total DAA scores (3.86 and 2.88, respectively) (**Table 6a**). HF whistles were detected very infrequently at Guam S 11 mi, where there were only 0.048 encounters/effort-day, mean encounter duration of 18 minutes, and a normalized total DAA score of 0.073 (**Table 6a**).

At Tinian W, clicks and HF&LF whistles had the greatest encounter rates (1.49 and 0.61 encounters per effort-day, respectively) and greatest DAA scores (6.56 and 3.73, respectively) (**Table 6b**). HF whistles and LF whistles at Tinian W had comparable encounter rates of 0.34 and 0.31 encounters/effort-day, respectively, but LF whistles received a greater total DAA score of 2.46, compared to a score of 0.844 for HF whistles. Mean encounter durations for all signal categories at Tinian W ranged from 0.5–1 h.

At Saipan N, clicks were encountered at the greatest rate (2.22 encounters/effort-day), and LF whistles at the lowest rate (0.685 encounters/effort-day) (**Table 6c**). HF&LF whistles and HF whistles were comparable, with intermediate encounter rates of 1.19 and 1.12 encounters/effort-day, respectively. However, HF whistles received the lowest DAA score of 1.76 and also had the shortest mean encounter duration of 21 min, LF whistles were relatively greater at 5.03 and 33 minutes, and the top two signal categories in terms of DAA and encounter duration were clicks and HF&LF whistles, with scores of 14.8 and 8.9 respectively, and mean encounter durations of 1–2 h.

Table 6. Detections by signal type for each site analyzed to date (Deployment 1).

	Clicks	HF&LF whistles	HF whistles	LF whistles
A: Guam S 11 mi				
Encounters per effort-day	0.516	0.161	0.0484	0.258
Mean Encounter Duration	0:51:19	0:49:42	0:18:30	1:09:30
Total Daily Acoustic Abundance per Effort-day x100	3.86	0.979	0.0726	2.88
B: Tinian W				
Encounters per effort-day	1.49	0.610	0.338	0.312
Mean Encounter Duration	0:38:18	0:54:33	0:31:25	0:54:37
Total Daily Acoustic Abundance per Effort-day x100	6.56	3.73	0.844	2.46
C: Saipan N				
Encounters per effort-day	2.22	1.19	1.12	0.685
Mean Encounter Duration	1:52:53	1:08:22	0:21:34	0:33:21
Total Daily Acoustic Abundance per Effort-day x100	14.8	8.90	1.76	5.03

HF = high frequency (>10 kHz) whistles; LF = low frequency (<10 kHz) whistles; x = times

Daily Acoustic Abundance by date and duration of MFAS events are shown in **Figures 5–7**. At Guam S 11 mi, DAA was consistently low, and periods of 1–5 days lapsed with no detections (**Figure 5**). MFAS was noted on three occasions, with one single 3-second ping detected on 22 September 2011, a series of pings lasting 1 h detected on 11 October 2011, and an MFA exercise lasting over 2 days detected on 17–19 October 2011. Dolphins were detected within 1–2 days of the shortest two sonar events, but were not detected on that EAR for 8 days following the end of the 2-day sonar event on 19 October 2011 at this site. The average duration of other periods without dolphin detections (including the one day prior to the 17 October sonar event) was 2 days, with nine of eleven of those periods lasting 1 or 2 days, and a maximum non-detection period of 5 days. No MFAS was detected at Tinian W (Figure 6). An MFAS event of intermediate duration (approximately 10 h) at Saipan N was followed by a day of reduced dolphin acoustic activity (**Figure 7**), but other periods of 1-2 days with few or no dolphin detections occurred sporadically throughout the Saipan N dataset.

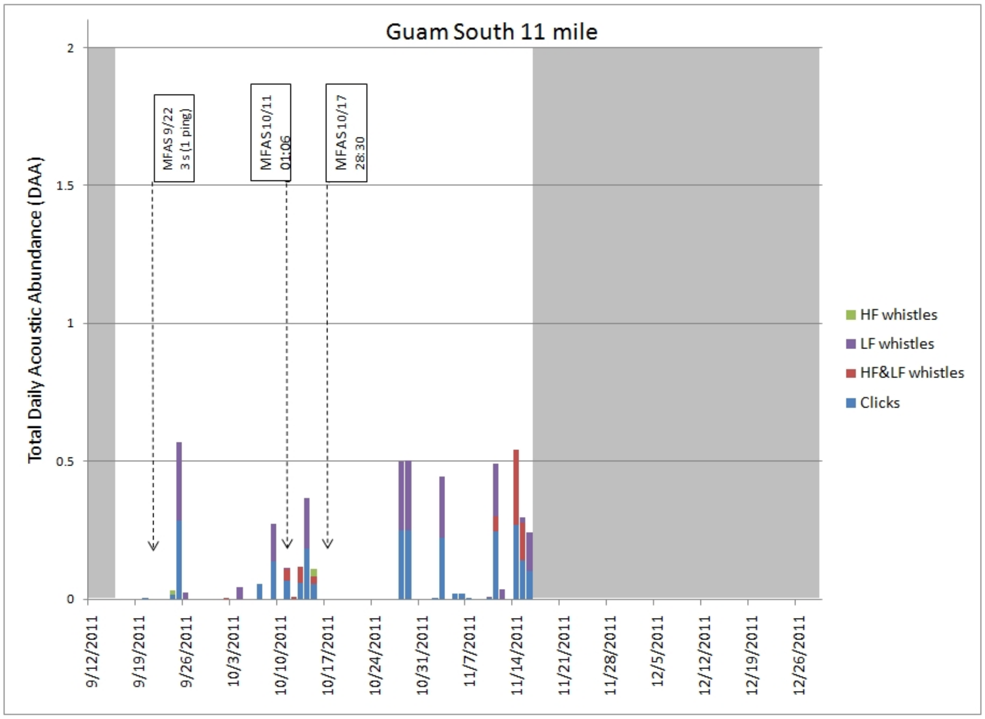


Figure 5. Daily Acoustic Abundance and MFAS events at Guam S 11 mi. The shaded area indicates that the EAR was not recording or deployed during this time.

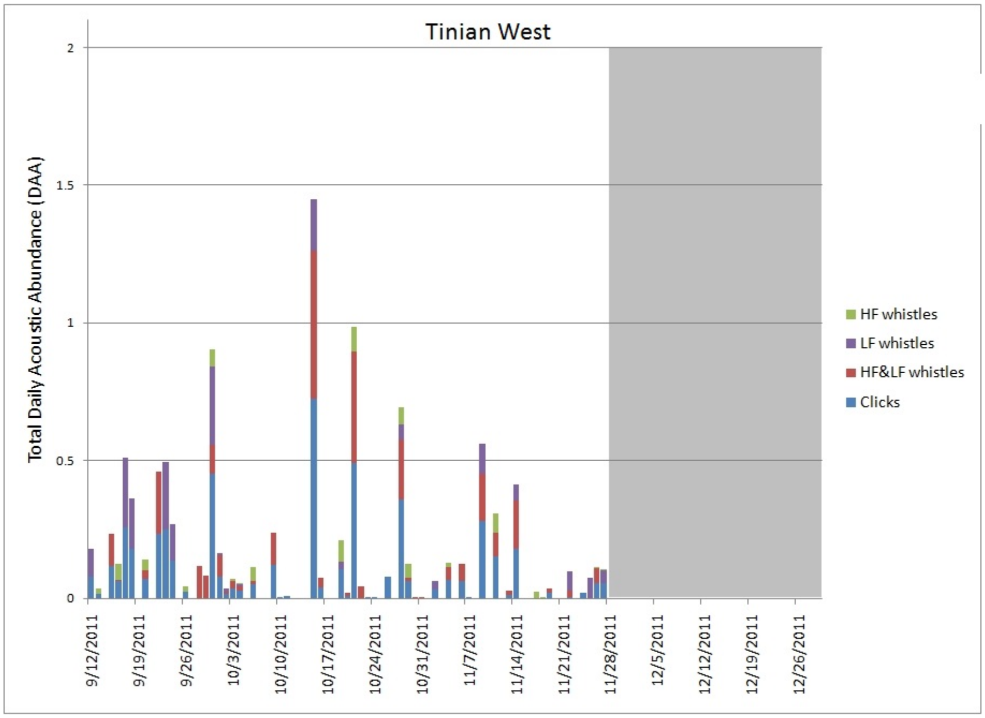


Figure 6. Daily Acoustic Abundance at Tinian W. No MFAS was detected on this deployment. The shaded area indicates that the EAR was not recording or deployed during this time.

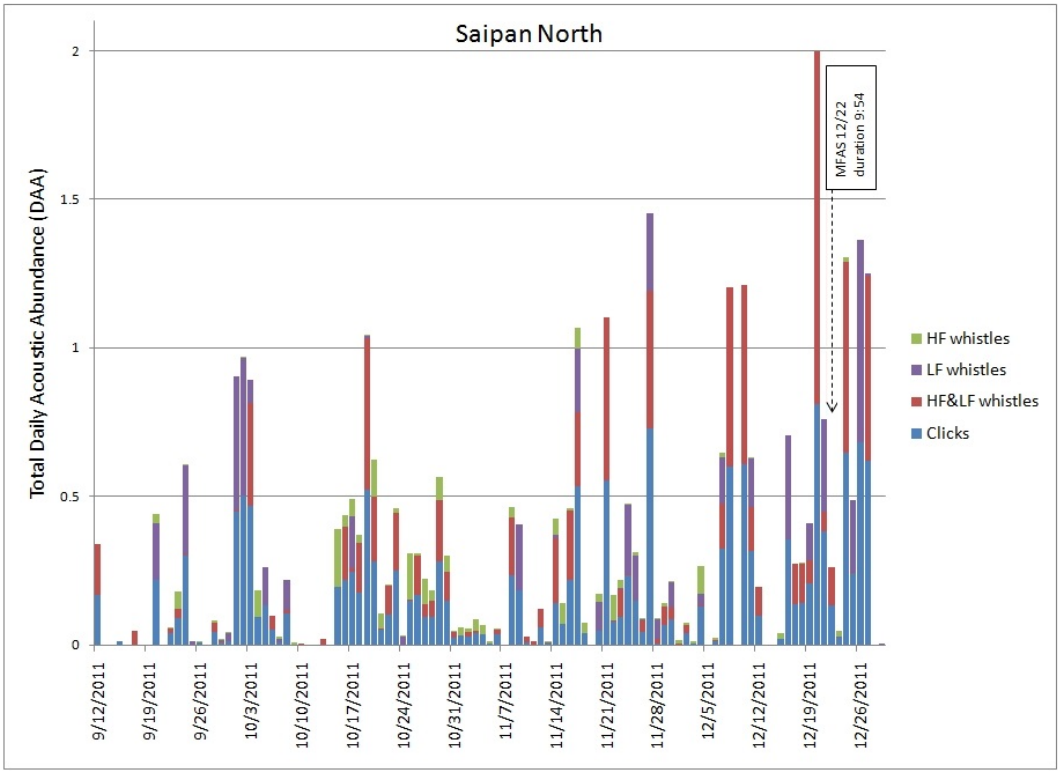


Figure 7. Daily Acoustic Abundance and MFAS at Saipan N.

At Tinian W, DAA increased from the start of recording to a peak in mid-October, and decreased thereafter until recording ceased on 28 November 2011 (**Figure 6**). Dolphins were often detected on 3–4 consecutive days, separated by periods of 1–2 days without detections. No MFAS events were detected at Tinian W during this deployment.

At Saipan N, DAA showed an increasing trend toward the end of the deployment in December (**Figure 7**). Dolphins were detected daily for long consecutive periods (5–23 days), with a few periods of 1–3 days with no detections. One instance of MFAS was detected on 22 December 2011 lasting approximately 10 h, with comparatively low dolphin DAA the following day, but high DAA resumed the second day after MFAS.

B. M3R analyses completed to date

The M3R algorithm detected and classified sperm whale and beaked whale signals on approximately 80 percent of days for all deployments except for Guam S 11 mi, which had beaked whale detections on only 11 percent of days (**Figures 8–11**). There were large variations in detections from day to day for these groups of animals. For example, a high detection rate (25–30 percent files with detections) on one day could be followed or preceded by days of relatively low detection rates (approximately 5 percent). Mean detection rates (percentage files per day with detections) were low overall, with standard deviation values greater than the mean in many cases, also indicating high variance in the detection rate (**Table 7**).

Table 7. Means and standard deviations of the percentage of files with M3R sperm and beaked whale detections per day by location and deployment.

Group	Tinian-1	Tinian-2	Saipan-1	Saipan-2	Guam N-1	Guam N-2	Guam S 11mi-1
Sperm	1.9 ± 3.4	3.4 ± 5.0	4.0 ± 4.6	2.4 ± 3.1	6.4 ± 7.0	3.6 ± 4.4	1.6 ± 2.0
Beaked	2.2 ± 2.5	4.2 ± 6.5	5.7 ± 5.0	3.6 ± 3.6	5.7 ± 4.9	6.8 ± 5.0	0.1 ± 0.1

The Guam North location had the highest mean detection rate of sperm whales overall during both deployments, whereas Guam N and Saipan N had equal mean detection rates of beaked whales during the first deployment, and Guam N had the highest mean beaked whale detection rate during the second deployment (**Table 7**). Mean detection rate of sperm whales and beaked whales increased during the second deployment at Tinian and decreased at Saipan; at Guam N the mean detection rate decreased for sperm whales but increased for beaked whales during the second deployment (**Table 7**).

The detection rate for both species was low overall at Guam S 11mi (**Table 7**; **Figure 8**). Peak detection rates (percentage of files per day) of sperm and beaked whales were in late December at Guam N (**Figure 9**), mid-November through mid-December at Saipan N (**Figure 10**), and mid-September at Tinian W (**Figure 11**).

With the exception of Guam S 11 mi, where very few beaked whale signals were detected (**Figure 8**), temporal patterns in sperm whale and beaked whale detection rates were nearly identical within each dataset (**Figures 9–11**). Although the proportion of sperm whale and beaked whale detections varied by a few percentage points, the peaks in detection rate (percentage of files per day) occurred on the same days throughout each recording period.

M3R detections of beaked and sperm whale signals showed a strong diel pattern (**Figures 12–15**), with the greatest number of detections during nighttime hours (1800–0600) and the fewest during daylight hours (0600–1800). The hourly patterns (peaks and troughs) for beaked whales and sperm whales were generally very similar, although proportions varied of each; Guam S 11 mi was the exception to this, with few beaked whale detections, and a midday peak in sperm whale detections in addition to the nighttime peak (**Figure 12**).

C. Automated baleen whale detections to date

During the first deployment period (September–December 2011), the baleen whale detector detected calls in only five files: two files with humpback whale detections at Saipan N, and three files with minke whale detections at Guam N (**Table 8**). No calls from blue, fin, or sei whales were detected in any locations during the first deployment. During the second deployment period (April–November 2012) 39 files with humpback whale sounds were detected over two consecutive days in April at the Saipan location, and no calls were detected from blue, fin, sei, or minke whales. No baleen whale sounds were detected at the other locations.

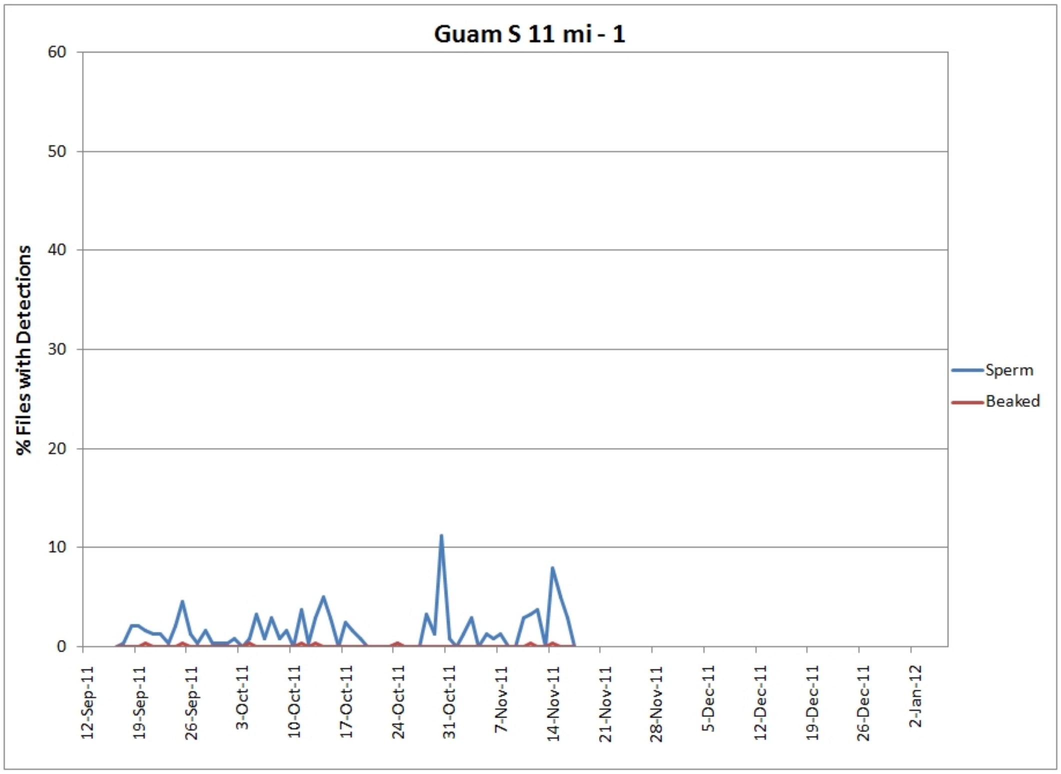


Figure 8. M3R results for beaked and sperm whales at Guam South 11 mile, first deployment, as percentage of files per day with detections. Modified from Au et al. (2014b).

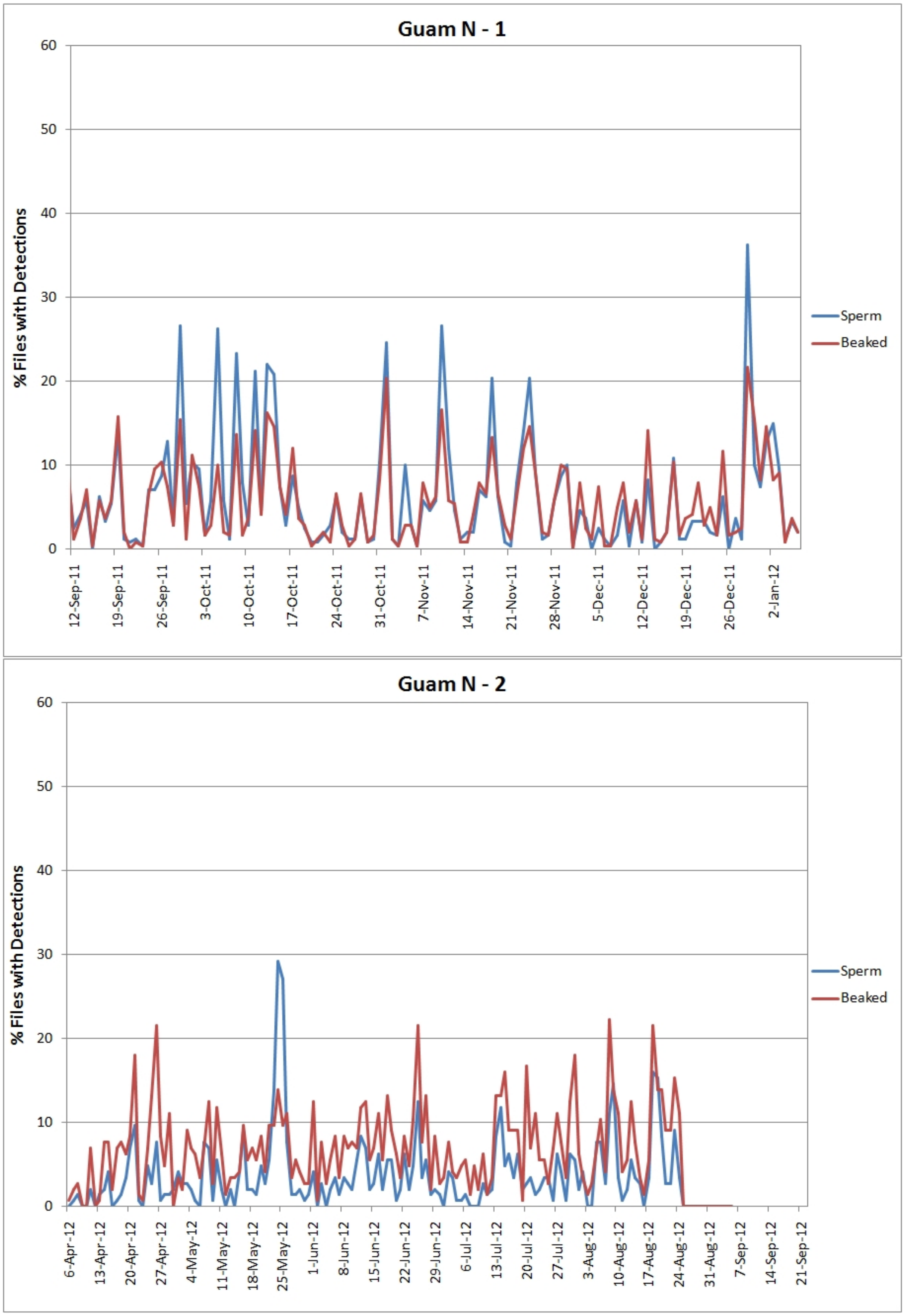


Figure 9. M3R results for beaked and sperm whales at Guam North, first deployment (top) and second deployment (bottom), as percentage of files per day with detections. Modified from Au et al. (2014b).

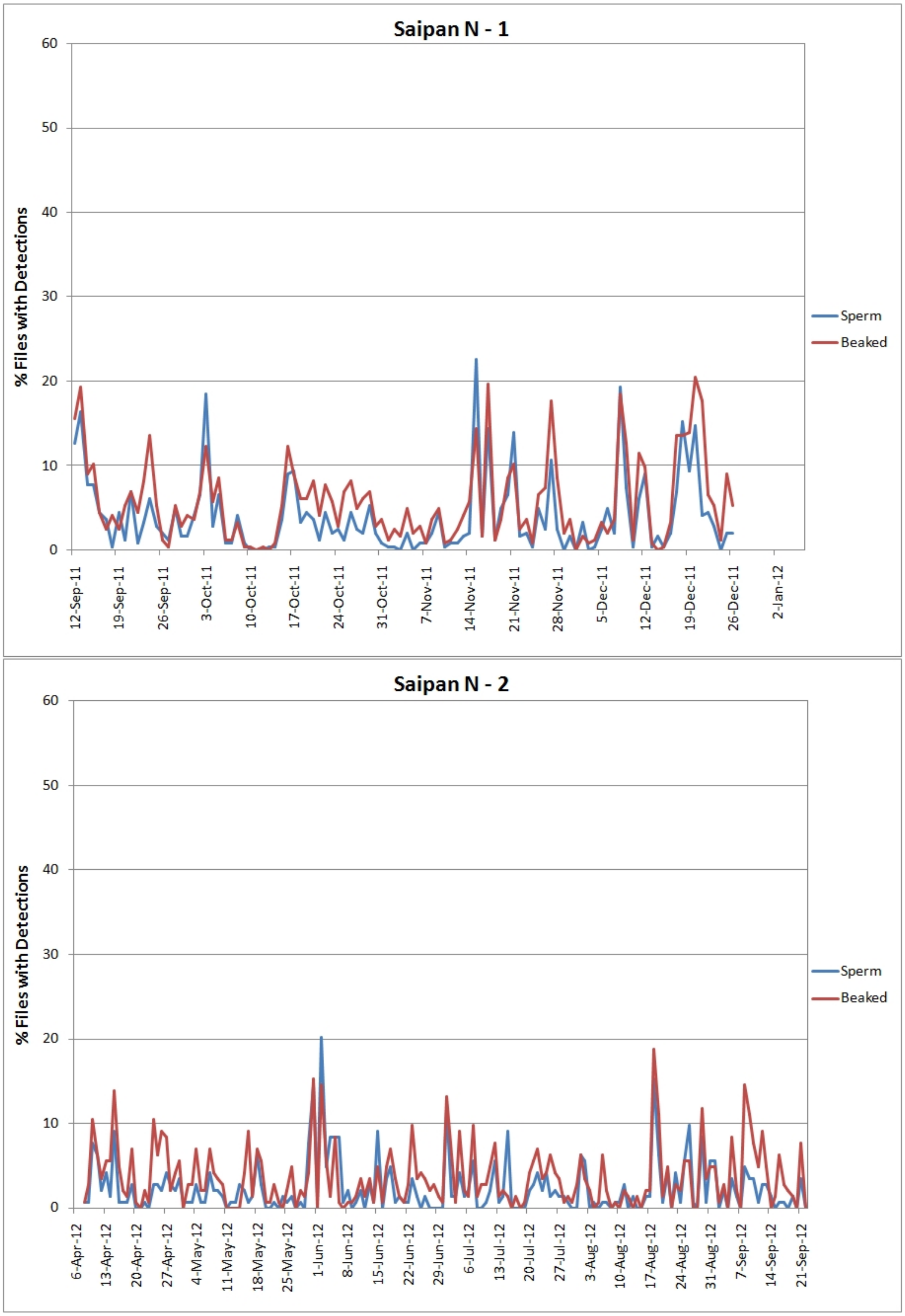


Figure 10. M3R results for beaked and sperm whales at Saipan North, first deployment (top) and second deployment (bottom), as percentage of files per day with detections. Modified from Au et al. (2014b).

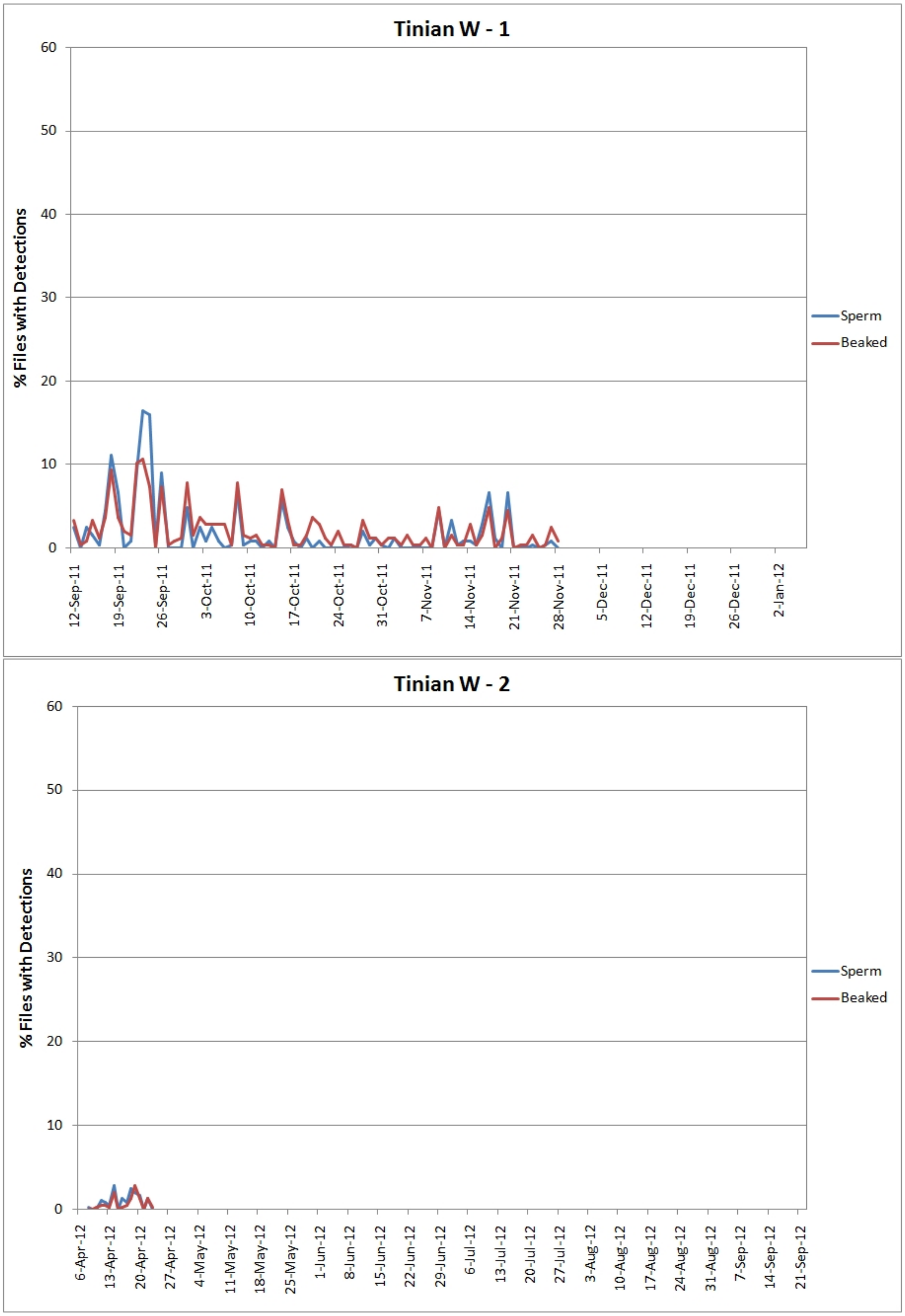


Figure 11. M3R results for beaked and sperm whales at Tinian West, first deployment (top) and second deployment (bottom), as percentage of files per day with detections. Modified from Au et al. (2014b).

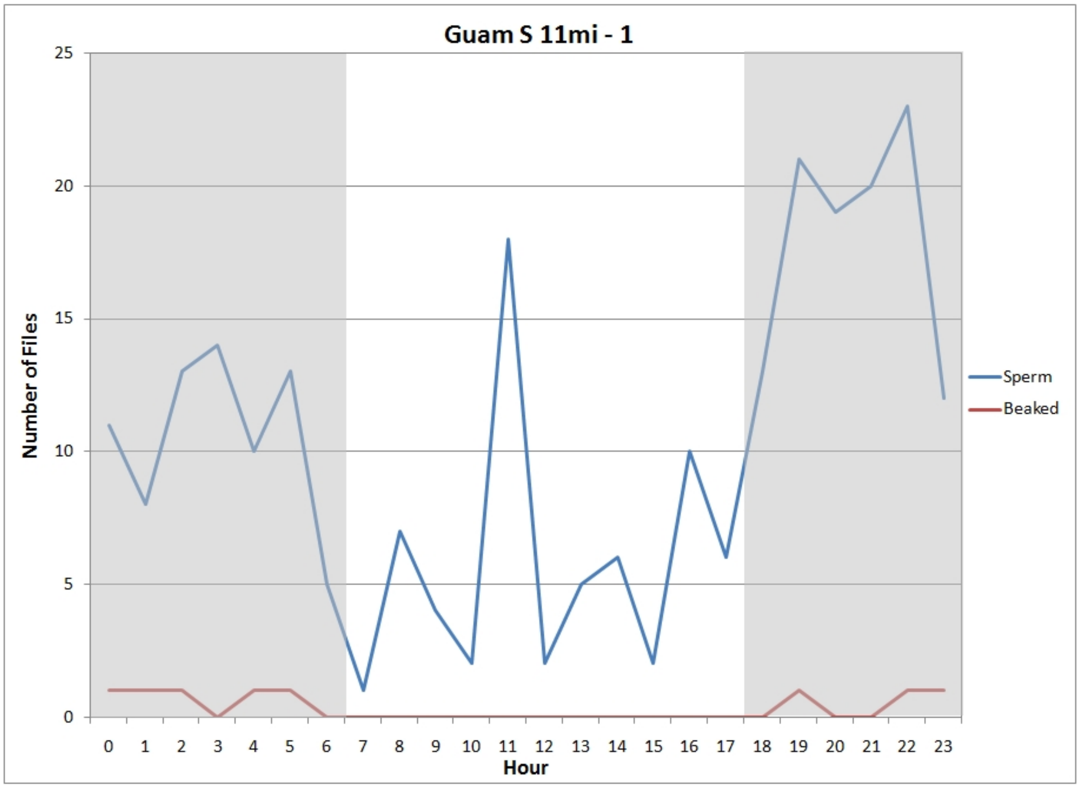


Figure 12. Diel pattern in M3R results for beaked and sperm whales at Guam South 11 mi, first deployment, as the total number of files with detections by hour of day. Shaded areas represent twilight and nighttime hours. Modified from Au et al. (2014b).

Figure 13. Diel pattern in M3R results for beaked and sperm whales at Guam North, first deployment (top) and second deployment (bottom), as the total number of files with detections by hour of day. Shaded areas represent twilight and night time hours. Modified from Au et al. (2014b).

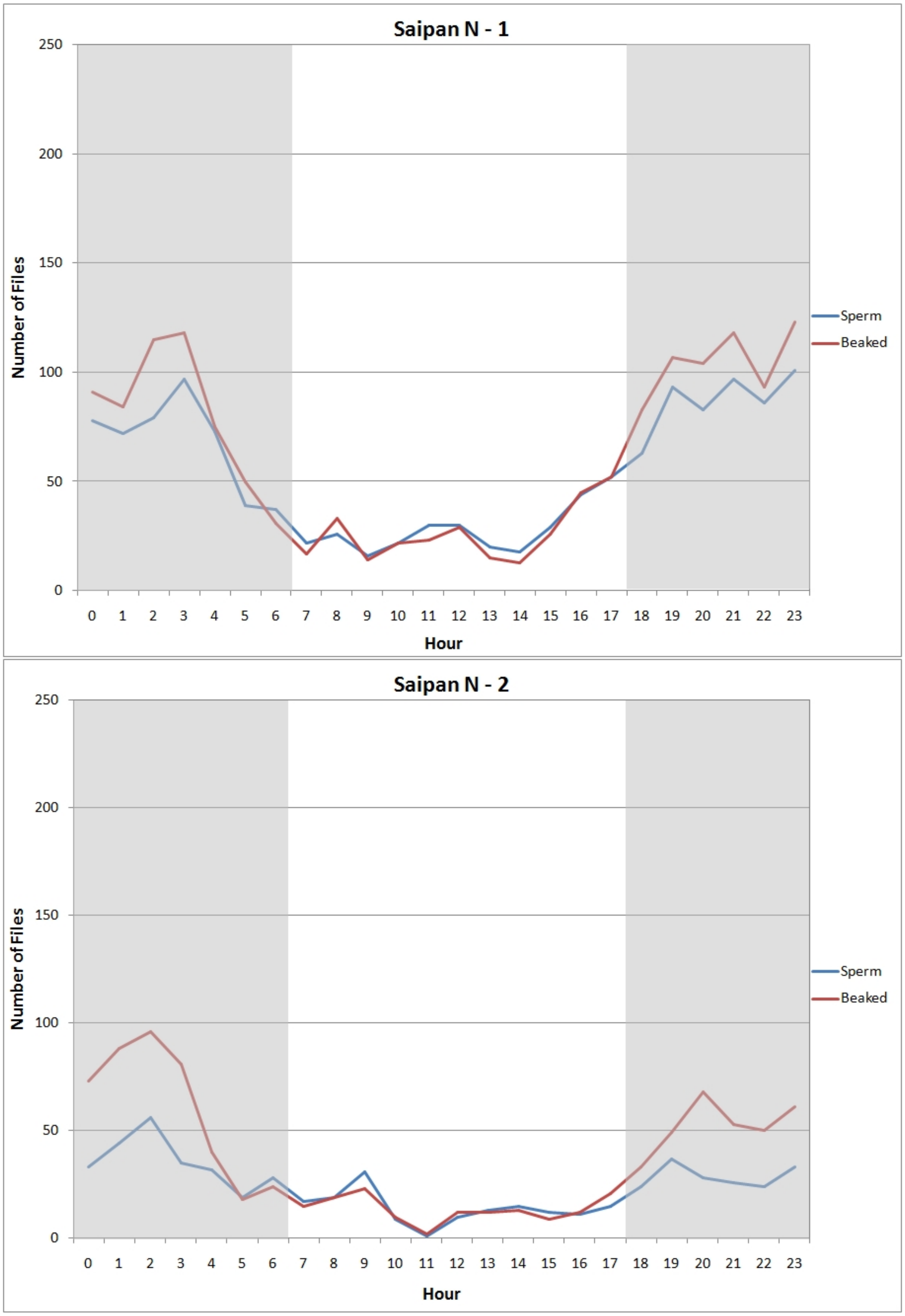
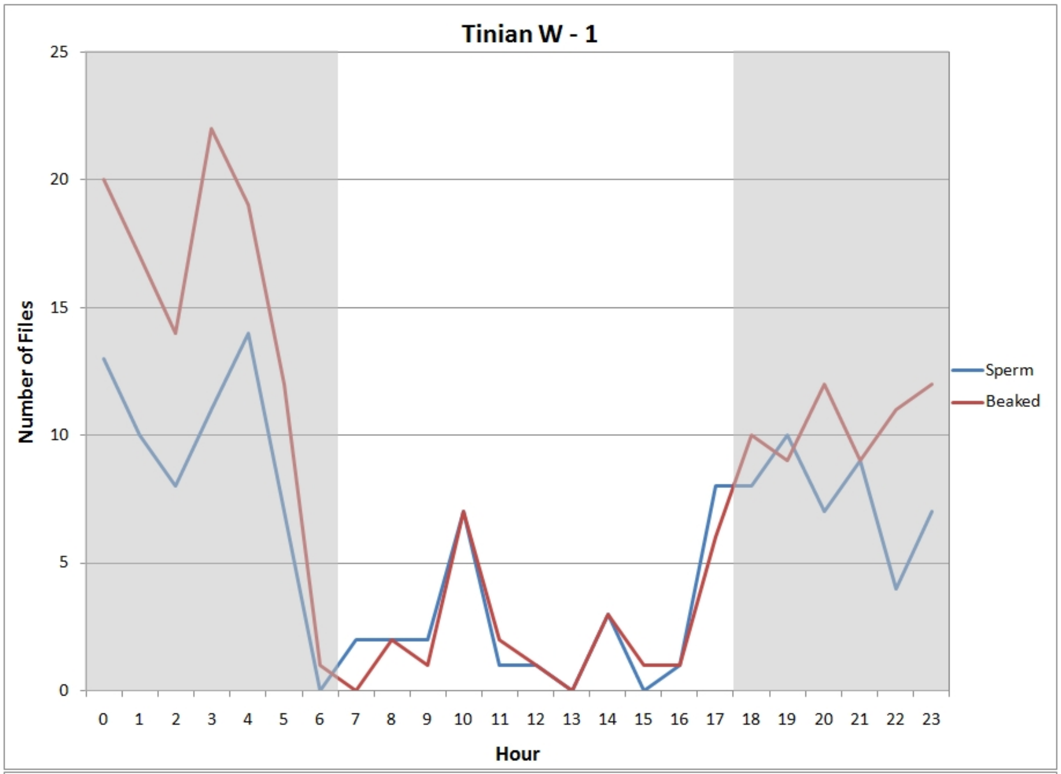


Figure 14. Diel pattern in M3R results for beaked and sperm whales at Saipan North, first deployment (top) and second deployment (bottom), as the total number of files with detections by hour of day. Shaded areas represent twilight and night time hours. Modified from Au et al. (2014b).



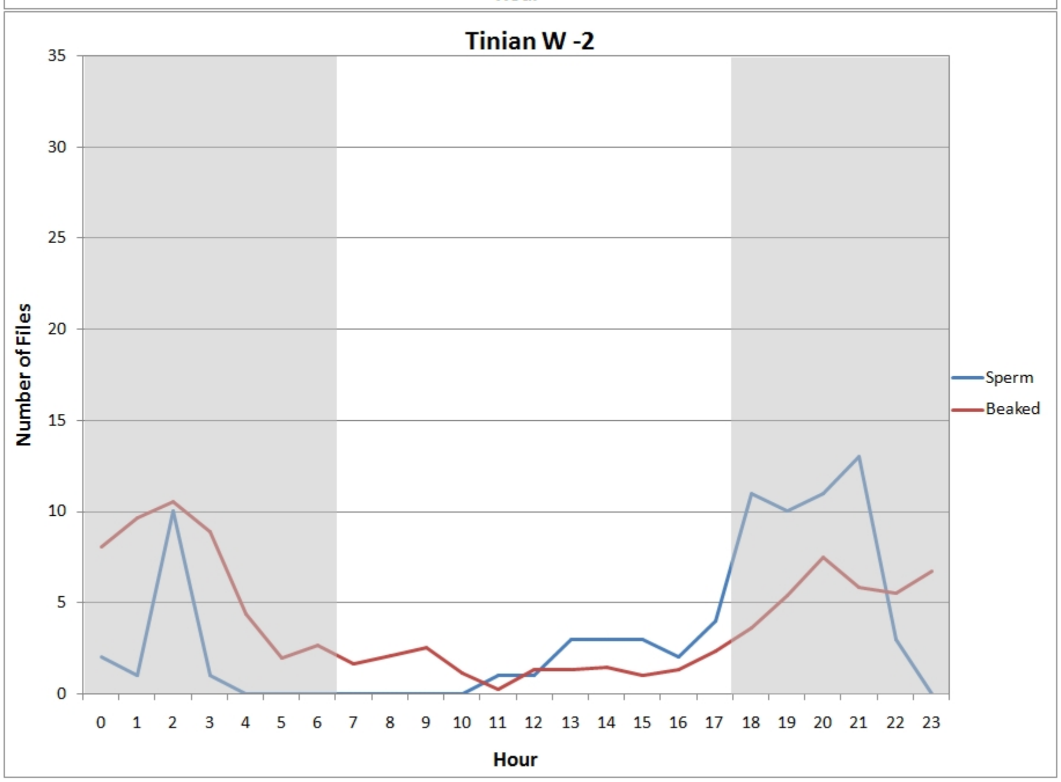


Figure 15. Diel pattern in M3R results for beaked and sperm whales at Tinian W, first deployment (top) and second deployment (bottom), as total number of files with detections by hour of day. Shaded areas represent twilight and night time hours. Modified from Au et al. (2014b).

Table 8. Number of files with detections made by the automated baleen whale detector.

Deployment Site	Blue whale (# files)	Fin whale (# files)	Sei whale (# files)	Minke whale (# files)	Humpback whale (# files)
First Deployment					
Guam N	0	0	0	3	0
Guam S 11 mi	0	0	0	0	0
Tinian W	0	0	0	0	0
Saipan N	0	0	0	0	2
Second Deployment					
Guam N	0	0	0	0	0
Tinian W	0	0	0	0	0
Saipan N	0	0	0	0	39

IV. Discussion

A. KB17 – Q4: What species of delphinids occur in offshore areas of the MIRC adjacent to Guam and Saipan?

The manual analyses of MIRC EAR datasets reveal varying levels of overall delphinid acoustic activity (inclusive of all signal categories) between different deployment sites, with the greatest encounter rate at Saipan N and the lowest encounter rate at Guam S 11 mi (**Table 4**). This may be indicative of a higher density of dolphins, longer residence times of dolphin groups, or both higher density and longer residence times at Saipan N. However, mean EAA was greatest at Guam S 11 mi, which can be interpreted as the greatest density of signals (clicks or whistles) per encounter. Mean and median encounter duration were also greatest at Guam S 11 mi. These results at Guam S 11 mi may indicate more intense foraging, socializing, or larger group sizes (or a combination of these), which would relate to greater signaling rates, despite fewer encounters overall. The low encounter rate at Guam S 11 mi may be related to its location at a remote pinnacle separated from the shelf of the island by water depths of over 3,000 meters, resulting in behavioral differences for groups of animals that traversed deep water to forage or congregate at the pinnacle. Tinian W had moderately high encounter rates and mean and median encounter durations similar to Saipan N, possibly indicating moderately high densities of animals and similar behavior acoustically to the dolphins off Saipan N.

The analysis of delphinid encounters based on whistle frequency reveals site-specific differences in presumed species assemblages. Based on characteristics reported in Oswald et al. (2003, 2007), the delphinid species commonly encountered during visual surveys in the MIRC region (Hill et al. 2013a,b) would belong to the following whistle categories: LF whistles: false killer whale, short-finned pilot whale, and rough-toothed dolphins; HF&LF whistles: bottlenose dolphins; and HF whistles: spinner dolphins and pantropical spotted dolphins. At all sites, clicks were detected with the greatest encounter rate and scored the highest normalized DAA, which one would expect as they commonly occurred in detections both with whistles and without whistles. However, each site exhibited different patterns within the whistle frequency categories.

At Guam S 11 mi, the most common whistles were LF whistles, followed by mixed HF&LF, with extremely low occurrence of HF whistles (more than an order of magnitude lower than the first two categories) (**Table 6a**). At Tinian W, HF&LF whistles were detected with the greatest encounter rate and DAA (**Table 6b**). Encounter rates of HF whistles and LF whistles at Tinian were comparable at about 0.3 per day, but LF whistles scored greater DAA than HF whistles. At Saipan N, HF whistles and mixed HF&LF whistles had similar encounter rates, about double the encounter rate of LF whistles (**Table 6c**), but again, the DAA score for LF whistles exceeded that of HF whistles by several times.

Different metrics of acoustic occurrence likely provide different types of information about the species present. Encounter rates may be more indicative of overall densities and residence times of animals, which would suggest that LF whistling species are more common at Guam S 11 mi than other species there, but all species occurred in low densities or infrequently within recording range. HF&LF whistling species are more common at Tinian and Saipan than the other species groups at either island, but all types of whistling groups are present in moderate densities and are more common at both sites than at Guam S 11mi. LF whistling species are least common at Saipan compared to the other two groups, although the lowest whistle encounter rate at Saipan N still exceeds the greatest whistle encounter rate at Tinian W, suggesting overall high densities of all species groups at Saipan N. The EAA metric may be more related to group size and behavior of species; for example, short-finned pilot whales may whistle more frequently individually, as well as occur in larger groups, resulting in greater Encounter Acoustic Abundance scores within the LF whistle category although encounter rates may have been low compared to other whistle groups.

Temporal trends in dolphin occurrence also seemed to vary between sites, with consistently low encounter rates at Guam S 11 mi throughout the September–November deployment, a peak in mid-October at Tinian W, and a peak in December at Saipan N. Interestingly, peaks/clusters of dolphin occurrence at Tinian W and Saipan N also showed rough periodicity of 6–10 days, which may indicate some relationship between their behavior and tidal or lunar cycles, such as spring tides and neap tides alternating at 7-day intervals each lunar month. However, the data sets all ceased recording at different times and as such may not provide complete pictures of temporal cycles on monthly or seasonal scales. Analyses of the second deployment, as well as more detailed efforts to incorporate other data, are needed to investigate the relationship of dolphin occurrence to other periodic/cyclical environmental variables, including diel time scales, lunar time scales, and seasonal scales.

B. KB17 – Q5: Is MFAS present in the EAR data sets?

MFAS was detected at Guam S 11 mi on three occasions, at Saipan N on one occasion, and was not detected at Tinian W (**Figures 5-7**). The duration of the MFAS event may have influenced the activity of dolphins following the event. Dolphin detections off Guam did not seem to change as a result of short MFAS events of up to an hour, whereas no dolphins were detected for 8 days following a 2-day long MFAS event (**Figure 5**). This 8-day period exceeded both the average and maximum duration without dolphin detections (2 d and 5 days, respectively) during times not associated with MFAS. An MFAS event of intermediate duration (approximately 10 h) at Saipan N was followed by a day of reduced dolphin acoustic activity (**Figure 5**); however, causation cannot be determined as there were other periods with little or no dolphin activity at this site throughout the deployment. These events are presented as anecdotal information only;

further investigation and a larger sample size would be needed to determine the relationship of MFAS duration to dolphin acoustic occurrence.

C. KB17 –Q6: Were high-frequency sei whale calls detected on any EARs?

Two of the EAR datasets, Guam S 11 mi and Saipan N, were scanned for high-frequency sei whale calls by visually browsing the LTSA within the frequency band of these calls, but none were detected. This does not necessarily indicate the absence of sei whales or their calls; signals may have been present but rare and/or with a low signal-to-noise ratio such that they would not be easily detectable in a compressed spectrogram. Compared to low-frequency (< 100 Hertz) calls from blue whales and fin whales, these relatively high-frequency sei whale calls would attenuate more rapidly and may not be detectable at long distances if whales were calling far offshore. Detectability of calls on EARs may be reduced further if the behavioral function of the call is for close-range signaling such that the calls are produced with low source levels. More focused searching for high-frequency sei whale calls would require more time-intensive effort, potentially including development of detectors and/or file-by-file manual searching of decimated data. Analysis of Tinian W and other deployments for these calls using the LTSA browsing method is pending.

D. KB14–Q5: What species of beaked whales (Ziphius/Mesoplodon) are in offshore areas of the MIRC adjacent to Guam and Saipan?

The results of M3R automated detection for *Ziphius* and *Mesoplodon* were grouped together in the analysis for this report. More rigorous analysis of confirmed beaked whale clicks would be needed to identify them based on known, species-specific signal features such as frequency range, sweep rate, inter-click interval, and waveform.

M3R detections of beaked whale signals occurred nearly daily on all MIRC deployments except for Guam S 11 mi, with infrequent periods of 1–2 days without detections (**Figures 8-11**). If the detector is accurate, these results suggest regular use of these areas (Guam N, Saipan, and Tinian) by beaked whales (**Figures 9-11**), with most foraging taking place at night (**Figures 12-15**). However, further validation of the detector is necessary to confirm the identity of these signals and to characterize detector performance. The nearly identical temporal patterns in beaked whale and sperm whale detection rates on a daily basis are questionable and point to the need for verification of the detector results.

E. KB14 –Q6: What is the seasonal occurrence of baleen whales in offshore areas of MIRC adjacent to Guam and Saipan?

Automated baleen whale call detection resulted in very few detections of baleen whales in the MIRC data sets, and as a result no clear conclusions can be drawn about species occurrence or seasonality. One explanation for the paucity of detections may be because the timing of recording was offset from seasonal migrations and peak occurrence for baleen whales. Humpback whales and other migratory baleen whale species are well documented to occur primarily in winter months in other tropical and subtropical habitats. However, only two of the MIRC EARS deployed in September 2011 recorded through December (Guam N and Saipan N) and only one recorded into early January; no recording took place between 6 January and 6 April thus, the study potentially missed the prime whale overwintering period for northern hemisphere habitats. Alternatively, very few baleen whales may use the MIRC region and/or the low detection rate of the software may be related to a high false negative rate (missed calls); further year-round recording and verification of automated detections would be necessary to investigate this theory. Lastly, the EAR recording parameters (30 seconds on every 6 to 10 minutes) were not ideally configured to record long-duration calls, such as those made by blue whales that last 20 seconds or longer.

F. KB14 – Q7: What is the seasonal occurrence of sperm whales in offshore areas of the MIRC adjacent to Guam and Saipan?

Sperm whale encounters (start and end of clicking) were manually logged using Triton while browsing for other odontocete signals. In addition, the M3R automated detector resulted in detections of purported sperm whale clicks throughout the EAR datasets. The results of manual detection suggest that sperm whale occurrence is irregular, but no obvious seasonal patterns have emerged within the limited data analyzed to date (September–December). These results contrast with the M3R automated detector, which output sperm whale detections during almost every day of recording at each site. Future work could include a more rigorous comparison of sperm whale manual analyses with automated detector results to identify periods of time when methods either agree or disagree, as a means of cross-checking and validating the detector results on a daily/seasonal time scale.

M3R detections of sperm whale signals occurred nearly daily on all MIRC deployments, with infrequent periods of 1-2 days without detections, suggesting regular use of these areas by sperm whales (**Figures 8–11**). Most foraging took place at night (**Figures 12–15**). Temporal patterns in sperm whale detections showed high overlap with beaked whale detections and therefore warrant further investigation. Further validation of the detector is necessary and warranted to confirm the identity of both beaked and sperm whale signals (as well as the other species groups detected by M3R in MIRC data) and to characterize detector performance.

V. Conclusion

A. Summary of what has been learned through this effort to date – Manual analyses

All three categories of whistling odontocetes (LF, HF, and LF&HF) were detected on the three EARs analyzed to date – Guam S 11 mi, Tinian W, and Saipan N. Guam S 11 mi had the lowest overall dolphin encounter rate and Saipan N, the highest. Detections of the different whistling assemblages occurred in different proportions at each site, with LF whistles being most common at Guam S 11 mi out of the three categories, and least common at Saipan N of the three categories (although still encountered there at higher rates than Guam S 11 mi). Sperm whales were detected at all three sites sporadically throughout the deployment, and MFAS was detected at Guam S 11 mi on three occasions and Saipan N on one occasion.

B. Degree of confidence in classification of species and species groups

The manual Triton analyses were conducted by an experienced cetacean bioacoustician (L. Munger), with a high degree of expertise in Triton and MATLAB software and processing protocols. The classification of delphinid whistles by frequency, as well as sperm whale clicks, was done consistently and with a high level of certainty based on visual inspection and audio playback. However, species assemblages based on whistle frequency are presumed, and natural variability in dolphin whistles may result in some species occasionally crossing over into different whistle bands. We were unable to identify signals to species at the level of Triton analysis and whistle categorization performed in this study. In the future, more intensive species identification could be undertaken using manual and/or automated techniques (e.g., the application of the Real-time Odontocete Call Classification Algorithm [ROCCA]; Oswald et al. 2007). However, ROCCA and other automated detection algorithms, including those implemented in this study, were developed using recordings from other regions of the Pacific (and other oceans). It is not known at present how different the acoustic repertoires of cetaceans in the MIRC region are compared to other areas, and further work is necessary to characterize and augment the library of recordings obtained in the presence of confirmed cetacean species in waters of Guam and CNMI. These efforts will be necessary to improve the performance of automated detectors and assign species identities to calls from remotely recorded archival data sets.

The results of the M3R detector are notable in that although detection rates for beaked and sperm whales were proportionally different, there was nearly exact overlap in temporal patterns (i.e., peaks in detection rate on the same days and within the same hours) (**Figures 8-15**). If the detector is accurate, this would suggest that beaked whales and sperm whales, although occurring in different abundance, are exhibiting exactly the same temporal patterns at every location, perhaps related to the same environmental variable such as availability of a particular prey item. However, it is also possible that the M3R detector output is inaccurate for one or both groups, and this could be due to a number of factors, including the choice of detection parameters.

The latter scenario may be more likely, as the pattern in manual detection of sperm whale clicks, with sporadic encounters and gaps of several days, does not corroborate the M3R detector output of daily sperm whale detections and detections during time periods when an analyst did not find sperm whales. This would suggest that the M3R detector results should be interpreted with great caution and further work is necessary to validate this method or develop alternative automated detection strategies. These future efforts could include using the sperm whale encounters that were logged by the analyst to identify sections of data to compare to the M3R detector and quantitatively evaluate its performance.

Another caveat is that the duty cycle for the EARs in the second deployment was 10 minutes versus 6 minutes for the first deployment, so caution must be taken in comparing the results between deployment periods and also data obtained in other locations. Further investigation would be needed to determine the probability of detection under different duty cycle regimes, and account for this in analyses and the presentation of results. For example, the probability of detecting signals from highly mobile or rare species may decrease with a longer duty cycle, and the probability of detecting and identifying long-duration signals, such as those from blue whales, may decrease with short-duration recordings.

C. Underway and future work

1. Manual analyses

Triton analyses are underway for the remaining MIRC EARs: Guam N from the first deployment, and the three EARs in the second deployment (April–November 2012). Work is ongoing to investigate temporal patterns in cetacean occurrence, including diel and longer temporal cycles. The analysis of the second MIRC deployment will provide a longer time series to be able to investigate lunar, monthly, and seasonal trends or cycles.

Ongoing analyses of the remaining MIRC EARs will provide a larger sample size/longer time series with which to compare spatial patterns in species assemblages. In the future, more detailed analyses could potentially be conducted to identify species, by implementing automated detectors (but see section V.B, above) and/or by detailed manual/aural analyses of representative signals.

The low number of MFAS detections within the MIRC first deployment EARs analyzed to date precludes any robust statistical analyses of detection rates. However, if more MFAS events are detected in the second deployment, a more rigorous analysis may be possible.

2. Autodetector performance evaluation (validation/ground truthing with Hawaii data)

The M3R detector performance was evaluated by Jarvis et al. (2008) and Jarvis (2012) using data sets for which it was originally developed, with classification precision of the M3R on test data sets found to be 85 percent or higher depending on the species. Additional independent validation efforts by Au et al. (2014) report high precision for data recorded off Kauai, Hawaii. However, because the species templates were developed in other regions of the world, further validation and scrutiny of the M3R detector performance in the Guam and CNMI region is warranted.

Validation of both odontocete and baleen whale automated detectors is being conducted in a related project using EAR data collected on the Hawaii Range Complex by Bio-waves, Inc. and results may inform our knowledge of detector performance for species that are common to both areas and produce the same signals. However, geographic variation in call types has been demonstrated for some species (e.g., several species of baleen whales), such that templates developed in other areas may not be ideally suited for MIRC data.

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