APPENDIX B

PASSIVE ACOUSTIC MONITORING OF CETACEANS WITHIN THE MARIANAS ISLANDS RANGE COMPLEX (MIRC) USING ECOLOGICAL ACOUSTIC RECORDERS (EARS)

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14. ABSTRACT
A long-term passive acoustic monitoring program was initiated in 2011 by the United States Navy Pacific Fleet in waters off Guam and the Commonwealth of the Northern Mariana Islands to investigate the acoustic occurrence of cetaceans in support of 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, in September 2011 and again in April 2012. EAR recording durations ranged from 63 to 119 days during the first deployment (September 2011–January 2012) and 16 to 168 days during the second deployment (April–September 2012). An EAR deployed southwest of Guam was unrecoverable after the second deployment.
Data from the EARs were analyzed for cetacean signals using automated detectors, manual searching, or both, depending on the taxon. Two different automated detectors were implemented: M3R CS-SVM to detect beaked whales and sperm whales, and Baleen5 to detect blue (Balaenoptera musculus), fin (Balaenoptera physalus), sei (Balaenoptera borealis), humpback (Megaptera novaeangliae), and minke (Balaenoptera acutorostrata) whales. Initially, beaked whale and sperm whale clicks were detected by M3R CS-SVM on approximately 80 percent of the days recorded at each EAR site. However, temporal patterns in the raw daily and hourly detection rates were nearly identical for beaked whales and sperm whales, suggesting potential problems with detector performance or the initial interpretation of raw outputs. Therefore, researchers conducted a manual validation of automated detector results and reinterpreted detector output using threshold criteria that resulted in improved measures of detector performance. These criteria reduced the number of candidate beaked whale files from 6,582 files with initial detections to 696 files that met criteria, and of 4,774 initial

sperm whale files, 847 that met the criteria.
Manual examination of a subset of files (n = 131) that met the revised interpretation criteria for the two species classes resulted in low precision (0.26, i.e., a 74 percent false positive rate) for mixed beaked whales, but high recall (1.00 = no missed calls) and moderate specificity (0.60 = 60 percent correct rejection of true negatives). For sperm whales, precision, recall, and specificity of the M3R CS-SVM detector were all above 0.75. True positive beaked whale signals were confirmed in 16 of the 131 reviewed files, and 54 of the reviewed files contained true positive sperm whale signals. Files containing confirmed beaked whales (Cuvier's [Ziphius cavirostris] and/or Blainville's [Mesoplodon densirostris]) were recorded on all EARs except the southwest Guam site and were detected in both deployments. Confirmed sperm whales were detected on all EARs and in both deployments. The higher automated detection rate for sperm whales in autumn was consistent with the seasonal pattern determined via an added manual analysis effort, as were the percentages of days on which sperm whales were detected by either means. Seasonal trends could not be inferred for beaked whales due to the low sample size of manually verified detections and relatively high false positive rate of the detector.
Sperm whale manual analyses documented sporadic occurrence throughout both deployments, with periods of up to 13 consecutive days with encounters separated by periods of days to weeks with no sperm whale detections. Sperm whales were most acoustically abundant at the EAR north of Guam compared to the other sites. Overall sperm whale occurrence was greater during the first deployment (autumn/winter) than the second (spring/summer).
Automated baleen whale detection results were reviewed manually, and additional manual searching for baleen whale calls, including those not targeted by the detector, was conducted throughout the entire first deployment (September to January) and for April of the second deployment. These months encompassed the automated detections and were also presumed to have the highest likelihood of baleen whale occurrence. Only five automated baleen whale detections (three minke and two humpback) were reported during the first deployment, and these were determined to be false positives. Humpback whale (Megaptera novaeangliae) song was manually detected on 4 days in December 2011 at Saipan N but missed by the automated detector. In addition, three unidentified baleen whale calls, potentially from a Bryde's whale (Balaenoptera edeni), were found manually in October and September 2011 at the EAR north of Guam. The three unidentified calls were of two slightly different types; both types had a similar near-constant tonal portion with a fundamental frequency of < 200 hertz (Hz) and harmonics between 400 and 600 Hz, but this tonal call was followed either by a half-second upsweep from 700 to 800 Hz (October call) or an approximate 0.2-second downsweep at approximately 400 Hz (November calls). During the second deployment, humpback whale song was detected both manually and automatically on two days in April at Saipan, and no other baleen whale calls were detected by either manual (April only) or automated (entire second deployment) means. The low rate of baleen whale detections in this study does not necessarily indicate rarity of baleen whales in the MIRC, as the likelihood of detection was constrained by several factors including a gap in recording during expected peak baleen whale occurrence, EAR recording duty cycle, and others.
Manual analyses of delphinid occurrence in the EAR data suggests spatial and seasonal differences in use of the MIRC by different species assemblages. The highest overall proportion of time that delphinids were present was documented for the EAR north of Guam, followed by Saipan, Tinian, and lastly southwest Guam. In contrast to sperm whales, measures of delphinid acoustic activity were higher during deployment 2 (spring and summer) than during deployment 1 (autumn and early winter). Delphinid encounters were further classified into signal groups based on the frequency of whistles (if present) contained within the encounter. Relative patterns in these delphinid signal groups varied among sites and between years, suggesting spatial and seasonal differences in species assemblages.
Mid-frequency active sonar (MFAS) was detected at all EAR sites except for Tinian. Duration of MFAS detections ranged from a single ping to multi-day detections. The multi-day detections were 16–19 October 2011 at Guam and 28 August–5 September 2012 at Saipan. Other than these occurrences, MFAS was detected for short periods (30 seconds to 10 hours) in September 2011, December 2011, July 2012, and 3 other days in September 2012 after the multi-day detection at Saipan. The southwest Guam EAR multi-day MFAS detection in October 2011 was associated with an absence of dolphin detections that encompassed 3 days of MFAS and the 8 days following the MFAS detection. This absence exceeded the mean dolphin absence of 2 days and maximum dolphin absence of 5 days when MFAS was not present at this EAR, and was significantly different from the mean dolphin absence duration of 2.1 days (Poisson distribution, $p < 0.05$). At all other EAR sites, dolphins were detected on most days during and following all other MFAS detections with no anomalously long absences. Acoustic responses to MFAS were not investigated in this study.

15. SUBJECT TERMS
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Passive Acoustic Monitoring of Cetaceans within the Mariana Islands Range Complex (MIRC) Using Ecological Acoustic Recorders (EARs)

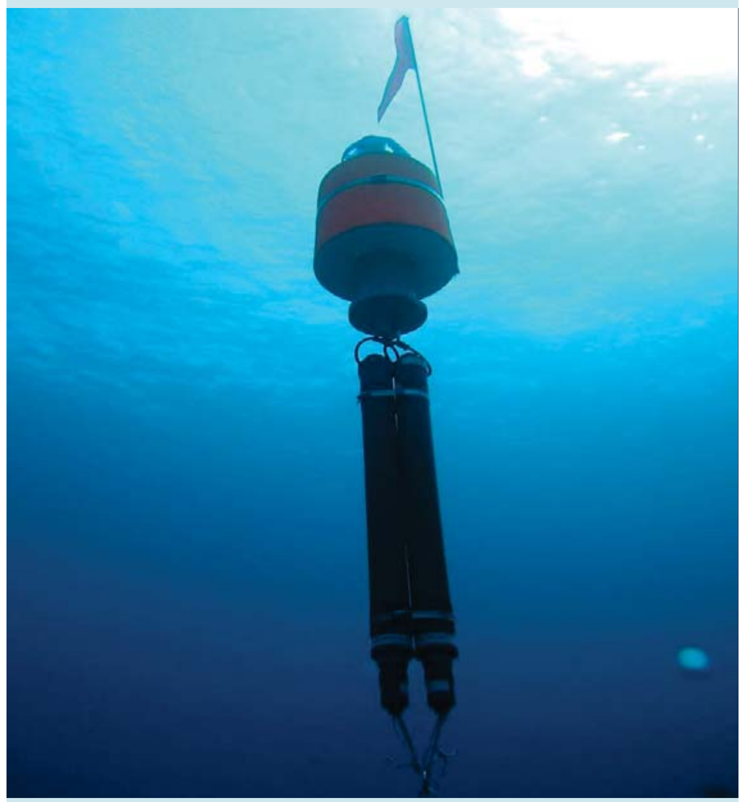

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Photo Credit:

Ecological Acoustic Recorder (EAR) with float and acoustic release secured to the bottom. Photo credit to the National Oceanic and Atmospheric Association, Coral Reef Ecosystem Division (NOAA-CRED).

Executive Summary

A long-term passive acoustic monitoring program was initiated in 2011 by the United States Navy Pacific Fleet in waters off Guam and the Commonwealth of the Northern Mariana Islands to investigate the acoustic occurrence of cetaceans in support of 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, in September 2011 and again in April 2012. EAR recording durations ranged from 63 to 119 days during the first deployment (September 2011–January 2012) and 16 to 168 days during the second deployment (April–September 2012). An EAR deployed southwest of Guam was unrecoverable after the second deployment.

Data from the EARs were analyzed for cetacean signals using automated detectors, manual searching, or both, depending on the taxon. Two different automated detectors were implemented: M3R CS-SVM to detect beaked whales and sperm whales, and Baleen5 to detect blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and minke (*Balaenoptera acutorostrata*) whales. Initially, beaked whale and sperm whale clicks were detected by M3R CS-SVM on approximately 80 percent of the days recorded at each EAR site. However, temporal patterns in the raw daily and hourly detection rates were nearly identical for beaked whales and sperm whales, suggesting potential problems with detector performance or the initial interpretation of raw outputs. Therefore, researchers conducted a manual validation of automated detector results and reinterpreted detector output using threshold criteria that resulted in improved measures of detector performance. These criteria reduced the number of candidate beaked whale files from 6,582 files with initial detections to 696 files that met criteria, and of 4,774 initial sperm whale files, 847 that met the criteria.

Manual examination of a subset of files (n = 131) that met the revised interpretation criteria for the two species classes resulted in low precision (0.26, i.e., a 74 percent false positive rate) for mixed beaked whales, but high recall (1.00 = no missed calls) and moderate specificity (0.60 = 60 percent correct rejection of true negatives). For sperm whales, precision, recall, and specificity of the M3R CS-SVM detector were all above 0.75. True positive beaked whale signals were confirmed in 16 of the 131 reviewed files, and 54 of the reviewed files contained true positive sperm whale signals. Files containing confirmed beaked whales (Cuvier's [*Ziphius cavirostris*] and/or Blainville's [*Mesoplodon densirostris*]) were recorded on all EARs except the southwest Guam site and were detected in both deployments. Confirmed sperm whales were detected on all EARs and in both deployments. The higher automated detection rate for sperm whales in autumn was consistent with the seasonal pattern determined via an added manual analysis effort, as were the percentages of days on which sperm whales were detected by either means. Seasonal trends could not be inferred for beaked whales due to the low sample size of manually verified detections and relatively high false positive rate of the detector.

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Automated baleen whale detection results were reviewed manually, and additional manual searching for baleen whale calls, including those not targeted by the detector, was conducted throughout the entire first deployment (September to January) and for April of the second deployment. These months encompassed the automated detections and were also presumed to have the highest likelihood of baleen whale occurrence. Only five automated baleen whale detections (three minke and two humpback) were reported during the first deployment, and these were determined to be false positives. Humpback whale (*Megaptera novaeangliae*) song was manually detected on 4 days in December 2011 at Saipan N but missed by the automated detector. In addition, three unidentified baleen whale calls, potentially from a Bryde's whale (*Balaenoptera edeni*), were found manually in October and September 2011 at the EAR north of Guam. The three unidentified calls were of two slightly different types; both types had a similar near-constant tonal portion with a fundamental frequency of < 200 hertz (Hz) and harmonics between 400 and 600 Hz, but this tonal call was followed either by a half-second upsweep from 700 to 800 Hz (October call) or an approximate 0.2-second downsweep at approximately 400 Hz (November calls). During the second deployment, humpback whale song was detected both manually and automatically on two days in April at Saipan, and no other baleen whale calls were detected by either manual (April only) or automated (entire second deployment) means. The low rate of baleen whale detections in this study does not necessarily indicate rarity of baleen whales in the MIRC, as the likelihood of detection was constrained by several factors including a gap in recording during expected peak baleen whale occurrence, EAR recording duty cycle, and others.

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Tables

Abbreviations and Acronyms

CNMI	Commonwealth of the Northern Mariana Islands
CRP	Cetacean Research Program
M3R CS-SVM	Class-Specific Support Vector Machine
DAA	Daily Acoustic Abundance
DoN	Department of the Navy
dB re 1 μPa	decibels referenced to one microPascal
EAA	Encounter Acoustic Abundance
EAR	ecological acoustic recorder
h	hour(s)
HF	high-frequency
HF/LF	high- and low-frequency mixed
HRC	Hawaii Range Complex
Hz	Hertz
kHz	kilohertz
LF	low-frequency
LTSA	long-term spectral average
MFAS	mid-frequency active sonar
MIRC	Mariana Island Range Complex
MISTCS	Mariana Islands Sea Turtle and Cetacean Survey
M3R	Marine Mammal Monitoring on Navy Ranges
NOAA	National Oceanic and Atmospheric Administration
PACFLT	U.S. Navy Pacific Fleet
PAM	passive acoustic monitoring
PIFSC	Pacific Islands Fisheries Science Center
ROCCA	Real-time Odontocete Call Classification Algorithm
U.S.	United States

1. Introduction

Cetacean species occurrence and habitat use in the waters off Guam and the Commonwealth of the Northern Mariana Islands (CNMI) are not well understood. Parts of this region are utilized by the United States (U.S.) Navy, which conducts training and testing activities in the designated military training area known as the Mariana Islands Range Complex (MIRC). These activities may include the use of military sonar, underwater explosives, and other actions that have the potential to harass or harm cetaceans and other marine life. Therefore, the U.S. Navy supports independent cetacean monitoring in this area to investigate species occurrence, abundance, habitat use, and population structure (Department of the Navy [DoN] 2014). The monitoring program includes visual surveys, photographic and genetic sampling, tagging, and passive acoustic monitoring (PAM); the latter is the topic of this report.

Prior to the twenty-first century, there was little systematic cetacean survey effort in waters of the CNMI and Guam, and much of what was known was based on strandings and anecdotal or compiled sighting reports (Eldredge 1991, Eldredge 2003, Wiles 2005, Jefferson et al. 2006). The Mariana Islands Sea Turtle and Cetacean Survey (MISTCS) in January–April 2007 was the first systematic line-transect survey aboard a large vessel for sea turtles and cetaceans in waters around Guam and the Northern Mariana Islands (DoN 2007; Fulling et al. 2011). MISTCS included visual surveys and acoustic data collection with towed hydrophone arrays and sonobuoys. A 5-day aerial survey was also conducted in August 2007 (Mobley 2007). In 2010, cetacean search effort was conducted during large research vessel transits between Guam and Honolulu, and opportunistically within the CNMI during an oceanographic cruise (Oleson and Hill 2010). Also beginning in 2010, small-vessel-based cetacean surveys have been conducted biannually around Guam and the CNMI by the National Oceanic and Atmospheric Administration (NOAA) 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; 2014). These surveys included photo-identification, biopsy sampling, opportunistic acoustic recordings, and deployment of satellite telemetry tags on cetaceans.

These surveys have documented the occurrence of several cetacean species. During the 2007 MISTCS survey, the most frequently encountered large whales were sperm whales (*Physeter macrocephalus*), followed by Bryde's (*Balaenoptera edeni*) and sei whales (*Balaenoptera borealis*) (DoN 2007; Fulling et al. 2011). Humpback whales (*Megaptera novaeangliae*) were also detected acoustically and visually. Pantropical spotted dolphins (*Stenella attenuata*) were the most frequently encountered delphinid species, followed by false killer whales (*Pseudorca crassidens*) and striped dolphins (*Stenella coeruleoalba*) (DoN 2007; Fulling et al. 2011). There were also three sightings of beaked whales (two *Mesoplodon* sp. and one ziphiid whale). Of nine cetacean sightings during 21 days of opportunistic survey effort in 2010 off Guam and the southern CNMI, one was identified as Risso's dolphin (*Grampus griseus*), one as short-finned pilot whale (*Globicephala macrorhynchus*), and two as striped dolphins; the remainder were unidentified dolphin species (Oleson and Hill 2010). Species sighted during small-vessel surveys in 2010 through 2014 were, in order of most frequently encountered: spinner dolphins (*Stenella longirostris*), pantropical spotted dolphins, bottlenose dolphins (*Tursiops truncatus*), and short-finned pilot whales (Hill et al. 2014, Hill et al. 2015). Sperm whales, false killer whales, pygmy killer whales (*Feresa attenuata*), rough-toothed dolphins (*Steno bredanensis*), and melon-headed whales (*Peponocephala electra*) were encountered infrequently (Hill et al. 2014, Hill et al. 2015). Blainville's beaked whales (*Mesoplodon densirostris*), Cuvier's beaked whales (*Ziphius cavirostris*), and unidentified beaked whales/unidentified Mesoplodont whales were also encountered (Hill et al. 2015). One dwarf sperm whale (*Kogia sima*) sighting was also reported (Hill et al. 2014). Some of these sightings consisted of mixed species groups in which bottlenose dolphins were closely associated with one or more of the following species: pilot whales, false killer whales, rough-toothed dolphins, and spinner dolphins (Hill et al. 2014). An incidental sighting of a humpback whale was also reported off Saipan in January 2013 (Uyeyama 2014).

The aerial- and vessel-based survey efforts and related tagging efforts conducted in 2007–2014 provided valuable new information on species occurrence and distribution within waters of Guam and the CNMI. These types of surveys, however, are typically limited by time, logistics, weather, and other constraints, and therefore may not provide completely representative data. Complementary data on species occurrence have been obtained using PAM by high-frequency acoustic recording packages, which documented the occurrence of humpback and sperm whales (common), blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), and minke (*Balaenoptera acutorostrata*) whales (rare), as well as Cuvier's (*Ziphius cavirostris)*, Blainville's (*Mesoplodon densirostris)*, and unidentified beaked whales (regularly occurring but variable) at Saipan and/or Tinian in 2010–2013 (Oleson et al. 2015). However, recording coverage by high-frequency acoustic recording packages was not complete over the 3 years and only 1 year had data recorded throughout the entire winter period. Small-vessel surveys conducted by PIFSC CRP/PACFLT in 2010 through 2014 did not detect any baleen whales, despite some winter/spring effort in two of the survey years. Small-vessel effort was more concentrated nearshore due to offshore weather conditions and logistical considerations of a small vessel operating from shore (Hill et al. 2013a,b; 2014). However, during recent shore-based visual effort and small-vessel surveys in February-March 2015, humpback whales were sighted west of Saipan (Hill et al. pers. comm[1]). During the MISTCS effort in 2007, although survey effort was conducted offshore and in winter/spring months, two-thirds (66 percent) of the effort took place in conditions of Beaufort sea state 5 or above. This limited observers' ability to visually detect and identify small odontocetes (Fulling et al. 2011).

In 2011, PACFLT initiated a long-term PAM program to better understand the year-round occurrence of baleen whales, beaked whales, and other odontocete species in the MIRC. HDR subcontracted the Hawaii Institute of Marine Biology, 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 to report on the findings. In this report, the results of this effort are presented with respect to the following U.S. Navy monitoring questions, numbered according to the subcontracted task orders from which they originate (contract # N62470-10-D-3011, task orders KB14 and KB17).

[1] *Marie Hill, Allan Ligon, Adam Ü, and Amanda Bradford. NOAA PIFSC Cetacean Research Program blog post, 23 March 2015. https://pifscblog.wordpress.com/2015/03/23/humpback-whales-in-the-marianas/*

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?

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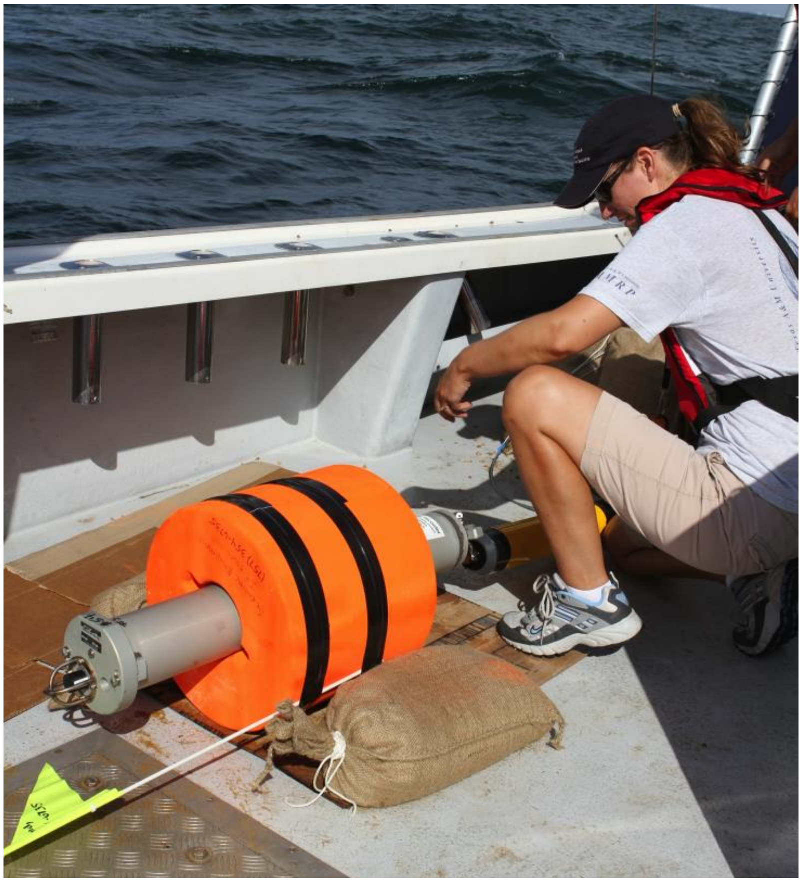
2. Methods

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). During the first deployment, four EARs sampled at 80 kilohertz (kHz), providing an effective bandwidth of approximately 0 to 40 kHz (anti-aliasing = 90 percent), with a recording duty cycle of 30 seconds ‘on’ every 6 minutes (8.3 percent). During the second deployment, the recording duty cycle interval was changed to 30 seconds ‘on’ every 10 minutes (5 percent). See **Table 1** for EAR programming specifics. Each 30-second recording was saved as an individual sound file and these recordings are hereafter referred to as 'files.'



Photos by Dan Engelhaupt (left) and NOAA (right).

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

Table 1. Recording parameters of MIRC EARs.

Sampling Rate	80 kHz
Recording Duration	30 seconds
Recording Interval	Deployment 1: 360 seconds (6 minutes) Deployment 2: 600 seconds (10 minutes)
Anti-Aliasing Filter	90%
Hydrophone Sensitivity	Approx. -193 dB re 1μPa
Clock	Local Time
Disk Space	320 gigabyte maximum
Energy Detection	Disabled

dB re 1μPa = decibels referenced at 1 microPascal; kHz = kilohertz

Two of the EARs were deployed in waters off Guam, labeled Guam S 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 among instruments from 62 days to 118 days (**Table 2**). These recording durations were shorter than anticipated (approximately 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. 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 location was not recovered, most likely due to a battery failure on the release.

Table 2. EAR deployment sites and recording summary.

Site	Latitude/ Longitude	Depth (meters)	Recording Period	# of 30-s Recordings	Total Recording Hours
Deployment 1					
Guam N	13° 41.781' N 144° 45.186' E	820	9/10/2011- 1/06/2012	28,320	236
Guam S	13° 13.392' N 144° 28.303' E	952	9/16/2011- 11/17/2011	14,839	124
Tinian W	15° 04.602' N 145° 26.676' E	869	9/12/2011- 11/28/2011	18,478	154
Saipan N	15° 27.292' N 145° 50.938' E	850	9/12/2011- 12/29/2011	25,279	211
Deployment 2					
Guam N	13° 41.789' N 144° 45.209' E	778	4/06/2012- 9/05/2012	21,818	182
Guam S	13° 13.388' N 144° 28.277' E	944	NR	NR	NR
Tinian W	15° 04.605' N 145° 26.667' E	860	4/08/2012- 4/23/2012	2,141	18
Saipan N	15° 27.283' N 145° 50.931' E	840	4/8/2012- 9/22/2012	23,981	200

s = seconds; # = number, NR = not recovered

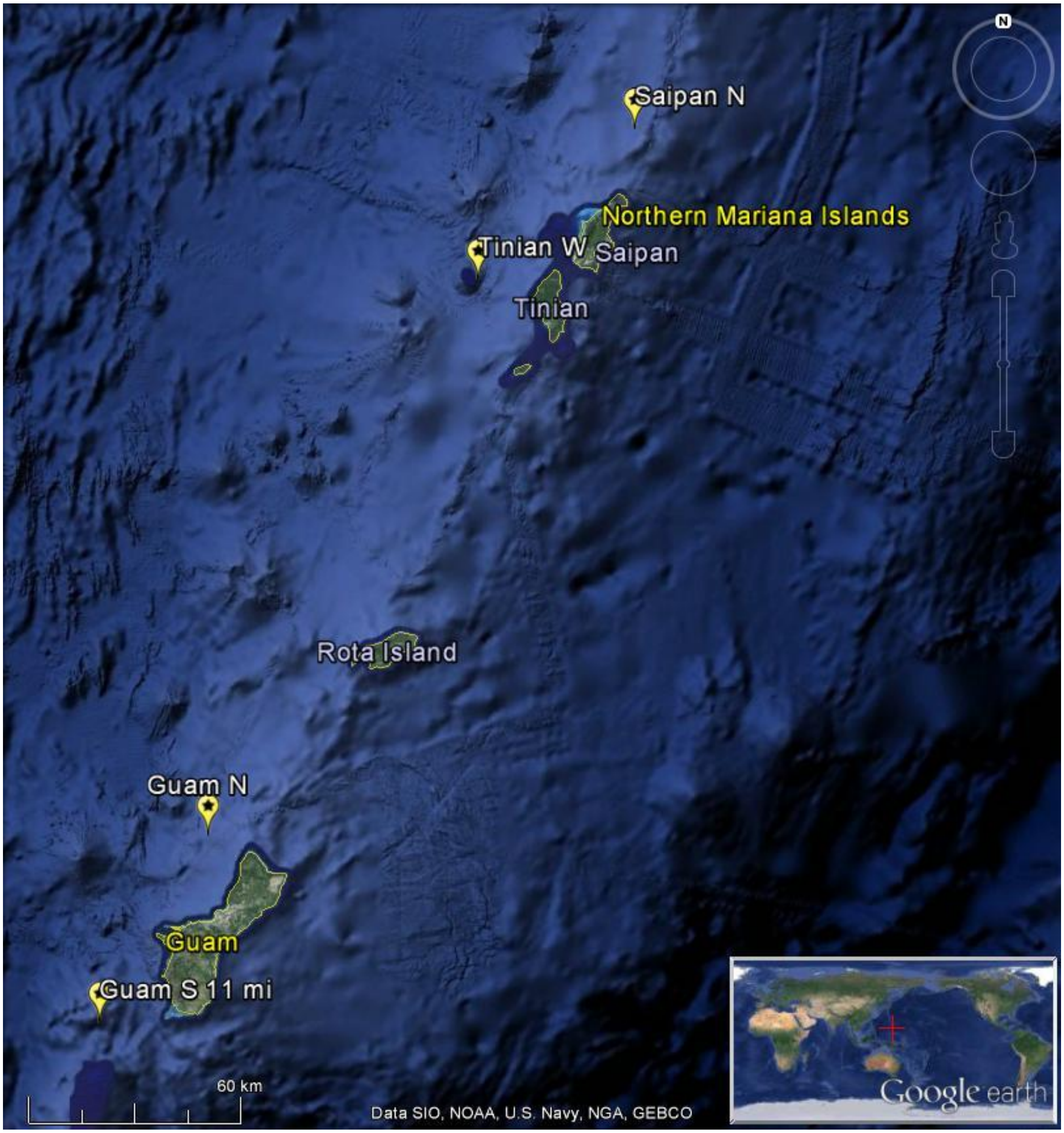


Figure 2. Map of MIRC EAR deployment sites. Yellow icons indicate EAR deployment sites.

2.2 Data Analysis

2.2.1 Automated Detection

2.2.1.1 BEAKED AND SPERM WHALES

The potential occurrence of beaked whale and sperm whale clicks in the MIRC EAR data was investigated using the Class-Specific Support Vector Machine (M3R CS-SVM) portion of the Marine Mammal Monitoring on Navy Ranges (M3R) detection and classification software (Jarvis et al. 2008; Jarvis 2012) and custom MATLAB™ programs. The M3R CS-SVM portion of the M3R software uses nine-dimensional feature vectors formed by computing the time between six consecutive zero crossings of the signal waveform about the peak and three normalized envelope amplitude peaks; together these feature sets capture the time-frequency structure of the signal (Jarvis et al. 2008). The M3R CS-SVM is the primary Navy software used to detect and identify deep-diving odontocetes at the following U.S. Navy ranges: the Atlantic Undersea Test and Evaluation Center, the Southern California Offshore Range, and the Pacific Missile Range Facility. The M3R CS-SVM software contains templates of biosonar signals recorded in the aforementioned regions from short-finned pilot whales, Risso's dolphins (*Grampus griseus*), sperm whales, Cuvier's (*Ziphius cavirostris*) and Blainville's beaked (*Mesoplodon densirostris*) whales, and spinner dolphins. For this report, the focus is on M3R CS-SVM detector results for beaked whales (including Cuvier's and Blainville's) and sperm whales, which have unique click characteristics among the odontocetes (Madsen et al. 2002, 2005; Møhl et al. 2003; Johnson et al. 2004; Zimmer et al. 2005).

During initial analyses using the M3R CS-SVM, a 30-second sound recording (referred to here as a "file") was considered a detection of the target species if it contained any individual clicks classified as the target species (Munger et al. 2014). If clicks within a given file were classified into multiple species classes, that file was presumed to contain all of those species. However, as a consequence of a recent evaluation of the M3R CS-SVM detector applied to EAR data from the Hawaii Range Complex (HRC) (Lammers et al. 2015, Oswald et al. 2015), analysts concluded it would be more appropriate to interpret detector output on a per-file basis, which would take into account the context of surrounding detections and classifications within the same file, rather than a per-click basis as was done initially. This was accomplished for the HRC automated detector results (Lammers et al. 2015, Oswald et al. 2015) and also for this study by establishing thresholds for the minimum number of individual clicks that must be present within a given file, as well as a minimum percentage of clicks that must be classified as the target species within that file for the file to be considered a detection. Detection threshold criteria were established and used to evaluate detector performance as follows.

Manual verification of M3R CS-SVM detections and an evaluation of detector performance were conducted for a subset of MIRC EAR recordings by Bio-Waves, Inc. As with validation efforts for the HRC, manual verification of beaked whale and sperm whale click classifications within the MIRC was conducted using the following techniques: examining wave forms, spectrograms, frequency spectra, Wigner-Ville plots; playback of sounds; and measurement of click characteristics and inter-click intervals (Oswald et al. 2015). Results of the manual review were used to calculate precision, recall, and specificity. Respectively, these are measures of the proportion of detections correctly classified as the target species, the proportion of available target species' signals that were correctly detected and classified, and the proportion of signals not produced by the target species that were correctly rejected (equations 1–3). Missed detections for each species were identified from all of the manually verified files (n = 131). For each of these measures, a "detection" was considered to be a file that met the threshold criteria.

Eq. 1: Precision is calculated as:

$$P = \frac{\#\, true\ positives}{\#\, true\ positives + \#\, false\ positives}$$

Eq. 2: Recall is calculated as:

$$R = \frac{\#\, true\ positives}{\#\, true\ positives + \#\, missed\ detections}$$

Eq. 3: Specificity is calculated as:

$$S = \frac{\#\, true\ negatives}{\#\, true\ negatives + \#\, false\ positives}$$

Files to review were chosen for sperm whales, Cuvier’s beaked whales, Blainville’s beaked whales, and a ‘mixed beaked whales’ class (made up of detections of both Cuvier’s and Blainville’s beaked whales). Initially, the following criteria were used to select beaked whale files for review: files must contain at least five detected clicks and at least 70 percent of the detected clicks must be classified to the species of interest. However, due to the small sample size of files that contained five or more clicks classified as beaked whales, the click number threshold for beaked whales was subsequently eliminated. Therefore, precision and recall were calculated for beaked whales and results were interpreted using only the criterion of 70 percent or more clicks classified to the beaked whale species class of interest.

For sperm whales, files were chosen for review that contained 10 or more detected clicks with at least 70 percent of those clicks classified as sperm whales. These criteria were chosen to balance the trade-offs of improving precision while providing an adequate sample size of files to examine. Varying the percentage-of-clicks threshold (e.g., 80 percent, 55 percent, and 60 percent) was investigated, but increasing the threshold resulted in inadequate sample sizes and decreasing the threshold reduced precision below an acceptable value without significantly increasing recall. Therefore, precision and recall were calculated for sperm whales and results were interpreted using the 10-click minimum and 70 percent or more classification threshold. Additional manual analyses for sperm whales, conducted concurrently with manual delphinid analyses (see Section 2.2.2.1), corroborated the M3R CS-SVM revised interpretation.

2.2.1.2 BALEEN WHALES

An automated baleen whale detector, Baleen5, was developed by Dr. Helen Ou (Hawaii Institute of Marine Biology) 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 sei whale calls”), minke whale (“boings”), and humpback whale (Ou et al. 2015). 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 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. An analyst manually reviewed recordings with automated detections to confirm whether detections were true positives.

Manual searching for additional baleen whale calls was conducted in the long-term spectral average (LTSA) for the months September–April as described in **Section 2.2.2.2** (Manual Analyses: Baleen Whales). An LTSA is a composite spectrogram made up of Fast 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 identify periods of possible signals of interest. The goals of the manual analysis were to detect any baleen whale calls missed by Baleen5 and evaluate detector performance, as well as to search for high-frequency sei whale calls, for which the detector was not trained.

2.2.2 Manual Analyses

2.2.2.1 DELPHINIDS AND SPERM WHALES

Delphinid and sperm whale signals were manually detected using Triton, a MATLAB™-based analysis package developed at Scripps Institution of Oceanography (Wiggins 2003) and adapted for use with EAR data. Triton was used to create LTSAs of the recordings. For this analysis, an LTSA was produced for each EAR dataset with 20-hertz (Hz) frequency bins and 10-second time bins.

Delphinid and sperm whale sounds were detected by visually examining the full-bandwidth LTSA for the entire data set for the presence of transient occurrences of tonal and broadband acoustic energy 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. A sample LTSA and spectrogram display containing delphinid whistles and clicks from the Guam S EAR is shown in **Figure 3**.

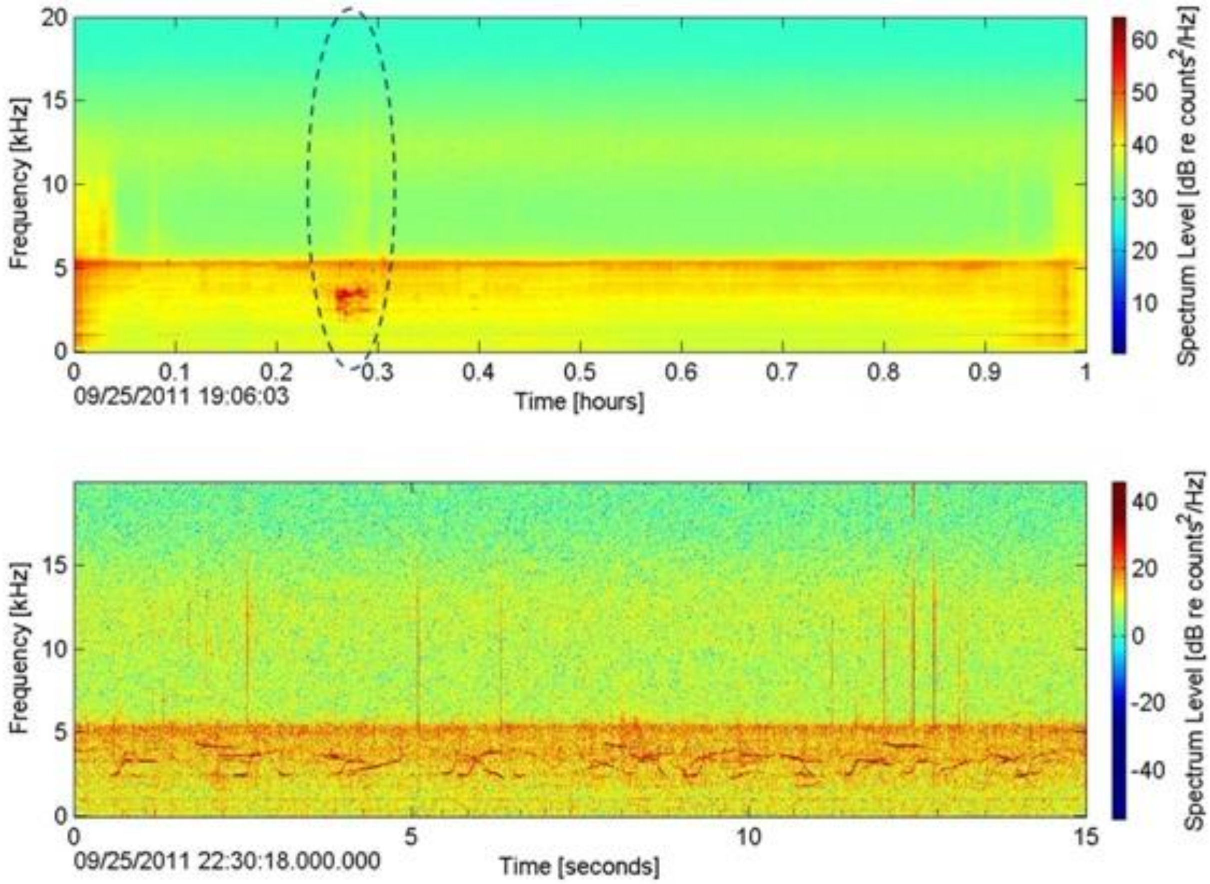


Figure 3. Figure window from Triton showing LTSA (top), with circled region of high energy in delphinid whistle frequency band, and expanded spectrogram (bottom) verifying presence of delphinid whistles and clicks. Data from Guam S.

Delphinid or sperm whale signals were grouped into encounters for logging and analysis. An encounter was defined as a time period consisting of one or more recordings containing signals (whistles and/or clicks) occurring within 30 minutes of the next recording with signals. Therefore, the start and end of each encounter were separated from the next encounter by more than 30 minutes. Four categories of delphinid encounters were logged: one category for clicks only, and three categories based on whistle frequency for encounters that contained whistles. 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 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. These whistle frequency bands were chosen because they are representative of different delphinid species assemblages. Research on dolphin whistle characteristics has shown that these frequency bands loosely correspond to the body size of animals, with smaller species generally producing higher frequencies and larger species generally producing lower-frequency sounds (Wang et al. 1995; Azzolin et al. 2014). Based on whistle 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 most often be classified into the following whistle categories: LF whistles = false killer whale, short-finned pilot whale, and rough-toothed dolphins; HF/LF whistles = bottlenose, spotted, and striped dolphins; and HF whistles = spinner, spotted, and striped dolphins. Dolphin species identification based on whistle characteristics (e.g., using the Real-time Odontocete Call Classification Algorithm [ROCCA]; Oswald et al. 2003, 2007) was not performed as part of this study. Dolphin whistle classifiers developed to date have been trained and validated using acoustic recordings from other regions/oceans and their application to novel, visually unconfirmed recordings in the MIRC is therefore not yet warranted.

Sperm whale encounters were also logged by the analyst as they were conducting the manual search, as they were readily identifiable in the LTSA. Sperm whale clicks are distinctive because of their low frequency relative to other odontocete clicks; their peak frequencies are between approximately 2 and 15 kHz (Madsen et al. 2002; Møhl et al. 2003). Encounters containing sperm whale clicks were characterized by duration (start and end time), but no further detail about click types or rates was logged.

Within each delphinid encounter, the five recordings with the greatest intensity/rate of signaling were assigned an Acoustic Index score based on the number and type of signals present (**Table 3**). For encounters with fewer than five recordings containing dolphin signals, zeroes were scored for the remainder of the five detections. The five Acoustic Index scores within an encounter were then averaged to produce a measure of the amount of signaling for each encounter, termed the Encounter Acoustic Abundance (). The EAA was then 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), and the sum of the day's weighted EAA values was termed Daily Acoustic Abundance (DAA). The highest possible DAA score would be 4, which would indicate an encounter with the highest possible acoustic abundance score of 4 (**Table 3**) that lasted 24 hours (1 day). For sperm whales, the start and end times of encounters were logged, but no abundance scores were assigned.

Table 3. Acoustic Index scores used to calculate delphinid Encounter Acoustic Abundance based on numbers of dolphin whistles, burst pulses ('BP'), 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 and sonar or BP	2
Whistles >10	2.5
Sonar & BP >5	2.5
1–5 whistles, sonar, and BP	3
6–10 whistles and sonar or BP	3
6–10 whistles, sonar, and BP	3.5
>10 whistles and sonar or BP	3.5
>10 whistles, sonar, and BP	4

Results were characterized for all categories of delphinid encounter as well as sperm whale encounters. The metrics analyzed included encounter rates, encounter durations, and DAA (DAA for delphinids only). These were summed and normalized by the number of instrument effort-days (i.e., number of recording days within a given time frame) in order to be comparable among EAR sites. Diel (hourly) patterns were investigated by determining the hour of the day in which the temporal midpoint of each encounter occurred. The encounter midpoints for each hour of the day were tabulated for each EAR site and for each delphinid signal group as well as for sperm whales.

2.2.2.2 BALEEN WHALES

Manual analyses for baleen whales were conducted to ground-truth the Baleen5 automated detector and search for additional baleen whale calls that were missed or not targeted by the detector. To manually detect baleen whale calls, the LTSA (see section 2.2.2.1) of the frequency band from 0 to 2 kHz was scanned for all deployment 1 data (September 2011–early January 2012) and for the first month of deployment 2 (April 2012). Signals of interest in this band included high-frequency sei whale calls, similar to those recorded during MISTCS 2007 and described by Norris et al. (2012). These calls were only recently documented and were not included in call types recognized by the automated baleen whale detector (described in **Section 2.2.1.2**). Additionally, any other known baleen whale call types (e.g., from fin, humpback, blue, sei, or minke whales) or unknown call types potentially from baleen whales were noted if present and identified to species when possible. The duration and duty cycle of EAR data (30 seconds on every 6 or 10 minutes), however, was not ideally configured for detecting baleen whale calls produced infrequently or sporadically, or long-duration (tens of seconds) calls.

2.2.2.3 MFAS

The occurrence of MFAS was documented by browsing the full-bandwidth LTSA for the entire data set and zooming in to raw spectrograms to aurally and visually verify the presence of MFAS pings (**Figure 4**). Because of variable ping intervals (seconds to minutes) and the assumption that some pings would be missed due to duty-cycled EAR recording, MFAS pings were considered part of the same "detection" if they occurred within 2 hours of one another.

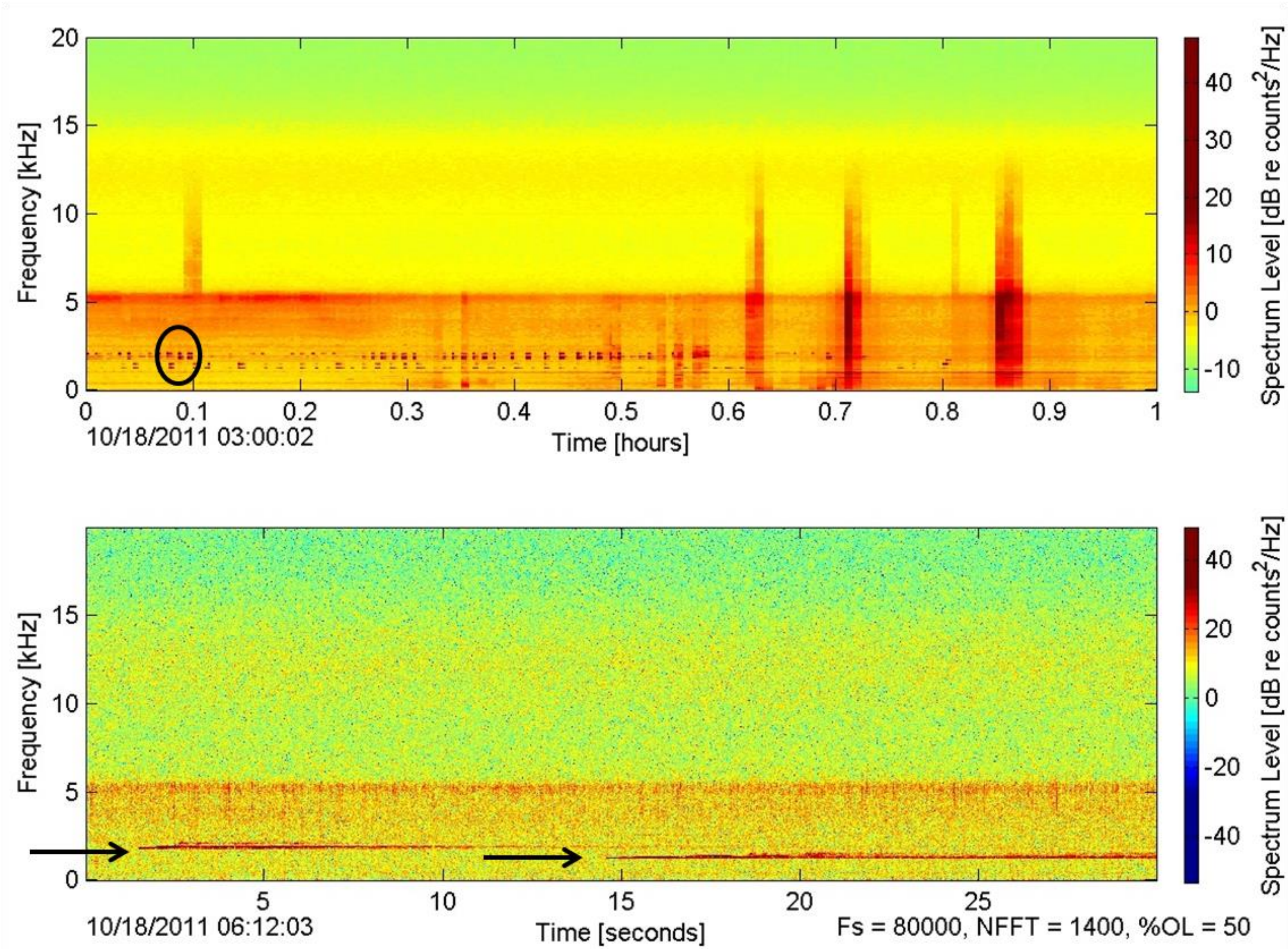


Figure 4. Sequence of MFAS pings shown in LTSA (above) and raw spectrogram (below). Example pings are circled in LTSA; they continue beyond circled region throughout the display window. Data from Guam S, 18 October 2011. Spectrogram parameters in lower right corner of plot; Fs = sample rate, NFFT = number of points in Fast Fourier Transform, % OL = percent overlap.

3. Results

3.1 Beaked and Sperm Whales

3.1.1 M3R CS-SVM raw output and initial interpretation

The M3R CS-SVM algorithm detected and classified sperm whale clicks in 4,774 files and beaked whale clicks in 6,582 files (for all beaked whale species combined) (**Table 4**). Initially, a file was considered to be a detection of the species class of interest if it contained one or more clicks classified to that species class. During preliminary analyses, these raw detection output files were tabulated and plotted, showing nearly identical temporal patterns on daily and hourly time scales for beaked whales and sperm whales, as well as for other delphinid species for which the detector was trained (Munger et al. 2014). These nearly identical temporal detection patterns for multiple taxa that are behaviorally and biologically different suggested potential problems with detector performance, interpretation of results, or both. Therefore, an effort was undertaken for this final report to validate the detector results and evaluate its performance based on revised interpretation criteria, and interpret the output based on these revised criteria to provide the best possible postulation of beaked and sperm whale occurrence.

Table 4. Total numbers of M3R CS-SVM raw detections, detections that met revised interpretation criteria, and manually reviewed detections, for sperm and beaked whales.

	M3R CS-SVM # files with raw detections	M3R CS-SVM # files that met revised interpretation criteria	Number of files manually reviewed	Number of true positives	Number of false positives	Sources of false positives
Sperm Whale	4774	847	69	54	15	Unid Odont (14), Boat (1)
Mixed Beaked Whale	6582	696 Blainville's = 117 Cuvier's = 517	62 Blainville's = 23 Cuvier's = 33	16 Blainvilles = 3 Cuvier's = 3	46 Blainvilles	Unid Odont (29), Sperm Whale (11), Misc (6)

3.1.2 M3R CS-SVM validation and performance evaluation

A total of 131 files from the MIRC were included in the manual validation and M3R CS-SVM performance evaluation for sperm and beaked whales conducted independently by Bio-Waves, Inc. This comprises 1.17 percent of .wav files in the dataset that had M3R CS-SVM detections of beaked whale, sperm whale or both (n = 11,237) and 6.5 percent of files that met the revised interpretation criteria for sperm and beaked whales (n =1,543). A total of 847 files met the sperm whale detector revised interpretation criteria (≥ 10 detected clicks, ≥ 70 percent of clicks within the file classified as sperm whale), and 69 of these files were manually reviewed (**Table 4**). A total of 696 files met the mixed beaked whale revised interpretation criteria (≥ 1 detected click, ≥ 70 percent of clicks within the file classified as a beaked whale), and 62 of these files were manually reviewed (**Table 4**). When examined by species, beaked whale files that met revised criteria were as follows, with the number of files reviewed in parentheses: Blainville's beaked whale n = 117 (23); Cuvier's beaked whale n = 517 (33) (**Table 4**).

Manual validation of files with at least 70 percent of clicks classified as sperm whales and 10 or more clicks resulted in a precision of 0.78, a recall of 0.82 and a specificity of 0.77 (**Table 5**). In other words, 22 percent of reviewed files were false positives, 82 percent of true sperm whale clicks were detected and correctly classified, and 77 percent of detected clicks not produced by sperm whales were correctly rejected by the classifier. Manual validation of files with at least 70 percent of clicks classified as Blainville's or Cuvier's beaked whales with no criteria for the number of detected clicks resulted in precision of 0.13 and 0.09, respectively (**Table 5**), meaning that 87 percent and 91 percent of reviewed files with automated detections were false positives, respectively. Additionally, recall for the Blainville's beaked whale class was 0.25 and for the Cuvier's beaked whale class recall was 0.75 (**Table 5**). This means that 25 percent of files actually containing Blainville's beaked whale clicks and 75 percent of files actually containing Cuvier's beaked clicks were detected and correctly classified. Specificity was calculated as 0.83 for Blainville's beaked whales and 0.76 for Cuvier's beaked whales, meaning that a high proportion of files not classified as either of those beaked whale species were correctly rejected. For the 'mixed beaked whale' class (percentage of clicks classified as Blainville's plus percentage of clicks classified as Cuvier's ≥ 70 percent), recall was 1.00 (no beaked whales were missed), and precision was 0.26 (74 percent of classified files were false positives) (**Table 5**). Additionally, specificity was calculated to be 0.60, meaning that 60 percent of files not classified as beaked whales were correctly rejected. When the threshold of five or more clicks was included as a criterion for the mixed beaked whale category, precision doubled (0.43) and specificity improved (0.81), but recall decreased from 1.00 to 0.75. Therefore, this criterion was not adopted because detecting all beaked whale signals (and missing none) was presumed to be a high priority.

Table 5. Performance of M3R CS-SVM detector for manually reviewed files, applying revised interpretation criteria of ≥ 70 percent of clicks classified as the species of interest and minimum of 1 click (beaked whales) or 10 clicks (sperm whales).

M3R CS-SVM Species Classification	Manually Reviewed Files				Performance of M3R CS-SVM detector		
	True Positive	False Positive	False Negative*	True Negative**	Precision	Recall	Specificity
Blainville's Beaked Whale	3	20	9	99	**0.13**	**0.25**	**0.83**
Cuvier's Beaked Whale	3	30	1	97	**0.09**	**0.75**	**0.76**
Mixed Beaked Whale	16	46	0	69	**0.26**	**1.00**	**0.60**
Sperm Whale	54	15	12	50	**0.78**	**0.82**	**0.77**

*False negatives (missed detections) included any files within the entire manually examined dataset (n = 131) that were identified to the species of interest and were outside of the criteria.

**True negatives included manually reviewed files that did not meet revised interpretation criteria and were verified to not contain signals from the species of interest.

Ninety-three percent of false positive detections of sperm whales were determined to be unidentified odontocetes upon manual review (**Table 6**). For files classified as mixed beaked whales, most false positives were determined to be unidentified odontocetes (63 percent) or sperm whales (24 percent); other sources included boats and other anthropogenic or unknown noise (**Table 6**).

Table 6. Manual classification by Bio-Waves analysts of files classified by M3R CS-SVM according to revised criteria as sperm whales (Pm), Cuvier's beaked whales (Zc), Blainville's beaked whales (Md), or mixed beaked whales (MBW).

Manual Classification	M3R CS-SVM Classification			
	Pm	Zc	Md	MBW
Echosounder and Unidentified Odontocete	-	-	-	1
Boat	1	-	1	1
Boat and Unknown	-	1	-	1
Noise	-	1	-	1
Sperm Whale	53	8	3	11
Sperm Whale and Unidentified Odontocete	1	-	-	-
Unidentified Odontocete	14	12	15	29
Blainville's Beaked Whale	-	6	3	11
Blainville's Beaked Whale and Sperm Whale	-	1	-	1
Cuvier's Beaked Whale	-	3	-	4
Unknown	-	1	1	2
Files not Checked	778	484	94	634
Total	**847**	**517**	**117**	**696**

3.1.3 M3R CS-SVM revised interpretation (beaked and sperm whales)

When the revised interpretation criteria were applied to M3R CS-SVM detections, the numbers of candidate mixed beaked whale and sperm whale detections were reduced by 82 percent and 89 percent, respectively (**Table 4**). This reduction in candidate detections is illustrated for a 2-month subset of data at Guam N (**Figure 5**). The application of revised criteria also reduced the apparent temporal overlap in detection rates for beaked whales and sperm whales that occurred in the initial interpretation of M3R CS-SVM results (**Figure 5**; see also Munger et al. 2014). Presumably, the application of revised interpretation criteria eliminated a large number of false positive detections. Although the raw/initial detections (with no interpretation criteria) were not manually reviewed as part of this study, a manual validation effort conducted for raw M3R CS-SVM detections in a similar study in the HRC found high false positive detection rates for beaked whales (100 percent) and sperm whales (80 percent), with 85 percent or more of the false positive detections in either class attributed to unidentified odontocetes (Oswald et al. 2015). The use of revised criteria for M3R CS-SVM interpretation eliminated enough of these false positives such that a small number of true positive beaked whale detections could be verified in both the HRC (Lammers et al. 2015) and this study (**Table 7, Figure 6**), and the sperm whale detector performance in the MIRC improved substantially compared to the HRC, such that the results can be interpreted reliably and are supported by manual analyses (see **section 3.1.5**).

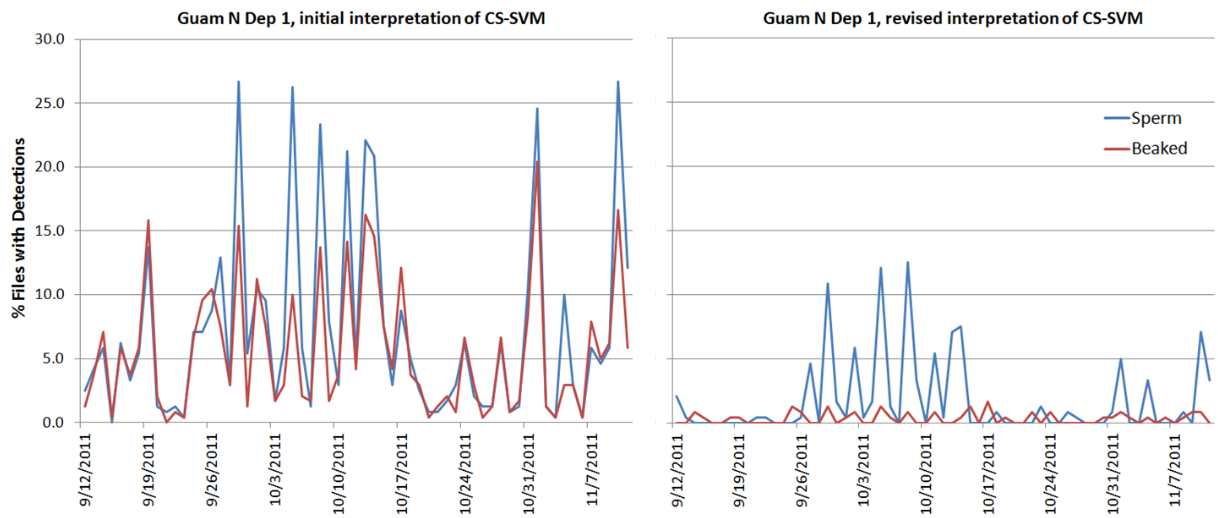


Figure 5. Comparison of percentage of files per day with M3R CS-SVM automated detections of sperm and beaked whales under initial interpretation (left) and revised interpretation (right), for a subset of data at Guam N during the first deployment.

Sperm whale M3R CS-SVM detections that met revised criteria occurred at every EAR location (**Table 7a; Figure 6**). To extrapolate based on precision of 0.78 calculated from the manually reviewed data, 661 of the 847 files that met the revised interpretation criteria for sperm whale files would be presumed to contain true sperm whale signals. Beaked whale files that met the revised interpretation criteria only occurred at Guam N, Saipan N, and Tinian W, but not at Guam S (**Table 7b; Figure 6**). To extrapolate based on precision of 0.26 for the mixed beaked whale class, 181 of the 696 files that meet the beaked whale detection criteria would be presumed to contain true beaked whale signals, although with low precision analysts cannot determine which of the detections are true without manually examining each one.

Table 7. Results by site for sperm whales (a) and mixed beaked whales (b) (files that meet criteria).

(a)

Site	Sperm Whale Not Checked*	Sperm Whale True Positive	Sperm Whale False Positive	Total
Guam N	407	11	7	**425**
Guam S	22	12	0	**34**
Saipan N	221	23	8	**252**
Tinian W	118	8	0	**126**
Total	**778**	**54**	**15**	**847**

(b)

Site	Mixed Beaked Whale Not Checked*	Mixed Beaked Whale True Positive	Mixed Beaked Whale False Positive	Total
Guam N	215	5	14	**234**
Guam S	76	0	6	**82**
Saipan N	271	5	16	**292**
Tinian W	72	6	10	**88**
Total	**634**	**16**	**46**	**696**

*"not checked" = files that met revised detector criteria but were not included in manual verification

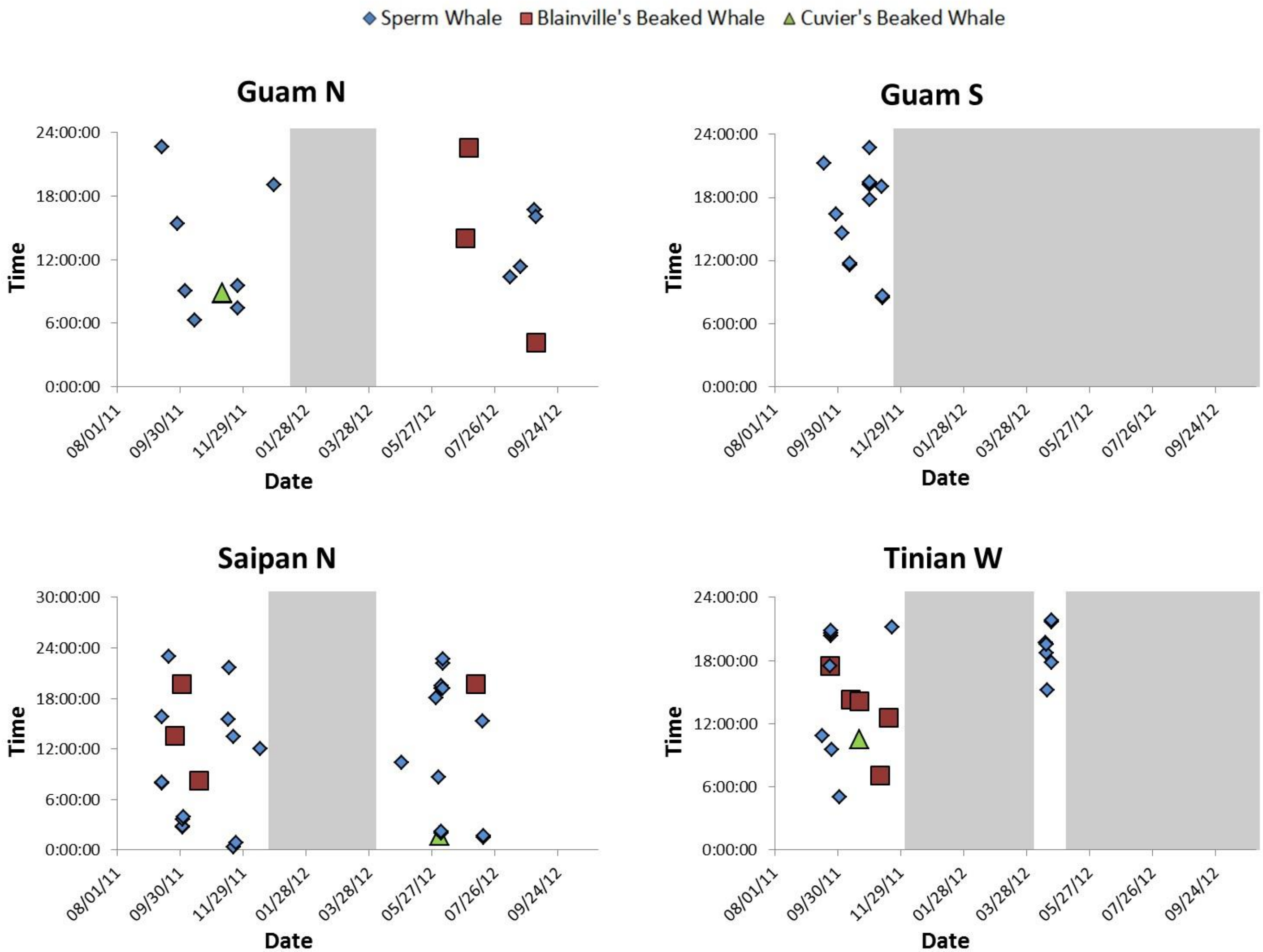


Figure 6. Files manually verified to contain true positive detections of sperm whale (blue diamonds), Cuvier's (green triangles) and Blainville's (red squares) beaked whale signals, plotted for each site. Each symbol represents one file with detections. Grayed periods indicate no recording.

The majority (76 percent) of the 847 files that met the sperm whale criteria occurred in the first deployment. There were intermittent periods of 1–4 days with no detections (**Figure 7**). Detections were most prevalent in October and November 2011. Gaps in detection were more frequent and numbers of files detected were lower throughout the remainder of deployment 1 and all of deployment 2 (**Figure 8**). A seasonal trend emerged with a peak in detections in autumn (September–November 2011), and low rates of detection in spring and summer months (April–August 2012) (**Figure 9**). Given the M3R CS-SVM precision of 0.78 (78 percent of files that meet criteria presumed to contain true positive sperm whale detections), the same relative seasonal trend can be presumed to hold true for true positive detections of sperm whales.

Of the 696 files that met the beaked whale criteria, 67 percent occurred in the first deployment (**Figure 10**) and 33 percent were in the second deployment (**Figure 11**). Manually verified true positive detections occurred throughout both deployments. Although a greater proportion of beaked whale detections were made during the first deployment (September 2011–January 2012) than the second (April–September 2012) (**Figure 12**), no conclusions can be drawn about seasonal or temporal patterns of true beaked whale occurrence without knowing which detections are true positives, given the low precision (0.26) of the detector for these particular datasets.

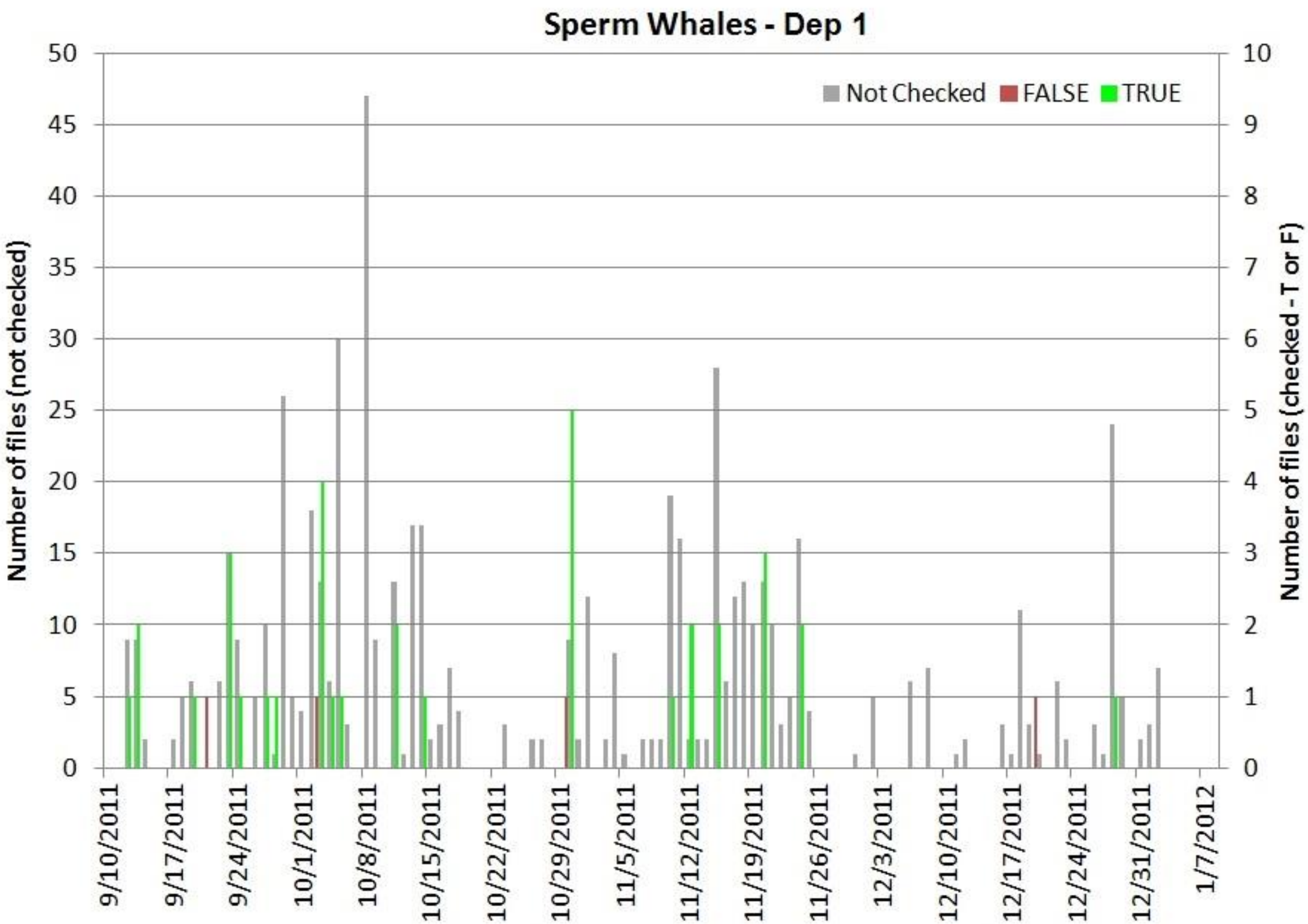


Figure 7. Files that met the M3R CS-SVM revised interpretation criteria for sperm whales, combined for all EAR sites, plotted by date for deployment 1. Gray bars indicate files that met criteria but were not reviewed manually and are plotted on the left vertical axis. Manually reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green).

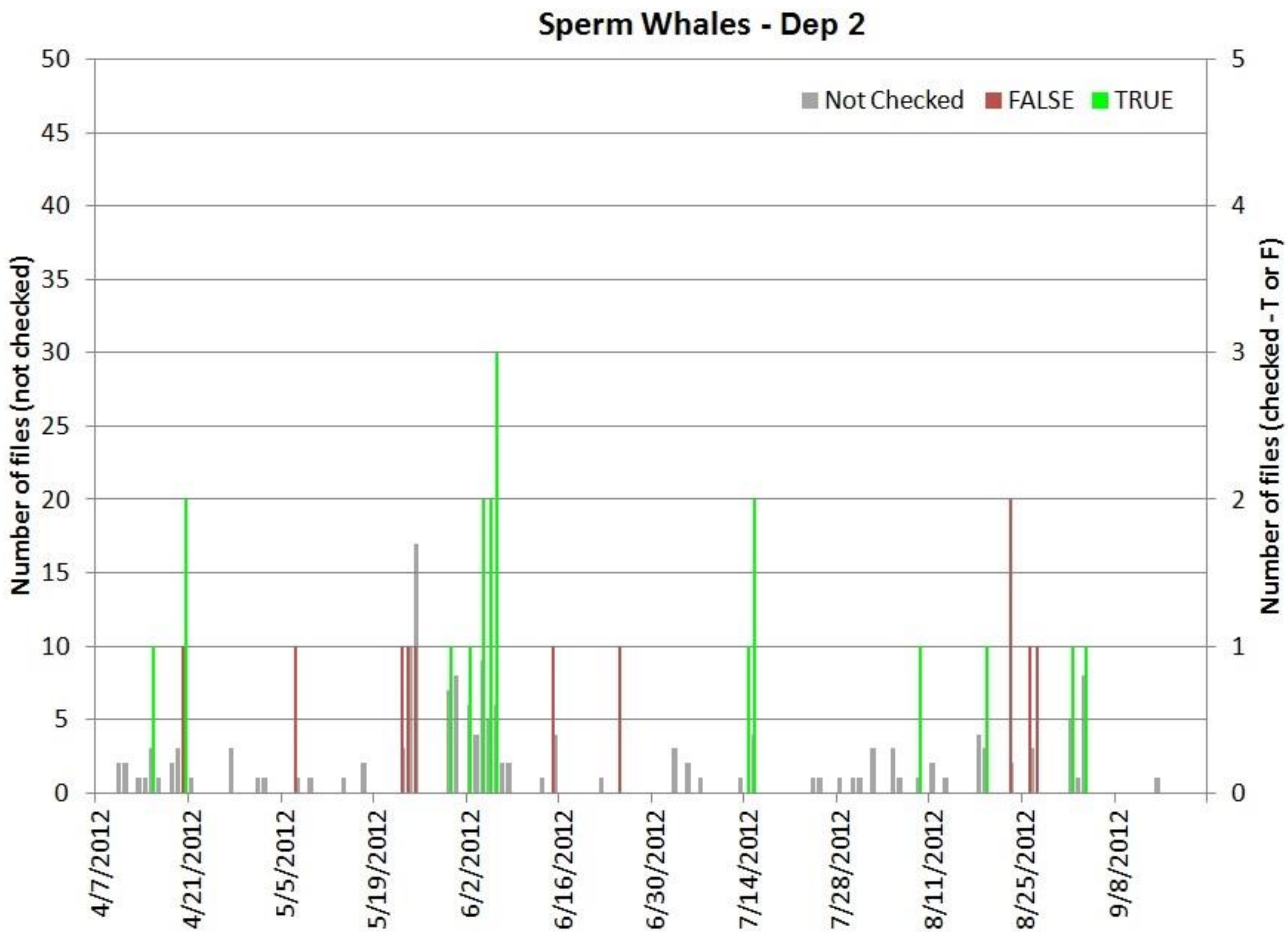


Figure 8. Files that met the M3R CS-SVM revised interpretation criteria for sperm whales, combined for all EAR sites, plotted by date for deployment 2. Gray bars indicate files that met criteria but were not reviewed manually and are plotted on the left vertical axis. Manually reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green).

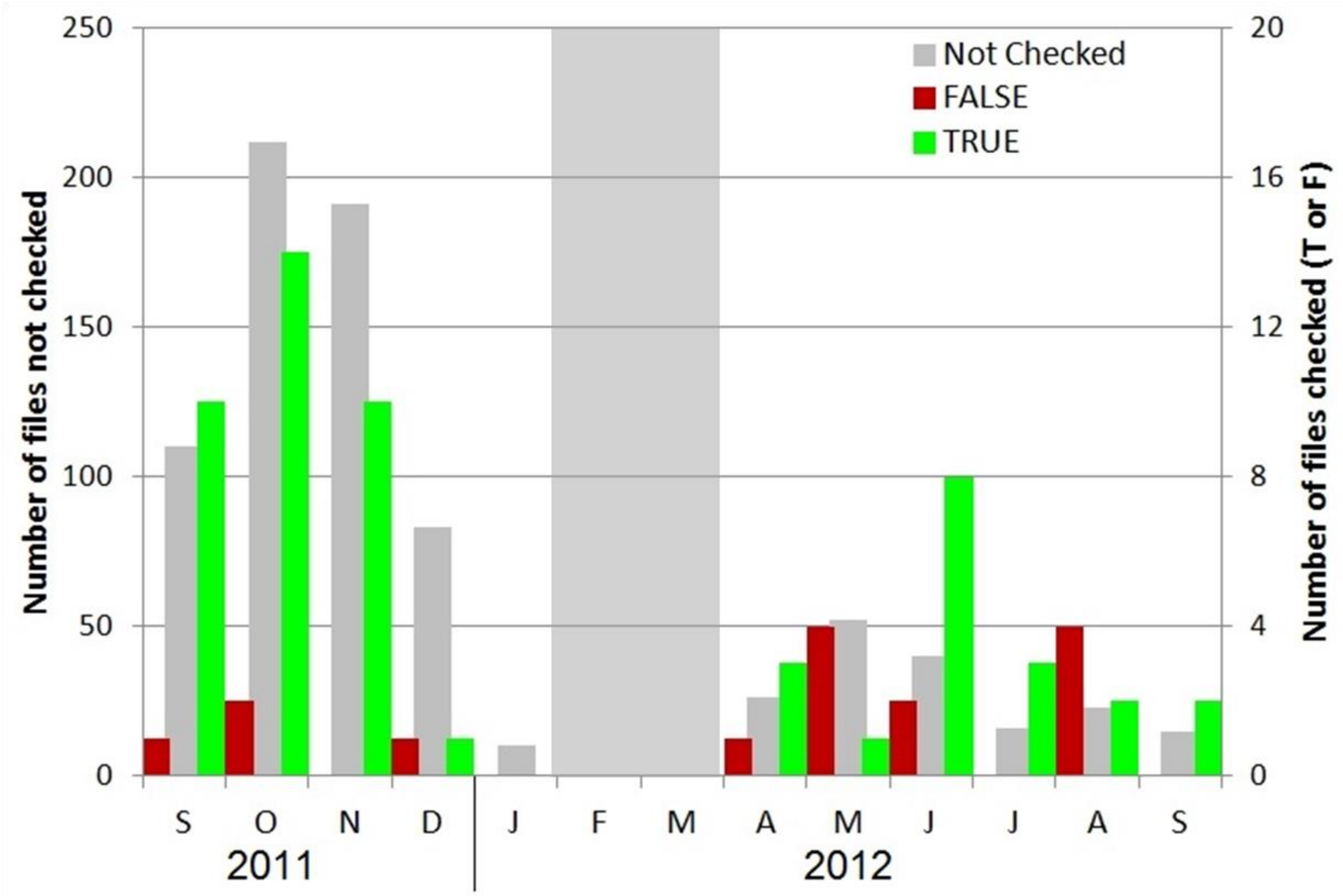


Figure 9. Files that met the M3R CS-SVM revised interpretation criteria for sperm whales, combined for all EAR sites, plotted by month. Gray bars indicate files that met criteria but were not reviewed and are plotted on the left vertical axis. Reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green). Grayed period indicates no recording.

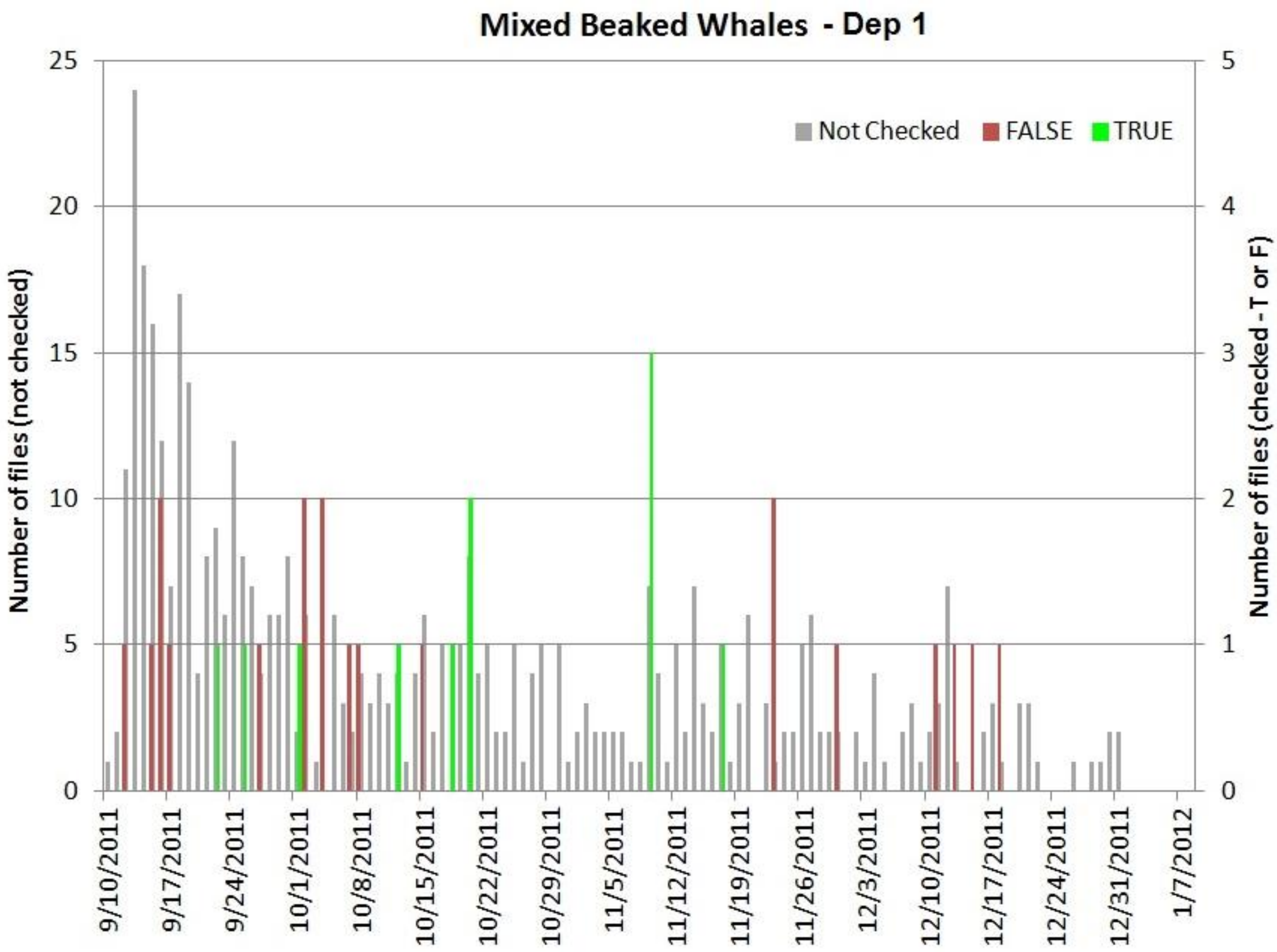


Figure 10. Files that met the M3R CS-SVM revised interpretation criteria for mixed beaked whales, combined for all EAR sites, plotted by date for deployment 1. Gray bars indicate files that met criteria but were not reviewed manually and are plotted on the left vertical axis. Manually reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green).

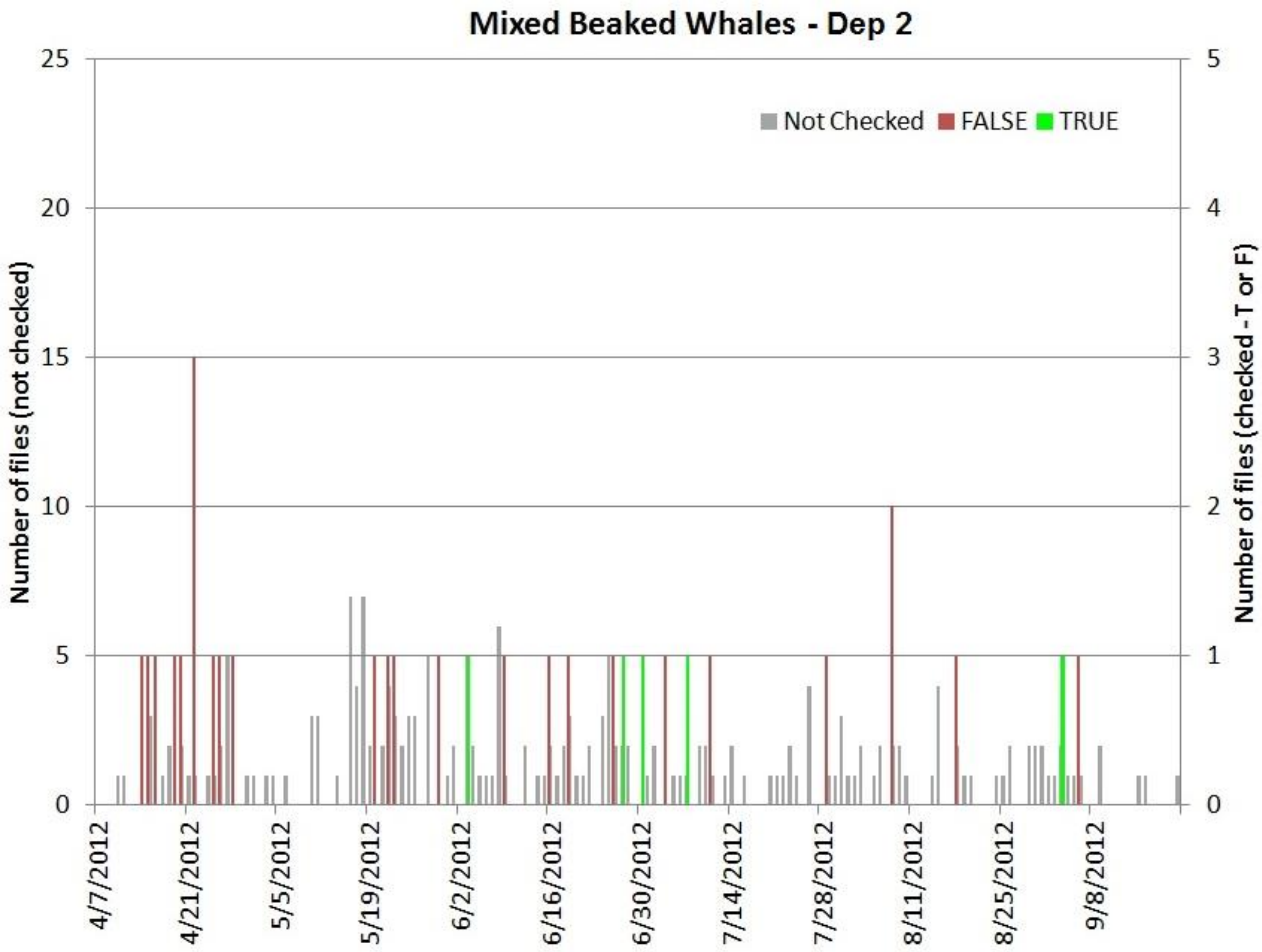


Figure 11. Files that met the M3R CS-SVM revised interpretation criteria for mixed beaked whales, combined for all EAR sites, plotted by date for deployment 2. Gray bars indicate files that met criteria but were not reviewed manually and are plotted on the left vertical axis. Manually reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green).

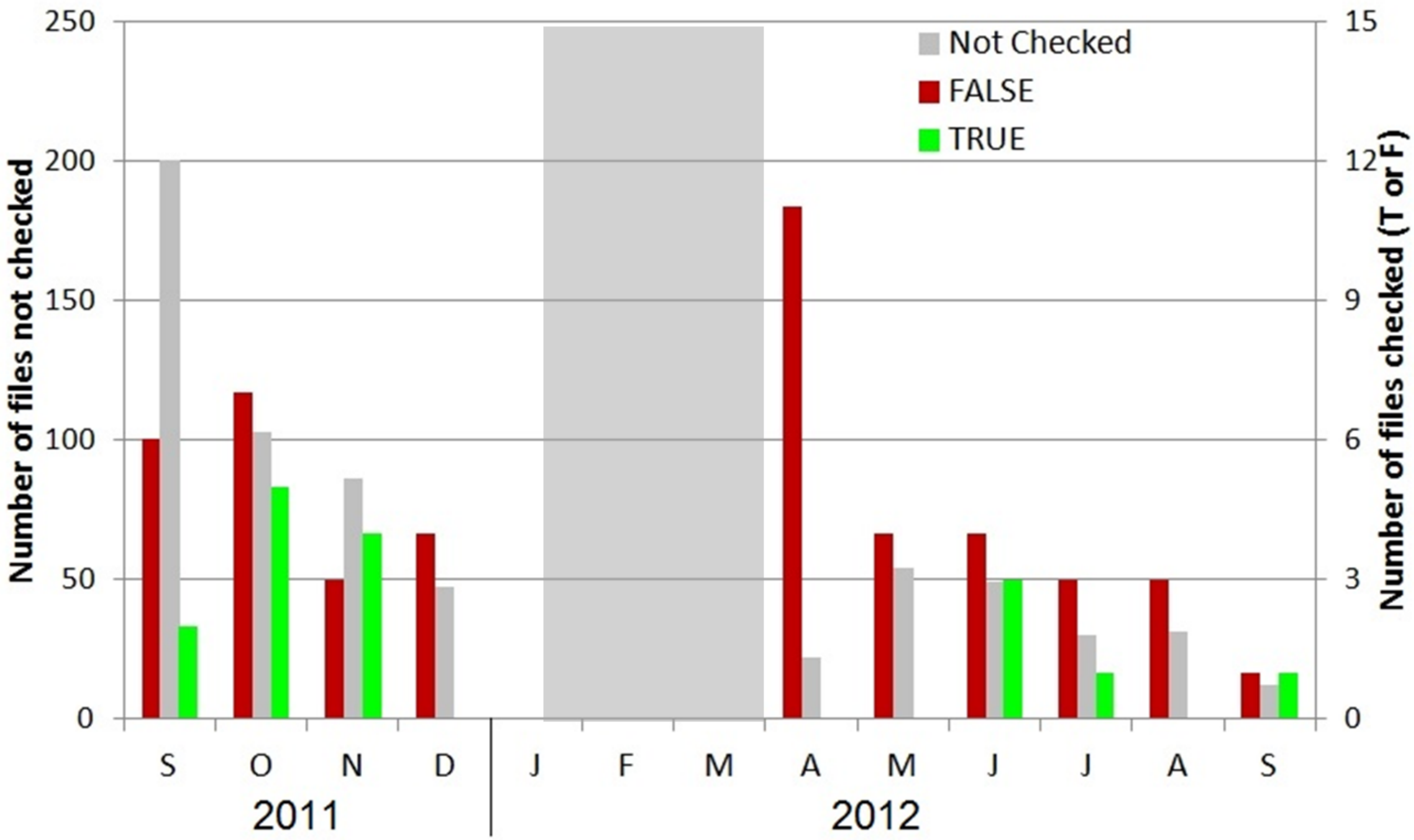


Figure 12. Files that met the M3R CS-SVM revised interpretation criteria for mixed beaked whales, combined for all EAR sites, plotted by month. Gray bars indicate files that met criteria but were not manually reviewed and are plotted on the left vertical axis. Manually reviewed files are plotted on the right vertical axis and include files that were determined to be false positives (red) and true positives (green). Grayed period indicates no recording.

3.1.4 Sperm Whale manual analysis

Sperm whale occurrence in the MIRC region varied by site and year. Generally, sperm whales were present a greater proportion of the time and had higher metrics of acoustic occurrence during the first deployment (September 2011–January 2012) than during the second (April–September 2012) (**Table 8**). During the first deployment, sperm whale encounters were most frequent at Guam N, followed by Tinian W, Guam S, and Saipan N. Mean encounter durations ranged from approximately 1 to 5 hours, and the longest sperm whale encounter, lasting 29 hours, was logged at Guam N. During the second deployment, sperm whale encounter rates and mean duration per effort-day were highest at Tinian W, but this could be an artifact of the shorter recording duration at this site combined with the sporadic occurrence of sperm whales (i.e., sperm whale encounters were captured by chance during the days Tinian W recorded). Median encounter duration was greater by 0.5 to 2 hours during the first deployment than the second for all available EARs (**Table 8**). Sperm whales were detected irregularly at each site, with days to weeks or months elapsing between encounters (**Figure 13**). During the second deployment, sperm whales were only rarely detected at Guam N for brief encounters (approximately 10 minutes to 2 hours) in April and May and none were detected in June or early July; however, at Saipan N there were sperm whales detected on 22 days during the April–mid July time frame, with most encounters >3 hours in duration (**Figure 13**). Later during the second deployment, sperm whales were encountered at Guam N on 26 days in late July through September, but sperm whales were only detected in one file at Saipan N after mid-July.

Table 8. Manual sperm whale (SW) detection summary for MIRC EAR deployments 1 and 2.

Site	# of SW Encounters	SW Encounters per effort-day	Mean SW Encounter Duration	Median SW Encounter Duration	Max SW encounter duration	% of days with SW
Deployment 1						
Guam N	91	0.72	5:06:22	3:42:30	29:06:30	47%
Guam S	20	0.32	1:17:18	0:30:30	10:12:30	17%
Tinian W	33	0.42	2:28:10	2:24:30	7:18:30	26%
Saipan N	24	0.22	3:08:00	3:21:30	14:18:30	18%
Deployment 2						
Guam N	49	0.32	2:53:21	1:15:30	20:50:30	22%
Guam S	ND	ND	ND	ND	ND	ND
Tinian W	18	1.13	3:18:17	1:55:30	9:20:30	50%
Saipan N	36	0.21	2:16:03	1:45:30	8:30:30	14%

max = maximum; SW = sperm whale; ND = no data; # = number; all times in hh:mm:ss format

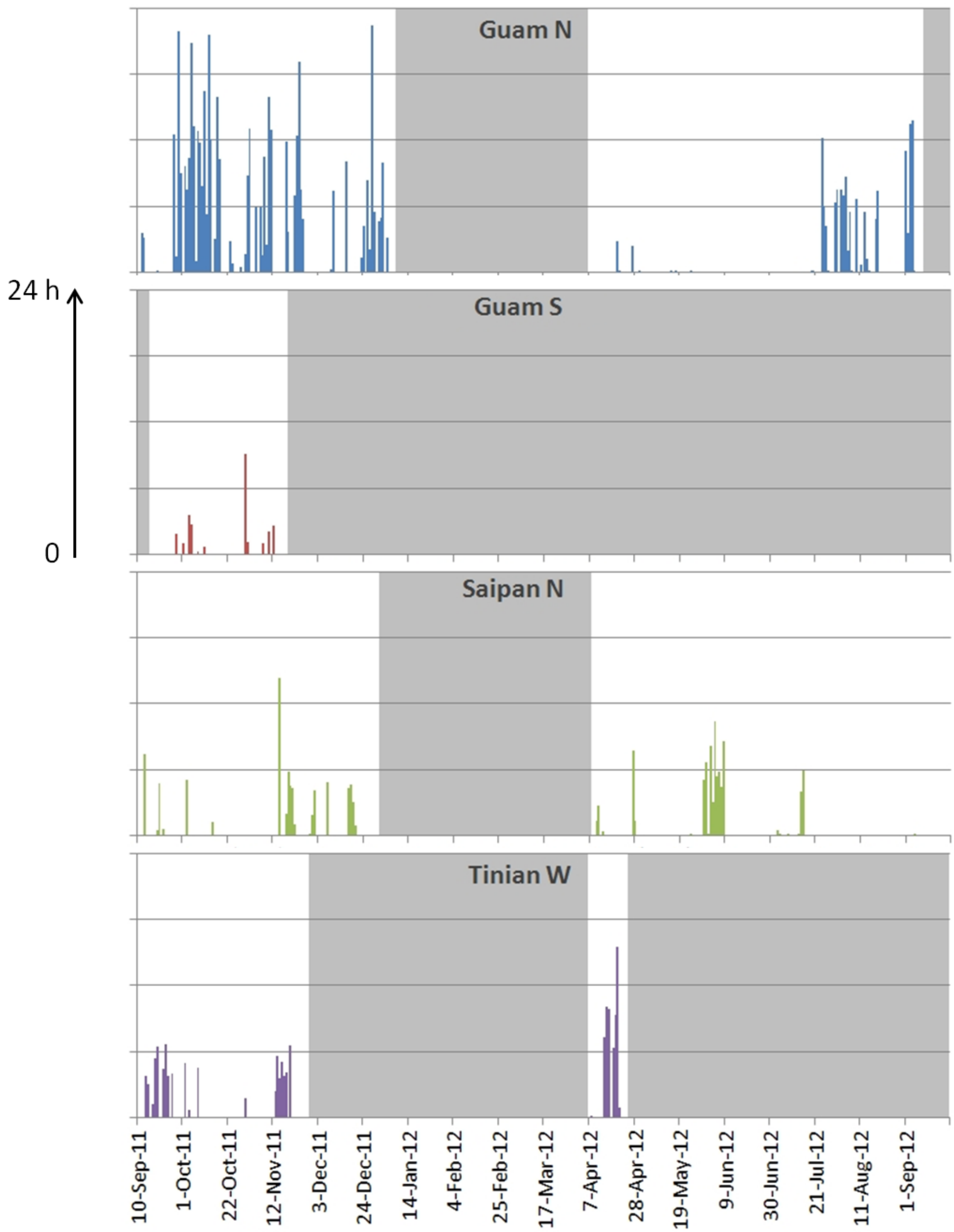


Figure 13. Summed daily duration of manually detected sperm whale encounters at each EAR during deployments 1 and 2, plotted by date. Vertical axis limits = 0 to 24 hours for each subplot. Grayed periods indicate no recording.

Sperm whale encounters exhibited a seasonal trend at Guam N, the site with greatest sperm whale occurrence (**Figures 14-15**). Encounter rates and daily duration of sperm whale presence were greatest in the months of September and October, and lowest in April through July. At Saipan N, sperm whale occurrence was less seasonal, with encounter rates and daily duration consistent throughout most months of the year; however, no sperm whale encounters were detected at Saipan N in August–September 2012 (**Figures 14-15**). At Guam S and Tinian W, only 3 or 4 months of data were recorded, respectively, and no seasonal trend could be inferred.

There was no clear diel trend in the distribution of sperm whale encounters (for all EARs combined) among the hours of the day, which did not significantly differ from a random uniform distribution (Kolmogorov-Smirnov test, $p > 0.10$) (**Figure 16**).

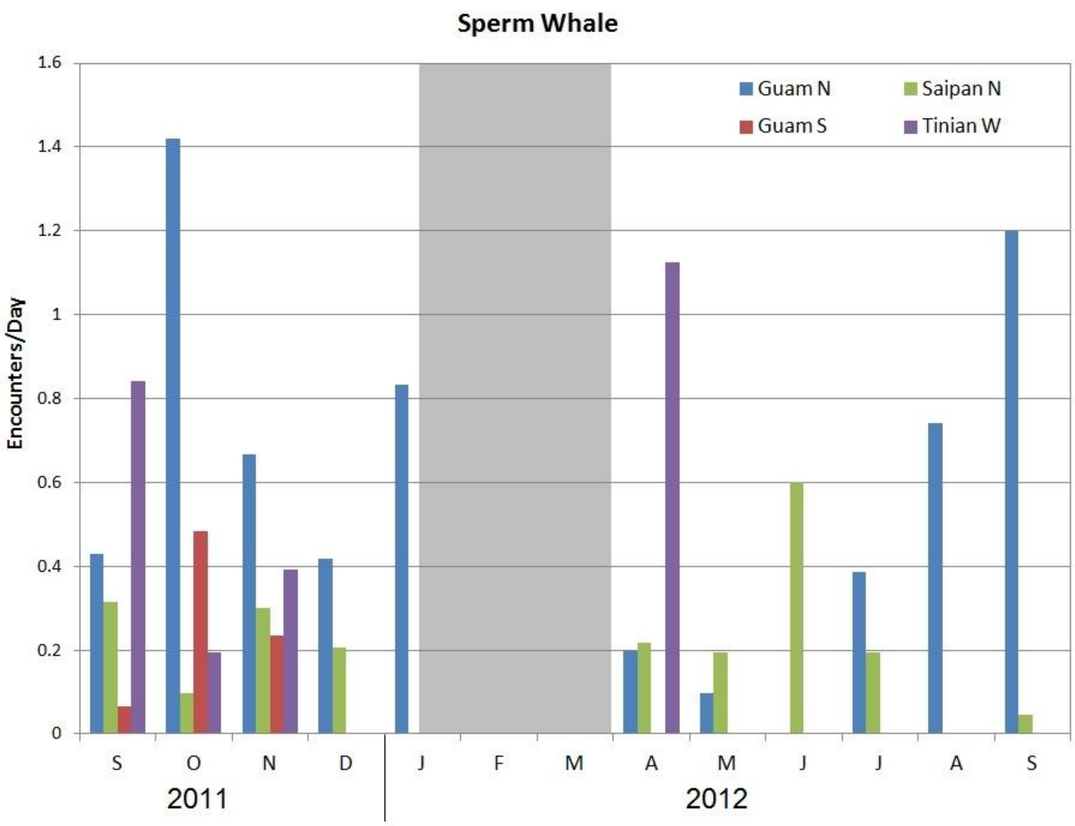


Figure 14. Sperm whale encounters/effort-day at all EAR sites, both deployments, plotted by month. Grayed period indicates no recording.

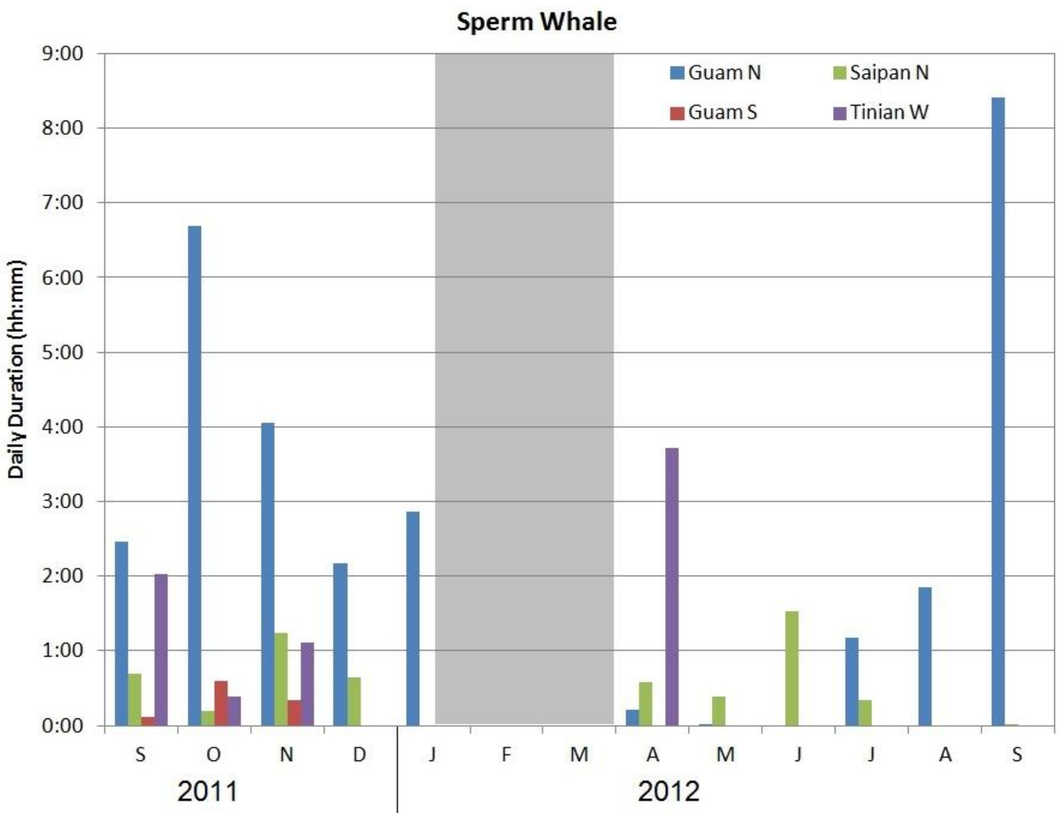


Figure 15. Sperm whale summed encounter duration per effort-day (Daily Duration) at all EAR sites, both deployments, plotted by month. Grayed period indicates no recording.

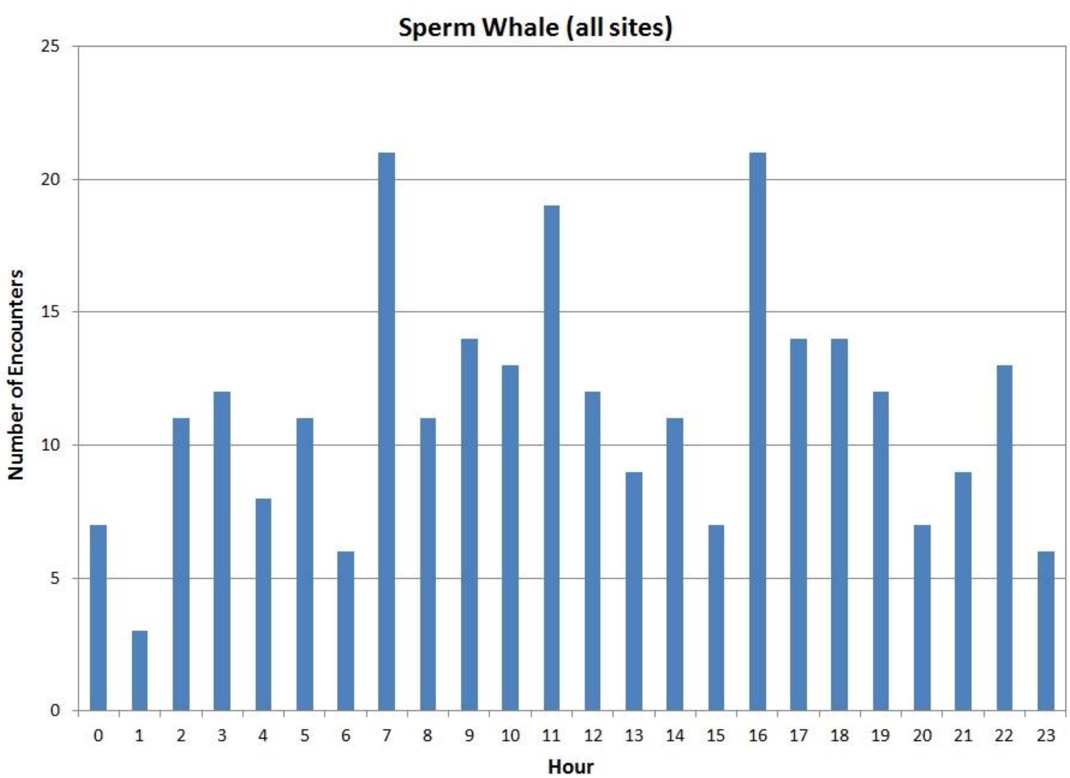


Figure 16. Number of sperm whale encounters within each hour of the day, combined for all EARs.

3.1.5 Comparison of sperm whale manual analysis to M3R CS-SVM revised interpretation

The manual analysis results for sperm whales provide support for the M3R CS-SVM revised interpretation, although a direct comparison of manual sperm whale detections and M3R CS-SVM sperm whale detections was not feasible in this study. The manual logging approach was encounter-based, where the start and end times were logged but not each file with clicks, whereas the M3R CS-SVM detector output was on a per-file basis. However, an at-a-glance comparison of seasonal patterns in automated detections (revised interpretation) and manually logged encounters show similar trends, with greater sperm whale occurrence (albeit using different metrics) during the autumn months of the first deployment than in the spring and summer months of second deployment (for automated detections see **Figures 7, 8, 9**; for manual detections see **Figures 13, 14, 15**). A coarse comparison between the two methods was possible for the percentage of days with sperm whale detections at each EAR. In most cases, sperm whales were detected on similar percentages of days either manually or automatically, to within 3-7 percent (**Table 9**). Exceptions to this were at Saipan N during the first deployment, when the percentage of days with automated detections exceeded manual by 11 percent, and at Tinian W during the second deployment, when the automated detector under-represented the percentage of days with sperm whales by 12 percent compared to manual detection (**Table 9**). Considering that only one automated detection on a given day was required to include that day in the percentage, the inflation of the percentage of days with automated detections relative to manual at Saipan N could have been caused by a small number of false positive detections. As for Tinian W deployment 2, the underestimate by the automated detector was likely an artifact of the relatively short deployment period of 16 days, where a 12 percent underestimate translates to only 2 missed days.

Table 9. Comparison of percentage of days with sperm whales (SW) detected manually and automatically by site and deployment.

Site	% of days with SW - manual	% of days with SW - automated (revised criteria)	Number of recording days
First Deployment (Sep 2011 - Jan 2012)			
Guam N	47%	40%	119
Guam S	17%	17%	63
Tinian W	26%	31%	78
Saipan N	18%	29%	109
Second Deployment (Apr 2012 - Sep 2012)			
Guam N	22%	19%	153
Guam S	ND	ND	ND
Tinian W	50%	38%	16
Saipan N	14%	18%	168

3.2 Baleen Whales

3.2.1 Automated detector results and manual review

During the first deployment period (September 2011–January 2012), the baleen whale detector, Baleen5, detected calls in only five files: three files with minke whale detections at Guam N and two files with humpback whale detections at Saipan N (**Table 10**). The minke whale detections were reviewed and determined to be false positives, and no confirmed calls from minke whales were found during manual searching of the entire first deployment. The two automated humpback whale detections at Saipan N during the first deployment could not be definitively associated with any manually confirmed humpback whale calls or positively identified to species with certainty, and therefore they were tentatively considered to be false positives.

Table 10. Baleen5 automated detections by site and species, evaluated via manual review and additional manual searching.

The five species targeted by detector are Ba = minke whale, Bb = sei whale, Bm = blue whale, Bp = fin whale, Mn = humpback whale.

Deployment Site	Automated Detections	True Positives	False Positives	False Negatives (missed)*
First Deployment				
Guam N	Ba: 3 All others: 0	0 0	Ba: 3 0	0 0
Guam S	0	0	0	0
Tinian W	0	0	0	0
Saipan N	Mn: 2 All others: 0	0 0	Mn: 2 0	Mn: 47 0
Second Deployment				
Guam N	0	0	0	0
Tinian W	0	0	0	0
Saipan N	Mn: 39 All others: 0	39 0	0 0	Mn: 6 0
Total by Species				
Blue Whale (Bm)	0	0	0	0
Fin Whale (Bp)	0	0	0	0
Sei Whale (Bb)	0	0	0	0
Minke Whale (Ba)	3	0	3	0
Humpback Whale (Mn)	41	39	2	53

*false negative (missed) detection rate based on manual analysis of first deployment (Sep 2011 - Jan 2012) and Apr 2012 of second deployment; unknown whether any calls were missed in the May-Sep 2012 time period

Manual searching for baleen whale calls during the first deployment yielded detections of humpback whale calls (song units) in 47 files on 4 days in December 2011 at Saipan N, (**Table 11**). At least 45 of these 47 manual humpback whale detections (95 percent) were missed by the Baleen5 automated detector, taking into consideration analyst uncertainty regarding the two automated detections of humpbacks tentatively considered to be false positives. No calls from blue, fin, or sei whales were detected using Baleen5 in any locations during the first deployment.

Table 11. Manual baleen whale detection summary for MIRC EAR data analyzed September–April.

Site	Species	Date(s)	# Files
Guam N	Unid baleen whale	10/22/2011	1
	Unid baleen whale	11/24/2011	2
Saipan N	Humpback	12/17/2011	5
	Humpback	12/22–12/24/2011	42
	Humpback	04/08–04/09/2012	45
Guam S	No baleen whale calls detected		
Tinian W	No baleen whale calls detected		

During the second deployment period (April–September 2012), 39 files with humpback whale sounds were detected by Baleen5 at the Saipan location on 08–09 April, and all were manually confirmed to be true positives. Six additional humpback whale files within this time period and location were found by manual review that were missed by the detector. No humpback whale sounds were detected at the other locations, and no calls were detected at any location from blue, fin, sei, or minke whales by manually searching the month of April of the second deployment.

The performance of the Baleen5 humpback whale detector within the MIRC dataset was therefore as follows: out of 92 files with manually confirmed humpback whale calls, the Baleen5 algorithm detected 39 true positives, 2 (tentative) false positives, and missed 53 files, for a precision of 0.95 (39 true positives of 41 total humpback detections) and a recall of 0.42 (39 true positive detections of 92 true humpback whale files available) (**Table 10**). In other words, a high percentage (95 percent) of automated detections were true positives, but over 50 percent of the calls found by manual searching were missed by the detector. The Baleen5 true positive humpback whale detections were all in the second deployment, which may have been related to low signal to noise ratio of the missed calls in the first deployment, instrument recording parameters (a 10-minute recording interval during deployment 2 as opposed to a 6-minute interval in deployment 1), or other factors, but further investigation was not conducted.

3.2.2 Other manual detections

No calls that matched HF sei whale calls (Norris et al. 2012) were detected by manually browsing LTSA data from the first deployment (September–January) and the month of April from the second deployment. Humpback whale song was manually detected at Saipan N on 4 days in December 2011 and 2 days in April 2012 (**Table 11**). Three unidentified baleen whale calls comprising two different call types were detected on 22 October 2011 (single call) and 24 November 2011 (two similar calls 0.5 h apart) on the Guam N EAR (**Table 11, Figure 17**). The call in October consisted of an approximate 1.5-second nearly constant-tonal portion with fundamental frequency < 200 Hz and harmonics between 400 and 600 Hz, followed within <1 second by an approximate 0.5-second upsweep from 700 and 800 Hz. The calls in November contained a similar near-constant tonal portion with harmonics, but these were followed (within <1 second) by an approximate 0.2-second downsweep at approximately 400 Hz. No baleen whale calls were detected manually at Guam S or Tinian W during the first deployment, and no baleen whale calls were detected at Guam N or Tinian W during April 2012.

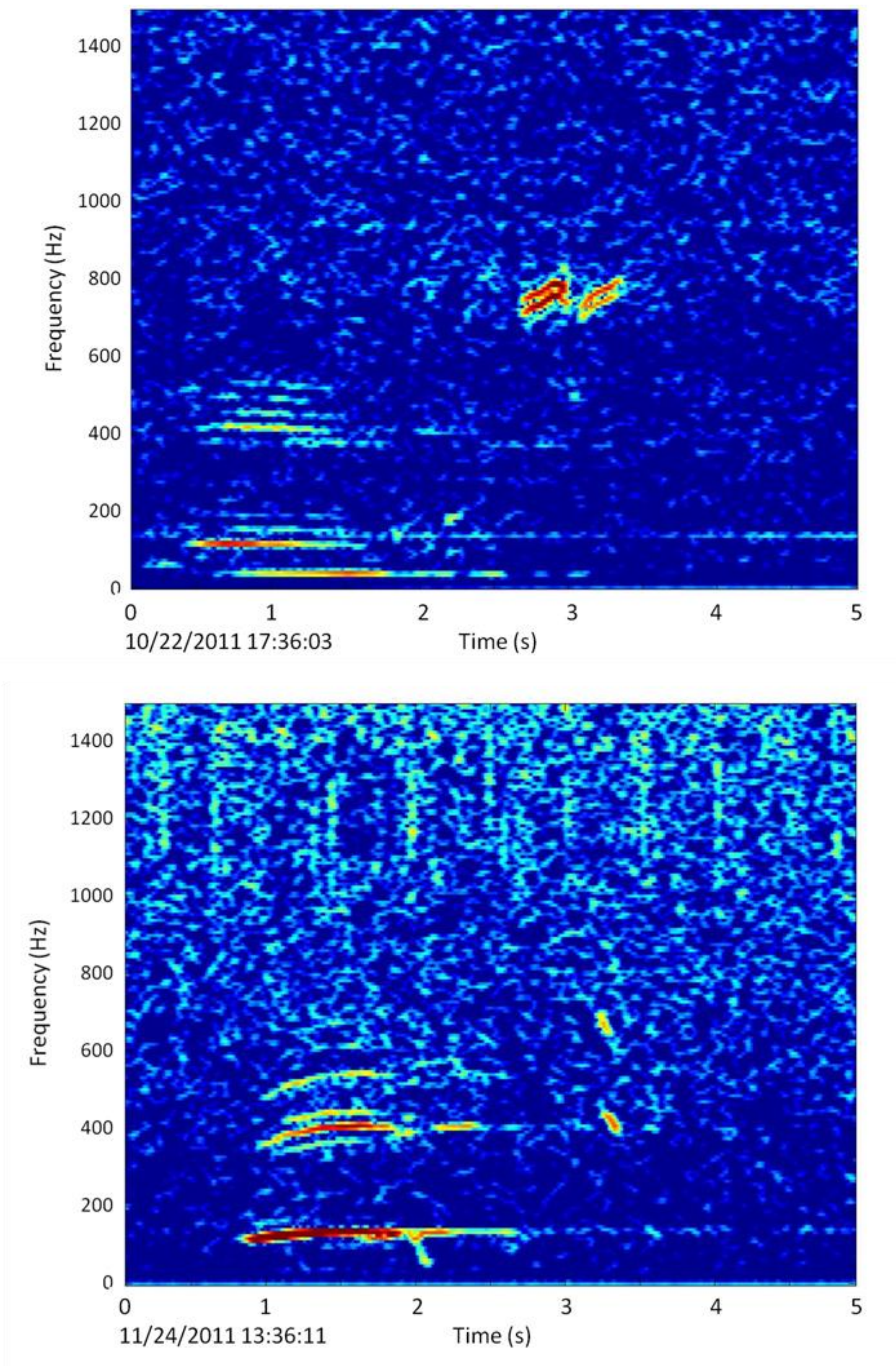


Figure 17. Unidentified baleen whale calls detected at Guam N on 22 October 2011 (top) and 24 November 2011 (bottom).

3.3 Delphinid manual analysis

Manual analyses of delphinid encounters were completed for all of the EAR data, comprising approximately 700 days with recording ("effort-days") from two deployments within the 1-year period from September 2011 to September 2012 (**Table 12**). No data were recorded in mid- to late January, February, or March 2012 (see **Table 2** for a summary of recording dates). Differences were observed in delphinid acoustic activity among EAR sites and between deployments. Dolphin signals were present the highest proportion of the time at Guam N, and this proportion increased from approximately 10 percent of the time during deployment 1 to 17 percent during deployment 2 (**Table 12**). Dolphins were present at Saipan N nearly as much of the time, i.e., 9 percent of the time during deployment 1 and 13 percent of the time during deployment 2. At Tinian W, dolphin signals were present approximately 5 percent of the time during both deployments, and at Guam S dolphins were present only approximately 2 percent of the time during the first deployment (**Table 12**).

The highest overall delphinid encounter rates (encounters per effort-day) were observed at Guam N and Saipan N (**Table 12**). During deployment 1, the encounter rate was greater at Saipan N than at Guam N (3.5 and 2.8 encounters/effort-day, respectively), but the reverse was true during deployment 2 (Saipan N = 3.2 and Guam N = 4.6). At Tinian W, encounter rates were similar during both deployments and below that of Guam N or Saipan N (approximately 1.9 encounters/effort-day), and at Guam S (deployment 1 only) the encounter rate was the lowest of the EAR sites with only 0.67 encounters/effort-day. Although Guam S had the lowest encounter rate, the mean EAA at this site was the highest of all the EARs during deployment 1. During deployment 2, mean EAA was highest at Saipan, but remained lower than the previous value at Guam S. Mean encounter durations ranged from approximately 0.5 to 1 hour, and median encounter durations ranged from 30 seconds to 30 minutes. The maximum delphinid encounter duration increased from the first to the second deployment for Guam N and Tinian W from approximately 4.5 to 7–8 hours, but decreased for Saipan N from 12.5 to 7 hours (**Table 12**).

Seasonal trends in overall delphinid occurrence were examined in terms of encounter rates ("encounters/day"), summed duration of dolphin presence per effort-day ("daily duration"), and daily acoustic abundance per effort-day ("sum DAA/day") for each month of recording (**Figures 18-20**). These values were obtained by calculating the sum of that quantity for the month and then dividing by the number of effort-days of recording that month at that EAR. At Guam N, peak values for these metrics were observed in June–August 2012; DAA during April was also relatively high for Guam N (**Figures 18-20**). At Saipan N, encounter rates were highest in October and November 2011, but daily duration of delphinid presence and DAA were greatest in July–September of the second deployment (**Figures 18-20**). Guam S and Tinian W recorded during only 3 and 4 months, respectively, which were insufficient time spans for establishing any seasonal patterns.

Table 12. Delphinid manual detection summary for MIRC EAR deployments

Site	# Effort-days	# En-counters	Encounters/ Effort-day	Mean EAA	Mean Encounter Duration	Median Encounter Duration	Max Encounter duration	Total Duration (hours)	Delphinid Presence %
Deployment 1 (9/10/2011–1/06/2012)									
Guam N	119	328	2.76	1.16	0:52:50	0:30:30	4:36:30	288.8	10.1%
Guam S	63	42	0.67	1.34	0:44:30	0:30:30	4:00:30	31.15	2.1%
Tinian W	78	145	1.86	0.87	0:35:08	0:18:30	4:12:30	84.9	4.5%
Saipan N	109	382	3.50	0.92	0:36:22	0:18:30	12:24:30	231.5	8.8%
Deployment 2 (4/6/2012–9/22/2012)									
Guam N	153	705	4.61	0.90	0:51:51	0:20:30	7:50:30	609.2	16.6%
Tinian W	16	30	1.88	0.69	0:40:10	0:00:30	6:40:30	20.1	5.2%
Saipan N	168	544	3.24	1.07	0:59:43	0:30:30	7:00:30	541.4	13.4%

EAA = Encounter Acoustic Abundance; # = number; all times in hh:mm:ss format

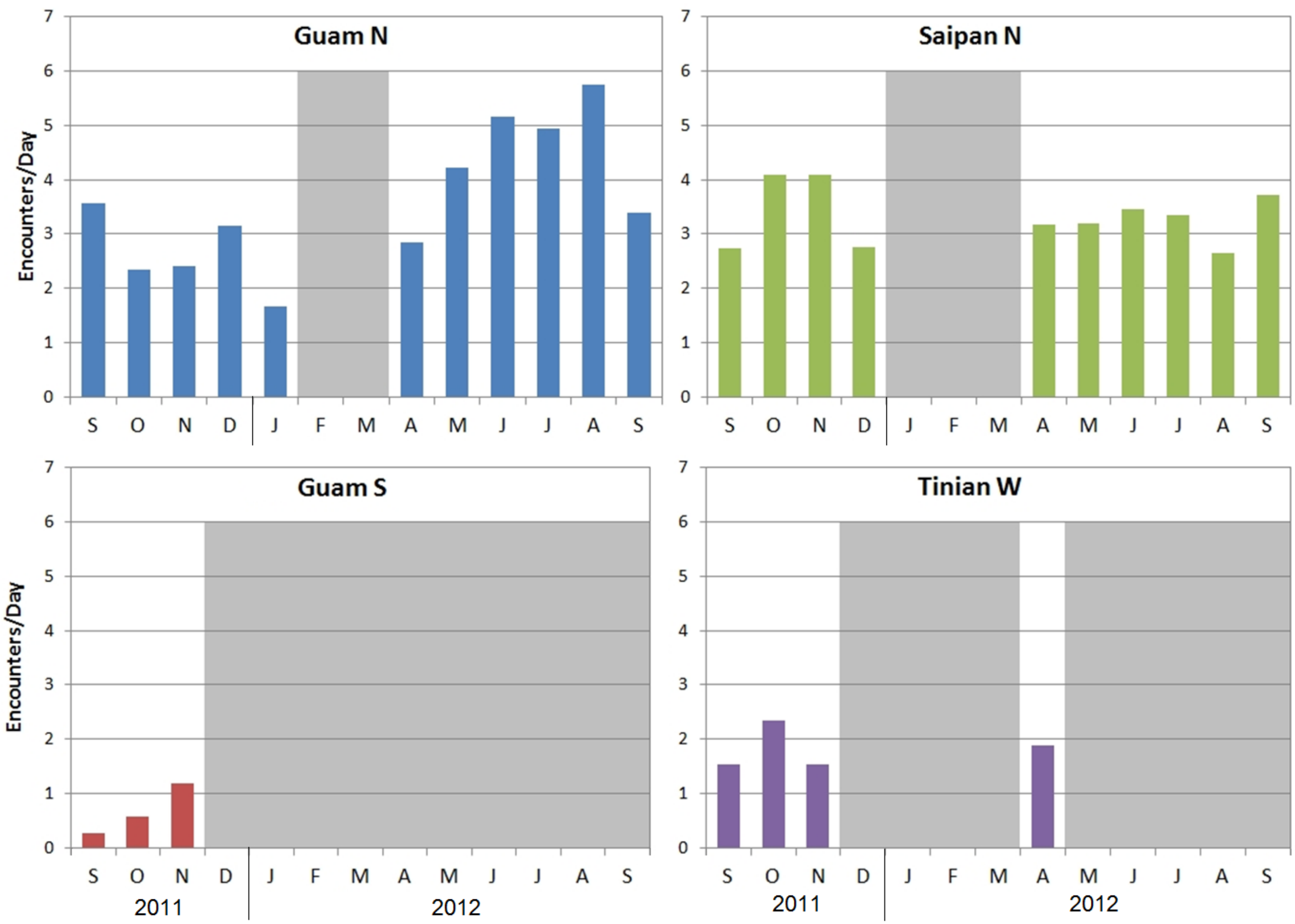


Figure 18. Delphinid encounters/effort-day plotted by month for each EAR, obtained from manual analysis. Grayed periods indicate no recording.

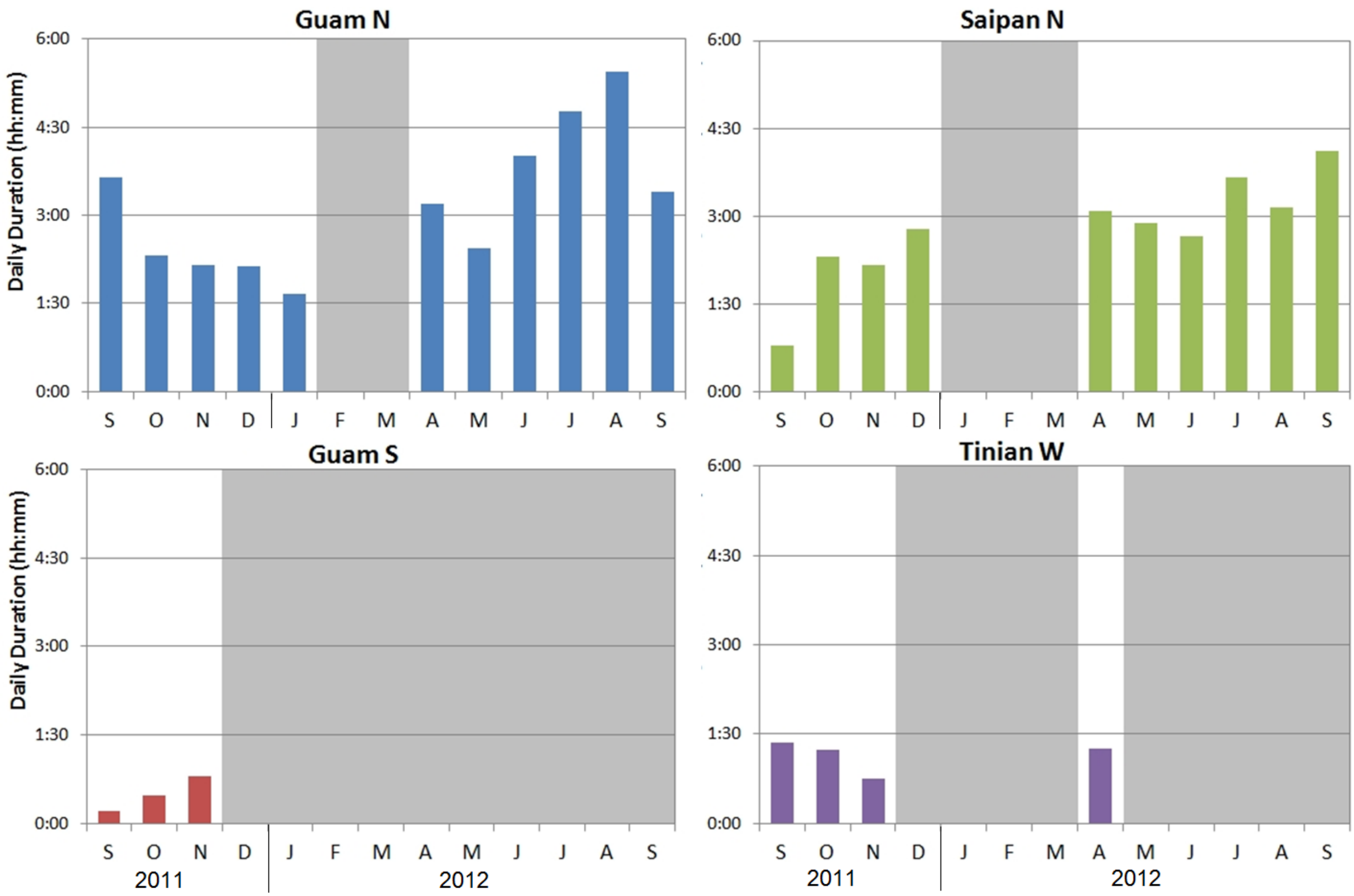


Figure 19. Delphinid summed encounter duration per effort-day (Daily Duration) plotted by month for each EAR, obtained from manual analysis. Grayed periods indicate no recording.

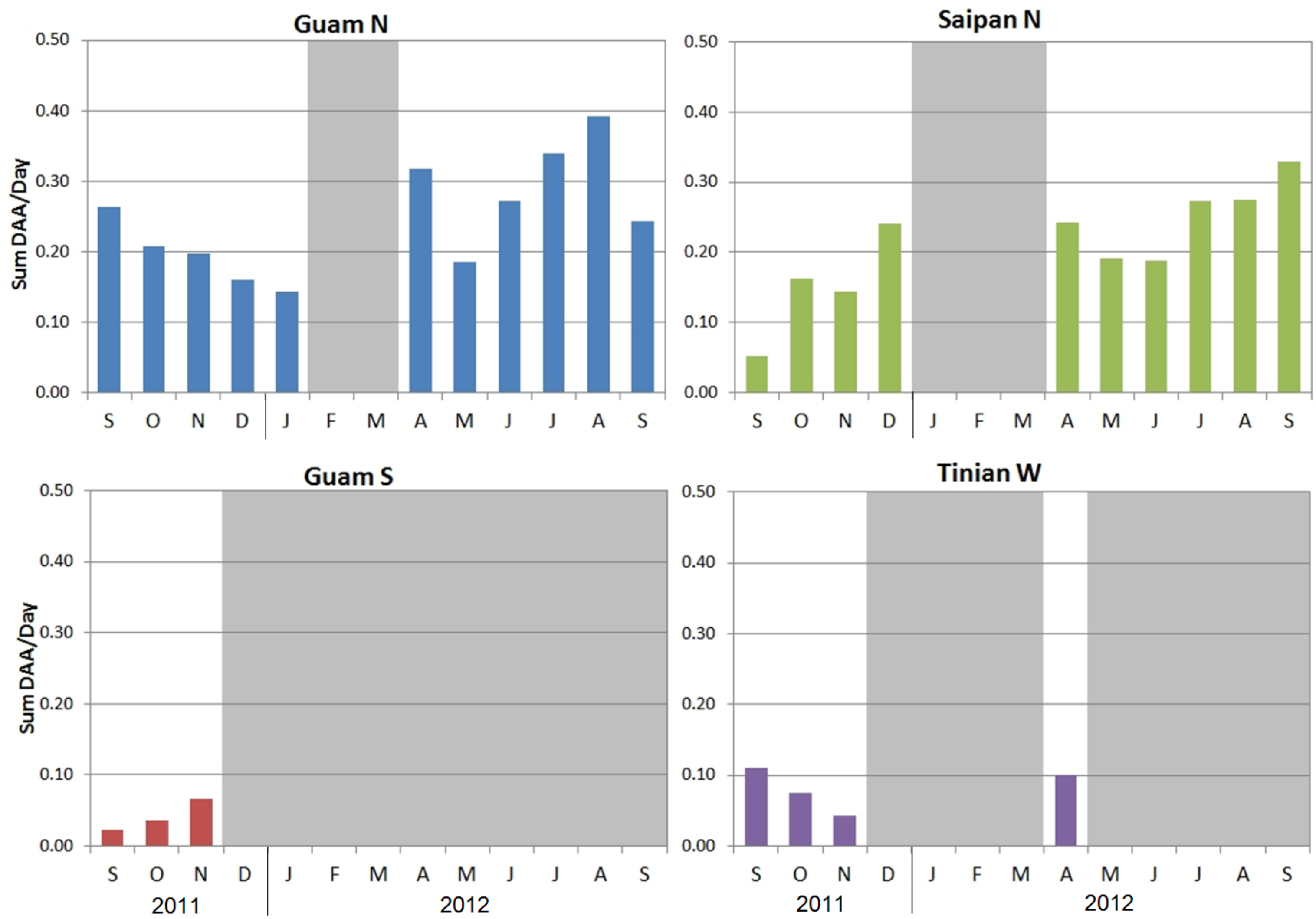


Figure 20. Delphinid summed DAA per effort-day plotted by month for each EAR, obtained from manual analysis. Grayed periods indicate no recording.

The occurrence of different signal groups (categories delineated based on whistle frequency) varied among sites and between deployments (**Table 13**). At Guam N, the most acoustically abundant group was the HF/LF signal group, followed by LF whistles, HF whistles, and Clicks Only (**Table 13**). Metrics of occurrence for the HF/LF and HF groups at Guam N were all higher during deployment 2 than deployment 1, whereas they were lower for the LF group during deployment 2 and comparable for the Clicks Only group. The HF/LF whistle group was most abundant at Guam N compared to the other three EAR sites.

Table 13. Delphinid detections by signal group for each site and deployment.

		Clicks Only	HF/LF whistles	HF whistles	LF whistles
A. Guam N					
Encounters per effort-day	Dep 1 Dep 2	0.75 0.84	1.3 2.2	0.24 1.2	0.51 0.34
Mean Encounter Duration	Dep 1 Dep 2	0:14:27 0:12:50	1:10:08 1:24:47	0:41:51 0:24:03	1:11:19 0:33:58
Total DAA per Effort-day x 100	Dep 1 Dep 2	0.68 0.58	12.8 25.4	0.84 2.19	5.53 1.71
B: Guam S					
Encounters per effort-day	Dep 1 Dep 2	0.21 NA	0.16 NA	0.048 NA	0.25 NA
Mean Encounter Duration	Dep 1 Dep 2	0:15:44 NA	0:49:42 NA	0:18:30 NA	1:09:30 NA
Total DAA per Effort-day × 100	Dep 1 Dep 2	0.21 NA	0.96 NA	0.07 NA	2.83 NA
C: Tinian W					
Encounters per effort-day	Dep 1 Dep 2	0.62 0.25	0.60 1.1	0.33 0.31	0.31 0.25
Mean Encounter Duration	Dep 1 Dep 2	0:08:24 0:03:00	0:54:33 0:59:55	0:31:25 0:20:30	0:54:38 0:18:00
Total DAA per Effort-day × 100	Dep 1 Dep 2	0.24 0.02	3.69 8.99	0.83 0.44	2.43 0.49
D: Saipan N					
Encounters per effort-day	Dep 1 Dep 2	0.54 0.77	1.2 1.0	1.1 1.0	0.68 0.40
Mean Encounter Duration	Dep 1 Dep 2	0:09:45 0:16:37	0:57:41 1:11:55	0:19:15 1:04:27	0:48:40 1:38:25
Total DAA per Effort-day × 100	Dep 1 Dep 2	0.27 0.77	8.82 9.84	1.74 6.95	4.99 7.04

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

At Saipan N, the most acoustically abundant signal group was the HF/LF group, followed by LF whistles, HF whistles, and Clicks Only (**Table 13**). The mean encounter duration and normalized total DAA for all signal groups were higher in deployment 2 than deployment 1 at Saipan N. For the LF group, this pattern contrasts with Guam N and Tinian, for which the LF acoustic abundance was lower during the second deployment. The HF group and the LF group were more acoustically abundant at Saipan N than at the other EAR sites. Guam N and Saipan N both had comparable occurrence of Clicks Only encounters.

At Tinian W, the HF/LF group was the most acoustically abundant, followed by LF whistles, HF whistles, and Clicks Only (**Table 13**). Metrics of occurrence increased for the HF/LF group during Deployment 2 relative to Deployment 1, whereas the LF group decreased, as did the Clicks Only group and HF group. This pattern between deployments was similar to that observed at Guam N, although overall encounter rates were lower at Tinian W.

At Guam S, where encounter rates were low overall, the most acoustically abundant group was the LF whistle group, followed by HF/LF, Clicks Only, and HF groups. Mean encounter duration was greatest for LF whistles and HF/LF whistles, and these signals groups also had the highest normalized total DAA scores (2.83 and 0.96, respectively) (**Table 13**). HF whistles were detected very infrequently at Guam S, 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 13**). No data were available for the second deployment at Guam S.

Seasonal trends in occurrence of delphinid signal groups were also examined for Guam N and Saipan N, the sites with best recording coverage (**Figure 21**). At Guam N, the HF/LF and HF whistle groups exhibited greater acoustic occurrence during the second deployment, with a peak in August 2012. The Clicks Only group remained relatively consistent, whereas the LF signal group decreased in the second deployment relative to the first. At Saipan N, the HF/LF and HF whistle groups showed peaks in encounter rates in October–November 2011 and September 2012; peak daily duration and DAA/day were observed in December 2011 and September 2012. The daily duration (summed duration of encounters normalized by effort) and sum DAA/day of the LF whistle group at Saipan N were maximum in August 2012 during the second deployment. Although encounter rates were generally higher for the Clicks Only group at Saipan N during the second deployment, the daily duration and sum DAA/day for this group remained relatively low compared to the other signal groups.

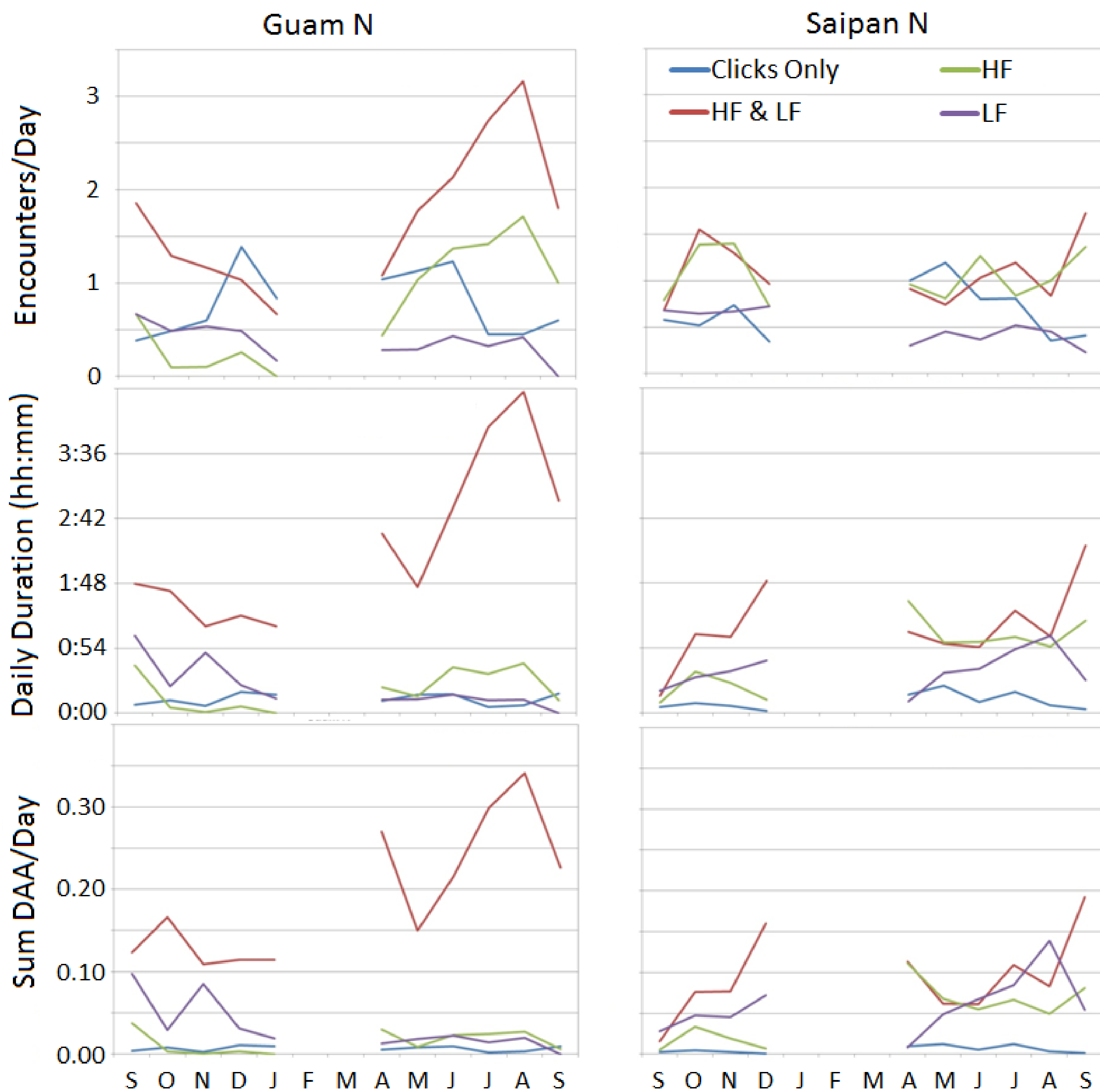


Figure 21. Delphinid encounter data plotted by month for each signal group (see legend), from September 2011 through September 2012, at Guam N (left) and Saipan N (right). Top: Number of encounters per effort-day. Middle: Summed encounter duration per effort-day. Bottom: Summed Daily Acoustic Abundance per effort-day. Blank areas indicate periods with no recordings.

Similarities and some notable differences were observed in the diel (hourly) pattern among the delphinid signal groups and among the EAR sites at Guam N, Saipan N, and Tinian W (the number of encounters detected at Guam S was not sufficient to investigate diel patterns). All signal groups except for the LF whistle group exhibited a significant nocturnal and/or crepuscular pattern in frequency of encounter occurrence at the three EAR sites examined. At Guam N, encounters of Clicks Only and HF groups were more frequently counted at night than during the day (**Figure 22**). The Clicks Only group showed significantly above-average encounter counts in all hours from midnight to 0500 and significantly below-average counts in 11 of the 13 hours between 0700 and 1800 (Poisson probability distribution for mean encounters per hour = 9.08, $p < 0.05$). The HF group had significantly more encounters in 6 of the 10 hours between 2100 and 0700, and significantly fewer in 6 of the 9 hours between 1200 and 2000 (Poisson probability distribution for mean encounters per hour = 8.92, $p < 0.05$). The HF/LF group at Guam N appeared to have a bimodal or crepuscular pattern rather than a nocturnal one, with peaks at 0700 and 1900 (**Figure 22**). Encounter counts for the HF/LF group at Guam N were significantly above average in five of the six hours between 0700 and 1300 and the hours of 1700 and 1900, whereas they were below average in 0000, 0400, 1300 and 2300 (Poisson probability distribution for mean encounters per hour = 20.33, $p < 0.05$). The LF group did not exhibit a pronounced diel pattern, with only two hours in which encounter counts differed from expected (lower in hour 0400 and higher in hour 1600; Poisson probability distribution for mean encounters per hour = 4.71, $p < 0.05$).

In contrast, at Saipan N the HF/LF group, as well as the HF and Clicks Only groups, exhibited a more pronounced decrease in daytime encounters relative to nighttime encounters, with relatively few encounters during most of the day (approximately five or fewer encounters each hour) and the majority of encounters detected between 1800 and 0400 (15 to 30+ encounters each hour) (**Figure 23**). For all three of these signal groups, encounter counts were significantly above average for 7 or more of the 10 hours between 1800 and 0400, and significantly below average for eight or more of the fourteen hours between 0400 and 1800 (Poisson probability distribution for mean encounters per hour = 7.83 [Clicks Only], 12.67 [HF/LF], 12.21 [HF], $p < 0.05$). At Saipan N, there was also a secondary smaller peak at midday (1100) that was significant for the HF/LF group and the LF group. For the LF signal group, there was a moderate midday peak in encounter counts from 1100 to 1400; however, during the remainder of the day, no strong diel pattern was evident, with two above-average hours at 0200 and 0600 and two below-average hours at 0800 and 2300 (Poisson probability distribution for mean encounters per hour = 5.88, $p < 0.05$).

At Tinian W, the overall number of encounters was low compared to Guam N and Saipan N; diel patterns similar to Saipan N were apparent, but only two to four hours during nighttime (1700–0600) were significantly above average for either the Clicks Only, HF/LF, or HF signal groups (Poisson probability distribution for mean encounters per hour = 2.17 [Clicks Only], 2.67 [HF/LF], 1.29 [HF], $p < 0.05$) (**Figure 24**). The LF signal group did not show a diel pattern at Tinian W.

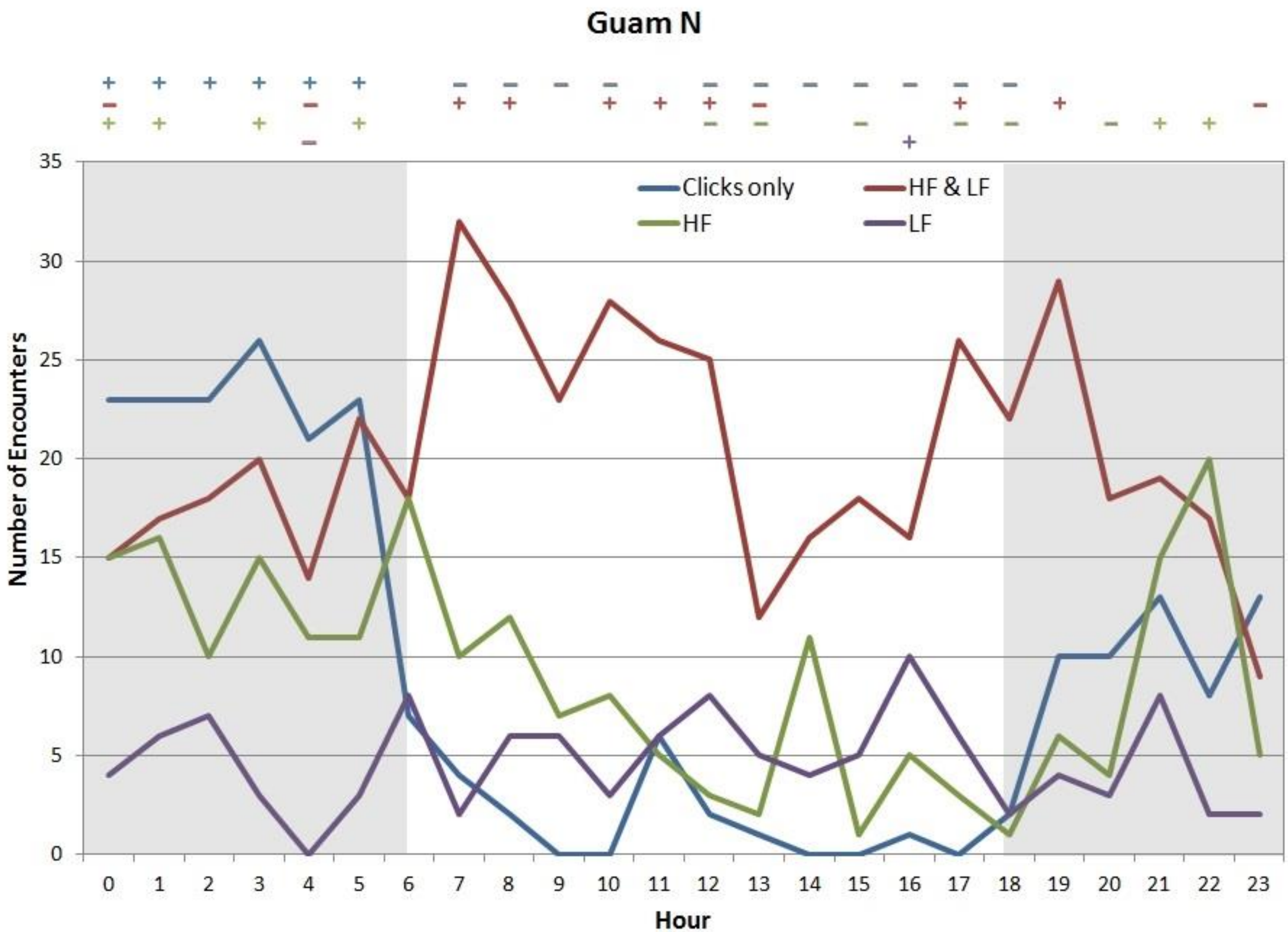


Figure 22. Number of delphinid encounters, classified by signal group, within each hour of the day at Guam N. Colors indicate signal group, '+' indicates hours with significantly above average encounter counts, '-' indicates hours with significantly below average encounter counts. Shaded area represents hours between average sunset and sunrise in Guam/CNMI.

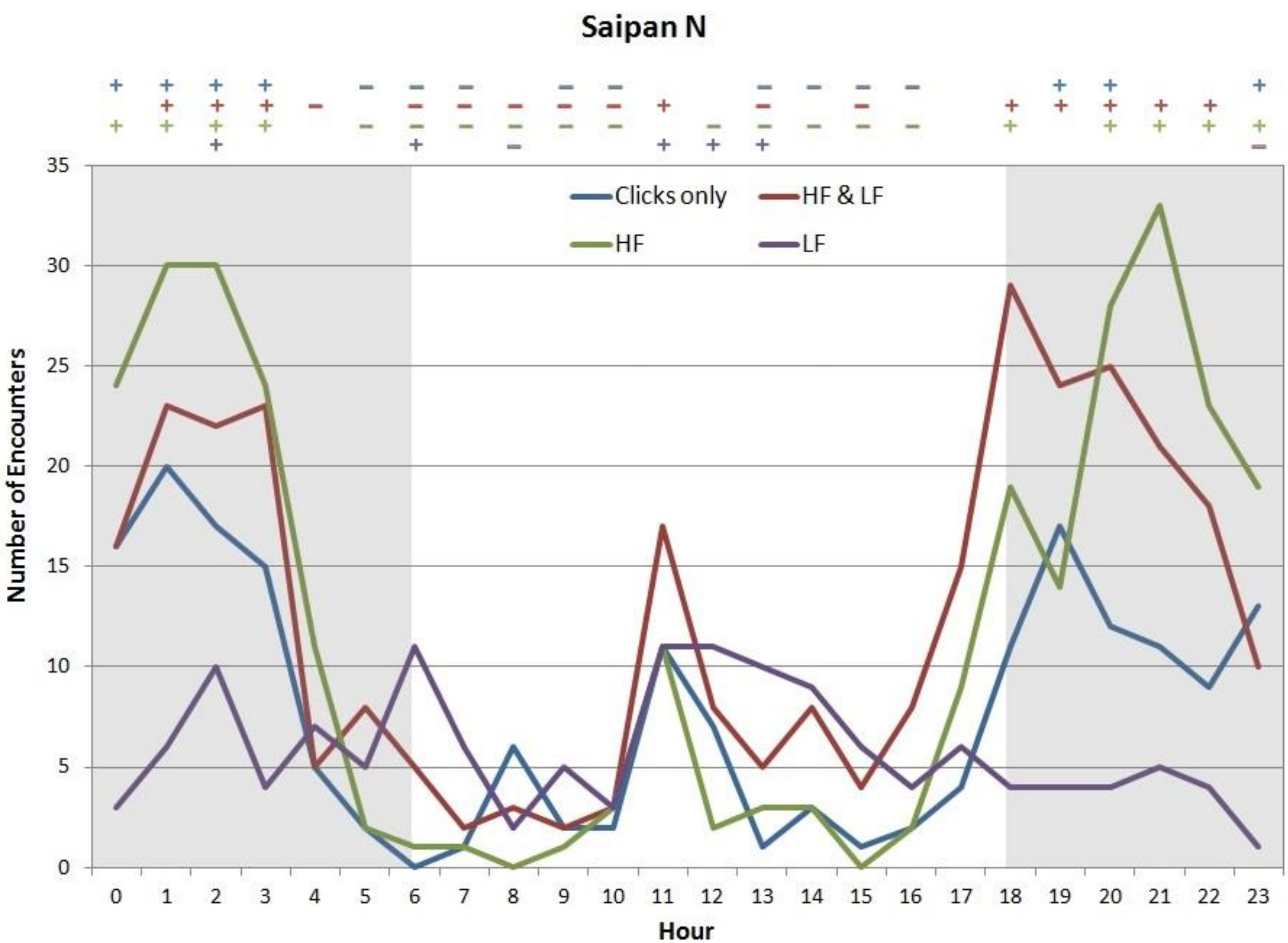


Figure 23. Number of delphinid encounters, classified by signal group, within each hour of the day at Saipan N. Colors indicate signal group, '+' indicates hours with significantly above average encounter counts, '-' indicates hours with significantly below average encounter counts. Shaded area represents hours between average sunset and sunrise in Guam/CNMI.

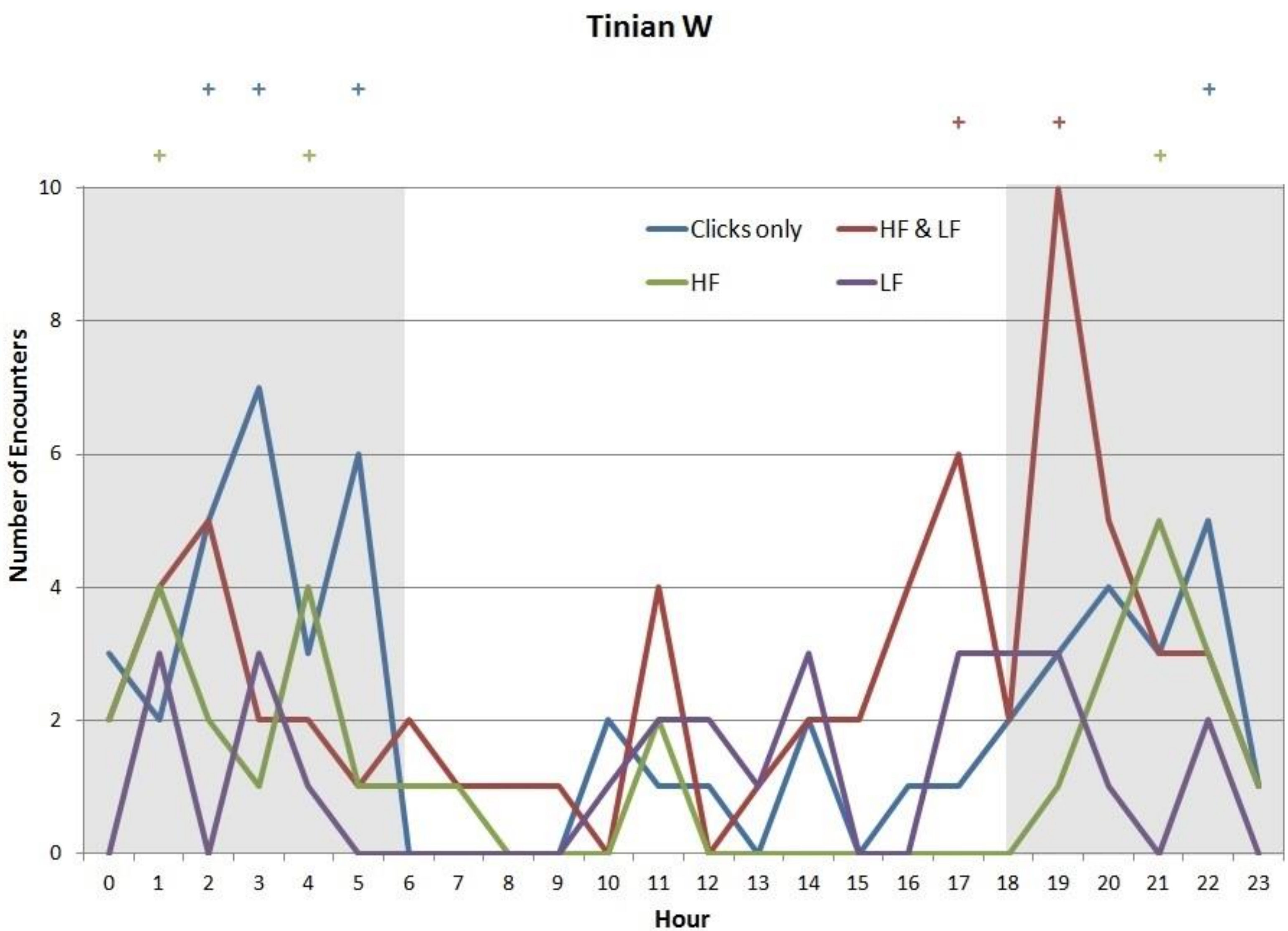


Figure 24. Number of delphinid encounters, classified by signal group, within each hour of the day at Tinian W. Note different y-axis scale than previous two plots. Colors indicate signal group, '+' indicates hours with significantly above average encounter counts, '-' indicates hours with significantly below average encounter counts. Shaded area represents hours between average sunset and sunrise in Guam/CNMI.

3.4 MFAS Detections

MFAS was detected at all EAR sites except Tinian W during the first deployment, and two of the three EAR sites during the second deployment (**Table 14**). MFAS was more prevalent (by number of days detected) at both Guam sites during deployment 1, and was most prevalent at Saipan N during deployment 2. Two multi-day MFAS detections were noted, one from 16 to 19 October 2011 near Guam and the other from 28 August to 5 September 2012 near Saipan.

Table 14. Summed duration in hh:mm:ss of MFAS detections by day at each site. Grayed cells indicate no recording by that EAR for those dates. No MFAS was detected at Tinian W in either deployment.

Date	Guam N	Guam S	Saipan N
09/22/2011		0:00:30	
10/10/2011	0:00:30		
10/11/2011	1:18:30 (chirp)	1:06:30	
10/16/2011	0:01:00		
10/17/2011	4:42:00	4:42:00	
10/18/2011	17:06:30	24:00:00	
10/19/2011	23:36:30	23:48:30	
12/22/2011			9:54:30
07/02/2012	0:40:30		
08/28/2012			3:51:00
08/29/2012			6:11:30
08/30/2012			16:22:00
08/31/2012			24:00:00
09/01/2012			18:00:30
09/02/2012	0:00:30		21:00:00
09/03/2012			24:00:00
09/04/2012			24:00:00
09/05/2012			20:10:30
09/07/2012			0:00:30
09/08/2012			2:21:00
09/21/2012			0:00:30

MFAS detection was plotted relative to delphinid DAA in **Figures 25-31**. At Guam N, delphinids were detected on most days throughout deployments 1 and 2, with eight periods of 1 to 2 days with no encounters (**Figures 25–26**). Delphinids were detected on all days during MFAS and most days following MFAS, with no anomalously long absences of detections.

At Guam S, delphinid encounter rates and DAA were lower overall than other EARs. In the absence of MFAS, 11 periods with no dolphin encounters ranged from 1 to 5 days, and lasted for 2 days on average (**Figure 27**). Dolphins were detected within 1 to 2 days of the shortest two MFAS detections, but were not detected on the Guam S EAR for a period of 12 days that included a 3-day MFAS detection on 17–19 October 2011 and the 8 days afterward. This was the longest period with no dolphin encounters and the duration was significantly different from the mean duration of 2.1 days (Poisson distribution, $p < 0.05$).

At Saipan N, dolphins were detected on most days, and there was a total of 10 non-detection periods for both deployments, each lasting 1 to 2 days (**Figures 28-29**). Dolphins were generally detected the days of and days after MFAS, including during and after a multi-day MFAS detection from 28 August to 5 September 2012 (**Figure 29**).

At Tinian W, dolphins were detected most days, and there were 13 periods of 1 to 2 days with no detections over both deployments (**Figures 30-31**). No MFAS was detected at Tinian W during either deployment.

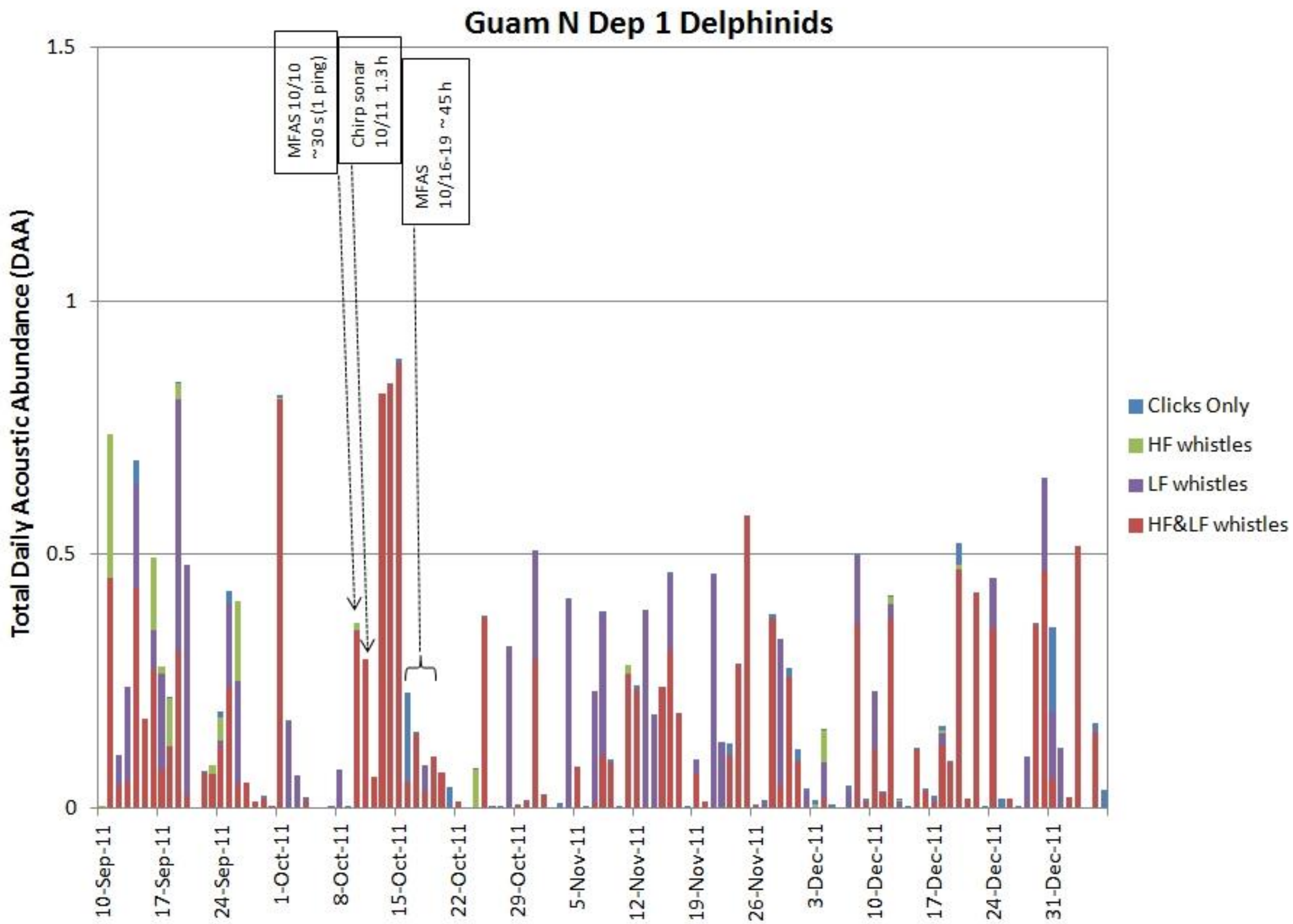


Figure 25. Delphinid Daily Acoustic Abundance and MFAS detections at Guam N, deployment 1.

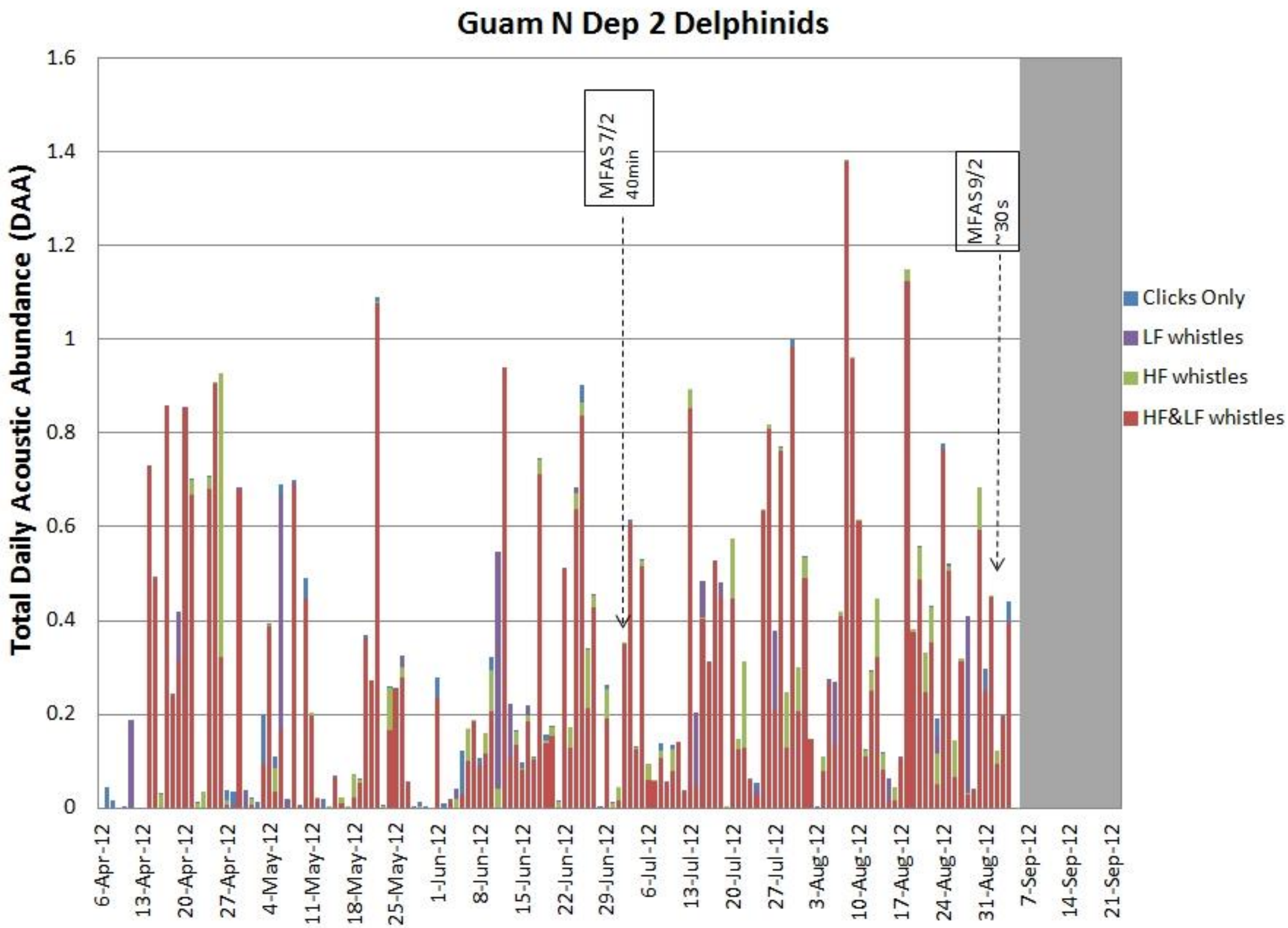


Figure 26. Delphinid Daily Acoustic Abundance and MFAS detections at Guam N, deployment 2. Grayed period indicates no recording.

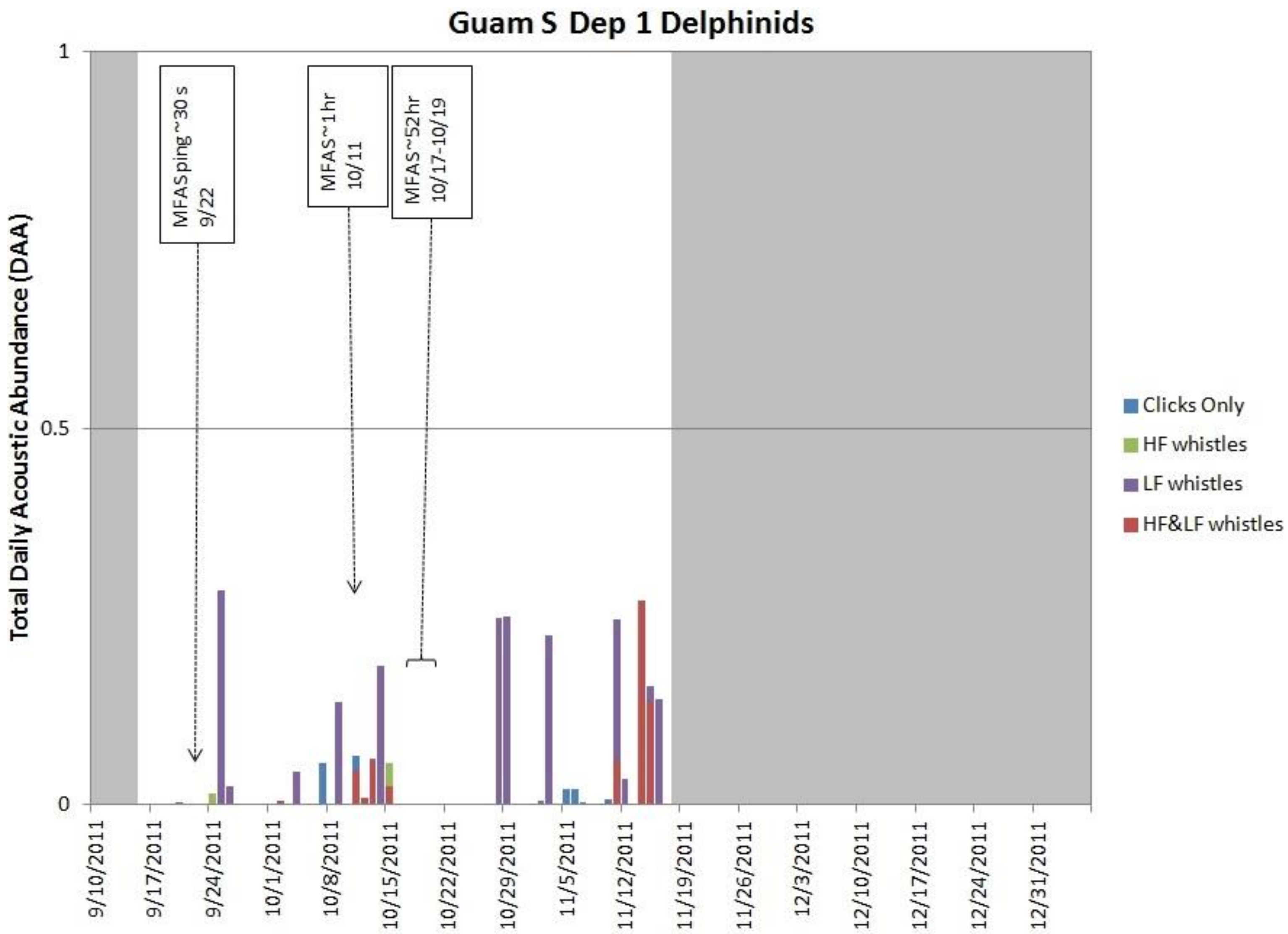


Figure 27. Delphinid Daily Acoustic Abundance and MFAS detections at Guam S, deployment 1. Grayed periods indicate no recording.

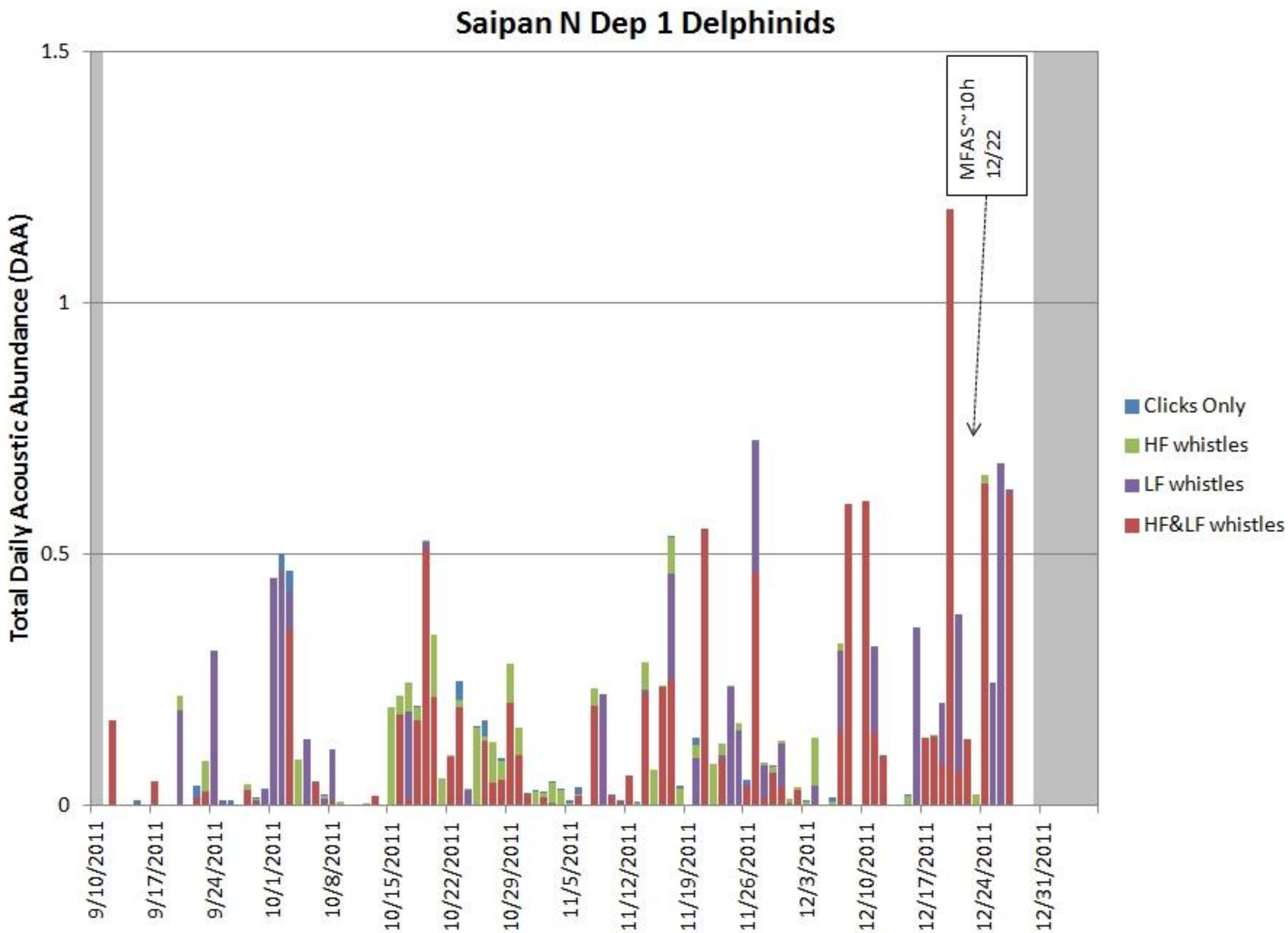


Figure 28. Delphinid Daily Acoustic Abundance and MFAS at Saipan N, deployment 1. Grayed periods indicate no recording.

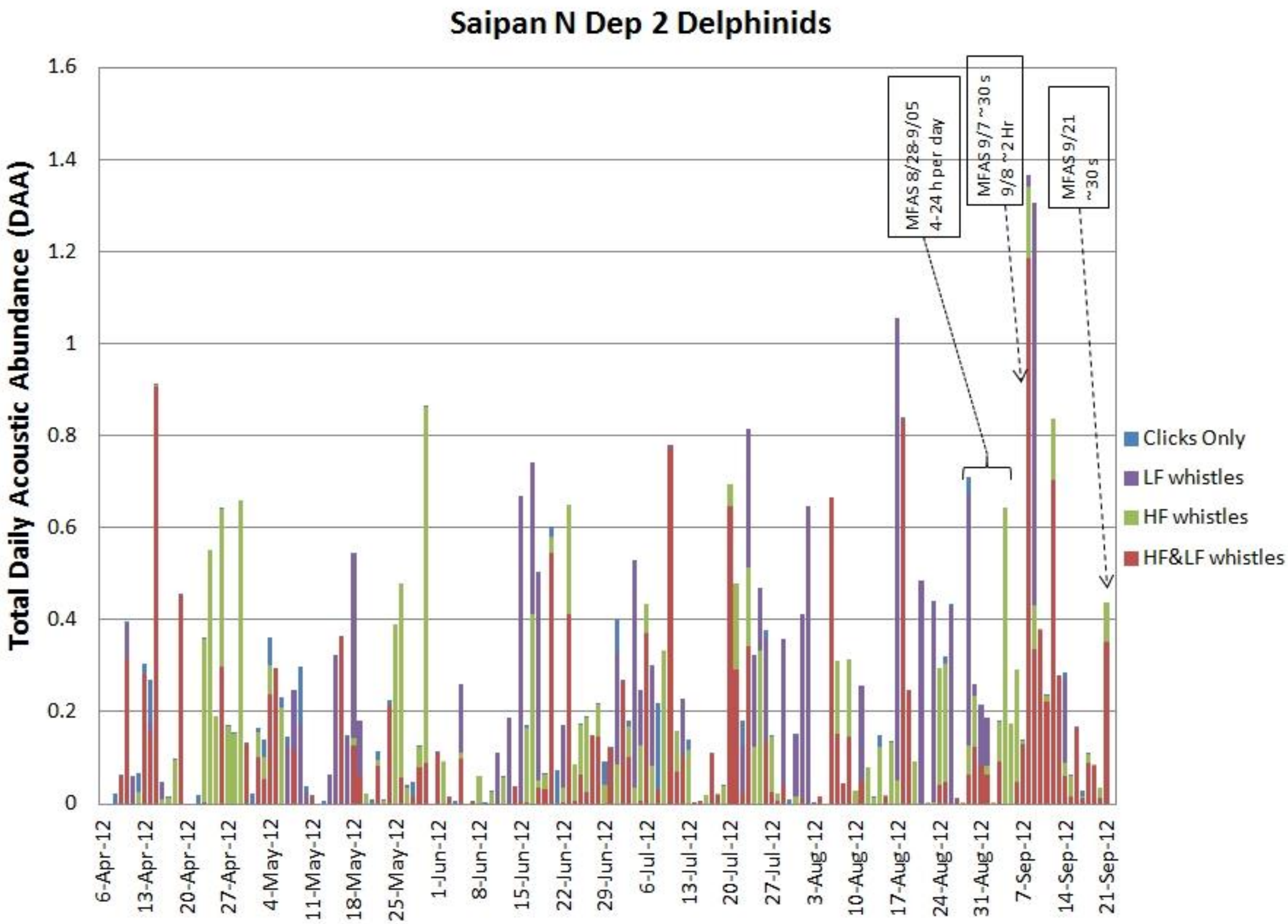


Figure 29. Delphinid Daily Acoustic Abundance and MFAS at Saipan N, deployment 2.

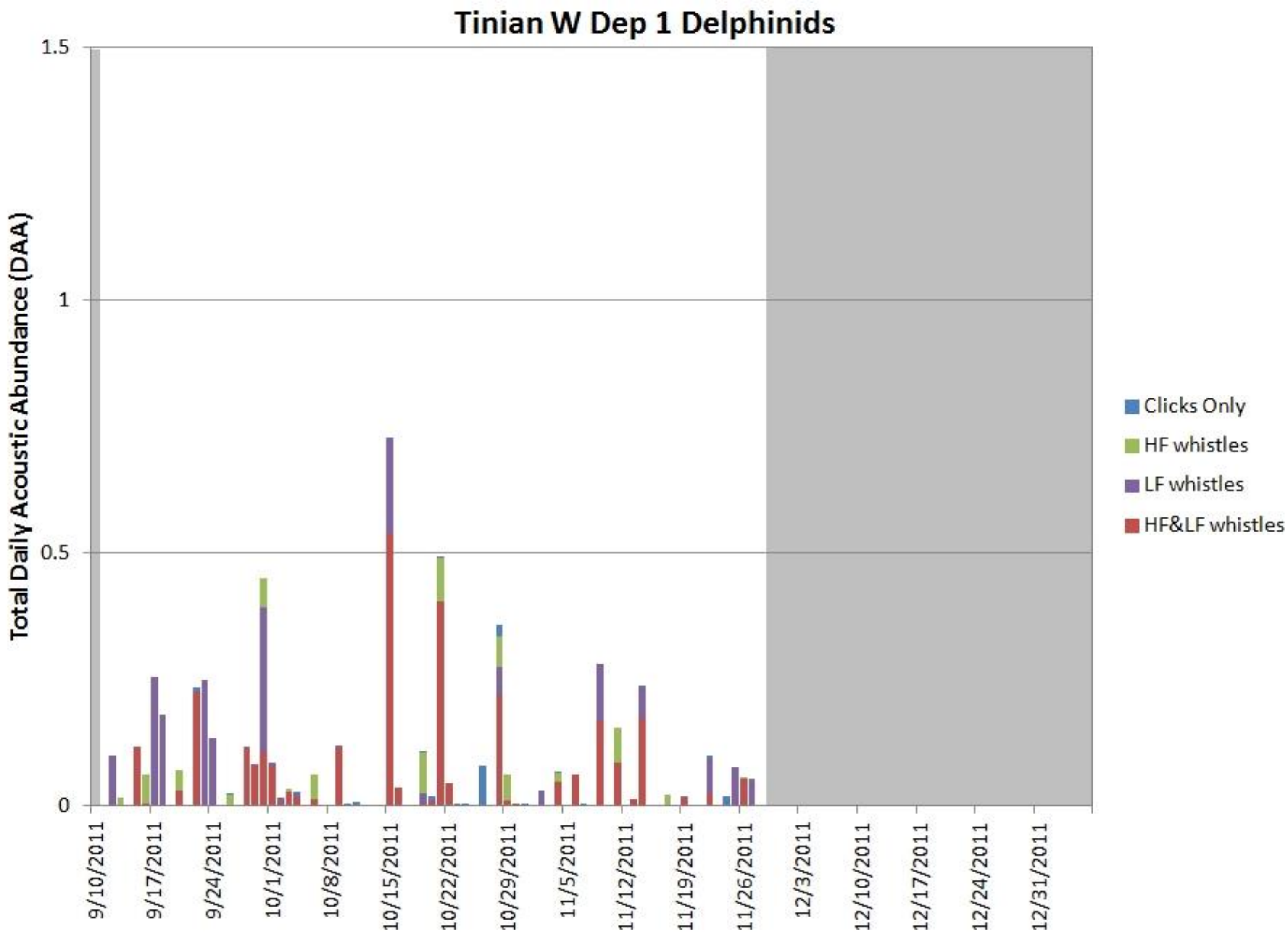


Figure 30. Delphinid Daily Acoustic Abundance at Tinian W, deployment 1. No MFAS was detected on this deployment. Grayed periods indicate no recording.

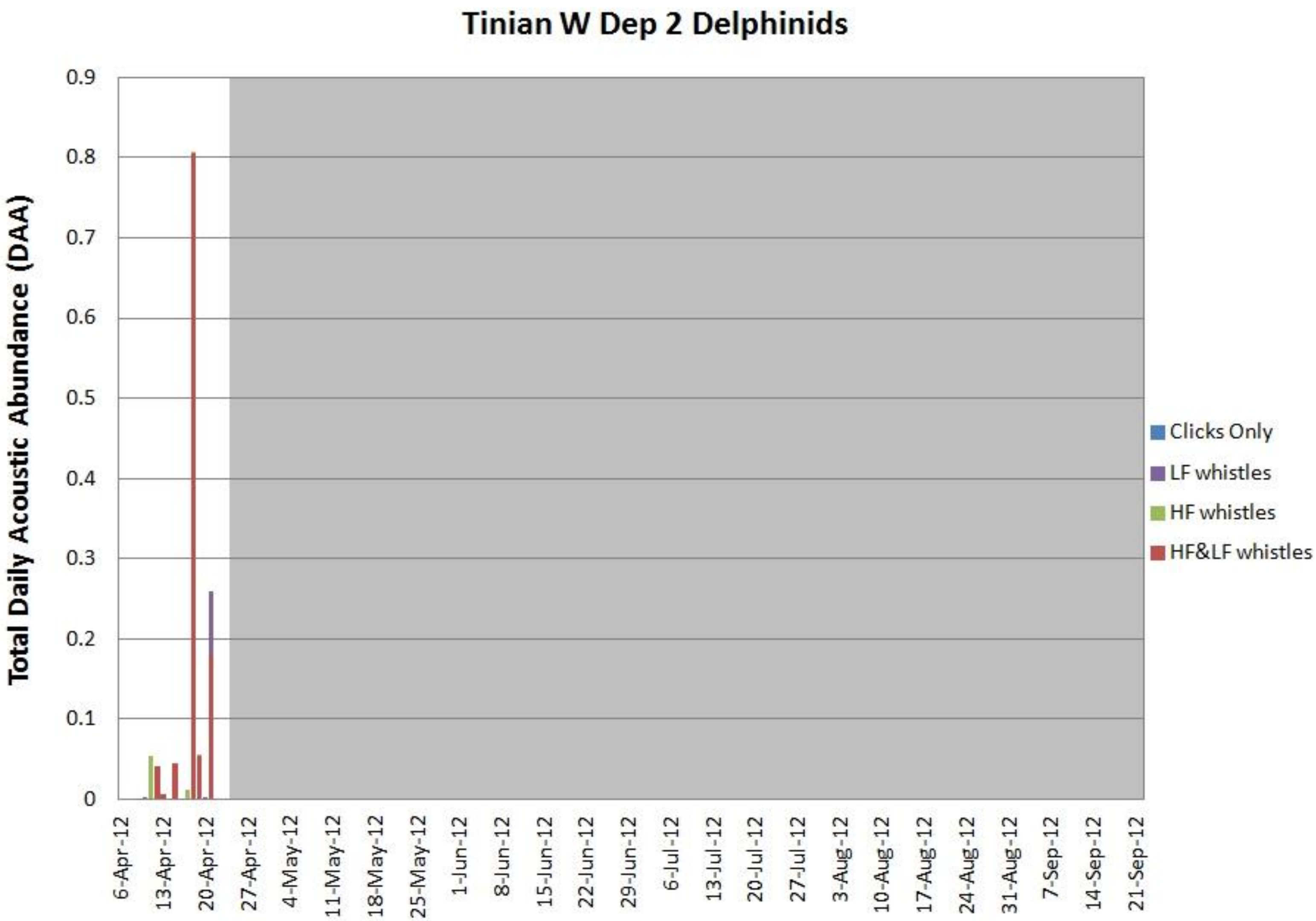


Figure 31. Delphinid Daily Acoustic Abundance at Tinian W, deployment 2. No MFAS was detected on this deployment. Grayed period indicates no recording.

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4. Discussion

4.1 KB14–Q1: What species of beaked whales (Ziphius/Mesoplodon) are in offshore areas of the MIRC adjacent to Guam and Saipan?

Sixteen files were manually verified to contain beaked whale signals from Cuvier's or Blainville's beaked whales. These detections occurred at all sites except Guam S. Due to the low precision of the detector, no inference could be made about seasonal or diel patterns. Initially, raw M3R CS-SVM output resulted in beaked whale click detections in 6,582 files, occurring on approximately 80 percent of days on all MIRC deployments except for Guam S. The similarity of temporal patterns in detector output for beaked whales and sperm whales suggested issues with detector performance or interpretation. It was subsequently decided to interpret detector results on a per-file basis rather than an individual click detection basis. A validation effort was conducted by Bio-Waves, Inc. using a small subset of MIRC data to review files (n = 131) and evaluate detector performance using revised interpretation criteria. When threshold criteria for a mixed beaked whale class (at least 70 percent of clicks within a given file classified as either Blainville's or Cuvier's) were applied, precision of the M3R CS-SVM detector was 0.26, recall was 1.00, and specificity was 0.60. For each beaked whale species considered separately, precision and recall decreased but specificity increased relative to the mixed beaked whale class. These performance metrics represent an improvement over initial results and reduced the problematic temporal overlap with sperm whales present in the initial interpretation. In addition, although precision was low, recall was high, suggesting that few or no beaked whale signals were missed by the detector, which may be advantageous for data sets in which target signals are rare.

Based on precision of 0.26 and recall of 1.00, it can be extrapolated that 181 of the 696 files that met the threshold criteria within the entire dataset contain true positive beaked whale signals, although with low precision it is not possible to determine which of the detections are true without manually examining each one. In addition, the specificity of 0.60 suggests that 40 percent of detections may have been incorrectly rejected (classified as a different species when they were actually produced by beaked whales). It is important to note that sample size was relatively low for this validation effort, and increasing the sample size of manually reviewed beaked whale detections may affect measures of detector performance. In addition, the low overall proportion of files containing beaked whale detections (696 files that met detector criteria out of 134,856 files in the data set, or < 1 percent of the data) suggests that beaked whale signals are rare within these EAR data. **The focus of the M3R CS-SVM detector and subsequent validation efforts on Cuvier's and Blainville's beaked whales does not exclude the possibility that other species of beaked whale occur in the MIRC.** Sightings of unidentified *Mesoplodon* have been documented in recent vessel-based surveys (e.g., Fulling et al. 2011; Hill et al. 2014), and previous incidental sightings from the Mariana region include at least two other *Mesoplodon* species (*M. ginkgodens* and *M. carlhubbsi*), Longman's beaked whale (*Indopacetus pacificus*) and Baird's beaked whale (*Berardius bairdii*), although the latter is considered extralimital (DoN 2013; Uyeyama 2014).

The ability to detect and correctly classify beaked whale signals was constrained by the recording schedule and sample rate of the EARs. A more recent M3R CS-SVM detector version (updated since the time of this study) incorporates inter-click intervals (ICI) into its classification algorithm, but the short duration (30 seconds) of EAR recordings in this study limits the duration of click sequences (and the number of consecutive clicks) available for estimation of ICI and its variance. The 80 kHz sample rate of the EARs in this study results in an effective bandwidth of 40 kHz that does not capture all of the energy in beaked whale clicks, and it also affects the frequency information available to the detector for other odontocete signals (e.g., delphinid clicks), possibly reducing its classification accuracy (Oswald et al. 2015). Increasing the recording bandwidth would provide more information to automated detectors and analysts for correct classification of species. In addition, it is unknown whether or how much beaked whale click characteristics in the MIRC might differ from those in other regions, and using detectors that were trained on signals from other areas, as was the case with M3R CS-SVM, may affect performance in the MIRC.

4.2 KB14–Q2: What is the seasonal occurrence of baleen whales in offshore areas of MIRC adjacent to Guam and Saipan?

Relatively few detections of baleen whales were made by either automated or manual means. Humpback whale calls (song units) were only detected at Saipan N, where they were detected manually on four days in December 2011 and detected both automatically and manually on two days in April 2012 (Figure 32). Three minke whale automated detections were determined to be false positives and no confirmed minke whale calls were found by manual searching in September 2011–January 2012 and April 2012. No blue, fin, or sei whale calls were detected automatically in either deployment, or by manual searching in September 2011–January 2012 and April 2012. The humpback whale detections in December 2011 and April 2012 (winter and early spring) are consistent with the known seasonality of humpback whales in other areas of the central tropical Pacific, but no recording took place between early January and early April, precluding further investigation of winter use by humpbacks or other baleen whales. Manual analyses in September 2011–January 2012 and April 2012 corroborate the lack of blue, fin, sei, and minke whale detections during these months. No baleen whale calls were detected automatically in the second deployment from May-September 2012, but this may not indicate the absence of baleen whales in those months. Manual analyses for baleen whales in May-September 2012 were not conducted as part of this project.

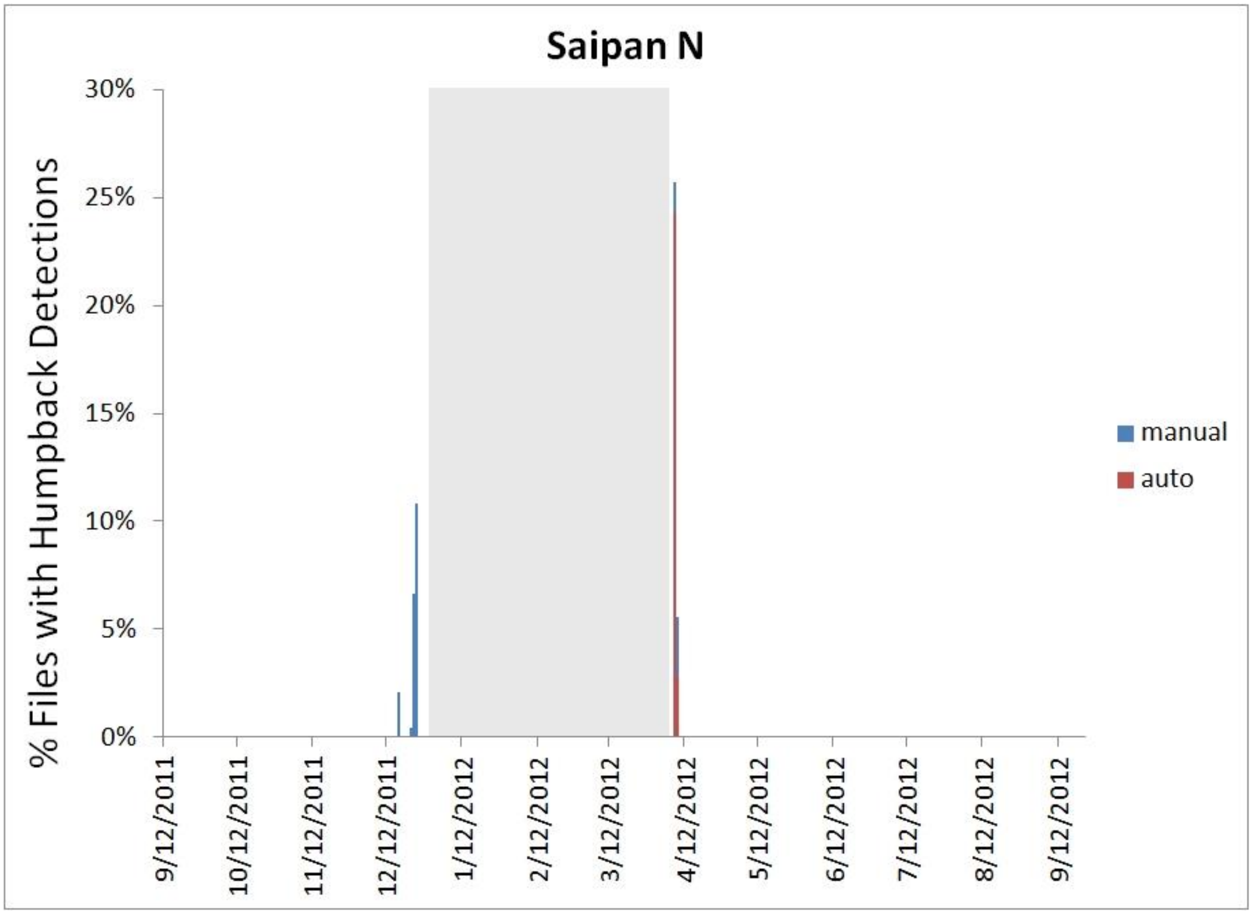

Figure 32. Percentage of files per day with manual (blue) and automated (red) humpback whale detections for Saipan N. Grayed period indicates no recording.

Three unidentified baleen whale calls were found by manual searching at Guam N, one in October and two in November 2011; no seasonal trend could be inferred from so few detections. These calls may have been produced by Bryde's or sei whales (best guesses), or possibly humpback whales**.** Calls made by Bryde's whales and sei whales are not well understood in this region or others in the Pacific Ocean. The first unidentified call at Guam N (**Figure 17**) somewhat resembled known Bryde's whale calls recorded elsewhere in the Pacific (eastern tropical Pacific and coast of Japan) (**Figure 33**; Oleson et al. 2003, Heimlich et al. 2005), with a tonal portion consisting of dominant or fundamental frequency <60 Hz and several overtones, but the subsequent upsweep at approximately 750 Hz did not closely match any described calls for this species. The second two unidentified baleen whale calls from Guam N consisted of tonal signals with higher fundamental frequencies of approximately 135 Hz, followed by a brief downsweep (**Figure 17**). It is unlikely based on their characteristics (frequency, duration, contour shape) that these few unidentified calls were produced by blue or fin whales, both of which are more widely documented and described. Although these calls did not closely match known recordings of Bryde's or sei whale calls (including the HF sei whale call documented by Norris et al. 2012), that does not rule out the possibility they represent an undescribed call type produced by one of these species. However, they were only rarely detected in the dataset.

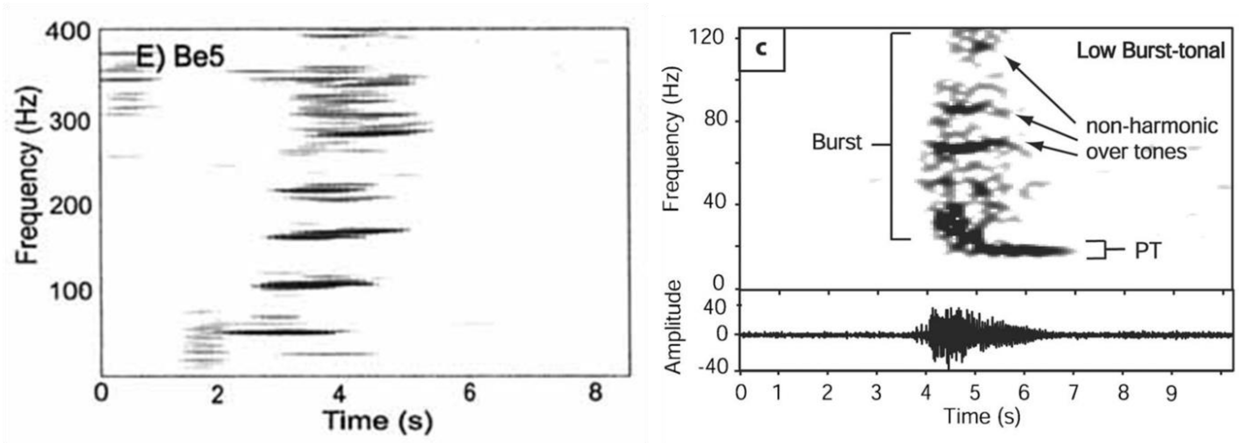

Figure 33. Example Bryde's whale call spectrograms from Oleson et al. 2003 (left) and Heimlich et al. 2005 (right).

The rarity of baleen whale detections within this dataset in general does not necessarily indicate that baleen whales are rare within the MIRC region. One explanation for the paucity of baleen whale detections may be the gap in recording during the expected peak occurrence of baleen whales in the area. 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 (**Figure 32**). Thus, the study may have missed most of the baleen whale overwintering period for northern hemisphere habitats. A second caveat is that the EAR recording parameters (30 seconds on every 6 or 10 minutes) reduced the probability of detecting infrequent or rare calls, as well as the ability to detect and/or identify long-duration calls such as some blue whale call types that last 20 seconds or more. Furthermore, the location of the EARs may have been a factor, as baleen whales may primarily use areas farther offshore that are outside the recording range of the EARs. Finally, the Baleen5 detector parameters may not have been optimized for the MIRC dataset, and an evaluation of its performance with EAR data in Hawaii suggests that it may not perform as desired for certain species (Oswald et al. 2015). Although manual analysis was conducted for the entire first deployment (September–January) and April of the second deployment to verify automated detections and find additional calls (and corroborates the rarity of detections during these months), this effort was not extended into summer, and therefore it is unclear whether the lack of automated detections in May–September of the second deployment reflects a true lack of calls. It also remains a possibility that the analyst missed calls during manual searching, especially low signal-to-noise calls that would not be clearly visible in the LTSA.

The performance of Baleen5 could only be evaluated for humpback whales in this study due to few or no detections of other species for which it was trained and no manually confirmed calls from other target species. For similar reasons, in the HRC analysis, performance was assessed only for humpback whales and minke whales (Oswald et al. 2015). In the present study, the precision of the Baleen5 humpback detector was 0.95, meaning 95 percent of automated detections were true positives, and recall was 0.42, meaning 42 percent of the available calls were correctly detected. Over half (58 percent) of the manually detected humpback whale files were missed by the detector, all of which were in December of the first deployment. These calls may have been missed due to possible differences in signal-to-noise ratio of these song units compared to the ones in April during the second deployment, different recording parameters in the first deployment compared to the second, or other factors, but these were not investigated further as part of this study. The high precision for the Baleen5 humpback whale detector in the present study is similar to the precision of 0.94 in the HRC, and fewer calls were missed in the present study compared to the 0.06 recall (94 percent missed) in the HRC (Oswald et al. 2015). Precision and recall for the minke whale detector could not be calculated in the present study, as there were only 3 false positive detections and no manually confirmed calls. In the HRC, precision and recall were both relatively low at 0.29 and 0.48, respectively, for the Baleen5 minke whale detector (Oswald et al. 2015), suggesting that the automated detection results for minke whales in the MIRC may not be reliable, particularly in May–September of the second deployment without manual searching to corroborate the lack of detections.

The high precision and low recall of the Baleen5 humpback whale detector in this study do not necessarily indicate poor performance, but rather highlight the importance of tuning detector parameters for the specific dataset and region, and to consider detector trade-offs in the context of specific research questions. For example, high precision and low recall for humpback whales may be acceptable in areas such as Hawaii that have exceptionally high whale densities and calling rates, whereas in areas where calls are rare, a decrease in precision would be acceptable in exchange for missing fewer calls (increase in recall). When both precision and recall are low, as they were for the Baleen5 minke whale detector in the HRC (Oswald et al. 2015), additional efforts to improve detector performance may be desirable before applying it to other long-term datasets. Finally, it is unknown whether or how much baleen whale call repertoires in the MIRC might differ from those in other regions, and this may affect performance of detectors such as Baleen5 that were trained on calls from other regions.

4.3 KB14–Q3: What is the seasonal occurrence of sperm whales in offshore areas of the MIRC adjacent to Guam and Saipan?

Sperm whales were manually detected on all MIRC EARs in all months of the year for which there were recordings. Sperm whale occurrence was greatest at Guam N and was highest during autumn months (September–October), with detections on 47 percent of days during deployment 1. Sperm whale occurrence at Guam N was lowest during spring and summer months (April–July), with detections on 22 percent of days during deployment 2. At Saipan N, sperm whale occurrence was less seasonal, with detections on 22 percent and 21 percent of days during deployments 1 and 2, respectively. Sperm whale encounters lasted an average of 1–5 h and up to 29 h, and were detected on up to 13 consecutive days with periods of days to weeks in between encounters. No diel trend in acoustic activity was observed.

Initially, M3R CS-SVM classified sperm whale detections in 4,774 files, on approximately 80 percent of the days with recordings at each site, with a strong diel trend and more detections at nighttime. However, detector results were reinterpreted using per-file criteria of ≥ 10 clicks and ≥

70 percent clicks classified as sperm whale, and a total of only 847 files met these criteria. Manual validation of a subset of files (n = 69) that met the criteria resulted in a precision of 0.78, a recall of 0.82 and a specificity of 0.77 for the M3R CS-SVM detector. This means that a total of 661 of the 847 files that met the revised interpretation criteria for sperm whale files would be expected to contain true sperm whale detections. A seasonal trend emerged with a peak in sperm whale detections in autumn (September–November 2011), and low rates of detection in spring and summer months (April–August 2012); this was corroborated by manual analysis.

The precision and recall values for the M3R CS-SVM sperm whale detector were relatively high and an improvement in performance compared to EAR data in the HRC (Lammers et al. 2015, Oswald et al. 2015), emphasizing the importance of testing classifier performance for every region in which classifiers are used even if the recording equipment is the same in both areas. Differences in ambient noise conditions, other species present, and signal-to-noise ratio can all differ among locations and affect classifier performance. It is also important to note that this dataset comprises a much smaller sample of ground-truthed files than was examined for the HRC dataset and this may also contribute to a perceived increase in precision and recall. A larger subset of manually validated data would give more confidence to the evaluation of the M3R CS-SVM detector and the interpretation of results; however, this was beyond the scope of this project.

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

Delphinid acoustic encounters in this study were classified based on whistle frequencies into "signal groups," a proxy for species assemblages. All signal groups were detected at all MIRC EAR sites. Based on whistle characteristics reported in Oswald et al. (2003, 2007), the delphinid species most commonly encountered during visual surveys in the MIRC region (Hill et al. 2013a,b) would most often be classified into the following whistle categories: LF whistles = false killer whale, short-finned pilot whale, and rough-toothed dolphins; HF/LF whistles = bottlenose, spotted, and striped dolphins; and HF whistles = spinner, spotted, and striped dolphins. The same signal group classification scheme was shown in the central Pacific (HRC) to correspond well with species identified using ROCCA. That is, the LF group corresponded well with rough-toothed dolphins and 'blackfish' (short-finned pilot whales and false killer whales); whereas the HF/LF corresponded to bottlenose dolphins and *Stenella* sp., and the HF group to *Stenella* sp. (Lammers et al. 2015). Note that *Stenella* sp. are difficult to distinguish via automatic means and also overlap in frequency range, meaning that the HF/LF and HF categories likely overlapped substantially. The purported species assemblages above are tentative and based on the most common visually encountered delphinid species in the MIRC, as well as acoustic species groupings based on recordings in other regions of the Pacific Ocean. It is not known at present how the acoustic repertoires of these delphinid species in the MIRC region may differ compared to other areas.

The association of the above delphinid species assemblages with manual signal group categories does not exclude the presence of other odontocete species in the MIRC. The level of manual analysis undertaken for this study did not identify acoustic encounters to the species level, and therefore the presence in EAR data of less common species, such as Risso's dolphin (*Grampus griseus*) and killer whales (*Orcinus orca*), is undetermined. For some species known to occur in the MIRC, such as melon-headed whales (*Peponocephala electra*) and pygmy killer whales (*Feresa attenuata*), few confirmed acoustic recordings are available for training and it was not possible to investigate their occurrence in the EAR data.

The analysis of delphinid encounters based on whistle frequency reveals site-specific differences in overall dolphin occurrence. The greatest encounter rates (≥ 3 encounters/day) and total duration of dolphin presence (≥ 9 percent of the time) were observed at Guam N and Saipan N, and the lowest encounter rate and duration were at Guam S (0.7 encounters/day, present 2 percent of the time). Tinian W had moderately high encounter rates and encounter durations (1.9 encounters/day and 5 percent, respectively).

The abundance of different signal groups varied geographically. The HF group and the LF group were more acoustically abundant at Saipan N than at the other EAR sites, suggesting higher densities of spinner dolphins/*Stenella* sp. and blackfish/rough-toothed dolphins at Saipan compared to the other sites. The HF/LF whistle group was most abundant at Guam N compared to the other three EAR sites, suggesting higher densities of bottlenose dolphins and *Stenella* sp. north of Guam compared to other locations. Species composition also varied by EAR site. At Guam N, Saipan, and Tinian, the most abundant signal group was HF/LF whistles, followed by LF whistles, HF whistles, and then Clicks Only. At Guam S, the most common group was LF whistles, followed by HF/LF whistles, with extremely low occurrence of HF whistles. This may indicate a difference in species composition at Guam S compared to the other three sites, with LF-whistling species such as pilot whales being the most frequently encountered, as opposed to bottlenose dolphins and *Stenella* sp. being predominant at the other EARs.

The delphinid signal groups exhibited some site-specific differences in seasonal variation. Metrics of occurrence for the HF/LF and HF groups at Guam N were all higher during deployment 2 (April–September) than deployment 1 (September–January), whereas they were lower for the LF group during deployment 2. This suggests higher activity of bottlenose dolphins and *Stenella* sp. in late spring and summer months (covered by deployment 2) than in autumn/winter (deployment 1), and lower activity of blackfish and rough-toothed dolphins at Guam N in spring/summer compared to autumn/winter. However, at Saipan N, although encounter rates were slightly lower during the second deployment, the mean encounter duration and normalized total DAA for all signal groups were higher in deployment 2 than deployment 1, suggesting a seasonal increase in signaling by all delphinid species in spring/summer compared to autumn/winter. This increase in most delphinid groups in spring/summer compared to autumn/winter contrasts with the pattern of sperm whale occurrence, which was higher in the autumn/winter deployment than the spring/summer deployment. Alternatively, these patterns may reflect inter-annual variability rather than seasonal variability; additional recording over multiple seasons and years would be needed to investigate this.

The diel pattern in delphinid occurrence varied by site and by signal group. At Saipan N, there was a pronounced increase in encounters at night for the HF/LF, HF, and Clicks Only groups, whereas at Guam N the HF/LF encounter counts were high during crepuscular periods (morning and dusk) rather than at nighttime, but the HF and Clicks Only groups still showed a nocturnal pattern. This suggests potential differences in species composition and/or behavior between

Saipan N and Guam N. For the LF group, there was little to no diel pattern evident, suggesting that the behavior of the LF-whistling species differs from the other groups. Sample sizes were low at Tinian but indicated a nighttime increase similar to Saipan, and at Guam S the sample size of encounters was insufficient to determine diel patterns.

Different metrics of acoustic occurrence likely provide different types of information about the species present. Encounter rates and summed durations may be indicative of overall densities and/or residence times of animals. These metrics varied by signal group and location, indicating potential differences in species composition and proportional habitat use among sites. The most common signal group at Guam N, Saipan and Tinian was the HF/LF whistle group, but all types of signal groups were present. At Guam S, occurrence metrics were the lowest of all the sites, and the LF whistle group was more common at Guam S than other species there. The low encounter rate at Guam S 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 must traverse deep water to forage or congregate at the pinnacle. The EAA metric may be more related to group size and the behavior of species; for example, short-finned pilot whales may whistle more frequently individually and occur in larger groups, resulting in greater EAA scores within the LF whistle category although encounter rates may have been low compared to other whistle groups.

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

MFAS was detected at Guam N, Guam S, and Saipan N, but was not detected at Tinian W. Duration of MFAS detections ranged from a single sonar ping to multi-day detections. Most MFAS during deployment 1 was detected on multiple days in October 2011 at Guam N and Guam S, and most MFAS during deployment 2 was detected on multiple days in August–September 2012 at Saipan N. Dolphins were detected during the days of and days following MFAS at most sites, with the exception of one instance at Guam S, where dolphins were not detected for a period of 12 days that included a 3-day MFAS detection on 17–19 October 2011 and the 8 days afterward. This was the longest period with no dolphin encounters at this EAR and the duration was significantly different from the mean duration of 2.1 days (Poisson distribution, $p < 0.05$) without dolphins at this EAR. This 12-day period exceeded both the average and maximum duration without dolphin detections (2 and 5 days, respectively) during times not associated with MFAS at this site. However, during the same MFAS occurrence detected at the Guam N site, delphinids were detected during the days of and after MFAS, and during an even longer 9-day MFAS detection at Saipan N the following year, dolphins were detected during and after MFAS detection. **It is unclear from these data whether dolphins respond acoustically to MFAS and what factors influence the response, if any, but it is conceivable that responses vary depending on the characteristics of the animals, the environment, and the specifics of the MFAS activity**. A finer-scale investigation of dolphin acoustic response to MFAS is warranted, but may not be feasible with the existing EAR data due to the limited duty cycle and small sample size of MFAS detections (particularly those exceeding 2 hours). Potential improvements to this approach include near-continuous or continuous recording, coordination with military offices to time EAR deployments around active sonar events (with sufficient baseline recording before onset), and an array configuration to allow localization of animals and other sound sources. Localization is crucial for determining sound exposure levels experienced by animals.

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

No HF sei whale calls were detected by an experienced analyst who searched the entire Deployment 1 dataset and April of deployment 2. 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 Hz) calls from blue whales and fin whales, these relatively HF sei whale calls would attenuate more rapidly and may not be detectable at long distances if whales were calling far offshore, or if calls were produced with low source levels. In addition, the duty-cycled recording schedule of the EAR (30 seconds on every 6 or 10 minutes) would be expected to reduce the probability of detecting rare signals. More focused searching for HF sei whale calls would require more time-intensive effort, potentially including the development of automated detectors and/or file-by-file manual searching of decimated data.

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5. Conclusion

This study documents the occurrence of several cetacean species/taxa of importance to the U.S. Navy. A small number of Cuvier's and Blainville's beaked whale signals were manually confirmed to occur within the MIRC. Humpback whales were detected manually on a few days in December 2011 and both manually and automatically on two days in April 2012 at Saipan, and three unidentified baleen whale calls representing two call types (tonal signal at 100–200 Hz with harmonics, followed by either an approximate 0.5-second upsweep at 800 Hz or a <0.2-second downsweep at 400 Hz) were detected manually at Guam N in autumn. No other baleen whale species were detected, but this may be related to the lack of recording over most of the winter, duty cycle and location of the instruments, and possibly other factors, rather than a lack of occurrence. Sperm whales were both automatically and manually detected at all EARs in all months with recording effort, and there was some spatial variation in measures of acoustic abundance and seasonal occurrence. All delphinid signal groups (representing different species assemblages) were also detected at all EARs. Delphinid seasonality and diel patterns varied by signal group and site. MFAS was detected at Guam N, Guam S, and Saipan N, for periods ranging from a few seconds to 9 days. Most days during and after MFAS contained delphinid vocalizations, but at one EAR, there was one multi-day MFAS detection where dolphins were not detected during or after sonar for a longer than average period. High-frequency sei whale calls were not detected during manual searching of September 2011–January or April 2012.

The M3R CS-SVM automated detector produced low overall numbers of detections in this study. Initially, M3R CS-SVM produced raw detections (of beaked whales, sperm whales, and other delphinid species for which it was trained) in 8 percent of the total EAR data, but the application of revised interpretation criteria reduced the number of potential beaked and sperm whale detections to less than 1 percent of the total data set. The low automated detection rates of beaked whales and sperm whales, combined with the low manual detection rates for the subsets of data examined, may indicate that these species are infrequent or rare within the recording area of EARs deployed in the MIRC. This is supported by the relatively high recall of 1.0 and 0.82 by the M3R CS-SVM detector for the mixed beaked whales and sperm whales, respectively, indicating that within the subset of detections (n = 131) reviewed manually, no beaked whale files were missed and 18 percent of sperm whale files were missed. The location of the EARs may have played a role in low detection rates of beaked and sperm whales. The depth of the EARs ranged from approximately 780 to 950 meters, but sperm whales and beaked whales both forage primarily in habitats >1,000 m deep, and thus may prefer habitats farther offshore than the area monitored by the EARs.

The automated detector implemented for baleen whales, Baleen5, also produced a low number of detections overall, in only 44 files. Manual detection rates during September 2011-January 2012 and April 2012 were also low, corroborating the low rates of automated detections in these months, but it is unknown if baleen whale signals were present in May–September 2012.

The initial concerns regarding the results of the automated detectors, particularly M3R CS-SVM, were not due to faulty performance of the detectors. M3R CS-SVM was designed to be used with continuous data streams acquired on navy hydrophone ranges in the Bahamas (AUTEC) and Southern California (SCORE), and the classifier was trained for cetacean species and populations occurring in those particular geographic regions. As with other automated detectors and classifiers, M3R CS-SVM has been shown to perform well in situations for which it was designed (Jarvis et al. 2008, 2014; Jarvis 2012), and provides valuable and useful data when interpreted correctly.

The HRC and MIRC EAR data sets presented several challenges to the M3R-CS-SVM detector, including duty-cycled data, more limited bandwidth of recordings, and other differences in EAR hardware and specifications compared to AUTEC and SCORE Navy range hydrophones. In addition, both the HRC and MIRC are geographic regions where acoustic repertoires of local cetacean populations are still poorly known, and signals from species occurring in these areas are novel to the detector. Any dissimilarities between acoustic repertoires of populations in the new region compared to known regions should first be understood before assuming that a detector will perform equivalently in the new region compared to the one for which it was developed and tested. Consequently, any time an automated detector is applied to a novel region and/or data from a novel recording platform, a thorough validation and ground-truthing effort is needed to understand and characterize the detector’s performance. A cursory visual assessment of data files containing automated detections is not sufficient; individual detections should be examined and the sources of false positives, false negatives, etc. should be quantified for as large a sample size as feasible. Further adjustments to detector parameters will likely be necessary based on ground-truthing efforts, and trade-offs in detector performance should be considered in the context of the research goals and questions. For example, it may be desirable to maximize precision in areas with high animal/signal density, but in areas where animals/signals are rare, it may be better to maximize recall.

Automated detections were useful in some cases to provide a starting point for manual validation and verification of rare detections, for instance beaked whales. In addition, the M3R CS-SVM detected sperm whales more accurately in the MIRC data than it did in EAR data collected in the HRC (Lammers et al. 2015, Oswald et al. 2015). This highlights the need to validate detectors for all regions and datasets. However, in some cases, the performance of detectors was not optimized for the goals of this study. Although precision of the Baleen5 humpback whale detector was high, recall was relatively low, and 4 days of humpback whale song at Saipan were missed by the detector. High precision and low recall may not be desirable for a dataset in which calls are rare. The M3R CS-SVM specificity for beaked whales was 0.60, which is a reduction in performance compared to HRC and an indication that some true beaked whale detections may have been misclassified. More validation is needed to confidently interpret M3R CS-SVM results. Both of the detectors implemented in this study, as well as other commonly used detectors/classifiers such as ROCCA, were developed using recordings from other regions of the Pacific and/or other oceans. It is not known at present how the acoustic repertoires of cetaceans in the MIRC region differ compared to other areas. Dedicated acoustic recordings are needed for visually confirmed cetacean species in waters off Guam and CNMI. These efforts will assist in evaluating and improving the performance of automated detectors and assigning species identities to calls from remotely recorded archival data sets.

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