An Analysis of Marine Acoustic Recording Unit (MARU) Data Collected off Jacksonville, Florida in Fall 2009 and Winter 2009-2010

Submitted to:

Naval Facilities Engineering Command Atlantic under
HDR Environmental, Operations and Construction, Inc.
Contract No. N62470-10-D-3011, Task Order 021

HDR

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21 November 2012; Jan 2014 revision

Suggested Citation:

Norris, T.F., J.O. Oswald, T.M. Yack, and E.L. Ferguson. 2012. An Analysis of Marine Acoustic Recording Unit (MARU) Data Collected off Jacksonville, Florida in Fall 2009 and Winter 2009-2010. Final Report. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-10-D-3011, Task Order 021, issued to HDR Inc., Norfolk, Virginia. Prepared by Bio-Waves Inc., Encinitas, California. 21 November 2012. Revised January 2014.

Photo: Sperm whale surfacing taken by Cornelia Oedekoven, courtesy of U.S. Navy.

Work conducted under following contract between Bio-Waves, Inc. and HDR, Inc.
MSA #: CON-005-4394-009
Subproject #164744, Task #003

Executive Summary

Acoustic data collected from Marine Autonomous Recording Units during 26 days in fall (13 September to 8 October) and 37 days in winter (3 December to 8 January) 2009-2010 were analyzed for acoustic detections of marine mammals and patterns resulting from these detections. The study site coincided with the United States (U.S.) Navy's planned Undersea Warfare Training Range (USWTR) located approximately 60 to 150 kilometers offshore Jacksonville, Florida. Acoustic data consisted of two types of recordings, 2-kilohertz (kHz) and 32-kHz sample rate recordings. All 32-kHz sample rate data were downsampled to 2-kHz in order to make them comparable to the 2-kHz recordings and allow better low-frequency resolution for reviewing. These 2-kHz sample rate files were reviewed primarily for baleen whale calls, which are generally expected to occur below 1 kHz. The 32-kHz files were reviewed for all other species (e.g., sperm whale [*Physeter macrocephalus*]) and species groups (e.g., delphinids and 'blackfish') with vocalizations above 1 kHz. Data were first reviewed using long-term spectral averages (LTSAs), and then reviewed in greater detail from spectrograms using the MATLAB program Triton (Wiggins 2007). Vocalization events (defined as any continuous vocalization or series of vocalizations with no more than a 10-minute gap) were logged and later compiled into spreadsheets for graphing and additional analyses. Summary graphs of daily vocalization events and graphs of percent total time containing vocalizations by site were compiled. Probability of vocalization event occurrence was calculated for each species relative to sonar events. Species and species groups detected included minke whale (*Balaenoptera acutorostrata*), North Atlantic right whale (*Eubalaena glacialis*), sei whale (*Balaenoptera borealis*), (possible) humpback whale (*Megaptera novaeangliae*), sperm whale, 'blackfish,' and unidentified delphinids. Results indicated that minke whales were not present during fall, but occurred almost continuously during the winter deployment period. Right whale vocalization events were much shorter in duration and less frequent than those of the minke whale, and also were most concentrated during winter, as expected, but were also detected frequently at deep sites, which was somewhat unexpected. Sperm whales were detected in both seasons at similar rates, exclusively at mid-depth sites (i.e., near the continental shelf break), and showed a strong diel pattern with almost all vocalization events occurring at night from dusk until dawn. There were less obvious patterns for delphinid vocalization events, possibly because we were not able to identify vocalization events to species, and therefore, multiple species were grouped into one category. Blackfish were detected infrequently, but were most common at the shallow-water sites. There was only one possible vocalization event of a humpback whale, and none identified for fin or blue whales (*Balaenoptera physalus* and *Balaenoptera musculus*, respectively). Minke whales showed the strongest relationship between sonar events and vocalizations, with the probability of minke whale vocalization events occurring simultaneously with sonar events being much less than in the absence of sonar. A preliminary qualitative analysis of two extended periods of delphinid whistles that occurred simultaneously with sonar revealed that call-matching (i.e., mimicry) was likely occurring. Recommendations for future work are provided, and these include a more detailed analysis of vocalizations (instead of vocalization events) for some species in order to reveal important patterns and trends. The results reported here provide an assessment of marine mammal occurrence and distribution within the U.S. Navy's planned USWTR and insights on species specific vocal responses to sonar events.

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Acronyms and Abbreviations

°C	degrees Celsius
AIFF	Audio Interchange File Format
ASW	Anti-Submarine Warfare
AUTEC	Atlantic Undersea Test and Evaluation Center
dB	decibel(s)
dB re: 1 μPa @ 1 m	decibels referenced to one microPascal at 1 meter
DIFAR	Directional Frequency Analysis and Recording
DoN	Department of the Navy
FM	frequency-modulated
HF	high-frequency
hr	hour(s)
Hz	Hertz
JAX	Jacksonville
kHz	kilohertz
km	kilometer(s)
km^2	square kilometers(s)
LF	low-frequency
LTSA	long-term spectral averages
m	meter(s)
MARU	Marine Acoustic Recording Unit
MFAS	Mid-Frequency Active Sonar
min	minute(s)
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuary
OPAREA	Operating Area
psu	practical salinity units
sec	second(s)
U.S.	United States
USWTR	Undersea Warfare Training Range

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1. INTRODUCTION

Passive acoustic monitoring using autonomous recorders deployed on the seafloor is an effective method for long-term monitoring of marine mammals (Mellinger et al. 2007). Autonomous recorders have been used to investigate the distribution, occurrence, and acoustic behaviors of a variety of marine mammals in diverse habitats and geographic locations (Clark et al. 2002; Clark and Clapham 2004; Baumgartner et al. 2008a; Johnston et al. 2008). Recently, researchers have used data collected using autonomous recorders to investigate the effects of noise from seismic, sonar, and oceanographic sound sources on the calling behavior of baleen whales (Nieukirk et al. 2004; Di Iorio and Clark 2010; Castellote et al. 2012; Melcón et al. 2012; Risch et al. 2012). However, there have been few studies using autonomous-recorder data to examine the effects of noise on acoustic behaviors of odontocetes.

A recent study by McCarthy et al. (2011) utilized a large (1,500-square kilometer [km^2]) seafloor array of 82 cabled hydrophones to examine the effects of mid-frequency active sonar (MFAS) on the temporal distribution and vocal behaviors of Blainville's beaked whales (*Mesoplodon densirostris*) at the United States (U.S.) Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. The authors examined the number and temporal distribution of Blainville's beaked whales before, during, and after multi-ship MFAS activity. Results indicated that vocal activity declined during active sonar exercises and increased upon cessation of sonar transmissions. Acoustic detections during sonar operations generally occurred on the periphery of the hydrophone-array range and vocal event durations decreased for those groups that remained on the range. These results demonstrate the utility of multi-sensor seafloor hydrophone systems in assessing impacts of noise on marine mammal vocal behavior.

In the fall 2009 and winter of 2009-2010, nine Marine Acoustic Recording Units (MARUs) were deployed by the U.S. Navy along the seafloor (**Figure 1**) to examine marine mammal vocal activity in relation to U.S. Navy sonar activity. The study area was located inside the U.S. Navy's Jacksonville (JAX) Range Complex (in the JAX Operating Area [OPAREA]), a large (142,000-km^2) area that runs from Savannah, Georgia to New Smyrna Beach, Florida and extends offshore approximately 460 kilometers (km). This area is used by the U.S. Navy for training and other operations. The study area (hereafter referred to as the JAX-MARU study area) was chosen to overlap closely with the planned Undersea Warfare Training Range (USWTR), a much smaller (1,717-km^2) area that is located approximately 60 to 150 km offshore of the coast between Jacksonville and St. Augustine, Florida (Foley et al. 2011; **Figure 2**).

The MARU deployment area was located in a 1,300-km^2 region that included continental shelf waters, the continental shelf break, and deep waters offshore of the shelf break. MARUs were deployed in three depth ranges: on the shelf (44- to 46-meter [m] depth, referred to hereafter as 'shallow sites'), just beyond the shelf (approximately 183-m depth, referred to as 'mid-depth sites'), and offshore of the shelf break (approximately 305-m depth, referred to as 'deep sites'). Three recorders were deployed at each of the three depth ranges, for a total of nine MARUs for each of the two (fall and winter) deployment periods (**Tables 1 and 2**). Two types of MARUs were deployed: (1) units that recorded using a 32-kilohertz (kHz) sampling rate (32-kHz recorders), and (2) units that recorded using a 2-kHz sampling rate (2-kHz recorders). The 32-kHz recorders were deployed at Sites 2, 4, 5, 6, 7, and 9 (**Figure 2**). The 2-kHz recorders were deployed at Sites 1, 3, and 8 (**Figure 2**). The 32-kHz units each recorded for approximately 21 days during both fall and winter (13 September to 4 October and 4 December to 26 December, respectively). The 2-kHz units each recorded for approximately 25 and 33 days during fall and winter (13 September to 8 October and 5 December to 8 January, respectively) (**Tables 3 and 4**).

The MARU deployment sites were selected based on the expected location of planned U.S. Navy training exercises, rather than on habitat preferences or expected species distribution of marine mammals. The intent for deployment location and timing of MARUs was to target specific Anti-Submarine Warfare (ASW) training exercises, with the units deployed 7 to 10 days prior to the first exercise and recording for at least 7 to 10 days after the last exercise (J. Bell, Naval Facilities Engineering Command Atlantic, pers. comm.). This approach would allow marine mammal vocal behaviors and sonar activity to be recorded before, during, and after the U.S. Navy training exercises.

The JAX-MARU study area is located within the South Atlantic Bight, where the physical and biological oceanographic parameters are largely controlled by the Gulf Stream (Department of the Navy [DoN] 2008). The North Atlantic Oscillation and the El Niño/Southern Oscillation also significantly influence climate in this region. The seafloor is primarily composed of smooth, bottom surfaces and shallow gradients (DoN 2008). Bottom depths in the region range between 10 and over 2,700 m (DoN 2008). Sea surface temperatures range from 20 degrees Celsius (°C) in the winter to over 30°C in the summer, and sea surface salinity ranges from 33 to 36.5 practical salinity units (psu) (DoN 2008).

Six species of marine mammals listed as endangered under the Endangered Species Act potentially occur in the JAX OPAREA (DoN 2008); five of these are baleen whale species fin whale (*Balaenoptera physalus*), North Atlantic right whale (*Eubalaena glacialis*), blue whale (*Balaenoptera musculus*), humpback whale (*Megaptera novaeangliae*), and sei whale (*Balaenoptera borealis*). The sixth is the sperm whale (*Physeter macrocephalus*), which is a toothed whale species. Critical habitat is designated for the North Atlantic right whale within the JAX OPAREA, in nearshore continental shelf waters (National Marine Fisheries Service [NMFS] 1994). Of the endangered large whales that may occur in the JAX OPAREA, only the North Atlantic right whale and sperm whale are commonly sighted in the study region, while the other species are believed to occur infrequently (i.e., as they migrate through the region) or are extralimital (i.e., outside of the normal range of the species) (DoN 2008; Foley et al. 2011). Non-endangered species of marine mammals that may occur in the area include minke whale (*Balaenoptera acutorostrata*), rough-toothed dolphin (*Steno bredanensis*), bottlenose dolphin (*Tursiops truncatus*), pantropical spotted dolphin (*Stenella attenuata*), Atlantic spotted dolphin (*Stenella frontalis*), spinner dolphin (*Stenella longirostris*), Clymene dolphin (*Stenella clymene*), striped dolphin (*Stenella coeruleoalba*), short-beaked common dolphin (*Delphinus delphis*), Fraser’s dolphin (*Lagenodelphis hosei*), Risso’s dolphin (*Grampus griseus*), melon-headed whale (*Peponocephala electra*), pygmy killer whale (*Feresa attenuata*), false killer whale (*Pseudorca crassidens*), killer whale (*Orcinus orca*), and short-finned pilot whale (*Globicephala macrorhynchus*) (DoN 2008). Minke whales and humpback whales are documented recently to occur in the JAX OPAREA during winter, and some researchers have postulated that minke whales may calve in the area (Nilsson et al. 2011).

This report provides a summary and preliminary analysis of the occurrence of marine mammal vocal events relative to deployment period, site, depth, and sonar activity. The primary goals of this study were to:

1. Identify and characterize marine mammal vocalization events to the highest possible taxonomic level.
2. Identify and characterize periods of sonar activity.
3. Examine and analyze vocalization events in relation to sonar activity.

The occurrence of vessels is included in the review and data summary, however, it was not analyzed in detail. In addition, a few extended sonar events were examined for possible acoustic mimicry by delphinid groups. Finally, we provide recommendations for additional analyses of this data-set and improvements to the study design and analysis procedures for the future.

1.1 Background

Below are the descriptions of the general distribution and vocalization characteristics for species that are expected to be found in the JAX-MARU study area.

1.1.1 Right Whale

The North Atlantic right whale occurs seasonally in the JAX-MARU study area, primarily from mid-November through March, but individuals have been seen off the southeastern United States as late as July (NMFS 2007). Right whale sightings are concentrated in continental shelf waters offshore northeastern Florida and southeastern Georgia (e.g., DoN 2008). The marine resources assessment that covered JAX summarizes the few right whale sightings made over deeper waters near the continental shelf break, not far from the JAX-MARU study area.

Right whales produce sounds that generally range in frequency from approximately 200 Hertz (Hz) to 15 kHz (Parks and Tyack 2005; Parks et al. 2005, 2007). Right whales are known to produce at least three primary sound types: (1) 'blow sounds' that are associated with exhalation; (2) 'broadband impulsive sounds' (e.g., the 'gunshot' call); and (3) 'tonal call types' including stereotyped and complex, variable frequency-modulated (FM) calls such as the upcall and downcall (Vanderlaan et al. 2003; Parks et al. 2005; Parks and Tyack 2005; Parks et al. 2007).

1.1.2 Sei Whale

The sei whale is an oceanic species found in subtropical, temperate, and subpolar waters worldwide (Horwood 1987). This species is considered to occur primarily in deep water along continental slopes and shelf breaks (Horwood 1987). Sei whales are known to migrate considerable distances from high-latitude areas in the summer to low latitudes in the winter (Rice 1998). Little is known about the distribution and movement of this species, and the population structure of sei whales in the western North Atlantic is not defined adequately. Sei whales are thought to be uncommon in U.S. Atlantic waters; however, there have been sightings of individuals or small groups in deep, offshore waters (Edds et al. 1984; Schilling et al. 1992; Stimpert et al. 2003; NMFS 2011). To our knowledge, there are no published sightings of sei whales in waters off northeastern Florida. Sei whale winter breeding areas are unknown (Rice 1998; Perry et al. 1999).

Little is known about sei whale acoustic behaviors. For the western North Atlantic, sei whale calls have been described to range from 35 Hz to 3.5 kHz in frequency and 0.7 to 1.5 seconds (sec) in duration (Baumgartner 2008b). Sei whale vocalizations recorded off the northeastern United States tend to consist of low-frequency (LF; i.e., less than 100 Hz) downsweeps or chirps (Newhall et al. 2009). In waters between Nova Scotia and Newfoundland, Thompson et al. (1979) recorded short (0.7 sec) pulse trains with peak energy around 3 kHz, whereas Knowlton et al. (1991) recorded similar calls off the coast of Nova Scotia with longer durations (1.4 to 2.6 sec), FM sweeps from 1.5 to 3.5 kHz, and 0.4 to 1 sec inter-call intervals. Baumgartner et al. (2008b) recorded 82- to 32-Hz FM downswept calls that lasted about 1.5 sec in the Great South Channel off Cape Cod, Massachusetts using an array of four MARUs.

1.1.3 Minke Whale

The Canadian East Coast minke whale stock inhabits waters from the Davis Strait to the Gulf of Mexico, and there is a strong seasonal component to its distribution (Waring et al. 2012). Minke whales are most abundant in New England waters in the spring and summer, and they are thought to migrate offshore as they move south in fall and winter months (Mitchell 1991). In waters offshore of northeastern Florida, three sightings of five minke whales were recorded near the planned USTWR (DoN 2011, 2012). During aerial surveys flown over the planned USWTR from January 2009 to April 2011, Nilsson et al. (2011) reported nine sightings (*n*=13 individuals), all occurring from December to February. The sightings included one mother/calf pair with an adult escort, which led them to suggest that the area is part of the species' calving grounds. Sightings of minke whales during aerial surveys of the planned USTWR flown from January 2009 through May 2012 are summarized in DoN (2012).

There is little published information about minke whale calling behavior in the western North Atlantic. Edds (1980) recorded FM downsweeps from minke whales in the St. Lawrence Estuary and suggested that these sounds may serve as a spacing function for animals in this feeding area. Mellinger et al. (2000) recorded two types of pulse trains from minke whales in the Caribbean Sea, 'speed-up' pulse trains and 'slow-down' pulse trains, with the former being more common and containing energy in the 200- to 400-Hz band and lasting approximately 45 sec. The less common 'slow-down' trains contained energy in the 200- to 300-Hz band and lasted approximately 60 sec. Mellinger et al. (2000) considered these pulse trains to be the same types of sounds that had been recorded in the Caribbean by Winn and Perkins (1976). Seasonal patterns for the same types of calls reported by Mellinger et al. (2000) also have been reported recently in the Stellwagen Bank National Marine Sanctuary (NMS), with a peak in September and the majority of days with calls occurring on MARUs from August to October (Risch et al. 2011). Beamish and Mitchell (1973) described high-frequency (HF; 4 to 7.5 kHz) clicks with a click rate of 6.75 (+/- 1) clicks/sec reportedly produced from a minke whale that circled their research vessel.

1.1.4 Humpback Whale

Humpback whales spend summers on high-latitude feeding grounds and migrate to winter grounds in the tropics, mostly around islands, shallow underwater banks, and along continental coasts (Rice 1998). The western North Atlantic population of humpback whales migrates to calving grounds in the Caribbean during the fall and winter (Rice 1998); however, extralimital sightings are reported for the Gulf of Mexico (Jefferson and Schiro 1997). Winter humpback whale sightings also have occurred in coastal southeastern U.S. waters during recent North Atlantic right whale surveys (Waring et al. 2012). Based on sparse sighting data, humpback whales in the JAX OPAREA are sighted most often during the winter months, primarily in nearshore waters that in part reflect the intense survey effort for right whales for that region and during that time of year (e.g., DoN 2008). There were two sightings of lone humpback whales during aerial surveys conducted for the U.S. Navy in the region of the planned USWTR from January 2009 to May 2012 (DoN 2012).

Male humpback whales sing long, complex songs, consisting of rhythmically repeating themes, phrases, and units (Payne and McVay 1971). In the wintertime, much of the western North Atlantic population occurs at breeding grounds in the Caribbean (Swartz et al. 2003), but singers also have been documented in late fall and spring at northern feeding grounds (Clark and Clapham 2004; Mattila et al. 1987) and along migration routes between these areas (Clapham and Mattila 1990). Songs contain most energy in the low hundreds of Hertz to several kilohertz, with energy for some units extending just beyond 24 kHz, and mean root mean square source levels (decibels referenced to one microPascal at 1 meter [dB re: 1 μPa @ 1 m]) ranging from approximately 144 to 169 dB (re: 1 μPa @ 1 m) with the highest average source level for individual units measured at 173 dB (re: 1 μPa @ 1 m) (Au et al. 2006). Non-song sounds that included various grunts and 'wops' (sounds generally less than 1 kHz and 1 sec in duration) were recorded recently in feeding areas in the Stellwagen Bank NMS off Cape Cod, Massachusetts (Stimpert et al. 2011). Social sounds, consisting of short-duration grunts and cries, have been recorded at breeding grounds in Hawaii from large surface active groups (Silber 1986) and in the presence of mother/calf pairs (Zoidis et al. 2008).

1.1.5 Sperm Whale

Sperm whales inhabit all ocean basins from tropical to polar waters (Rice 1998). In the western North Atlantic, sperm whales occur in waters over the continental shelf, slope, and offshore (Smith et al. 1996; Davis et al. 2002; Waring et al. 2001, 2012). Historic whaling records suggest an offshore distribution of sperm whales off the southeastern United States, over the Blake Plateau, and into deep waters (DoN 2008). There has been relatively sparse systematic survey effort in deep waters offshore of the shelf break for this region. Most of the recent survey effort in southeastern U.S. waters has focused on right whales, and thus has been conducted during the winter in nearshore waters where sperm whales are generally not found. Aerial surveys conducted during January 2009 through May 2012 resulted in only one sighting of two sperm whales in deep, offshore waters near the JAX-MARU study area (DoN 2012).

Sperm whales produce distinctive, broadband (100 Hz to 25 kHz) echolocation clicks for approximately 80 percent of the time that they are actively swimming (Miller et al. 2008). These "click trains" are frequently characterized by evenly spaced pulses of decaying amplitude, although the pulse repetition rate can vary (Backus and Schevill 1966). Sperm whale clicks can reach source levels of 223 dB re: 1 μPa @ 1 m for adult males (Møhl et al. 2000), and females and juveniles typically produce "usual" clicks (also referred to as "regular" clicks) that have a 0.5 to 1.0 sec inter-click interval and centroid frequency of 15 kHz (Madsen et al. 2002). Usual clicks are made ubiquitously by sperm whale female/juvenile groups during dives and can be used to track and monitor their presence when they are not at the surface. The usual clicks are thought to be used to scan for prey during dives, so they are typically associated with periods of feeding in sperm whales (Whitehead 2003). Adult males commonly produce high-amplitude, lower-frequency (500-Hz centroid energy) clicks with longer inter-click intervals (e.g., greater than 2-sec separation between clicks) also known as "slow clicks" (Madsen et al. 2002; Whitehead 2003). Creaks are a type of click train consisting of a click sequences with very short inter-click intervals that often decrease during the course of the creak. While creaks sometimes are associated with social behavior at the surface (Whitehead 2003), they are now known to indicate that a sperm whale is closing on a potential prey item at depth (Miller et al. 2004a). During socially-active periods, sperm whales also produce stereotyped patterns of 3 to 40 broadband, low-amplitude clicks, termed "codas," that typically occur for durations of 3 sec or less (Watkins and Schevill 1977).

1.1.6 Delphinids and Blackfish

Fifteen species of delphinids potentially occur in the JAX OPAREA (DoN 2008). Five large delphinid species (melon-headed whale, pygmy killer whale, false killer whale, killer whale, short-finned pilot whale) found in the JAX-MARU study area will be referred to collectively as 'blackfish.' Based on limited visual observations, habitat modeling, and known habitat associations, most of the blackfish species are expected to be found seaward of the shelf break in the JAX OPAREA. Pilot whales are expected to be most common along the shelf break and killer whales are expected to be found in both shallow and deep waters. Most of the small delphinid species (e.g., rough-toothed dolphin, pantropical spotted dolphin, spinner dolphin, Clymene dolphin, Fraser's dolphin, and Risso's dolphin) in the JAX-MARU study area are most common seaward of the shelf-break, while a few (bottlenose dolphin, Atlantic spotted dolphin, and short-beaked common dolphin) have distributions that range from shelf waters to offshore of the shelf (DoN 2008).

The sounds produced by delphinids can be divided into three general categories: echolocation clicks, burst pulses, and whistles. Echolocation clicks are short broadband pulses that are used for navigation and object discrimination (Au 1993). Burst pulses are broadband click ‘trains’ with very short, dynamic inter-click intervals. Both echolocation clicks and burst pulses have peak frequencies that can vary from tens, to well over 100 kHz (Norris and Evans 1967; Au 1980). Whistles are continuous, narrowband, and usually FM signals. They range from several tenths of a second to several seconds in duration (Tyack and Clark 2000). The fundamental frequencies of whistles generally range between 2 and 20 kHz, although they can extend to almost 30 kHz (Lammers et al. 2003; Oswald et al. 2004). Whistles produced by blackfish are generally lower in frequency (approximately 3 to 9 kHz) than those produced by smaller delphinids (approximately 6 to over 20 kHz) (Oswald et al. 2007).

2. METHODS

2.1 Data preparation

The acoustic data were provided to Bio-Waves by the U.S. Navy on hard drives in Audio Interchange File Format (AIFF) format. All AIFF data files were converted to .wav file format in order to make the data compatible with the review and analysis software (i.e., Triton, see **Section 2.2**). The data from the twelve 32-kHz MARUs were decimated to a 2-kHz sample rate to allow for improved spectrographic resolution during the review of LF calls.

2.2 LTSA Creation and logging

Triton software (Wiggins 2007) was used to create long-term spectral averages (LTSAs) for all 2-kHz and 32-kHz .wav file data. A custom MATLAB script was written to automate the LTSA creation process. JPEG images of all LTSAs were saved for each day. This allowed for a quick preliminary review and quality check of all data before a more detailed review occurred.

Once LTSAs of all the acoustic data were created, data analysts performed a detailed review and logging of all biological sounds (or possible biological sounds), sonar, and other anthropogenic events (e.g., ships, small boats, etc.) in both the 2-kHz and 32-kHz datasets. Data analysts reviewed all LTSAs (i.e., from each day for each site) using 0.5 to 1.0 hour (hr) windows. Acoustic 'events' were defined as one or more occurrences of biological, possible biological, or anthropogenic sounds. Individual sounds were grouped into separate events when an interval of less than 10 minutes (min) occurred between each sound. When more than 10 min of silence occurred between individual sounds, a new event was logged, starting with the start time of the new sound. If two separate, seemingly unrelated (i.e., different species or event type) events occurred simultaneously they were logged separately. JPEG images and .wav file clips of a portion of each logged event were saved. Events that could not be identified to a particular species or taxonomic group were logged as unknowns using a descriptive code in the comments field of the log. When an event from a known source was detected, it was logged using a broad descriptive code (e.g., marine mammal species, anthropogenic, or other) as well as a more detailed sub-code to define the sound type (i.e., taxonomic group, species, or anthropogenic sound type). Vocalization events for some species had to be grouped into lower taxonomic levels (e.g., delphinids and blackfish). *Blackfish* consisted of melon-headed whales, pygmy killer whales, false killer whales, killer whales, and short-finned pilot whales. *Delphinids* consisted of all delphinid species other than the blackfish. While the frequency ranges of whistles produced by delphinids and blackfish overlap, it was sometimes possible to distinguish blackfish from delphinids based on the fact that whistles produced by blackfish often have a narrower frequency range and fewer inflection points than those produced by delphinids (Oswald et al. 2004). The presence of distinctive pulsed sounds was also used to identify blackfish. Unknown sounds were compiled into Microsoft PowerPoint files containing images of the spectrograms and embedded sound files. These PowerPoint files were sent out for review by researchers who had expertise in the sounds produced by the taxonomic group to which the sound was considered most likely attributed (**Appendix B**).

2.3 Data Analysis

2.3.1 Data Summary

Event logs (Microsoft Excel files) were created for each day at every site for both the 2-kHz and 32-kHz data using the Triton logging methods described above. A custom-written MATLAB script was used to combine all event logs into a single Excel database. From the Excel database, event counts and durations were summarized by species and deployment for each recording site. Event durations were divided by the total recording time (i.e., percentage of recording time) at each site to standardize duration measurements among sites. Three site types were defined based on relative depths of MARU deployments: ‘shallow,’ ‘mid-depth,’ and ‘deep’ as defined in **Section 1** and depicted in **Figure 2**.

Combined event log data were organized into Excel pivot tables to provide summaries of event counts, the number of days each event occurred at each site, and durations for each deployment and site. We combined events for each type across all nine recorders within each deployment to determine event totals. Graphs of daily event occurrence were made for each species that had sufficient data to plot. Graphs of the percentage of time during which each species event was detected with respect to total recording time at each site were also plotted by species. The percentage of time that MFAS and ships were present with respect to total recording time was overlaid on a second y-axis as lines on these graphs.

2.3.2 Probability of Call Events and Sonar

Custom-written MATLAB scripts were used to calculate the probability of a marine mammal vocalization event occurring in the presence and in the absence of sonar. These methods were based on the methods used in Melcón et al. (2012). The MATLAB scripts were used to step through the acoustic event data for each day in 10-min increments. Matrices were then created of the presence or absence of marine mammal vocalizations for each species/species group and sonar for each 10-min interval. The probabilities of marine mammal vocalizations in the presence and absence of sonar were calculated based on these matrices. The probability of calling in the presence of sonar was as follows:

$$\frac{\#\ bins\ with\ vocalization\ events\ and\ sonar}{(\#bins\ with\ vocalization\ events\ and\ sonar) + (\#\ bins\ with\ only\ sonar)}$$

The probability of calling in the absence of sonar is:

$$\frac{\#\text{ bins with only vocalization events}}{(\#\text{ bins with only vocalization events}) + (\#\text{ of bins with no vocalization events or sonar})}$$

All probabilities are expressed as percentages to aid in the interpretation and discussion of the results.

2.3.3 Review of Potential Mimicry

Delphinid vocalization events that overlapped with sonar events were examined during a preliminary review for the presence of potential mimicry. Acoustic mimicry was generally defined as a signal (produced by a marine mammal) that was similar in shape (e.g., similar time-frequency contour), frequency, and/or duration to the sonar signal(s) preceding the whistle events. Based on these qualitative criteria, individual whistles were classified into two mutually exclusive categories:

(1) "possible mimicry"; and (2) "probable mimicry." *Probable mimicry* was defined as whistles with frequency contours, peak frequencies, and durations that were similar to sonar signals (**Figure 3**). *Possible mimicry* was generally defined as whistles with only one of these previous characteristics that were similar to the sonar signal (**Figure 4**). A whistle was also classified as possible mimicry if both frequency contour and duration were qualitatively assessed to be similar to the sonar signal. All occurrences of possible and probable mimicry were logged, and .wav files and JPEG images of spectrograms were compiled for review. Probable and possible mimicry whistles were counted to determine the proportion of mimicry to non-mimicry whistles. Detection-type categories (e.g., regular whistles, possible mimicry, probable mimicry, and sonar events) were plotted in time (hh:mm:ss [hr/min/sec]) versus start frequency (kHz) graphs to show when each respective event occurred with respect to one another. The proportions of each type of event detection were also plotted for each analysis period.

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3. RESULTS

3.1 Recordings and Reviewed Data

A total of 13,077 hr of recordings were made on all nine MARU deployments (**Tables 3 and 4**). From these recordings, a total of 16,120 hr of data were reviewed and analyzed. The discrepancy between the total hours of recordings made and those reviewed and analyzed is due to the fact that the 32-kHz data were reviewed twice, once for frequencies below 1 kHz (i.e., data were downsampled to 2 kHz) and once for frequencies between 1 and 16 kHz. Of the 16,120 hr of data reviewed, 10,132 hr consisted of 2-kHz data and 5,988 hr consisted of 32-kHz data. The fall deployment (Deployment 1: September to October 2009) consisted of 7,580 hr (47 percent) of data recorded and reviewed, while the winter deployment (Deployment 2: December 2009 to January 2010) was 8,540 hr (53 percent) of data recorded and reviewed.

3.1.1 Fall (Deployment 1)

During the fall deployment (Deployment 1), the delphinids had the greatest total duration of marine mammal events with just over 300 hr. Sperm whales had the second greatest total duration with just under 300 hr (**Table 5**). Ship events were detected for 659 hr, more than double the duration of either delphinids or sperm whales. The total duration of MFAS events was 535 hr summed from all nine MARUs in this deployment period.

3.1.2 Winter (Deployment 2)

For the winter deployment (Deployment 2), the minke whale by far had the greatest total duration of vocalization events, with 1,429 hr detected (**Table 5**). The sperm whale, with 395 hr, and delphinid species, with 235 hr, were second and third, respectively, in total duration of events. The species with the shortest total duration of total events was the humpback whale, with one event of only 1.5 min in duration (this was classified as a possible humpback whale event). Ship events were detected for approximately 551 hr, about one-third as many hours as minke whales and twice as many hours as delphinid total duration. MFAS events were detected for a total of approximately 95.5 hr summed from all nine MARUs in this deployment period.

3.2 Event totals

Based on the percentage of total event duration by species relative to the total recording time available, the minke whale was by far the most commonly detected species, and it was also only detected during the winter deployment (**Figure 5**). The sperm whale and the delphinid species group detection events were the next most detected events. The remaining species and species groups' vocalization events occurred at relatively low percentages (all approximately < 1 percent; **Figure 6**). Sonar events, echosounders, and shipping traffic events were calculated as percent of total recording time (**Figure 7**). MFAS occurred during both deployments, but was much more (> 5 times) prevalent in the fall deployment than in the winter deployment recordings, occurring just under 10 percent and 2 percent of the total recording times, respectively (**Figure 7**).

3.2.1 Fall (Deployment 1)

An analysis of the percentage of time that each type of event contributed to the total event duration indicated that sperm whale and delphinid vocalization events comprised approximately the same relative amount (approximately 8 percent) of the total (**Figure 5**). The remaining species and species groups (right whales, blackfish, possible blackfish, and unidentified baleen whales) represented less than 1 percent each of the total recording time (**Figure 6**). Minke whales, sei whales, and humpback whales were not detected in fall. Ship noise and MFAS events were detected for just less than 12 and 10 percent, respectively, of the total recording time (**Figure 7)**.

3.2.2 Winter (Deployment 2)

For the winter deployment, minke whale vocalization events far exceeded other species, representing slightly less than 20 percent of total recording time. Sperm whale events were approximately the same as in fall (approximately 8 percent) and delphinid events comprised approximately half of the total percentage observed in the fall recordings (approximately 4 percent) (**Figure 5**). Sei whale, right whale, possible humpback whale, unidentified baleen whales, blackfish, and possible blackfish each represented less than 1 percent of the total recording time (**Figure 6**). MFAS comprised less than 2 percent of the total recording time, while ship noise occurred just less than 8 percent of the total recording time (**Figure 7**).

3.3 Average Event Durations

3.3.1 Fall (Deployment 1)

Average vocal event durations were calculated by species for each site for the fall deployment (**Figure 8**). At the deep sites (Sites 1-3), delphinid species had the greatest average event durations (> 15 min). At mid-depth sites (Sites 4-6), sperm whales had the greatest average event durations (> 2 hr) followed by blackfish and delphinids (> 15 min). At shallow sites (Sites 7-9), blackfish had the greatest average event durations (Site 9 > 30 min; Site 7 > 15 min) followed by right whales (Site 8 > 15 min; Site 9 > 5 min).

3.3.2 Winter (Deployment 2)

Average vocal event durations were calculated by species for each site for the winter deployment (**Figure 9**). At the deep sites (Sites 1-3), minke whales had the greatest average event durations (> 1.5 hr). At the mid-depth sites (Sites 4-6), sperm whales had the greatest average event durations (> 3 hr), followed by minke whales (> 1 hr). At the shallow sites (Sites 7-9), minke whales (Site 7 > 1 hr; Site 9 > 20 min), blackfish (Site 9 > 30 min), and delphinid species (Site 9 > 30 min) had the greatest average event durations.

3.4 Right Whale

3.4.1 Fall (Deployment 1)

Right whale vocalization events were detected between 13 September and 5 October (**Figure 10**). Vocalization events were detected at all sites, but relatively infrequently (less than 0.5 percent of time; **Figure 11**). In general, right whale events were most prevalent at the shallow (Sites 7-9) and deep (Sites 1-3) recording sites, with Site 1 having the greatest percentage of time with right whale events

(0.46 percent). There were no obvious correlations with sonar events nor any obvious diel patterns based on examination of the percentage of time with vocal events and sonar graph (**Figure 10**). When longer events occurred, they were typically during daylight hours. Because the sample size for right whale vocalization events was so small, the probability analysis results were not considered meaningful and therefore are not presented.

3.4.2 Winter (Deployment 2)

Right whale vocalization events were detected between 5 December 2009 and 4 January 2010 during the winter deployment (Deployment 2) (**Figure 12**). Vocalization events were detected at all sites during the winter deployment (Deployment 2) (**Figure 13**), but more infrequently than during the fall deployment (Deployment 1) (**Figure 11**). The highest percentage of recording was approximately 0.2 percent, and the highest rates of right whale detections occurred at the mid-depth (Sites 4-6) and deep (Sites 1-3) recorder sites. Based on visual inspection of the daily vocalization events graph, no strong diel patterns were noticeable, nor were any obvious correlations with sonar events apparent from the percentage of time with vocal events and sonar graph (**Figure 12**). As in Deployment 1, because the sample size for right whale vocalization events was so small, the probability analysis results were not considered meaningful and therefore are not presented.

3.5 Sei Whale

3.5.1 Winter (Deployment 2)

Sei whale vocalization events were only detected during the winter deployment, between 12 December 2009 and 1 January 2010 (**Figure 14**). Detections occurred at every site, except Sites 7 and 9 (shallow sites), with very low (less than 0.6 percent) percentages of time with vocalization events per site. The greatest percentage (0.54 percent) occurred at Site 1, followed by Site 3 (0.42 percent), and Site 6 (0.23 percent). The remaining sites had extremely low percentages (less than 0.05 percent) (**Figure 15**). Sei whales were detected primarily during daylight hours, with the longest duration events occurring predominantly during daylight or near dusk (**Figure 14**). Because the sample size for sei whale vocalization events was so small, the probability analysis results were not considered meaningful and therefore are not presented.

3.6 Minke Whale

3.6.1 Winter (Deployment 2)

Minke whale vocalization events were detected only during the winter deployment (**Figure 5**), from 14 to 31 December (**Figure 16**). Both 'speed-up' and 'slow-down' pulse trains were predominantly detected, however other call types were also encountered. One such type included a peculiar call (LF pulse + HF click) that typically occurred a few minutes after one of the predominant call types, and included a HF component which has not been described elsewhere.

Minke whale vocalizations were detected during almost every day in the combined recordings, with the exception of the first and last days (3 December 2009 and 9 January 2010) of the deployment (**Figure 16**). Minke whale vocalizations were greatly reduced or completely ceased during most days with concurrent sonar events (**Figure 16**). For some days (18 through 25 December), vocalization events occurred throughout the entire day (**Figures 16**). Minke whale vocal events varied greatly in duration and temporal occurrence between sites (**Figures 17-24**). Minke whales made up the greatest percentage of time (approximately 53 percent) with events for any species/taxonomic group (**Figure 9**), and were detected predominately at deep recording sites (Sites 1 and 3; **Figure 26**). At shallow-water Sites 7 and 9, minke whales were detected at very low levels (less than 0.3 percent), and no detections were made at shallow-water Site 8 (**Figure 25)**. The probability analysis suggested a very strong negative correlation to sonar, as indicated by the greatly reduced probabilities of vocalization events occurring during sonar relative to when sonar was not present (**Figure 26**). In fact, for Sites 4, 5 and 6, there were no vocalization events that coincided with sonar during the entire deployment period.

3.7 Unidentified Baleen Whale

3.7.1 Fall (Deployment 1)

Unidentified baleen whale events were detected during the fall deployment between 14 September and 6 October (**Figure 27**). These events were relatively infrequent and short in duration. Unidentified baleen whales were primarily detected on deep recorders, with the majority of detections at deep-water Site 2 (0.21 percent) and deep-water Site 1 (0.06 percent) (**Figure 28**).

3.7.2 Winter (Deployment 2)

Unidentified baleen whale events were also infrequent and very short in duration during the winter deployment (**Figure 29**). There were no events over 1 hr in duration and most of the events occurred during daylight hours. Unidentified baleen whales were primarily detected at deep and mid-depth locations. The site with the greatest percentage of time with unidentified baleen whale detections was deep-water Site 2 (0.11 percent) followed by mid-depth Site 6 (0.10 percent) (**Figure 30**).

3.8 Other Baleen Whales

A possible humpback whale vocalization event was detected on 14 December for approximately 1.5 min (**Figure 31**). Due to the limited number of events, no graphing or further analyses were conducted. Fin whale and blue whale calls were not detected, so no analysis was possible.

3.9 Sperm Whale

For both fall and winter deployments, sperm whales were detected (**Figure 5**), but only at mid-depth sites (**Figure 32**). Sperm whale vocalization events were not detected at 2-kHz recorder sites (Sites 1, 3, and 8), which only recorded sounds below 1 kHz (**Figure 33**).

3.9.1 Fall (Deployment 1)

During the fall deployment (September through October), sperm whales were detected at all mid-depth sites (Sites 4-6) during every day of the 32-kHz recorder deployment (**Figure 34**). Sperm whale vocal events varied among sites in duration and daily occurrence patterns (**Figures 35 - 37**). The greatest percentage of time with sperm whale events during this deployment occurred at Site 4 (27 percent), followed by Site 6 (23 percent), and Site 5 (11 percent) (**Figure 38**). The graph of daily sperm whale vocalization events shows a strong diel pattern (**Figure 34**), with sperm whale vocalization events occurring predominantly between sunset and sunrise. There were only a few events that extended past dawn into the daytime (e.g., 21 September) or started and ended during the day (e.g., 22 September and 27 September). Occasional creaks and codas were observed amidst usual/regular clicking in the dataset, but this information was not quantified nor summarized in the daily graphs. Results of the probability analysis for the fall deployment did not indicate any consistent differences between the probability of calling events during periods with sonar and those without (**Figure 39**).

3.9.2 Winter (Deployment 2)

Sperm whales were detected during all but 2 days on the 32-kHz recorders during the winter deployment (**Figure 40**). Similar to the fall deployment, sperm whales were detected only at the mid-depth sites (Sites 4-6) (**Figure 41**). The greatest percentage of time with sperm whale events occurred at Site 6 (49 percent), followed by Site 4 (16 percent), and Site 5 (13 percent) (**Figure 41**). Sperm whales were not detected at the remaining sites (e.g., shallow and 2-kHz recorder sites) (**Figures 41**). Sperm whale vocal events varied among sites in duration and daily occurrence patterns (**Figures 42-44**). Sperm whale vocalization events during the winter deployment exhibited an even stronger diel effect than they did during the fall deployment, with nearly complete cessation of clicking just after dawn and resumption of usual/regular clicking just prior to dusk (**Figure 40**). Creaks and codas were also observed occasionally in the winter deployment. Results of the probability analyses indicate a lower probability of vocalization events during sonar than without (**Figure 45**).

3.10 Delphinid Species

3.10.1 Fall (Deployment 1)

Delphinid vocalization events were detected every day between 13 September and 4 October (**Figure 46**). Delphinid vocalization events were not detected for the remainder of the deployment (5-8 October), when only the 2-kHz sampling rate recorders were operating (these recorders were likely to catch only the lowest frequency portions of delphinid vocalizations, if any). Delphinid vocal events were detected at all sites during the fall deployment. The greatest percentage of time with delphinid events occurred at deep-water Site 2 (14.5 percent), while the lowest occurred at shallow-water Site 8 (less than 0.01 percent) (**Figure 47**). There were no consistent differences in percentage of time with delphinid events relative to site depth. There did not appear to be a strong diel pattern when examining the graph of daily delphinid vocalization events (**Figures 46**), but when events were viewed by call type category (**Figures 48-50**), in general, delphinid echolocation and mixed-vocal events were more common during nighttime hours (**Figure 49 and 50**). Mixed-vocal events were delphinid events that contained both clicks (echolocation and/or burst pulses) and whistles.

Delphinid vocalization events occurred during all sonar events that took place during the fall deployment (**Figure 46**). The probability of a delphinid acoustic events was generally only slightly greater with sonar than without; however, at Site 6, this difference was pronounced (27 percent probability with sonar vs. 12 percent probability without sonar) (**Figure 51**).

3.10.2 Winter (Deployment 2)

Delphinid vocalization events were detected every day from 4 to 27 December (**Figure 52**). Delphinids may have been present for the rest of the deployment, but during those days only the 2-kHz sampling rate recorders were operating. Delphinids were detected at all sites. The greatest percentage of time with delphinid events occurred at shallow-water Site 9 (16.4 percent), while the lowest occurred at shallow-water Site 8 (less than 0.01 percent) (**Figure 53**). Delphinid echolocation, whistle, and mixed-vocal events in the winter deployment were more evenly distributed during the day and night than they were during the fall deployment (**Figures 54-56**).

Delphinid vocalization events were detected during most sonar events that occurred during the winter deployment (Deployment 2). In contrast to the fall deployment (Deployment 1), the probability of acoustically detecting a delphinid was generally higher in the absence of sonar than in the presence of sonar. These differences were only pronounced, however at Sites 5 and 9 (1.6 percent during sonar vs. 5.4 percent without sonar and 4 percent during sonar *vs.* 19 percent without sonar, respectively) (**Figure 57**).

3.11 Blackfish Species

3.11.1 Fall (Deployment 1) and Winter (Deployment 2)

Although blackfish were detected during fall and winter deployments, relatively few blackfish detections occurred (**Figures 58 and 59**). Blackfish, probable blackfish, or possible blackfish were detected at all sites with 32-kHz recorders (Sites 2, 4, 5, 6, 7, and 9) but at none of the sites with 2-kHz recorders only (Sites 1, 3, and 8) (**Figures 60 and 61**). While components of the sounds produced by blackfish may extend below 1 kHz, it was not possible to differentiate sounds produced by blackfish from sounds produced by delphinids using the limited 1-kHz bandwidth of the 2-kHz recorder data. Overall, the percentage of time with blackfish vocalization events was low. Site 9 (shallow-water) had the highest percentage of time with blackfish vocalization events during both deployments (0.33 percent during Deployment 1 and 1.3 percent during Deployment 2). Because the sample size for blackfish vocalization events was so small, the probability analysis results were not considered meaningful and therefore are not presented.

3.12 Review of Potential Mimicry

Two time periods containing overlapping sonar and delphinid events were reviewed. Sonar and whistle events for each period were counted (**Figure 62**). The first period reviewed occurred on 16 September and lasted approximately 9 hr. During this period there were 112 probable and 35 possible mimicry events, which accounted for approximately 27 percent of all whistles, and 738 individual sonar pings were detected. The second period occurred on 10 December and lasted approximately 14 hr. During the second period there were 9 probable and 12 possible mimicry events, which accounted for approximately 47 percent of all whistles, and 1,543 individual sonar pings were detected. Time series plots of frequency vs. time for each detection type show that regular whistles varied more in frequency than mimicked whistles during both events (**Figure 63 and 64**).

3.13 Other Acoustic Events

Other acoustic event detections included unknown biological (e.g., fish), MFAS, and other non-biological sounds (e.g., engine noise from ships). The event totals for these other acoustic categories are summed across all nine MARUs for each deployment period. During both the fall and winter MARU deployments, sonar was detected on 9 days **(Figures 65 and 66).** However, during the winter deployments, sonar events were more infrequent and sporadic **(Figure 66)**. There was significantly more MFAS during the fall than during winter deployments (**Figure 7**). During the fall deployment, there were 88 unknown acoustic events (i.e., events that could not be classified) that occurred for a total of 4.27 hr. There were 647 ship events for a total of 657 hr. Echosounders during the fall deployment consisted of 17 events totaling a little over 4 hr. In the winter deployment echosounders consisted of 22 events totaling approximately 12.2 hr. In total, 1,176 events were classified as ‘possible,’ ‘probable,’ or ‘definite’ fish. During the winter deployment, there were 50 unknown events that occurred for a total of approximately 3 hr, with 564 ship events that occurred for a total of 551 hr. Finally, a total of 1,224 events were classified as possible, probable, or definite fish. The identity of questionable fish sounds (e.g., those that might be confused as marine mammal sounds) were confirmed by outside reviewers with expertise in fish bioacoustics (**Appendix B**).

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4. DISCUSSION

The results of the analysis of JAX-MARU data provides detailed information about the spatial, seasonal and diel occurrence patterns of several species and species groups that was not available previously. However, it should be noted that an absence of vocalization events does not necessarily mean an absence of animals, as vocalization is not an obligatory behavior for most species (although some species such as sperm whales vocalize almost continuously when in large groups). The information provided in this analysis is restricted to the general locations of deployments. However, for species that produce loud, low frequency signals (e.g. the baleen whales), some sounds may propagate far enough to be detected by several recorders, or from distant sources (e.g. near-shore right whales). This may complicate interpretation of occurrence patterns. In spite of these constraints, it is apparent that a much more detailed picture of marine mammal occurrence was provided than was previously available. For example, recent summaries and models of density estimates indicate that few if any minke whales, sperm whales and right whales are expected in the JAX-MARU/USWTR study area (DoN 2007, Don 2008), which contrasts with our findings.

4.1 Event Totals

Approximately 1,000 fewer hours (approximately 10 percent) of recordings were made during the fall deployment (7,580 hr) than the winter deployment (8,540 hr). The most commonly detected species during the fall deployment were sperm whales and delphinid species. During the winter, minke whales were the most commonly detected species, followed by sperm whales and delphinids. The remaining species (right whale, sei whale, humpback whale, and blackfish) all made up a very small proportion of total acoustic event durations.

4.2 Sonar Results

MFAS was present during both deployments, with significantly more sonar during the fall deployment (approximately 535 hr summed from all nine MARUs in this deployment period) compared to the winter deployment (approximately 95.5 hr summed from all nine MARUs in this deployment period) (**Table 5; Figure 7**). During the fall deployment, MFAS represented just under 10 percent of total time recorded, but less than 2 percent of the total time recorded during the winter deployment—almost a five-fold difference. When examining the percentage of total time with marine mammal and sonar events graphs, it is important to be aware that for the 2-kHz only recording sites (Sites 1, 3, and 8), any event (e.g., sonar or dolphin whistles) with frequencies greater than 1 kHz will not be represented in the graphs (or if energy occasionally extends down from frequencies above 1 kHz, then the percentage totals may be extremely biased). This does not necessarily mean that sonar event types did not occur at these sites, just that we could not detect them due to the sampling rate limitations of the recorders.

Response by an animal to acoustic stimuli, including MFAS, presumes that that the animal has sufficient auditory sensitivity to hear the stimulus. When considering the effects of sonar on marine mammals, it is also important to note that hearing sensitivity varies greatly amongst marine mammals (Richardson et al. 1995), with baleen whales presumably most sensitive in the lower (less than 2 kHz) frequencies, and odontocetes (with possible exception of mature male sperm whales) more sensitive to sound in the higher (greater than 2 kHz) frequencies (Ketten 1998). We did not attempt to incorporate hearing sensitivities in the interpretation of our results. However it is important to note that recently, Melcón et al. (2012) detected a reduction in the probability of vocalizations of blue whales (known to be extremely

LF signalers) during MFAS transmissions, suggesting that they can detect and respond to MFAS or related noise sources (e.g., U.S. Navy vessels).

4.3 Right Whale

In general, right whale vocalization events were relatively short in duration and represented less than 0.5 percent of recordings for all sites. Longer vocalization events (i.e., bouts) typically occurred during the daytime, with none exceeding 2 hr in duration. Other than this, there were no obvious diel patterns, although we did not statistically test for differences in the occurrence of call events for daytime and nighttime. Diel patterns in call rate have been reported for right whales in other regions (Parks and Tyack 2005; Munger et al. 2008; Parks et al. 2012), although both of these studies took place on feeding grounds.

The highest percentage of recordings per site was approximately 0.5 percent of time, and the highest rates of right whale detections occurred at the deep recorders during the winter deployment and on the shallow and deep recorders during the fall deployment. This suggests that the distribution of right whales may extend further offshore than sighting data has previously indicated.

Interestingly, Site 1 (the southwestern-most deep-water site) had the greatest percentage of time with right whale detection events (0.46 percent) in the fall deployment, and Site 2 (also a deep-water site) had the greatest percentage of time with right whale events for the winter deployment. Winter-time aerial surveys conducted by Foley et al. (2011) resulted in a sighting of a right whale giving birth just 20 km west of the planned USWTR and JAX-MARU study area in March 2010. Some right whale sightings occur farther offshore, near the continental shelf break (e.g., DoN 2008). The aforementioned sightings support the results of our acoustic analysis, which shows that right whale vocalization events were found outside of the shallow, near-shore areas currently designated as critical habitat, and possibly in deeper waters than previously believed. Alternatively, it is possible, even likely, that propagation of right whale signals allows detections at distances of several to tens of kilometers. Rone et al. (in press) were able to localize North Pacific right whales (*Eubalaena japonica*) at distances as far as 63 km, with an average range of 23 km using multiple Directional Frequency Analysis and Recording (DIFAR) sonobuoys in a study in the Gulf of Alaska. The acoustic propagation characteristics in the Gulf of Alaska study area and the JAX-MARU study area are quite different and differences in sound propagation between the two areas are likely. However, if the 23 km average distance of sound transmission is used from the Rone et al. study, the parallel distance of less than 23 km between shallow and deep MARUs in the current study and suggests that it is possible that calls detected on shallow MARUs could also be detected on the mid-depth and deep buoys. Acoustic propagation modeling would be required to definitively determine this possibility. It is also possible that animals are moving in and out of the critical habitat from deep water migration routes that have not been surveyed. It is not possible at present to discern between these two possibilities.

The majority of the vocalizations detected at the offshore sites consisted of gunshot calls. In the North Atlantic, gunshot calls have been documented to be produced only by males (Parks et al. 2005). However, in South Atlantic right whales (*Eubalaena australis*), both females and subadults have been observed to produce the gunshot call (Clark 1983). Detection of gunshots at offshore JAX-MARU sites suggests that these offshore areas may be occupied preferentially by males. Garrison (2007) modeled cow/calf pair migrations and predicted high occurrence in shallow water corridors in coastal regions off Florida. It is possible that there are sex-based differences in habitat use occurring in the JAX OPAREA area with males utilizing offshore waters and females and calves found more inshore, but confirmation of this possibility would require additional information and investigations.

4.4 Sei Whale

Sei whale vocalization events were only detected during Deployment 2 with a few concentrated events occurring from 5 through 7 December 2009, and the remaining events scattered throughout the rest of the deployment until 1 January 2010. These results could indicate that events only represent one or two animals, or a small compact group of animals, that happened to approach within the vicinity of only some of the recorders. It is not possible to ascertain the details of encounters without visual data or acoustically tracking individuals. Due to the sporadic nature of calling by sei whales, it is unlikely that the latter would be possible.

The fact that sei whales were only detected during the winter deployment, suggests that there may be a seasonal component to their calling behavior and/or migration patterns off the U.S. East Coast. Similar seasonal patterns have been documented for other baleen whale species (Mellinger et al. 2007; Stafford et al. 2001). The greatest percentage of time for sei whale vocalization events occurred at mid-depth (Sites 4, 5 and 6) and deep-water sites (Sites 1, 3, and 6), indicating a preference in sei whales for deep waters (Horwood 1987; DoN 2008). This preference is supported by the fact that sei whale vocalization events were detected at only very low received levels on only one of the shallow recorders (Site 8). Jefferson and Schiro (1997) reviewed the few sei whale sightings in the Gulf of Mexico and considered occasional sei whale sightings to be extralimital. In areas to the north of our study area (e.g., Great South Channel off Cape Cod), sei whales were detected and localized in May 2005 using an array of four MARUs surrounding a visual station (Baumgartner et al. 2008b). The JAX-MARU study area was located between the Gulf of Mexico and the Great South Channel and could indicate either migration through the area, or alternatively, an occasional influx of this species into the study area. Better temporal sampling would be needed to answer these questions.

4.5 Minke Whale

Minke whale vocalization events were only detected during the winter deployment, indicating a strong seasonal presence in the study area. Minke whales are believed to migrate south to warmer waters in the Caribbean and other areas in the winter and spring, where they produce long, stereotyped calls (Mellinger et al. 2000). The vocalization events detected during the winter deployment included both types of calls described by Mellinger et al. (2000) as well as additional sound types. The ‘LF pulse + HF click’ vocalization events that occurred infrequently (less than 1 percent of total time recorded) have not been described before, and are of interest due to their HF component (**Figure 67**). Although these sounds have yet to be positively attributed to a confirmed minke whale sighting, it seems reasonable to attribute them to minke whales because they only occurred after the typical pulse trains described by Mellinger et al. (2000). Beamish and Mitchell’s (1973) detailed account of a clicking minke whale that swam within 10 m of their recording vessel has been questioned by some due the occurrence of pilot whales immediately prior to and after the encounter with the minke whale. Clicks have not been detected in baleen whales except in humpback whales; however, clicks described for feeding humpback whales contained most of their energy in lower frequencies (less than 2 kHz) (Stimpert et al. 2007).

Recent information from autonomous recorders deployed in the waters off the northeastern United States indicate a seasonal peak in fall (August-October) which may indicate that animals are migrating south in the winter (Risch et al. 2011). Information about the peaks in minke whale detections at other recording sites (e.g., mid-Atlantic region) are needed to fill in the gaps in possible migration patterns of minke whales. The high prevalence of calling events for almost the entire winter deployment indicates a continuous presence of animals during that time period. Unfortunately, without localization or tracking capabilities from the MARUs, it cannot be determined if animals are continuously migrating through the study area, or if these are animals that are resident during the second half of December.

Based on the daily vocalization graphs (**Figure 16**) and results of the probability analysis of minke whale vocalization events with and without sonar (**Figure 25**), there appears to be a strong negative correlation with sonar, in that minke whale calls are greatly reduced, or cease completely. To our knowledge, changes in the acoustic behaviors of minke whales have not been examined in relation to sonar. It is possible that minke whales perceive sonar as a potential threat or predator, and they react by ceasing calling activity and/or moving out of the area. Alternatively it is possible that animals keep calling but leave the area. McCarthy et al. (2011) found that beaked whales, another elusive group of marine mammals, both reduced their vocal activity and moved away from sonar sources in the AUTEC range in the Bahamas. Recent playbacks of sonar to a minke whale tagged with radio-transmitter and time-depth recorder tag indicated strong horizontal and vertical responses to sonar (Kvadsheim et al. 2011). The tagged animal, which originally was surface feeding, dove to a depth of 40 to 50 m, increased its speed, and moved on a constant course away from the playback vessel. The animal later changed to shallow diving behavior and continued its movement away at a speed faster than the playback vessel. It is not possible to assess dive behaviors and movements of minke whales from the acoustic data in our effort; therefore, additional research is needed to determine if similar behavioral responses were occurring in addition to the vocal response seen in this study.

4.6 Unidentified Baleen Whales

Unidentified baleen whale vocalization events were detected during both fall and winter deployments, but only infrequently, and only for very brief durations (less than 35 min). These vocalization events mostly occurred at the deep-water Site 2 during the fall deployment and Sites 2 and 6 (deep-water and mid-depth sites, respectively) during the winter deployment (**Figures 28 and 30**). The species identity for these sounds is unknown and would require additional review or analysis of sounds to provide more information.

4.7 Sperm Whale

The sperm whale had one of the highest percentage of time of vocalization events for any species/taxonomic group by site during the fall deployment (**Figure 5**), and the second highest (after the minke whale) percentage of time with vocalization events during the winter deployment (**Figure 5**). They had the second highest total event durations in the fall and winter deployments (**Table 5**).

Feeding patterns in sperm whales can be assessed by examining stomach contents at time of catch from whaling data or in stranded animals, visual observations of ’fluking up’ (i.e., flukes raised high above the water surface indicating the start of a deep feeding dive) prior to a long dive, diving ad locomotive behaviors obtained from tagged whales, and passive acoustic observations of buzzes and creaks produced at depth. Studies of stomach contents in association with time of day have generally revealed no strong diel trend (Whitehead 2003). Analysis of sperm whale stomachs collected in Antarctica indicated that sperm whale stomachs were most full in late evening and early morning, suggesting that foraging occurred in the early evening or late night/early morning (Matsushita 1955; Whitehead 2003). Studies of social groups consisting of immature males and females near the Galápagos Islands provided evidence that feeding and socializing occurred throughout the day with fluking up occurring primarily at dusk (Whitehead 2003). Analysis of the acoustic behavior of these social groups suggested that the animals were foraging throughout the night, as indicated by the presence of "usual," or "regular," clicks and creaks (Whitehead and Weilgart 1991).

While acoustic data can provide strong indirect evidence of feeding behaviors, other than research summarized in Whitehead (2003), little has been documented with respect to diel acoustic patterns in sperm whales. Sperm whale diving behavior has been examined to provide information about feeding patterns, but many studies indicate no apparent diel dive trends (Watkins et al. 2002; Watwood et al. 2006). Aoki et al. (2007) detected diel patterns in sperm whale dive records off the Kumano Coast and Ogasawara Islands of Japan. They suggested that the patterns observed were related to oceanographic features and diel vertical migration of sperm whale prey. We observed diel patterns in sperm whale click events during both the fall and winter deployments. Qualitatively, these patterns appeared to be more pronounced in the winter, with nearly complete cessation of clicking events just after dawn and a resumption of clicking just prior to dusk (**Figures 34 and 40**). These results are consistent with Whitehead's (2003) acoustic observations of overnight feeding by sperm whales in the Galápagos Islands. Similar results also have been reported from other MARU deployments in the mid-Atlantic region (Kumar et al. 2011). The strong diel pattern that we observed in the JAX-MARU data occurred exclusively at the mid-depth (approximately 180 m) MARUs, which could suggest that sperm whales are feeding on prey vertically migrating in this area at night. Although the detection of sperm whale clicks at the mid-depth sites at night suggests that the whales are feeding in this location, the lack of click detections during the day does not necessarily mean that they are not present during this time. They may stay at the mid-depth locations throughout the day but not produce clicks, or they may be moving to another area during the day. It is not possible to discern among these two possibilities from the dataset analyzed here. Visual surveys that include dawn and dusk periods (e.g., if animals are moving inshore/offshore during night/day), or acoustic tracking of sperm whales using towed arrays or sonobuoys can be used to answer these questions. In addition, habitat analyses relating to potential sperm whale prey resources and investigations of the biological processes (e.g., vertical migration of mid-water species) that sperm whales are targeting during foraging are needed to understand the importance of the mid-water MARU sites for sperm whales.

The presence of creaks and buzzes was also indicative of feeding events. Two specific events stood out due to their unique variation in inter-click interval and click strength (**Figures 68 and 69**). Additionally, sperm whales were observed on multiple occasions to stop clicking when delphinid vocalization events occurred. Typically, they only resumed continuous clicking once the delphinids had presumably either left the area or stopped vocalizing. We realize that is this is only indirect evidence of potential competition for resources. More important, however, is the possibility that the mid-depth region of the planned USWTR is a productive feeding area for several species. This analysis provided only preliminary information about sperm whale feeding patterns. Further research and analysis is necessary to support these observations.

The presence of codas during both deployments may indicate that the sperm whale population in this area includes social groups of females and immature adults. Codas were included in sperm whale vocalization events, but were not separated out in the daily graphs due to their relatively low durations and rates of occurrence. Additional analysis of these data would be valuable to better understand the occurrence of social behaviors and composition of sperm whale groups in this region.

Results of the probability analysis for the fall deployment did not indicate any consistent differences in probabilities of sperm whale call events occurring with and without sonar. During the winter deployment, there was a more consistent difference in the probabilities of call events with and without sonar (i.e., all three sites had lower, or zero, probabilities of occurring with sonar than without). The data do not indicate a negative correlation (e.g., a cessation of vocalizations) by sperm whales during periods with sonar; however, more subtle effects (such as reduced foraging success, a change in dive durations, or subtle changes in vocal behaviors) could be occurring that were not detectable with the analyses conducted here.

4.8 Delphinid Species

Delphinid vocalization events were detected almost every day at all sites during both fall and winter deployments. The only periods when delphinid vocalization events were not detected were when only the 2-kHz recorders were operating (from 27 December to 8 January). Because the distribution of energy in sounds produced by delphinids primarily occurs above 2 kHz (Richardson et al. 1995), it is not unexpected that delphinids were rarely detected in the 2-kHz recordings. Since delphinid vocal events were detected in all 32-kHz recordings, it is likely that delphinids were similarly present at the 2-kHz recorder sites, but their vocalizations were not detectable given the limited frequency band (< 1 kHz) for these recorders. The greatest percentage of time with delphinid vocal events occurred at Site 2 (a deep-water site) during the fall deployment and at Site 9 (a shallow-water site) during the winter deployment. This suggests that delphinids may exhibit some seasonal differences in their distribution patterns. For example, Risso's dolphins occur along the continental shelf break from Cape Hatteras to Georges Bank from March through December (CETAP 1982; DoN 2008). In the winter months of December through February, however, they range more offshore (DoN 2008).

Slight diel variation in echolocation events was evident during the fall deployment, with echolocation clicks being more common during the night (**Figure 49**). This suggests that at least some of the species are foraging at night. Spinner dolphins in Hawaii forage primarily at night when the mesopelagic community migrates towards the surface (Benoit-Bird et al. 2001). Striped dolphins and common dolphins also feed on epipelagic and mesopelagic fishes and squids in the deep scattering layer (Overholtz and Waring 1991; Perrin et al. 1994). Both of these species may feed at night when the deep scattering layer migrates towards the surface. Goold (2000) suggested that increases in common dolphin vocal activity during the late evening and early morning were related to feeding on the deep scattering layer as it migrates vertically.

Diel patterns may have been masked by the fact that all delphinid species were combined into one category for this analysis. Because 15 delphinid species are expected to occur in the study area (CETAP 1982; DoN 2008), it would be nearly impossible to tease out individual species events without further analysis. Combining all delphinid species together may result in species-specific patterns being missed or confounded. For example, if one species produces more sounds during the daytime and another produces more sounds during the nighttime, these two patterns would effectively cancel each other out and make it appear as though there was continuous calling with no diel variation in delphinid vocal events.

The probability of delphinid vocalization events was higher with sonar than without sonar during the fall deployment and the opposite situation was true during the winter deployment. The differences in probabilities of vocalization with and without sonar were small (i.e., less than 5 percent) in most cases, with the exception of mid-depth Site 6 during the fall deployment and Sites 5 and 9 (mid-depth and shallow-water sites, respectively) during the winter deployment. It is possible that these opposing patterns are due to different behavioral reactions to sonar by different species or differences in social structure or social contexts (e.g., females and groups with dependent calves may have stronger reactions than sub-adults or male groups.) Similar to diurnal patterns in vocalization events, it may be that differences in the probabilities of delphinid vocal events were confounded by the fact that all delphinid species were lumped together for this analysis. For example, if one species responds to sonar by increasing their vocalization rate and another responds to sonar by decreasing their vocalization rate, then the two responses will potentially offset each other and it would appear that there is little or no response to sonar.

Because of the high variability in delphinid vocalizations (especially whistles) and the overlap in time, frequency, and spectral characteristics among multiple species, classifying delphinid sounds to the species level would require a more detailed statistical analysis, which was beyond the scope of this project. We are currently developing classifiers to identify whistles from several species of Atlantic dolphins (e.g., bottlenose dolphin, common dolphin, striped dolphin, Atlantic spotted dolphin, and pilot whales). Applying such classifiers to the JAX-MARU data reported here would allow a more detailed analysis of vocalization patterns and possible responses to sonar to be examined in greater detail. Because many of the delphinid detections consisted of only clicks, it would be useful to explore the possibility of developing click classifiers similar to those developed for the Risso's dolphin and the Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) in the eastern Pacific Ocean (Soldevilla et al. 2008).

4.9 Blackfish Species

The blackfish species group was detected on all 32-kHz MARUs deployed in the fall and winter deployments, although there were relatively few detections. Blackfish detections were most common at the shallow-water and mid-depth sites during the fall deployment and were much more common at shallow-water Site 9 than at any other site during the winter deployment. These results are particularly interesting based on habitat preferences for most blackfish species—which are expected to be found seaward of the shelf break in the JAX OPAREA (DoN 2008). Pilot whales and killer whales have been sighted in nearshore waters, and these species may account for the increase in blackfish detections at the shallow and mid-depth MARUs. The fact that so little is known about the occurrence and distribution of blackfish species in this area and that blackfish were detected acoustically highlights the importance of using passive acoustic methods to better understand these species distribution and occurrence.

The low number of blackfish detections in the MARU data may be because blackfish are just not common in the area, but also is likely due to the conservative approach we took to identifying blackfish detections. Detections were labeled as blackfish based on the presence of LF whistles, screams, and burst-pulsed sounds. Because many sounds produced by blackfish have time, frequency, and spectral characteristics that are similar to those produced by delphinids, it was often not possible to identify blackfish detections with absolute certainty. Blackfish species are included in the delphinid family, and so it was deemed more appropriate to label detections as delphinid species, when there was doubt, as opposed to over-estimating the occurrence of blackfish. Because of this conservative approach, the number of blackfish detections reported here is likely to be an underestimate. Applying classifiers to these data would allow more certain classifications and a clearer picture of the true occurrence patterns of blackfish in the area. Performing classification analysis on the blackfish and delphinid detections may result in an increase in the number of blackfish detections and make it possible to examine possible responses to sonar by these species. There is some limited evidence that pilot whales may respond acoustically to sonar signals (Rendell and Gordon 1999). This MARU dataset provides an opportunity to examine this in more detail.

4.10 Review of Potential Mimicry

DeRuiter et al. (in press) analyzed whistles produced by false killer whales, pilot whales, and melon-headed whales tagged with Dtags (acoustic data-logger tags) and found that some individuals matched their whistles to MFAS pings. For the false killer whales, overall whistle production rate increased with MFAS and whistle similarity was highest immediately following MFAS signal reception. Production rate of MFAS-like whistles decreased over the 25-sec period from the last MFA signal reception. Melon-headed whales had low whistle rates overall, but exhibited minor transient silencing after MFAS (DeRuiter et al. in press). They considered the changes in the whistles of false killer whales reminiscent of call type matching observed by others in studies of bottlenose dolphins (Janik 2000), killer whales (Miller et al. 2004b), and pilot whales (Sayigh et al. in press). We did not perform an analysis as detailed as that of DeRuiter et al. (in press), but such an analysis is possible, with the caveat that whistles would first have to be identified to species using a computer-based whistle classifier software.

Results of the preliminary review of two extended periods at shallow-water Site 9 (9-1 fall deployment and 9-2 winter deployment) that contained delphinid whistle events before, during, and after sonar events indicated call-matching (i.e., mimicry) of whistles with sonar. Although whistle mimicry of sonar was only qualitatively assessed, an examination of whistle frequencies and durations relative to sonar events preceding (up to 4 hours before) or overlapping with whistle events indicated a similarity in these whistle characteristics to sonar signals (**Figures 70 and 71**). In general, whistles labeled as 'mimicry whistles' or 'possible mimicry' whistles were lower in frequency (i.e., kHz) compared to non-mimicry (i.e., typical) whistles (**Figures 72 and 73**). However, in order to explicitly state that mimicry is occurring, a more rigorous quantitative analysis should be conducted.

5. CONCLUSIONS AND RECOMMENDATIONS

A wide range of marine mammal species was detected during the fall and winter MARU recordings analyzed in this study. Species and species groups that were detected included: right whale, sei whale, minke whale, sperm whale, possible humpback whale, delphinid species, and blackfish species. Analysis of these data yielded many unexpected results, including the almost continuous occurrence of minke whales at deep and mid-depth sites during the winter deployment. Sei whales were detected sporadically on several MARUs from the winter deployment. Additionally, we detected strong diel patterns in sperm whale vocalization events in the fall and especially winter deployments, indicating either a cessation of feeding during the daytime, or perhaps more likely, movements in and out of the study area at night. Sonar effects were relatively pronounced for the minke whale, but not strongly evident for most other species, using the gross analytical methods applied here.

Detection of more subtle effects would require high statistical power and/or a strong experimental design, which was not possible given the constraints of this study. This study should be considered a preliminary analysis of the effects of sonar, because vocal events were used as a proxy for calling behaviors. Due to time, funding, and sample size limitations, we were not able to quantify or characterize individual marine mammal sounds or perform a detailed examination of their occurrence before, during, and after sonar and other anthropogenic sound events. In spite of the broad approach we took in this analysis, we were able to detect a very strong response to sonar by the minke whale, a species which called almost continuously during the winter, but for which vocalizations were almost completely absent during sonar events. The probability analysis used in this study was based on Melcón et al. (2012), which detected differences in the probability of calling for whales in the North Pacific related to the presence or absence of sonar. The probability analysis provided a powerful and easy-to-automate method for analyzing large quantities of data. This approach might be suitable for those species with continuous and loud calling behavior (i.e., singing or acoustic displays by baleen whales, clicks by sperm whales), but not as effective for species with intermittent or infrequent calling, or whose sounds do not propagate very far (e.g., some right whale calls, all delphinid sounds, and beaked whale clicks). The results presented here suggest that there is a behavioral response to sonar, for at least one species, the minke whale. It is important to determine the extent of this response (i.e., how quickly it occurs, how long it lasts, etc.) in order to make decisions regarding mitigation. Additionally, because there was such a small sample size for some species, it will be important to re-evaluate those species' potential response to sonar, as more data is made available. The analysis of acoustic data from additional locations and seasons in and around the study area, combined with the dataset in this study will be essential to conduct more powerful statistical analyses, which will help elucidate occurrence patterns and effects of sonar on marine mammals in the JAX-MARU study area.

Recommendations and Future Analyses

Recommendations and suggestions for future analyses are listed below, with a brief discussion following each section. Our recommendations are organized into three categories: (1) general recommendations (**Section 5.1.1.**), (2) recommendations for future data analysis (**Section 5.1.2**), and (3) recommendations for future recorder deployments (**Section 5.1.3**). These recommendations are not ordered based on importance.

5.1 General Recommendations

1. Develop a website or online storage site to allow other researchers to easily view and provide feedback on unknown call types that are organized by region, depth, and season.
2. Develop or modify existing (e.g., Triton) software so that it allows both LF and HF bands to be viewed simultaneously to compare events occurring in both frequency ranges.
3. Consider logging events using minimum inter-event periods that are specific to each species or taxonomic group (e.g., 1 min, 10 min, or 20 min between the last call and a new event).

There have been numerous autonomous acoustic recorder monitoring efforts off the U.S. East Coast and in U.S. Navy range complexes, with thousands of hours of review and logging effort expended. It would be useful to have a repository (a cloud storage site) and/or a website dedicated to archiving unknown sounds. Spectrograms and audio clips of unknown sounds could be posted on a website for researchers and experts to review and classify. Expert confirmation of sounds should include documentation on which expert reviewers (outside or in-house) classified the sounds, and what characteristics were used in the classification. Any conflicts among experts in classification should be included so the signal type can be identified in future studies as ‘uncertain’ or ‘unresolved’ species identification. Sound libraries and archives of biological sounds currently exist (e.g., Cornell University’s Macaulay Library), but these are not necessarily geared towards a review of unknown sounds or unpublished marine sounds that have been reviewed by outside experts.

One method to improve the efficiency of reviewing and logging files would be to provide low-, medium-, and high-frequency spectrographic windows that display the signal at different frequency bands simultaneously. This would allow the data-analyst to review and easily log signals that span both high and low frequencies. Additionally, this would potentially allow for fewer passes through the data, which is probably the most time-consuming part of the initial data review. If increased error rates (i.e., missed detections and classifications) do not result from this approach, it would greatly decrease the costs of reviewing and logging acoustic data from autonomous recorders, especially high-bandwidth data (e.g., from High-frequency Acoustic Recording Packages).

An interval of 10 min was chosen for this study, to define the duration between the end of one vocalization event and the beginning of a new event. This interval was chosen as a trade-off between data processing efficiency and temporal-resolution when logging sounds. However, for some species, this time interval could have been decreased (to increase temporal resolution) or increased (to increase efficiency of logging). We propose that time-windows could be selected on a species-by-species (or in some cases on a seasonal or regional) basis. Prioritizing species of interest, before analysis begins, would allow proportionally greater time to be spent on those species of greater importance. For example right whale inter-call event periods could be shortened to 1 to 5 min (because events are of short duration, and are relatively infrequent in the JAX-MARU dataset), whereas it should be possible to use longer inter-event durations to log loud (i.e., high signal-to-noise) sperm whale and minke whale vocalization events, as was done in this study.

5.2 Recommendations for Future Data Analysis

1. Perform a detailed analysis of responses to sonar for species and taxonomic groups in which there were changes in the probability of calling in the presence of sonar:

a. Calculate the probability of calling with and without sonar using every call (not just calling events).

b. Compare calling rates before, during, and after sonar events.

2. Perform statistical comparisons of calling rates among shallow, mid-depth and deep sites, as well as seasons/deployments.
3. Examine the relative occurrence of different call types relative to sites (e.g., depths) and seasons.
4. Measure and describe acoustic characteristics of the minke whale click-pulse calls in more detail.
5. Run species-identification algorithms specific to the U.S. Atlantic region on the delphinid and blackfish events.
6. Conduct more detailed analysis of mimicry by looking at the timing of calls and the degree of call-matching (i.e., mimicry) of whistles to sonar signals using quantitative (instead of qualitative) measures.
7. Calculate the probability of calling in the presence and absence of ship noise to examine possible behavioral responses to ships.
8. Conduct habitat analysis for sperm whales to better evaluate diel feeding patterns and characterize the suggested feeding area within the planned USWTR.
9. Analyze usual click intervals, frequency of creaks, and coda vocalizations of sperm whales in this dataset and compare with known Atlantic sperm whale group composition and behavior.
10. For future analyses, use validated call detectors for call types for some species in which the detectors are reliable (e.g., right whale, minke whale, blue whale, fin whale).

We suggest detailed analyses of those species and taxonomic groups in which there were changes in the probability of calling events associated with sonar events. Results of probability analyses for the minke whale, and to a much lesser degree, delphinids, indicated that acoustic behaviors of these species might be affected by sonar. Additional analyses should include detailed time-series analyses in which effects of sonar on calling rates can be statistically assessed. More sophisticated and detailed analyses could examine the effects of sonar on the signal structure (Parks et al. 2007), the sequence of events, or the timing of calling events (Miller et al. 2004b) relative to sonar or anthropogenic noise. Also the effects of shipping and vessel traffic should be examined, especially for acoustically-sensitive species like the minke whale.

Distribution and relative abundance can be examined by statistically testing differences in calling rates among depths and sites. Sampling independence issues can be overcome by using explicit assumptions regarding animal movements and using a sample for each day. Total or average duration of calling events can be used as the sample units. Analysis of variance (if data can be transformed) or Kruskal-Wallis (if non-normal data distributions) tests can be used to test for differences among depths and/or sites.

Computer-based classifiers are currently being developed for whistles produced by delphinids in the U.S. Atlantic region (J. Oswald, Bio-Waves, in progress). When these classifiers are complete in Spring 2013, they can be used to classify whistles from delphinid and blackfish vocal events detected in this study. In addition, we recommend developing classifiers for echolocation clicks, as some of the delphinid and blackfish events recorded during this study did not contain whistles. The ability to identify whistles and click events to species would make it easier to interpret data, including identifying trends and patterns in vocal activity, as well as responses to sonar. Finally, use of classifiers would likely improve classification of blackfish detections.

Further analyses relating to sperm whale habitat characterization and vocalization behavior would provide a better understanding of feeding activity and group composition for this species. The preliminary finding of a diel feeding pattern in sperm whales within the planned USWTR's mid-depth region was unexpected and these data might be useful as inputs for a regional or site-specific habitat modeling effort using oceanographic and prey data for the fall and winter seasons.

5.2.1 Recommendations for Future Recorder Deployments

1. Consider 32-kHz (or higher sample rate) recorders for all sites, instead of 2-kHz recorders (unless only recording baleen whale vocalizations).
2. Increase the sample rate of recorders so that other species (e.g., beaked whales) can be detected.
3. Sample four times per year (for seasonal information).
4. Increase recorder spatial coverage (to increase statistical certainty of results).
5. Time-synch recorders so that bearings and/or locations of animals can be determined.

Unless baleen whales are the only species of interest, we recommend eliminating 2-kHz recorders, as it limits the species that can be recorded, makes comparison of sites problematic and data-management and analysis more complicated. The saving in data storage capacity should no longer be a major impediment given the availability and low cost of high-capacity hard drives. Although the 32-kHz data were noisier (presumably due to the hard drive writing data more frequently), improvements in the design of autonomous recorders, and a migration in design to Universal Flash Storage should improve recording quality and reduce self-noise (albeit increasing costs and potentially limiting total storage capacity). If this is not possible, then additional deployments with the highest-sample frequency units available should be considered. Although it is understood that detection rates for some winter and spring migratory species (e.g., most baleen whales) might be significantly lower in the summer, we recommend deployments during spring and summer to obtain a more complete picture of seasonal marine mammal occurrence. If funding and recorder availability are limited, then we at least recommend deployments during spring, as many species (especially baleen whales) will be engaging in reproductive and/or migratory activities during this season.

Spatial coverage should be increased to allow patterns of detections (in the area of interest) to be better characterized. More sampling units will also reduce statistical uncertainty and could allow density estimation methods to be applied (Marques et al. 2009, 2011, 2012; Martin et al. in press). Sampling both inside and outside areas of U.S. Navy training activities will allow for better interpretation of results. Costs of autonomous recorders units should decrease as more are used and price per units drop. Cheaper (i.e., lower capacity) units can be retrieved, data downloaded and redeployed, if insufficient units exist or if recording times are limited.

Synchronization of recorders should be considered for future deployments so that localization of signals is possible (i.e., for loud and/or LF calls). Baumgartner et al. (2008a) simultaneously collected both acoustic and visual data in the same area to confirm the species identity of the animals producing calls.

Localizations to individual calls were made so that they could be correlated to a visual sighting made at a station in the center of the MARUs. This approach would allow unknown calls to be identified to species. Aerial and shipboard surveys should continue to be conducted near the recorder sites, although there has been difficulty in past efforts using this approach to verify acoustic detections. Fish sounds were a considerable source of unknown sounds in this study, and required additional effort to log and verify (i.e., that they were not marine mammals). A video-recorder, or sound-activated underwater camera deployed at one or more sites, especially shallow-water sites, would allow many fish sounds to be verified.

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6. ACKNOWLEDGEMENTS

This work was conducted under a subcontract to HDR, Inc. NAVFAC Atlantic provided the funding and the data for this project. We thank Anu Kumar and Joel Bell for their useful discussions and initial guidance. The report was improved with input from NAVFAC Atlantic (Anu Kumar, Carrie Wall, and Joel Bell) and Melissa Soldevilla (NMFS-SEFSC). Amanda Cummings provided initial advice and guidance, especially regarding Triton. We would like to acknowledge Bio-Waves data analysts Shannon Coates, Talia Dominello, Kerry Dunleavy, and Cory Hom-Weaver for their tireless efforts in reviewing and categorizing the data. We would also like to thank Michael Oswald for writing MATLAB scripts used to analyze these data. We appreciate the assistance of all those who took the time to review and comment on this report. Finally we would like to thank all our outside expert reviewers for their assistance in reviewing and identifying 'unknown' vocalizations, including: Catherine Berchok, Danielle Cholewiak, Chuck Gagnon, Edmund Gerstein, Marc Lammers, David Mann, Jennifer Miksis-Olds, Denise Risch, Ana Širović, Melissa Soldevilla, Kate Stafford, Sofie Van Parijs, Susan Parks, and Carrie Wall. Dagmar Fertl (HDR) provided exhaustive editorial assistance.

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8. FIGURES

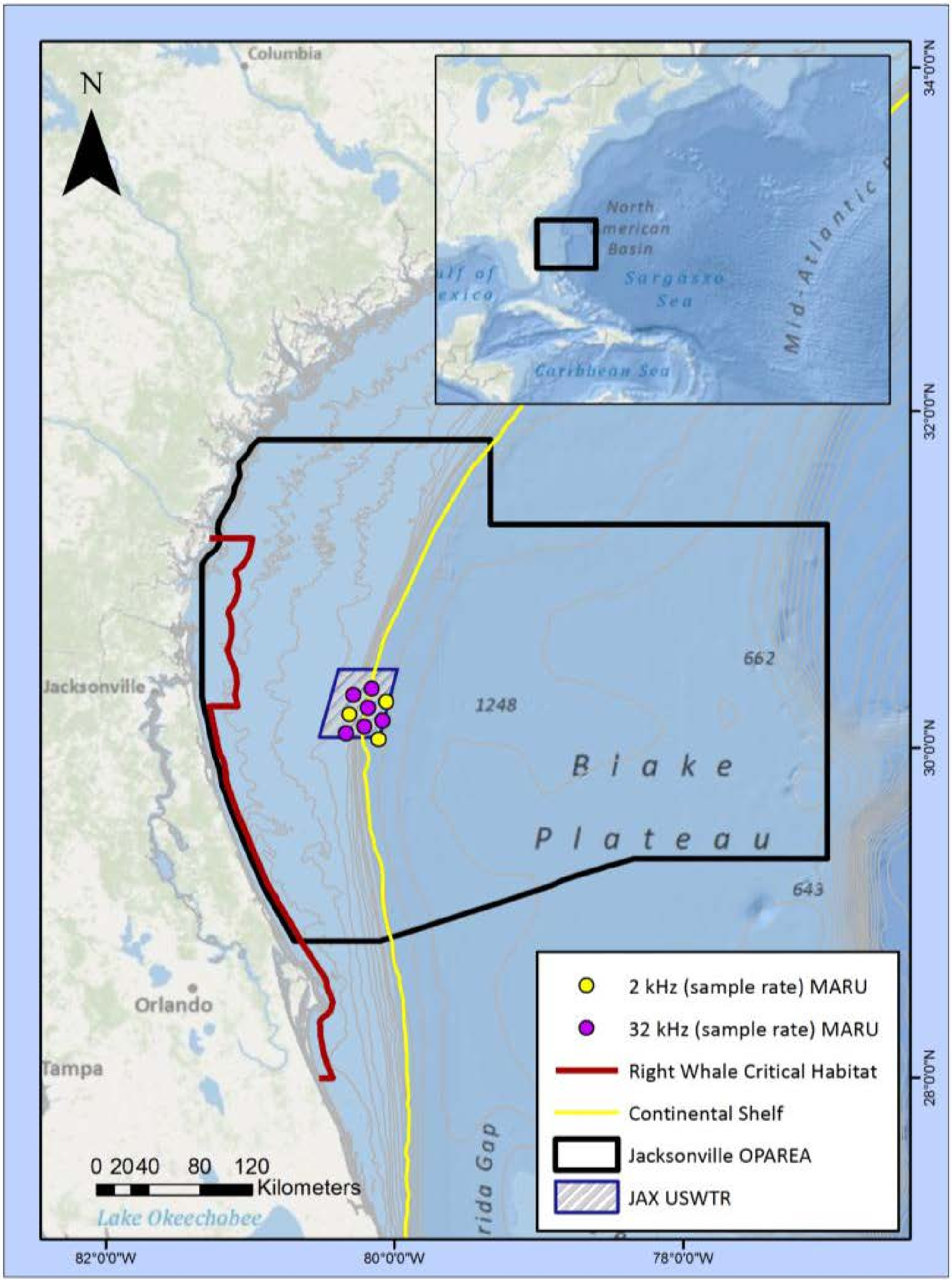

Figure 1. Locations of the MARUs Deployed in Fall and Winter 2009 in the Planned USWTR of the JAX OPAREA. The geographic location of MARUs for each deployment only varied slightly, so the location of fall 2009 was used to represent both deployments.

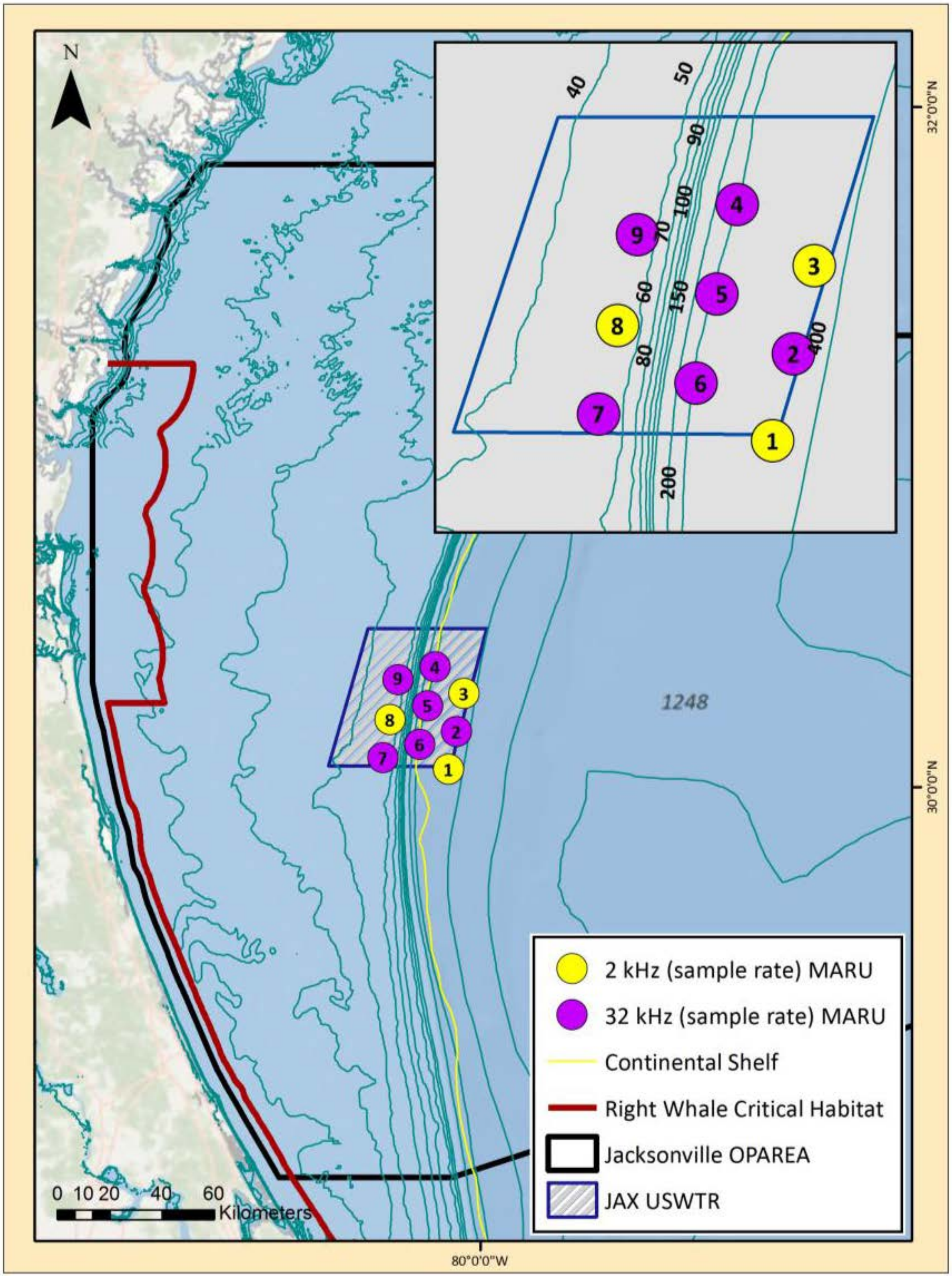

Figure 2. Locations of 2-kHz and 32-kHz Sample Rate MARUs in the Planned USWTR of the JAX OPAREA. MARUs include recorders 1, 2 and 3, labeled as "deep" sites; recorders 4, 5 and 6 labeled as "mid-depth" sites; and recorders 7, 8 and 9 labeled as "shallow" sites.

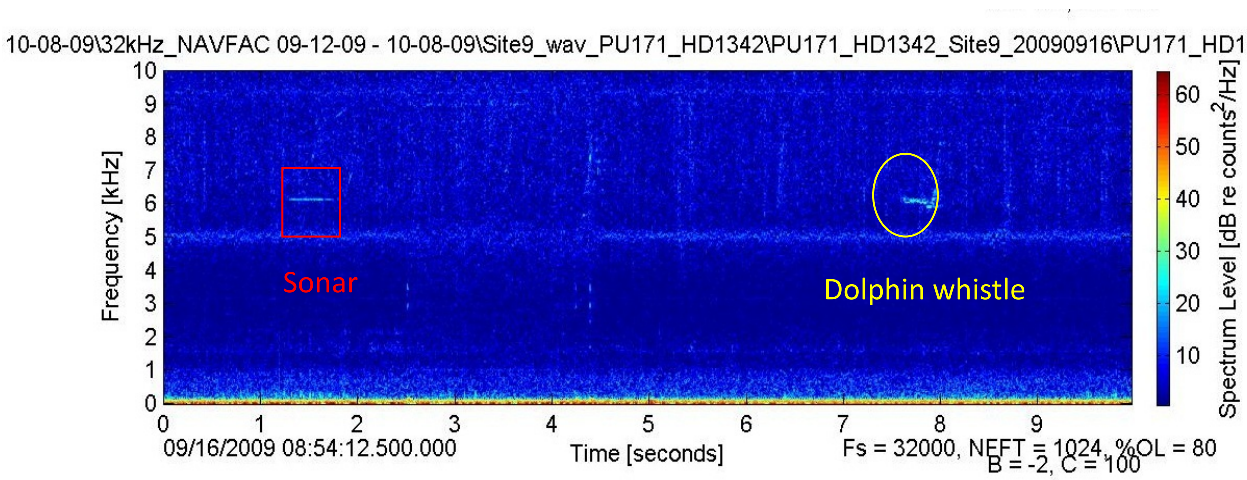

Figure 3. Spectrogram Example of 'Probable Mimicry.' Whistles are circled (yellow) and sonar is boxed (red). Note that the duration and frequency are similar, although the frequency contour of the whistle is slightly different.

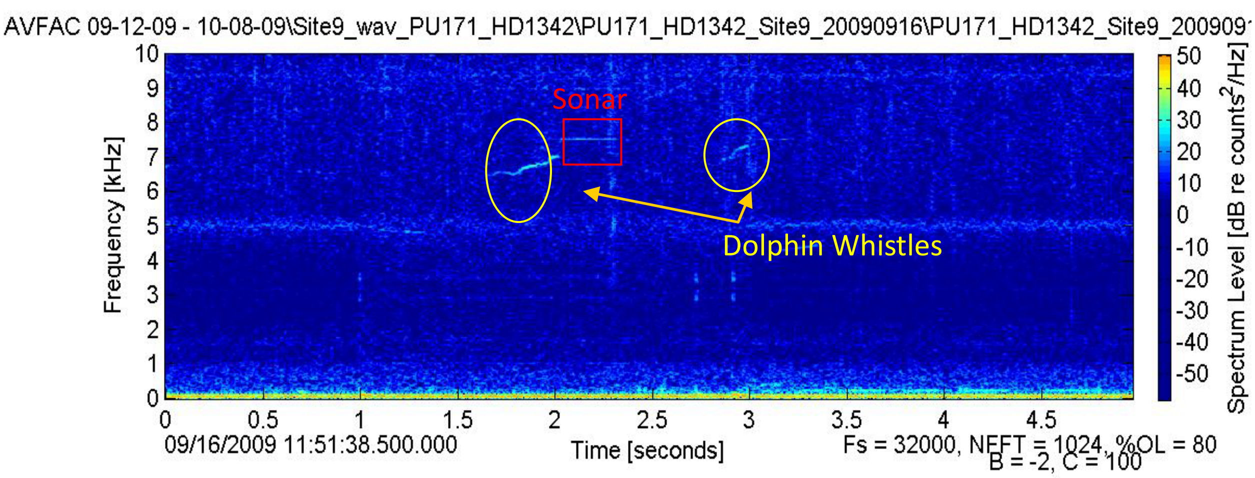

Figure 4. Spectrogram Example of 'Possible Mimicry.' Whistles are circled (yellow) and sonar is boxed (red). Note that the peak frequency similar, but the contours are different.

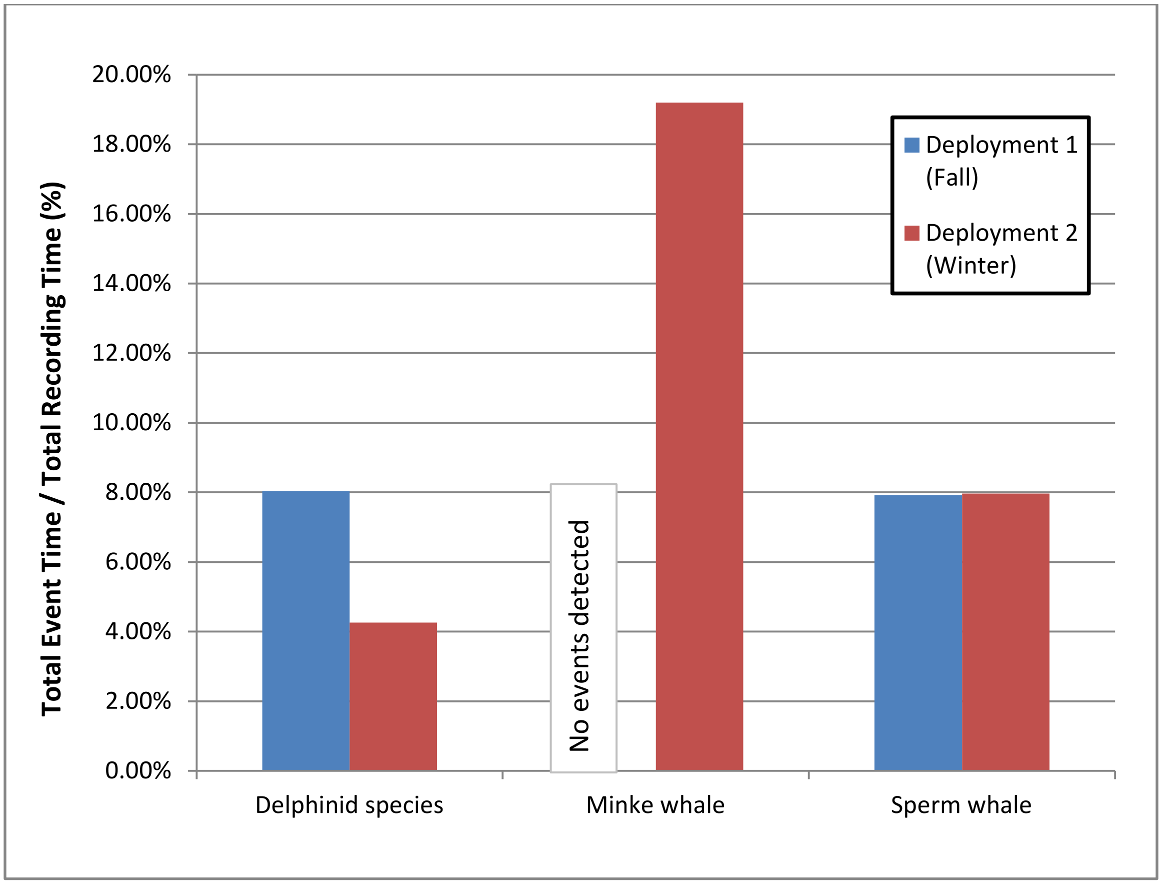

Figure 5. Percentage of Total Events Relative Total Duration of Recordings Available for Analysis for Three Species/Species Groups with Values Higher than 4 Percent. Minke whale events were not detected during the fall deployment.

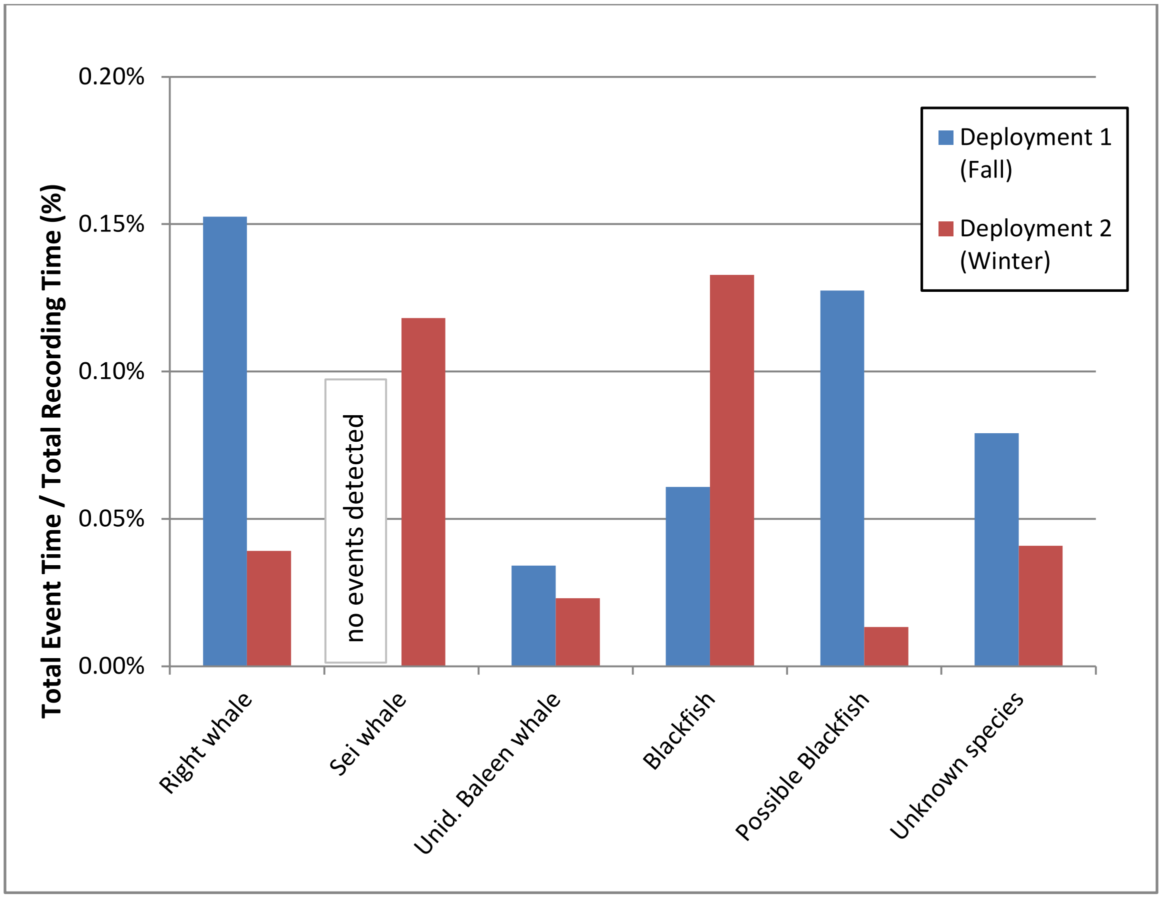

Figure 6. Percentage of Total Events Relative to Total Duration of Recordings Available for Analysis for Three Species/Species Groups with Values Less Than 1 Percent. Sei whale events were not detected during the fall deployment and 'probable' blackfish were not recorded in winter.

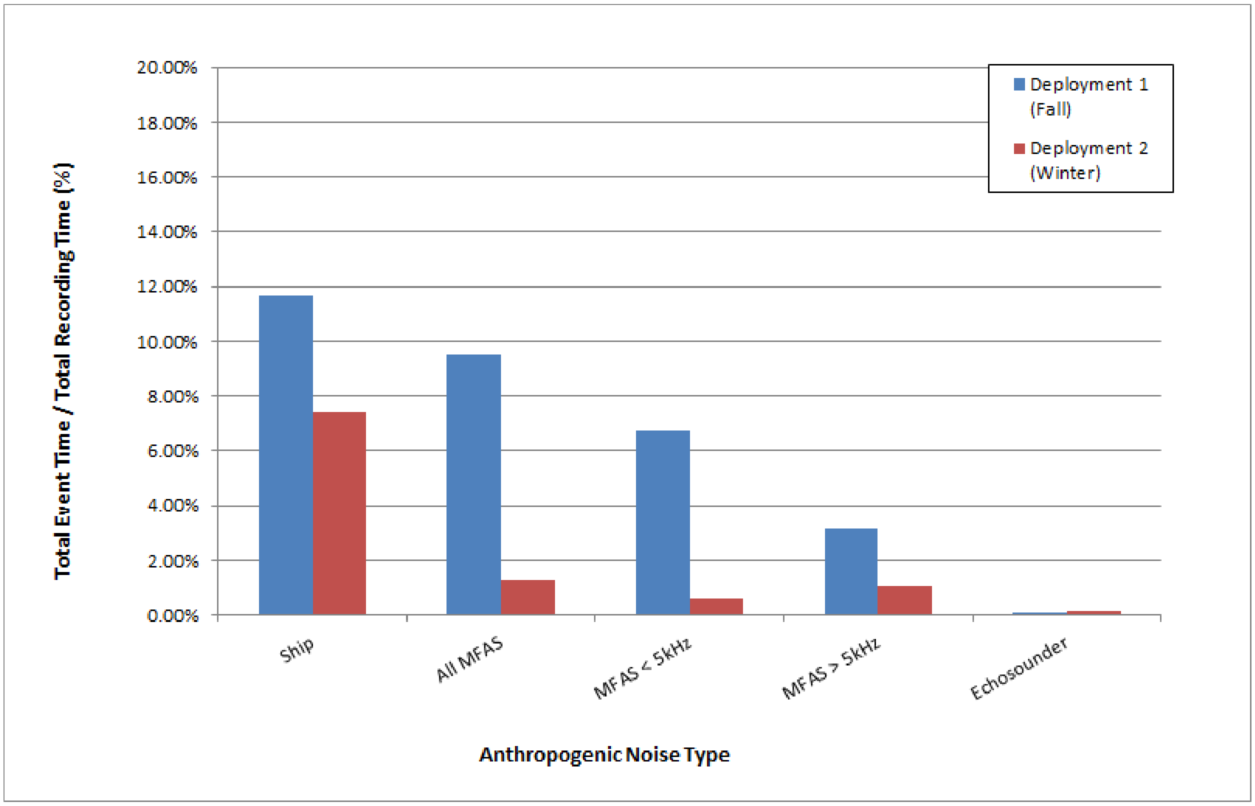

Figure 7. Percentage of Total Events Relative to Total Duration of Recordings Available for Analysis for Anthropogenic Noise Events.

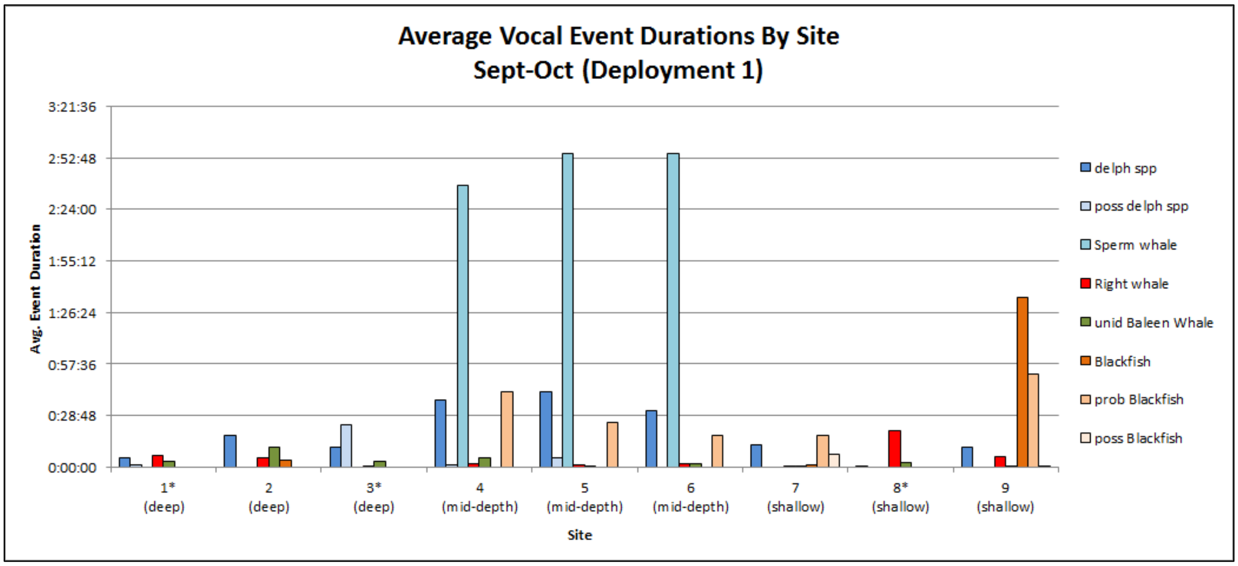

Figure 8. Deployment 1 - Average Vocal Event Duration by Site. The average vocal event duration (y-axis) is shown for each species (represented as colored bars) by deployment site (x-axis).

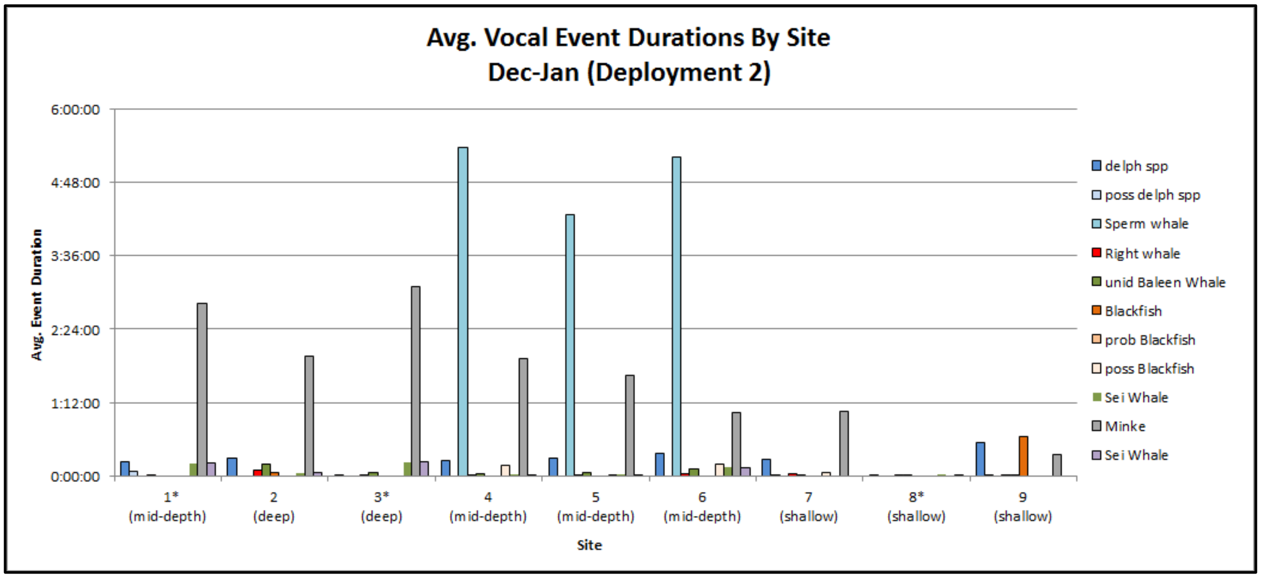

Figure 9. Deployment 2 - Average Vocal Event Duration by Site. The average vocal event duration (y-axis) is shown for each species (represented as colored bars) by deployment site (x-axis).

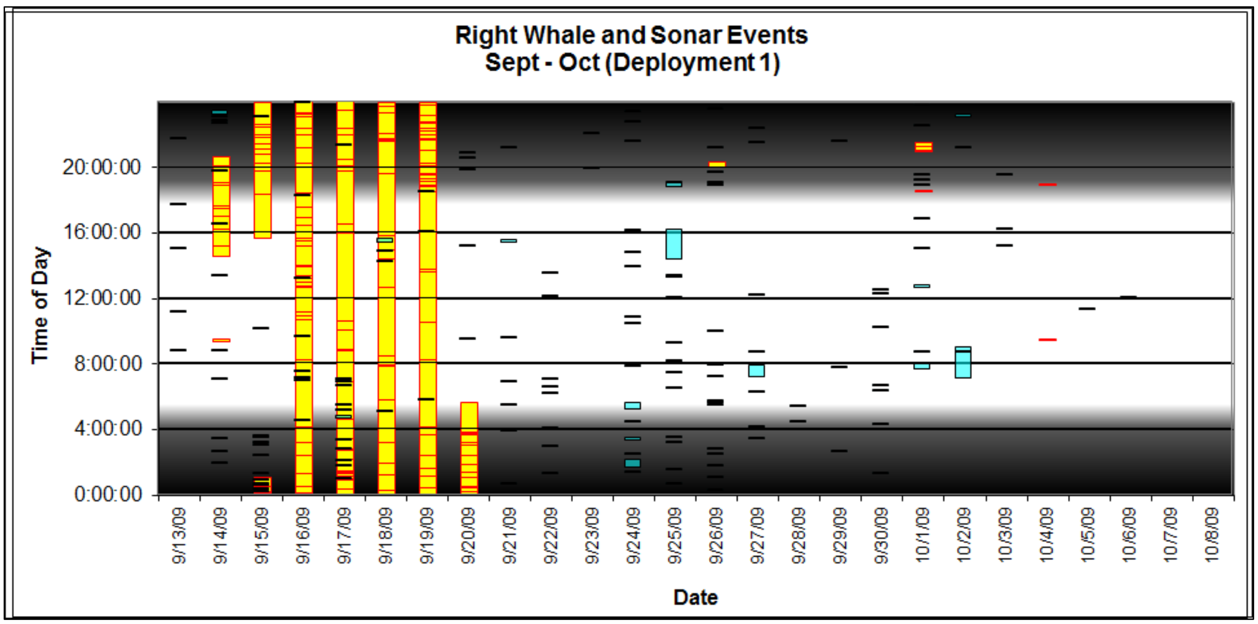

Figure 10. Deployment 1 - Right Whale Vocal and Sonar Events by Day and Time. Right Whale vocal events are shown in teal (shading is representative of event overlap, [i.e. an event occurring at multiple sites]) with time of day (y-axis) and date (x-axis). Sonar activities are shown in yellow with the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period.

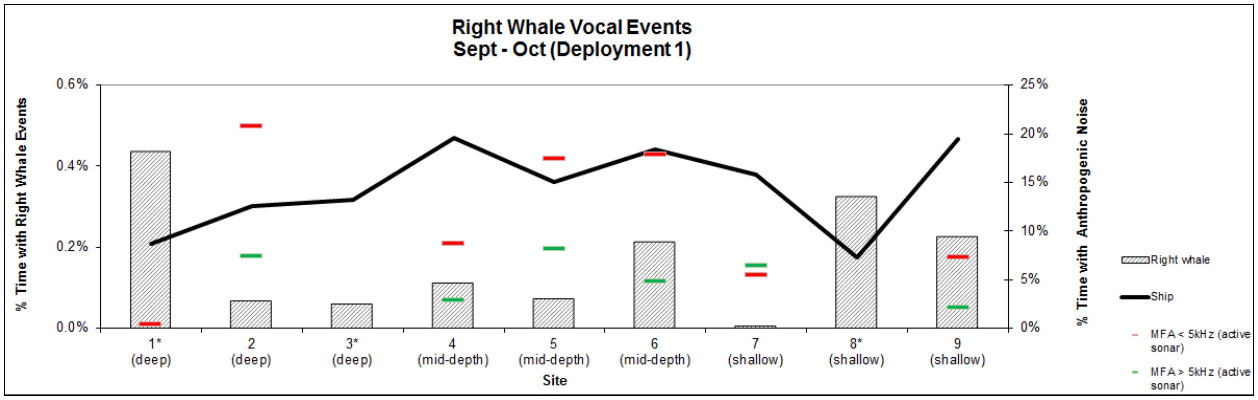

Figure 11. Deployment 1 - Right Whale Presence by Site. The percentage of total recording time with Right whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

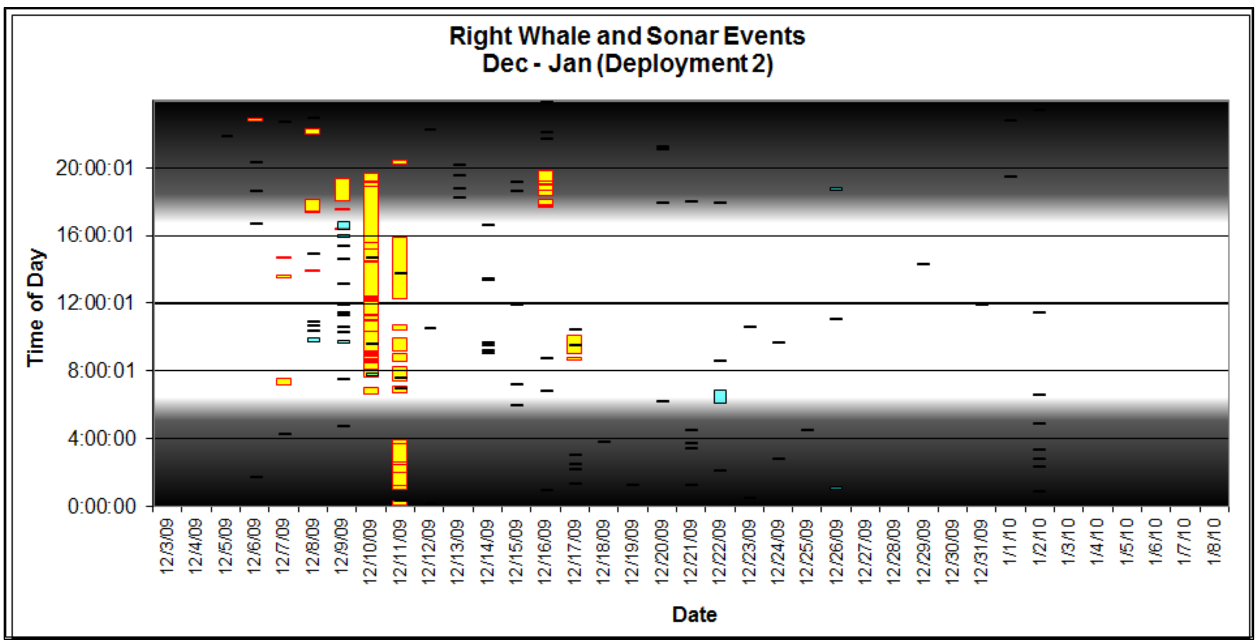

Figure 12. Deployment 2 - Right Whale Vocal and Sonar Events by Day and Time. Right whale vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]) with time of day on the y-axis and date on the x-axis. Sonar activity is shown in yellow with the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period.

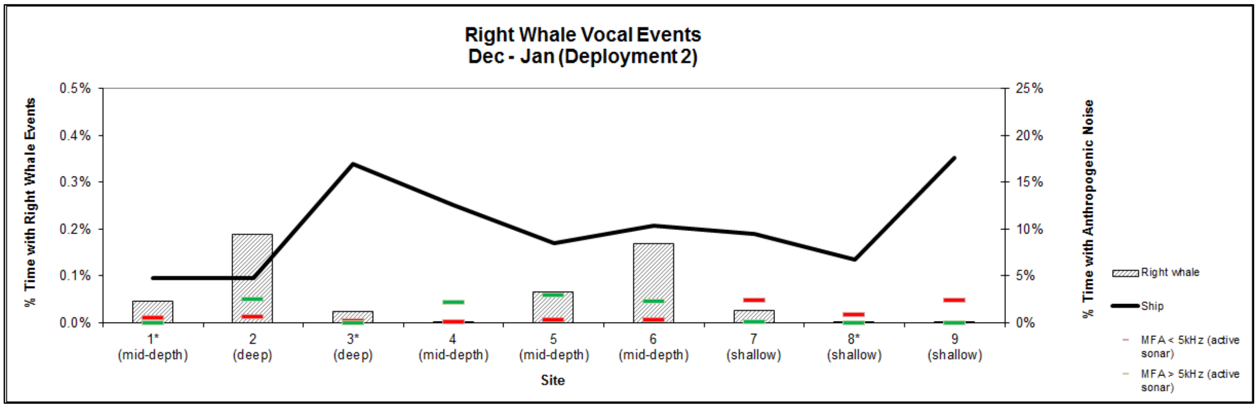

Figure 13. Deployment 2 - Right Whale Presence by Site. The percentage of total recording time with Right whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

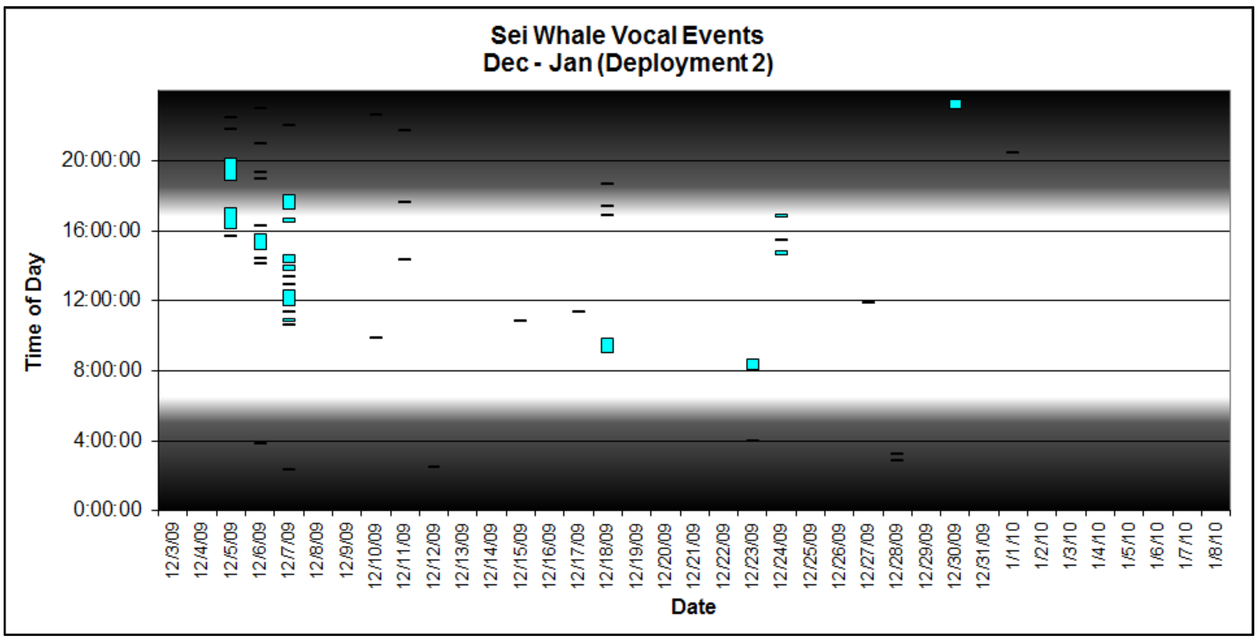

Figure 14. Sei Whale Vocal Events by Day and Time. Sei whale vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]) with time of day on the y-axis and date on the x-axis. Shading represents average daylight (white) and darkness (black) for the deployment period.

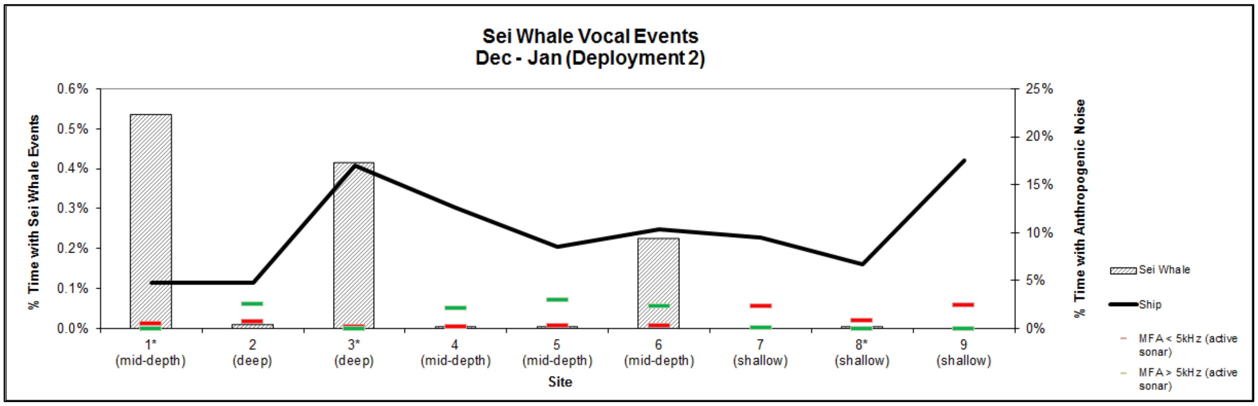

Figure 15. Deployment 2 - Sei Whale Presence by Site. The percentage of total recording time with sei whale vocal events is shown on the left Y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right Y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

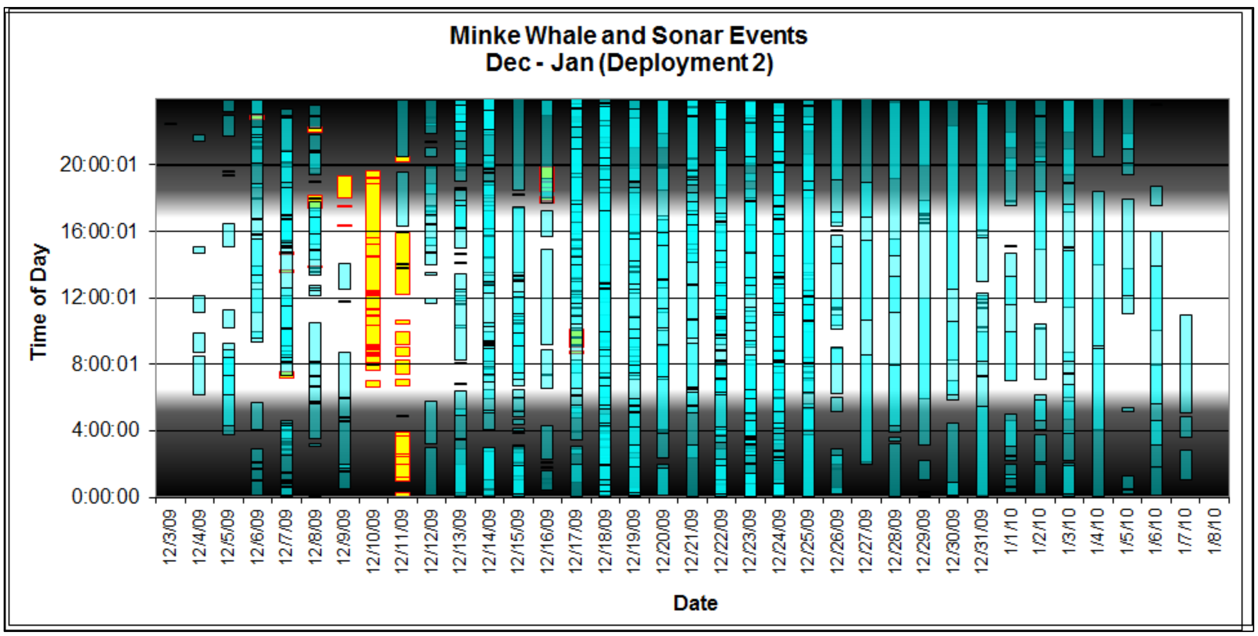

Figure 16. Deployment 2 - Minke Whale Vocal and Sonar Events by Day and Time. Minke whale vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]) with time of day on the y-axis and date on the x-axis. Sonar activities are shown in yellow with the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period.

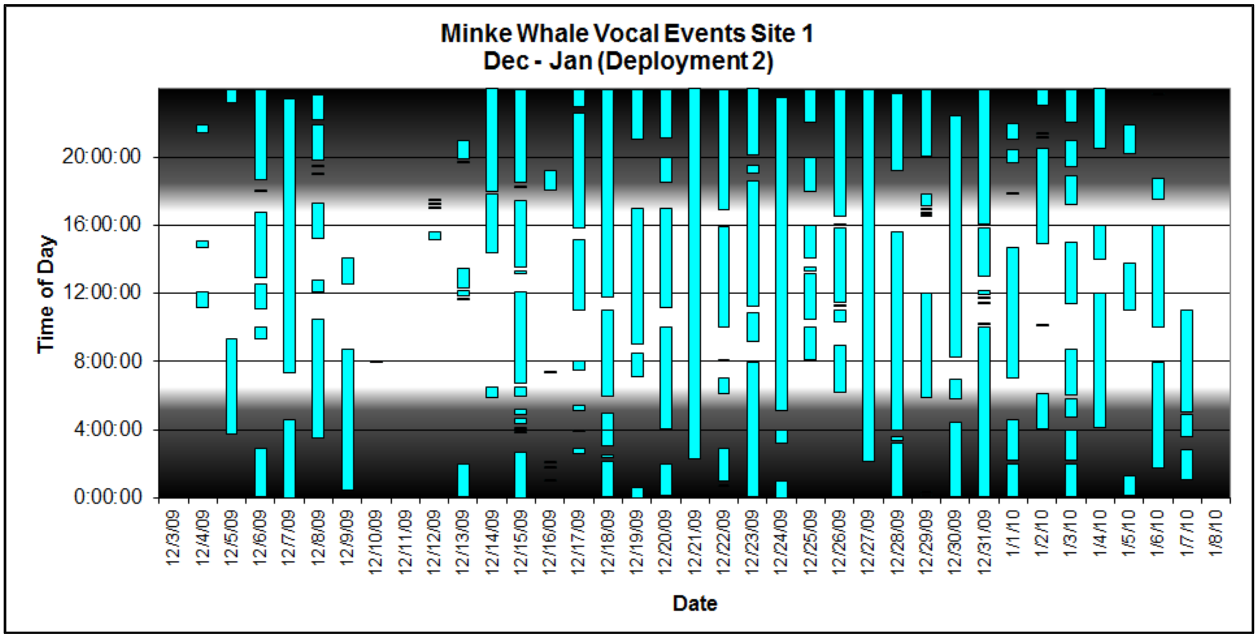

Figure 17. Deployment 2, Site 1 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

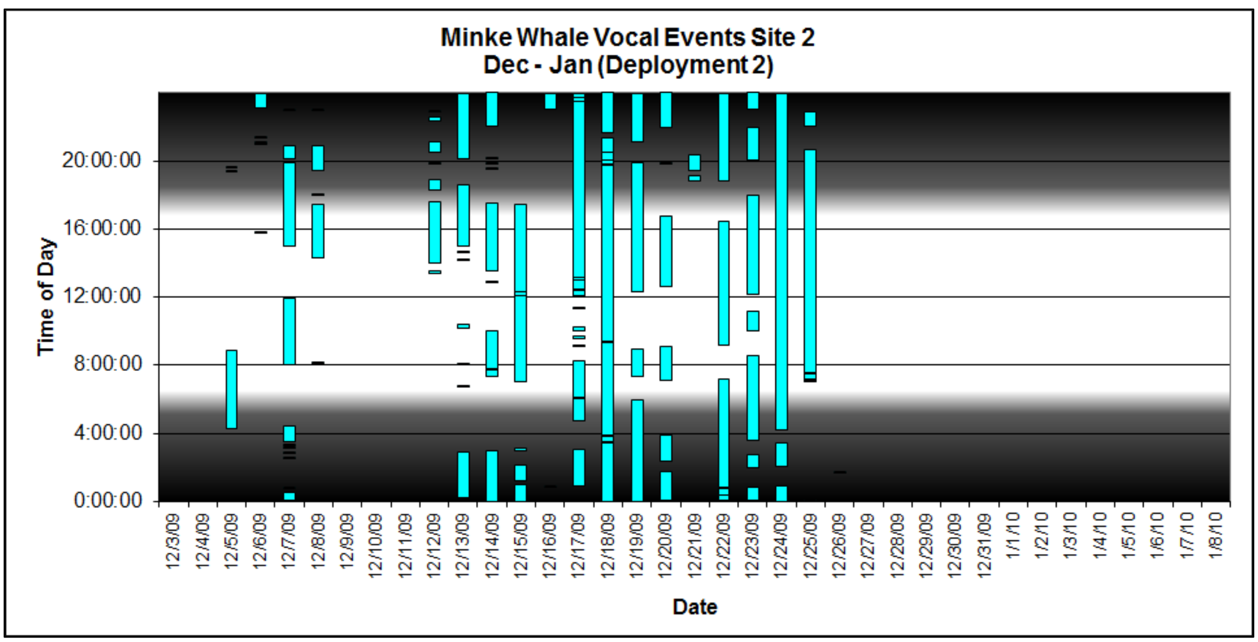

Figure 18. Deployment 2, Site 2 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

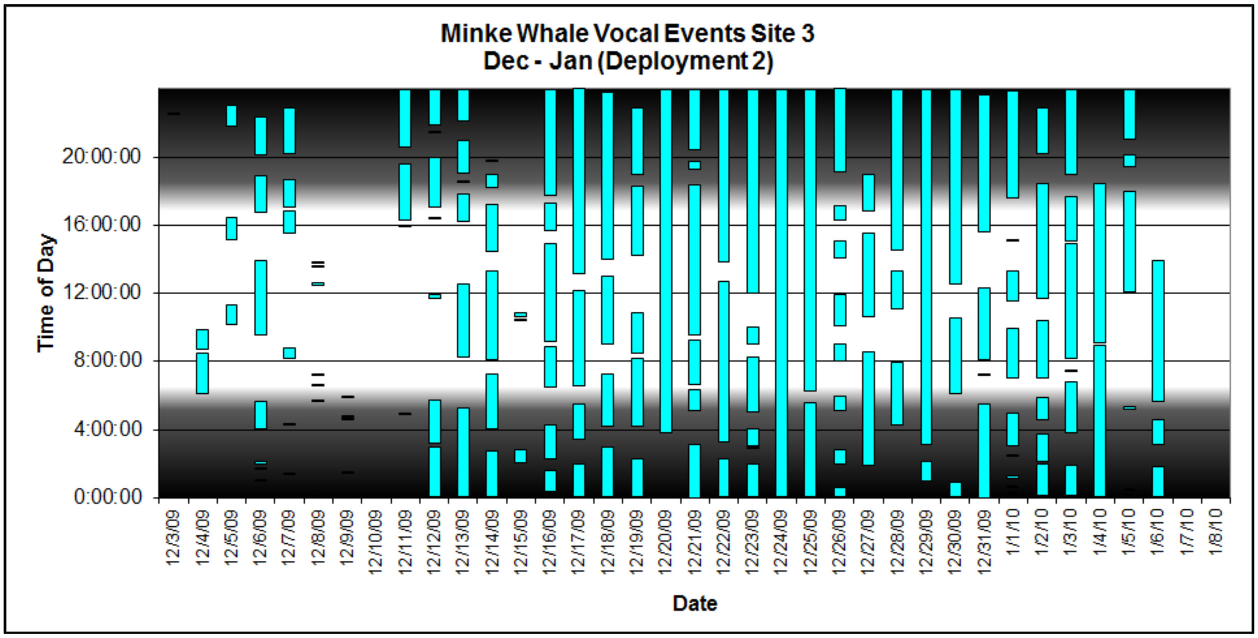

Figure 19. Deployment 2, Site 3 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

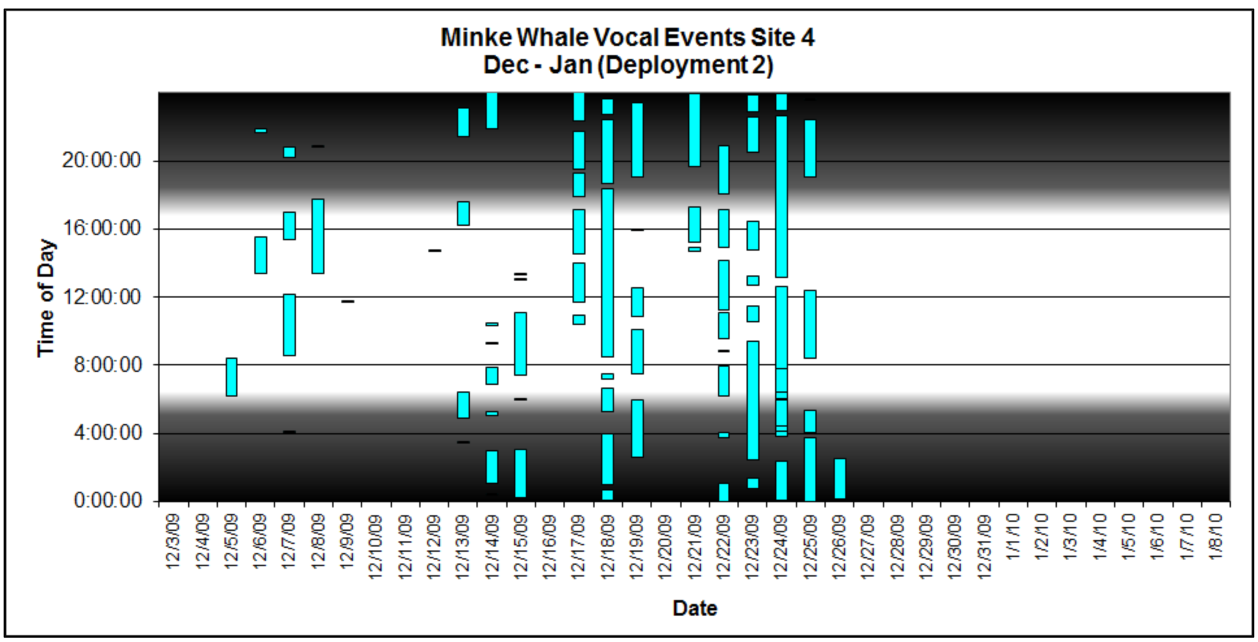

Figure 20. Deployment 2, Site 4 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

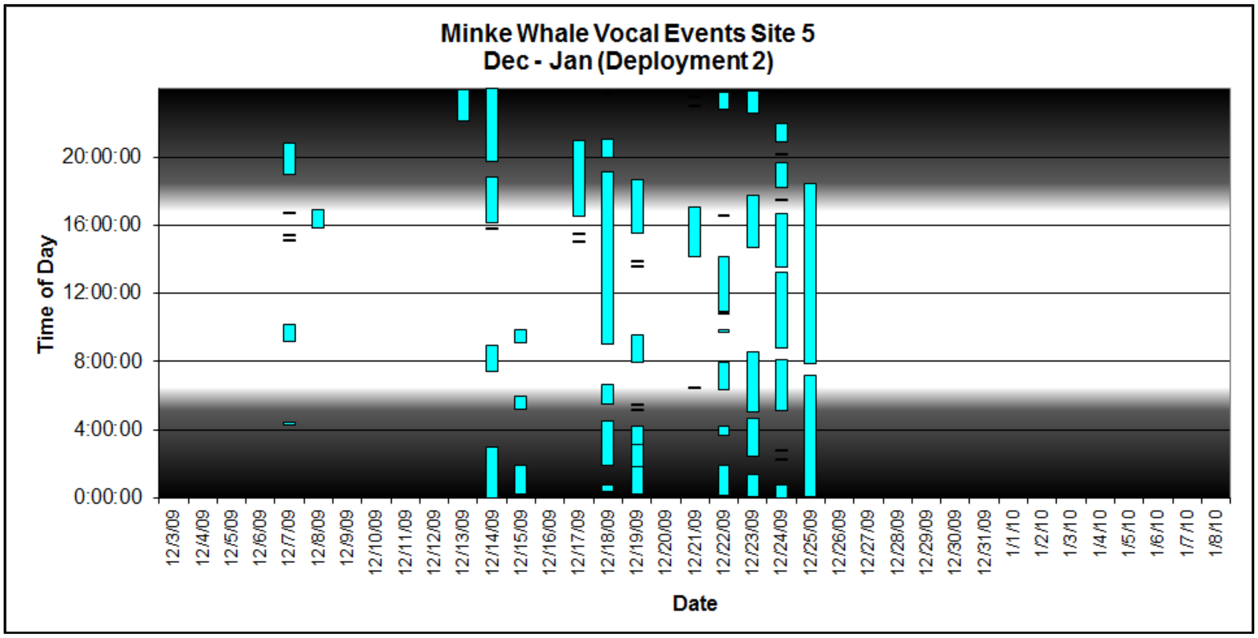

Figure 21. Deployment 2, Site 5 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

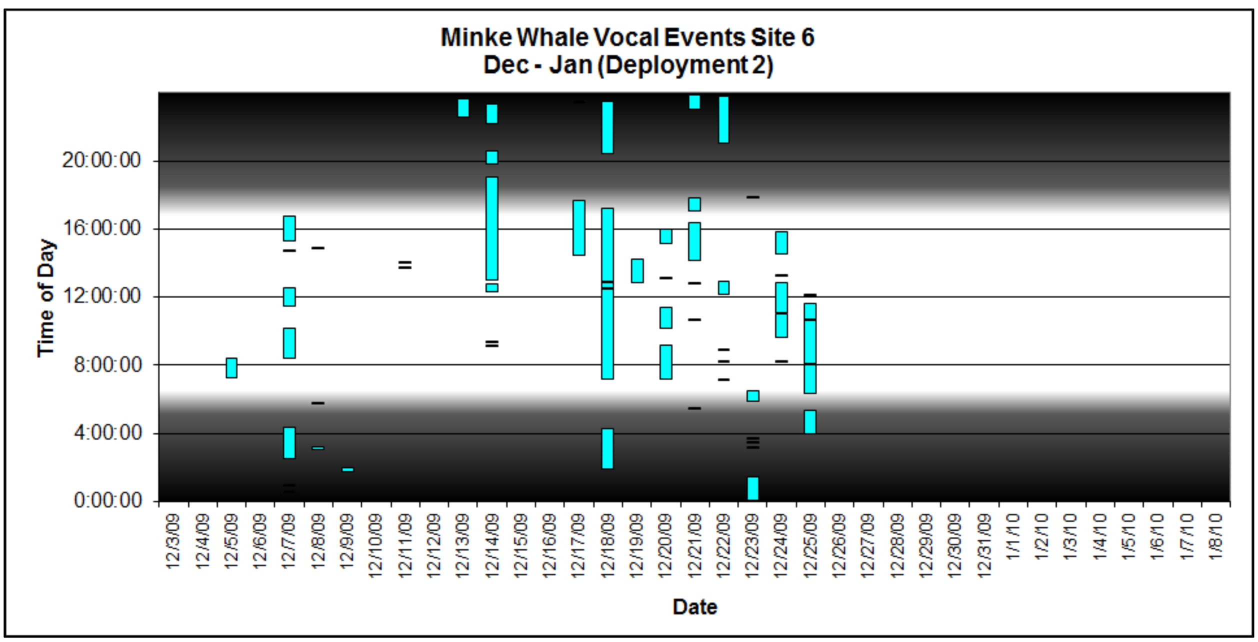

Figure 22. Deployment 2, Site 6 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

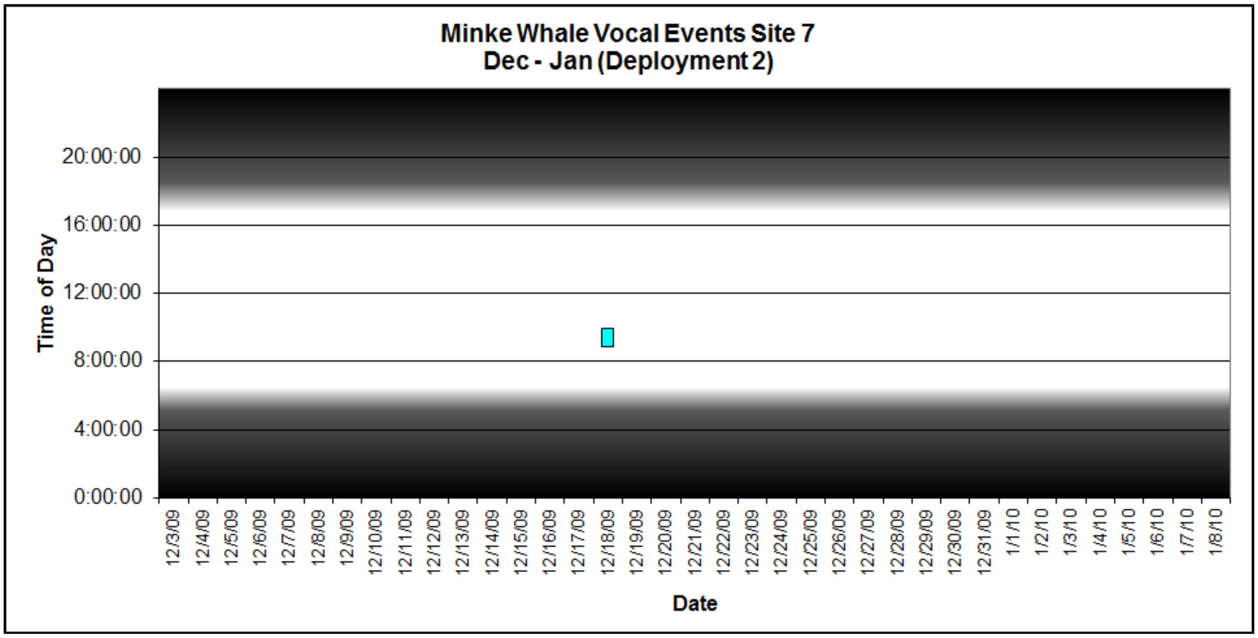

Figure 23. Deployment 2, Site 7 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

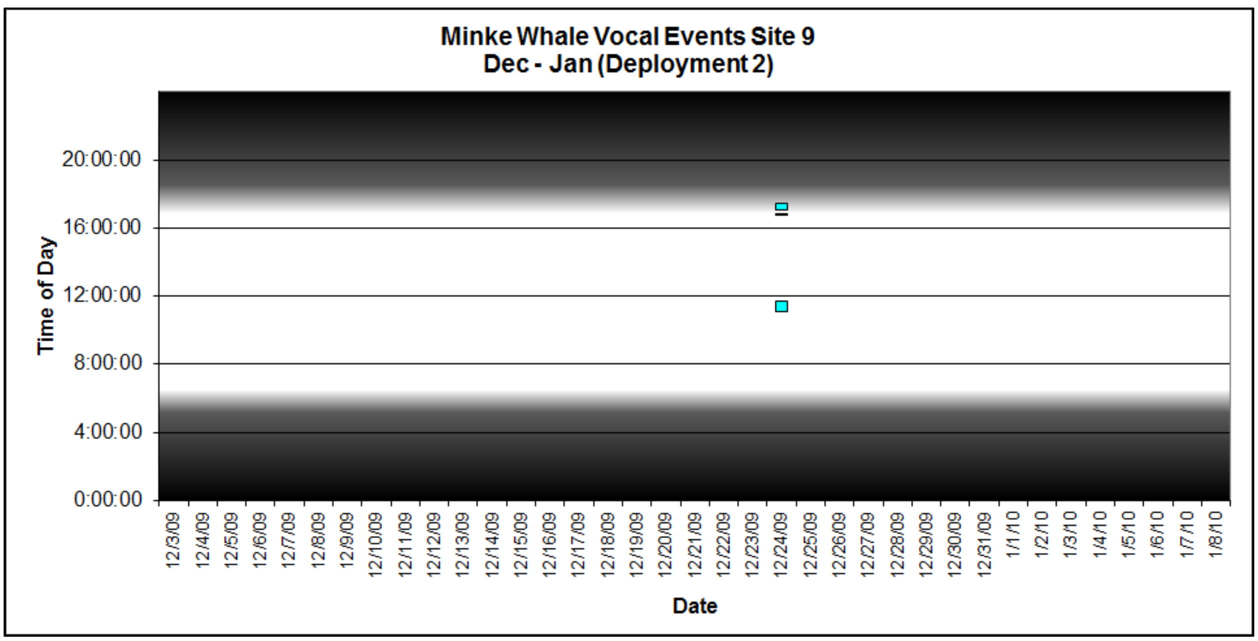

Figure 24. Deployment 2, Site 9 - Minke Whale Vocal Events by Day and Time. Minke whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

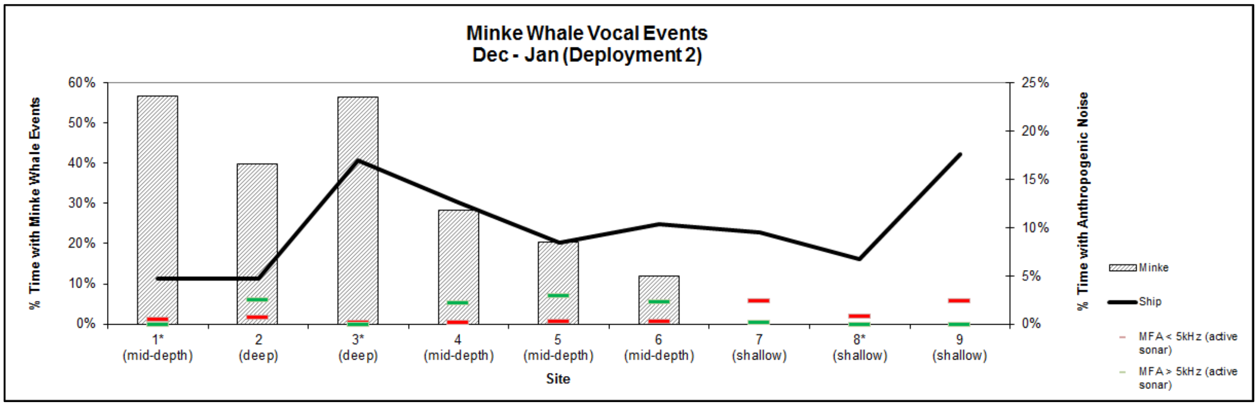

Figure 25. Deployment 2 - Minke Whale Presence by Site. The percentage of total recording time with minke whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

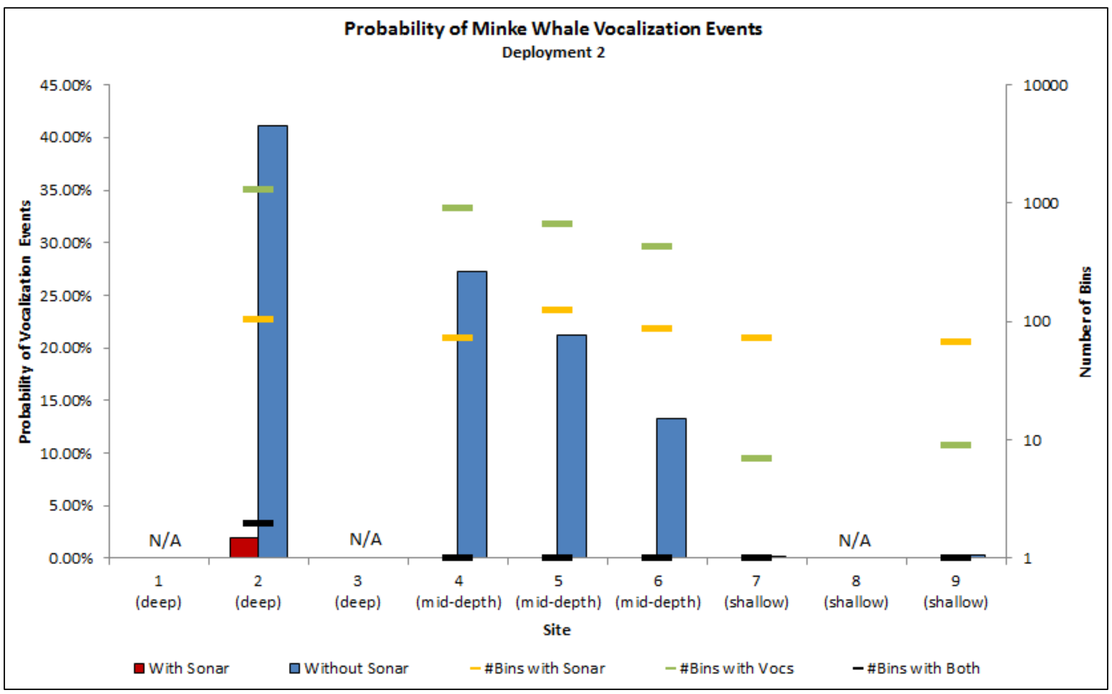

Figure 26. Probability of Occurrence of Minke Whale Vocalizations in the Presence of Sonar (Red Bars) and in the Absence of Sonar (Blue Bars) for Deployment 2. Probabilities were calculated based on the number of 10-minute bins containing sonar only, vocalizations only, and both sonar and vocalizations. The number of 10-minute bins containing sonar only, are shown as yellow lines, the number of bins containing vocalizations only are shown as green lines, and the number of bins containing both sonar and vocalizations are shown as black lines.

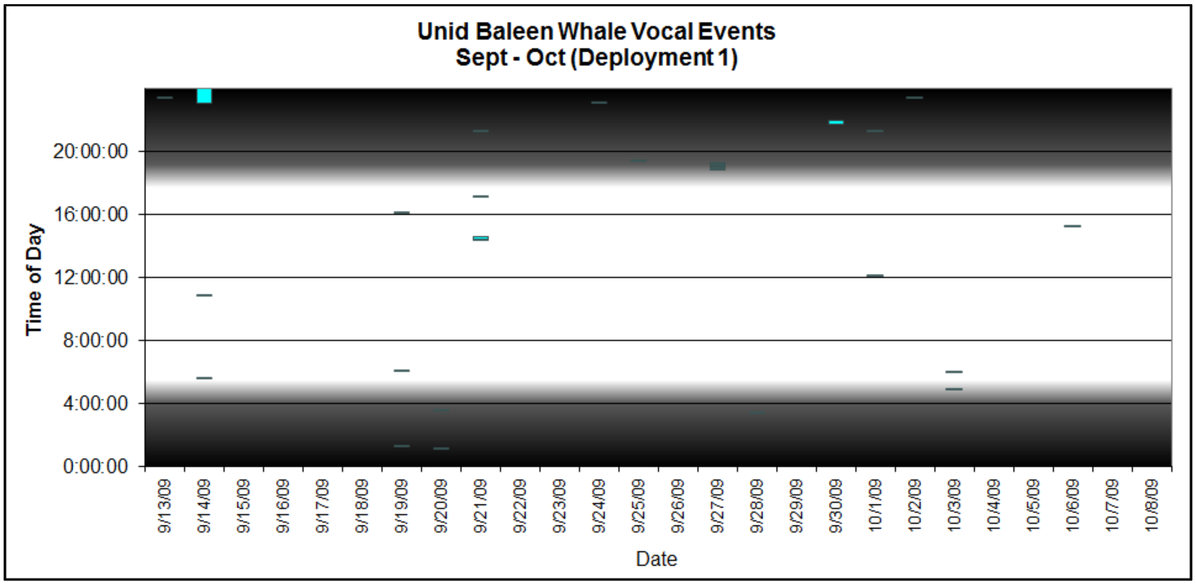

Figure 27. Deployment 1 - Unidentified Baleen Whale Vocal Events by Day and Time. Unidentified baleen whale vocal events are shown in blue with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

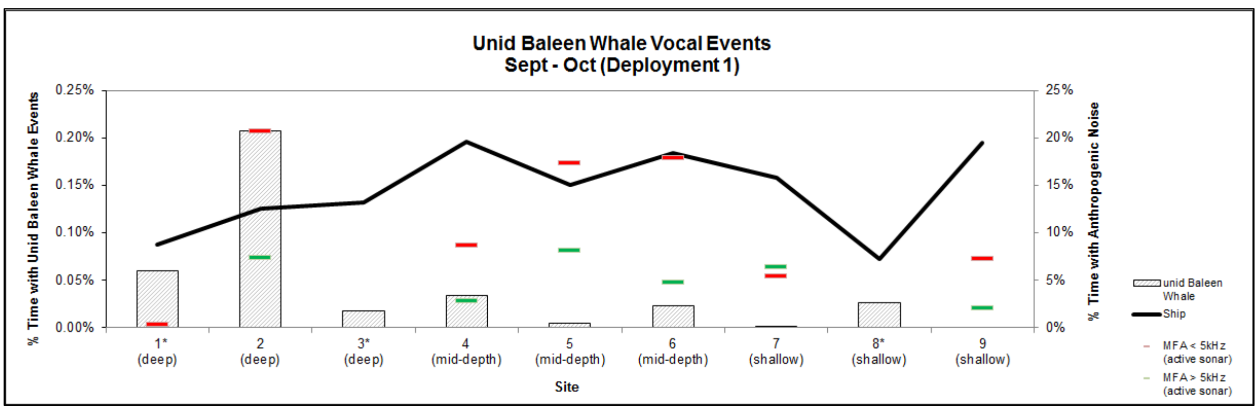

Figure 28. Deployment 1 – Unidentified Baleen Whale Presence by Site. The percentage of total recording time with unidentified baleen whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

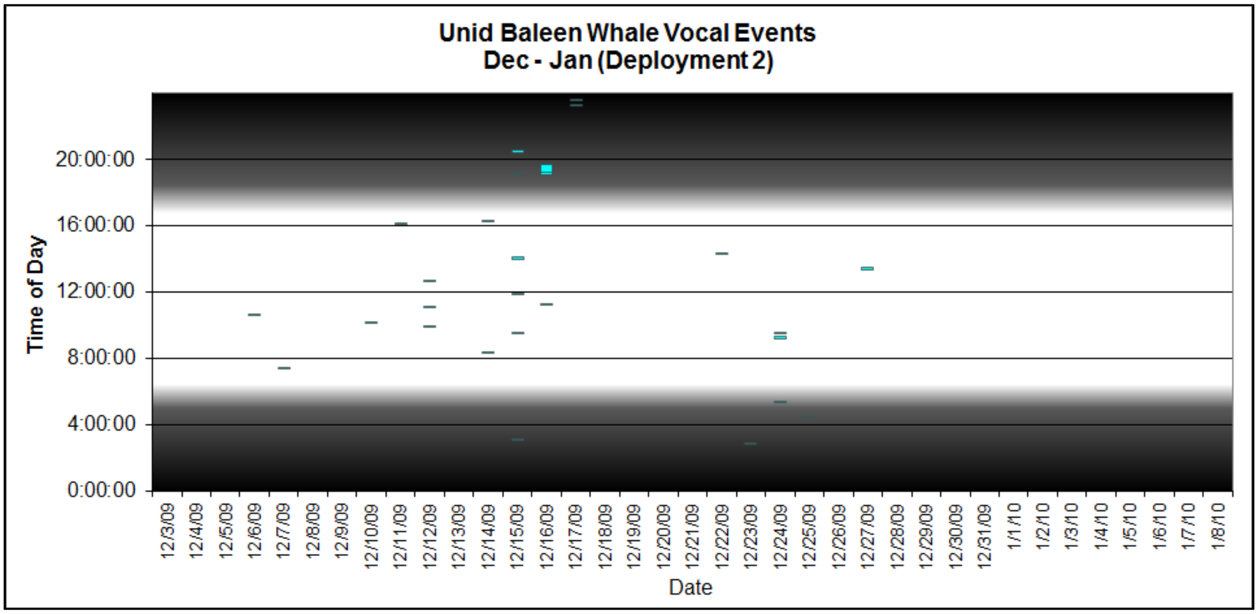

Figure 29. Deployment 2 - Unidentified Baleen Whale Vocal Events by Day and Time. Unidentified baleen whale vocal events are shown in blue with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

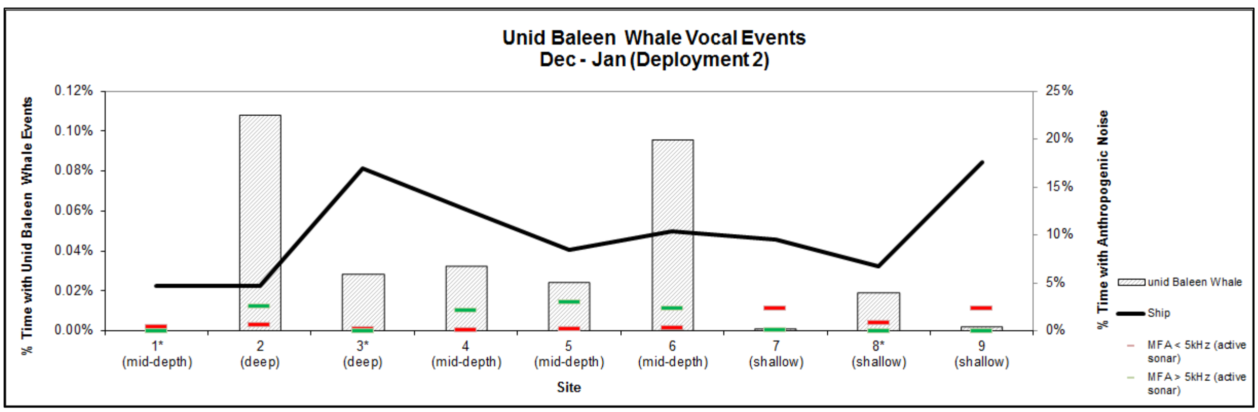

Figure 30. Deployment 2 - Unidentified Baleen Whale Presence by Site. The percentage of total recording time with unidentified baleen whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

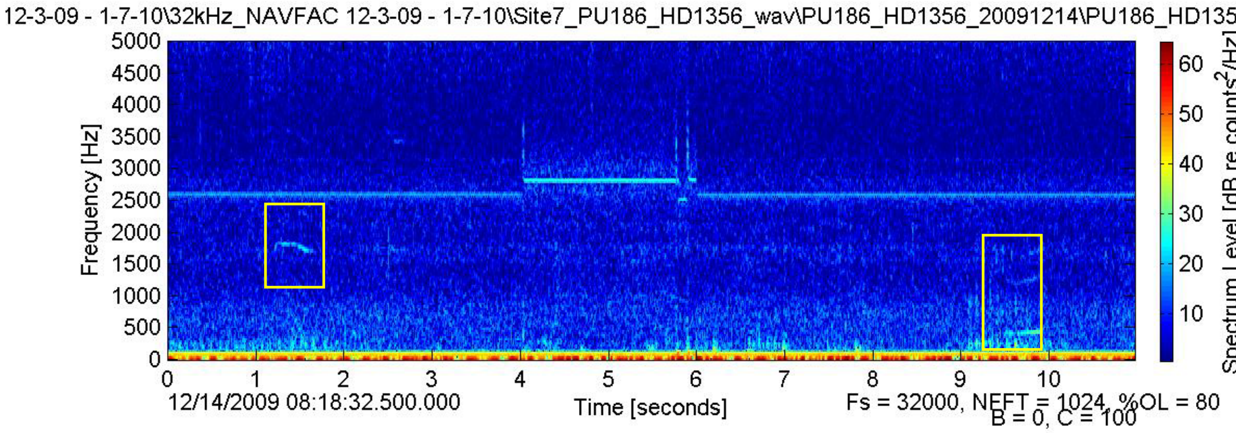

Figure 31. Spectrogram of Possible Humpback Whale Vocalization Event. Two possible signals are boxed (in yellow).

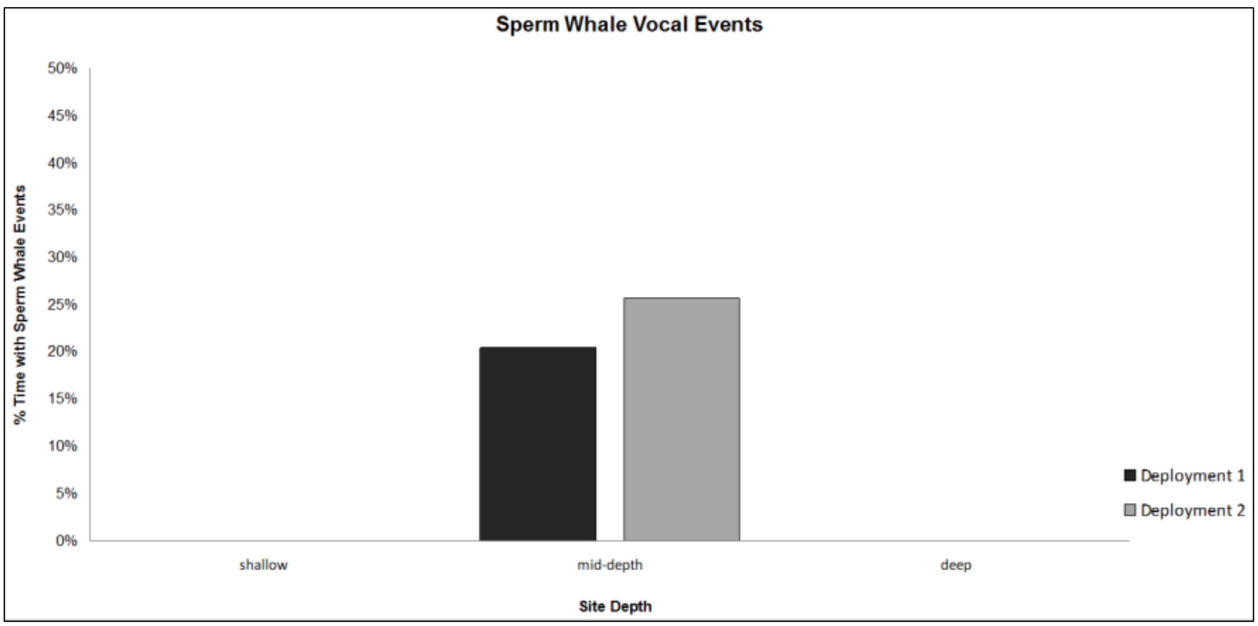

Figure 32. Sperm Whale Vocal Events by Site Depth. The percentage of time with sperm whale events is plotted for each recorder site depth category for Deployment 1 (black) and Deployment 2 (gray).

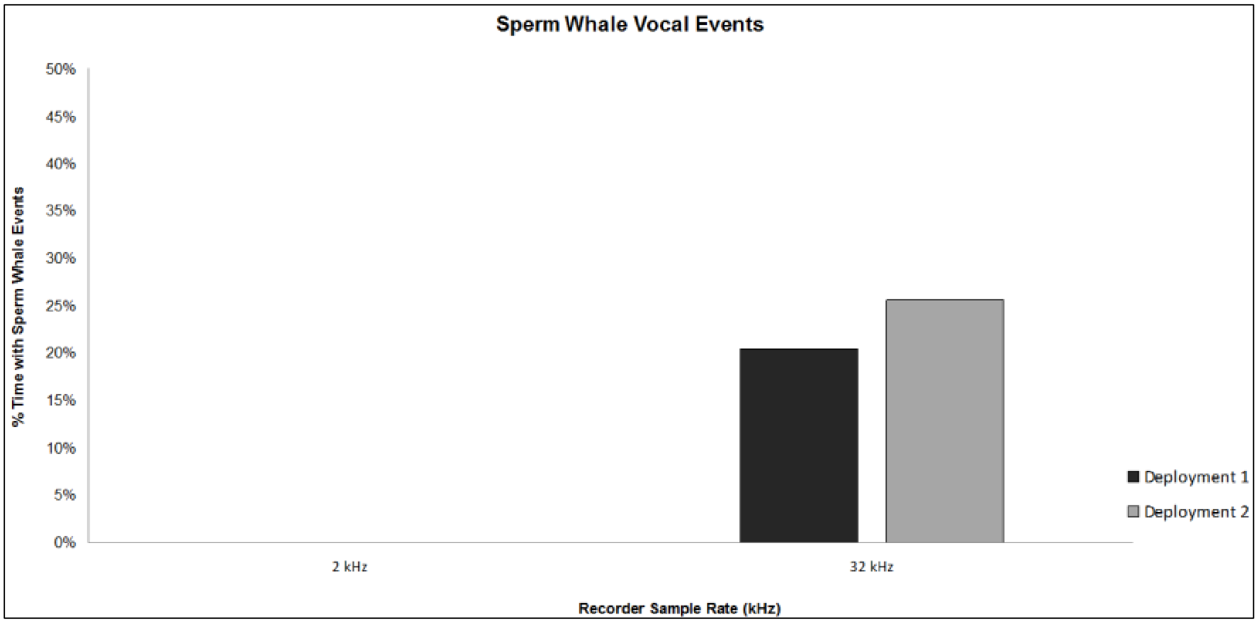

Figure 33. Sperm Whale Vocal Events by Recorder Type. The percentage of time with sperm whale events is plotted for each recorder sample rate category for Deployment 1 (black) and Deployment 2 (gray).

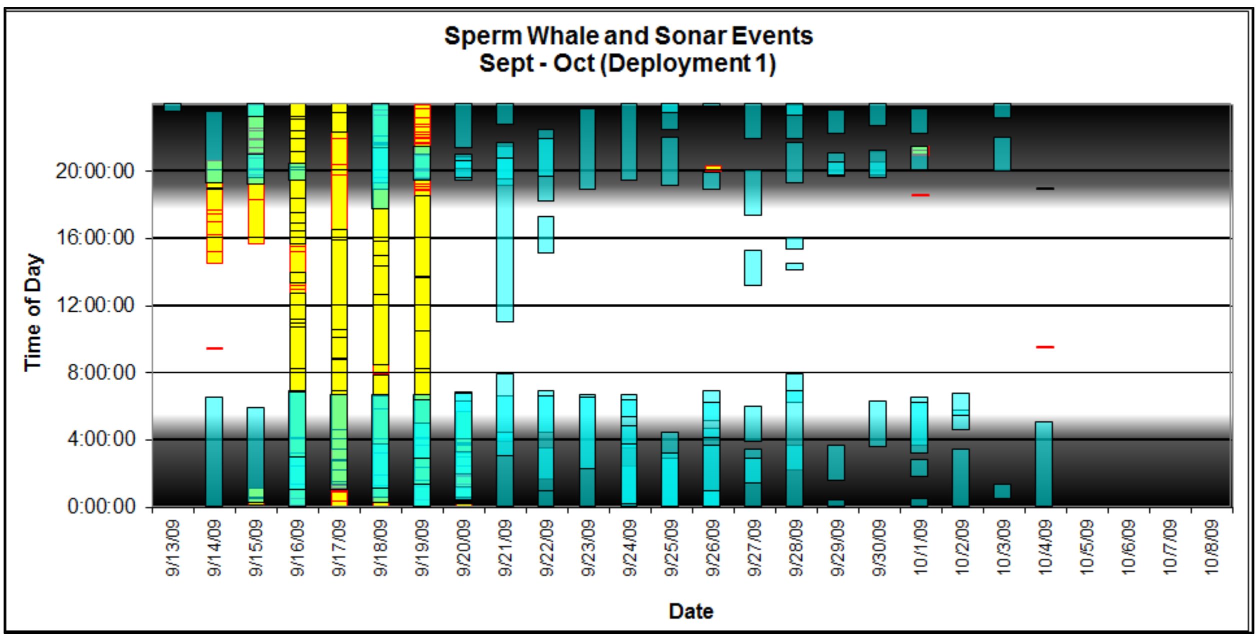

Figure 34. Deployment 1 - Sperm Whale Vocal and Sonar Events by Day and Time. Sperm whale vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]), with time of day on the y-axis and date (x-axis). Sonar events are shown in yellow with the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

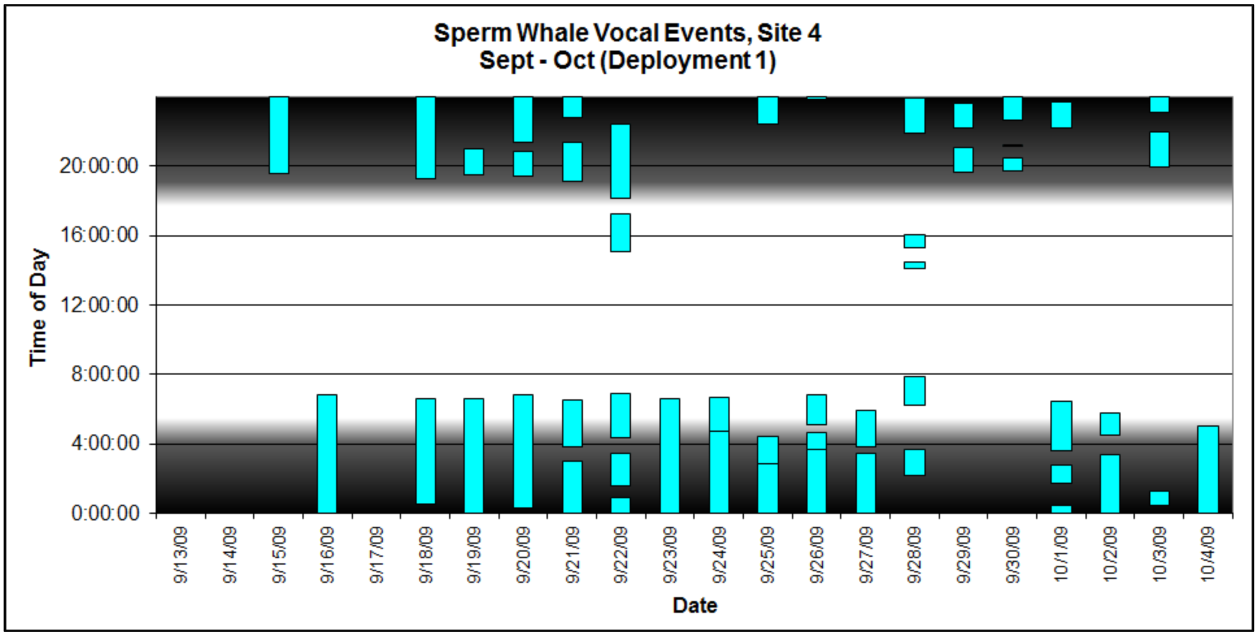

Figure 35. Deployment 1, Site 4 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

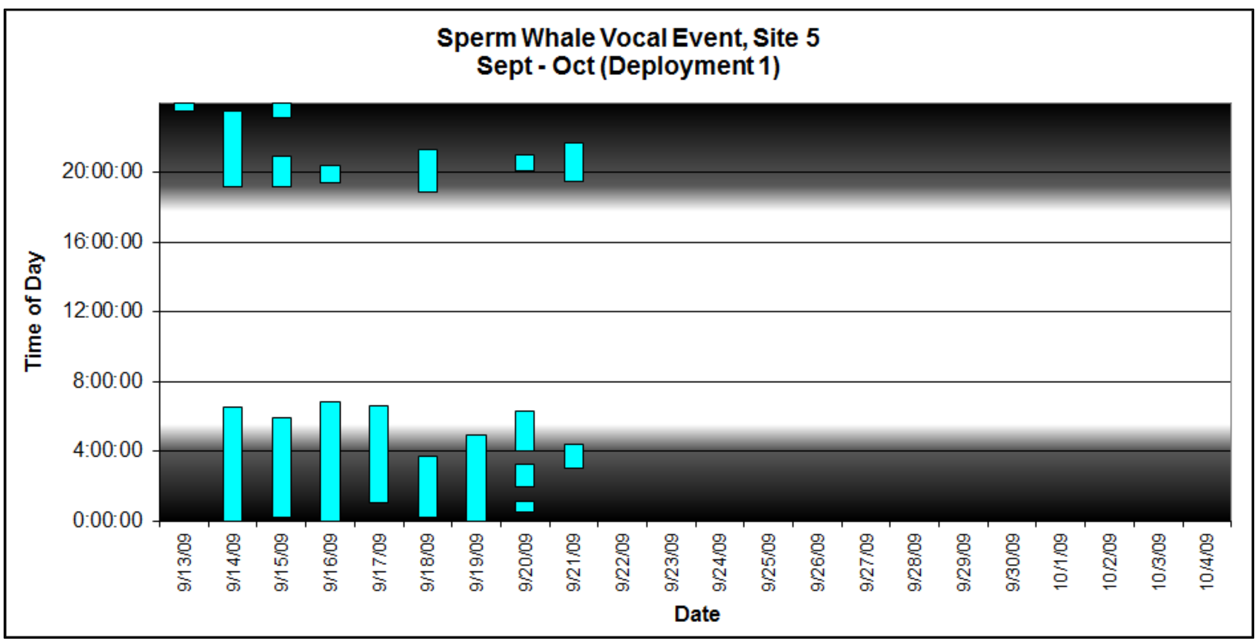

Figure 36. Deployment 1, Site 5 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

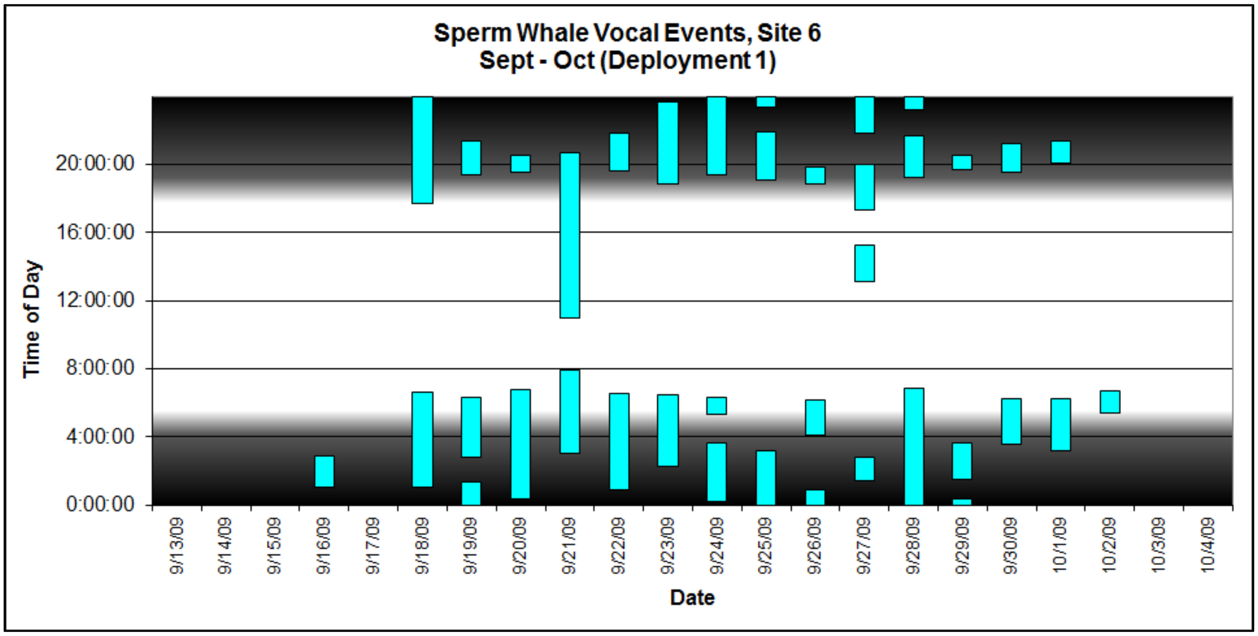

Figure 37. Deployment 1, Site 6 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

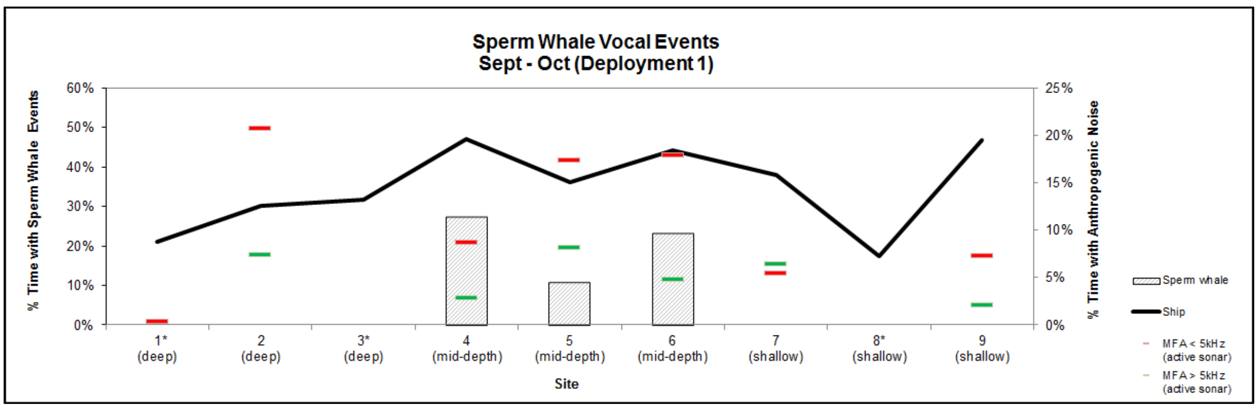

Figure 38. Deployment 1 - Sperm Whale Presence by Site. The percentage of total recording time with sperm whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

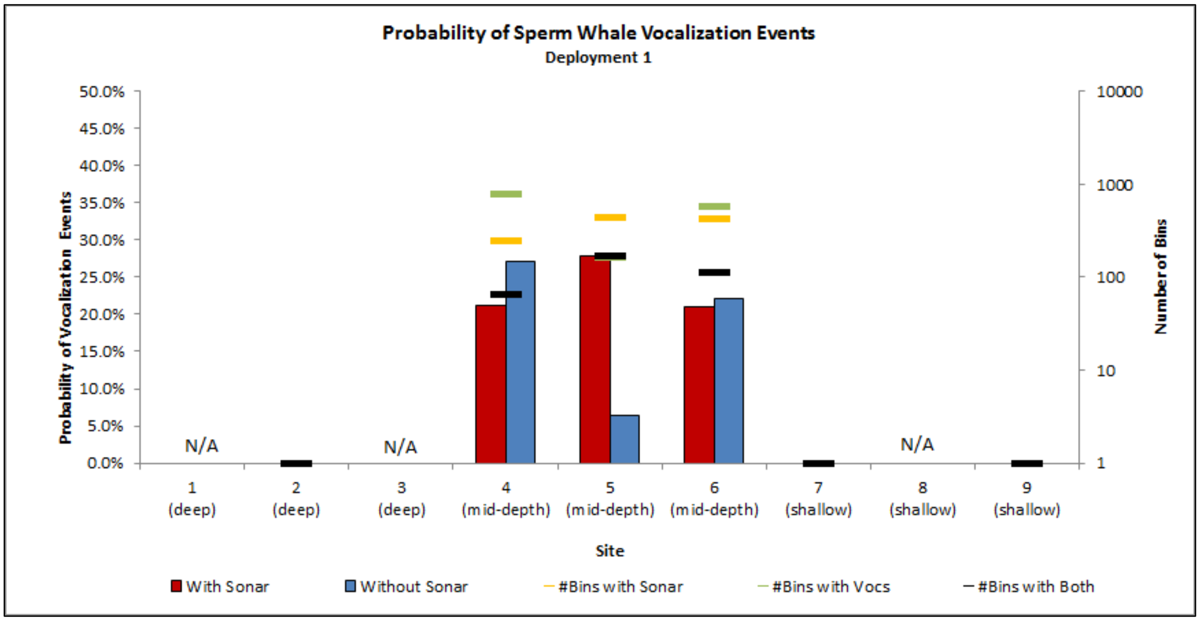

Figure 39. Probability of Occurrence of Sperm Whale Vocalizations in the Presence of Sonar (Red Bars) and in the Absence of Sonar (Blue Bars) for Deployment 1. Probabilities were calculated based on the number of 10-minute bins containing sonar only, vocalizations only, and both sonar and vocalizations. The number of 10-minute bins containing sonar only, are shown as yellow lines, the number of bins containing vocalizations only are shown as green lines, and the number of bins containing both sonar and vocalizations are shown as black lines.

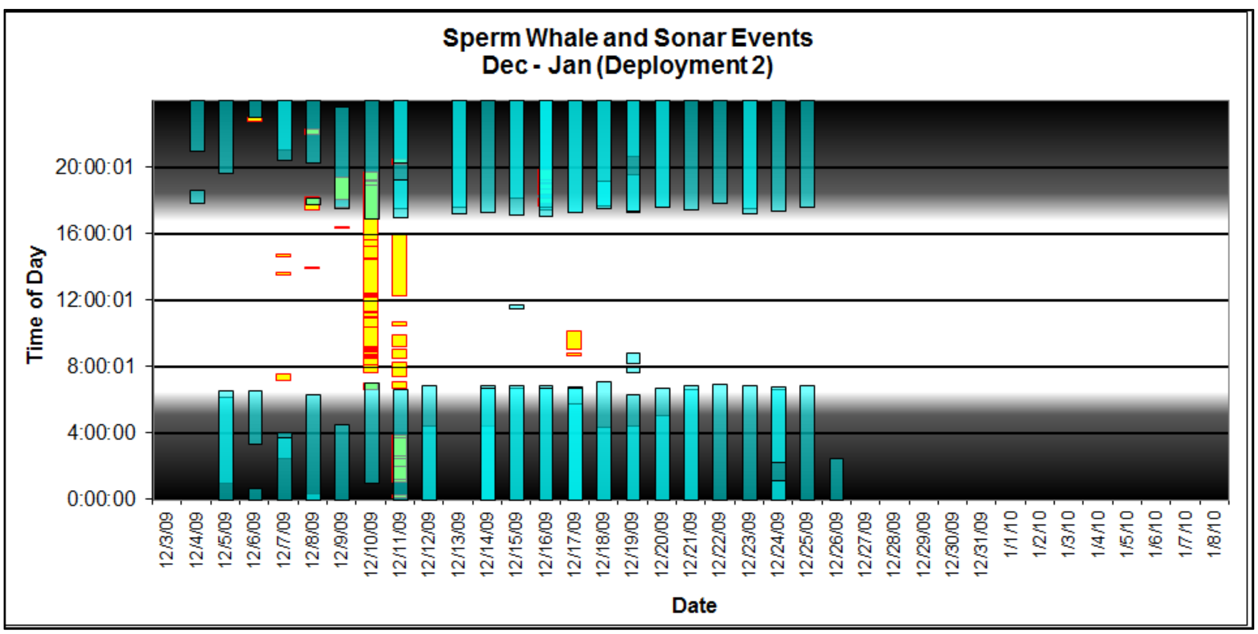

Figure 40. Deployment 2 - Sperm Whale Vocal and Sonar Events by Day and Time. Sperm whale vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]), with time of day (y-axis) and date (x-axis). Sonar events are shown in yellow with the

same axes. Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

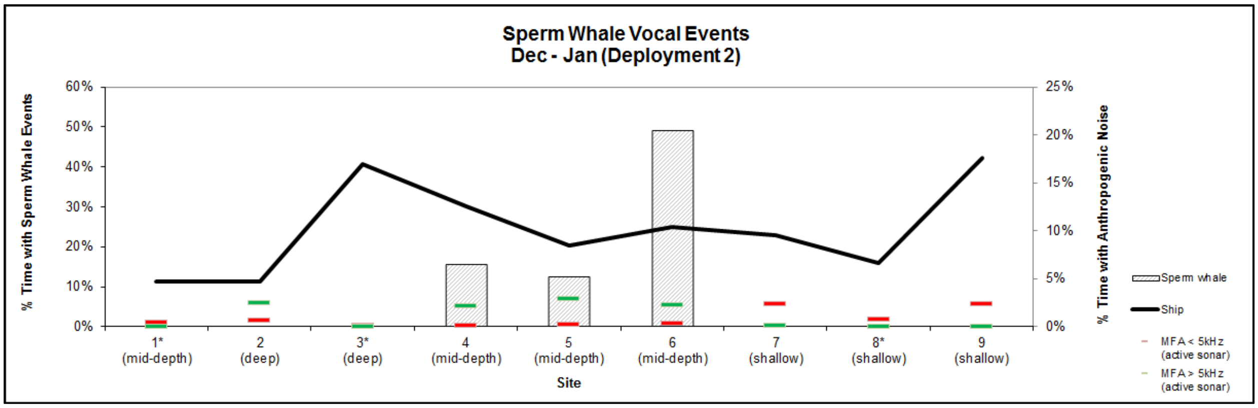

Figure 41. Deployment 2 - Sperm Whale Presence by Site. The percentage of total recording time with sperm whale vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Stars next to site numbers indicate that only 2-kHz data was available at this site.

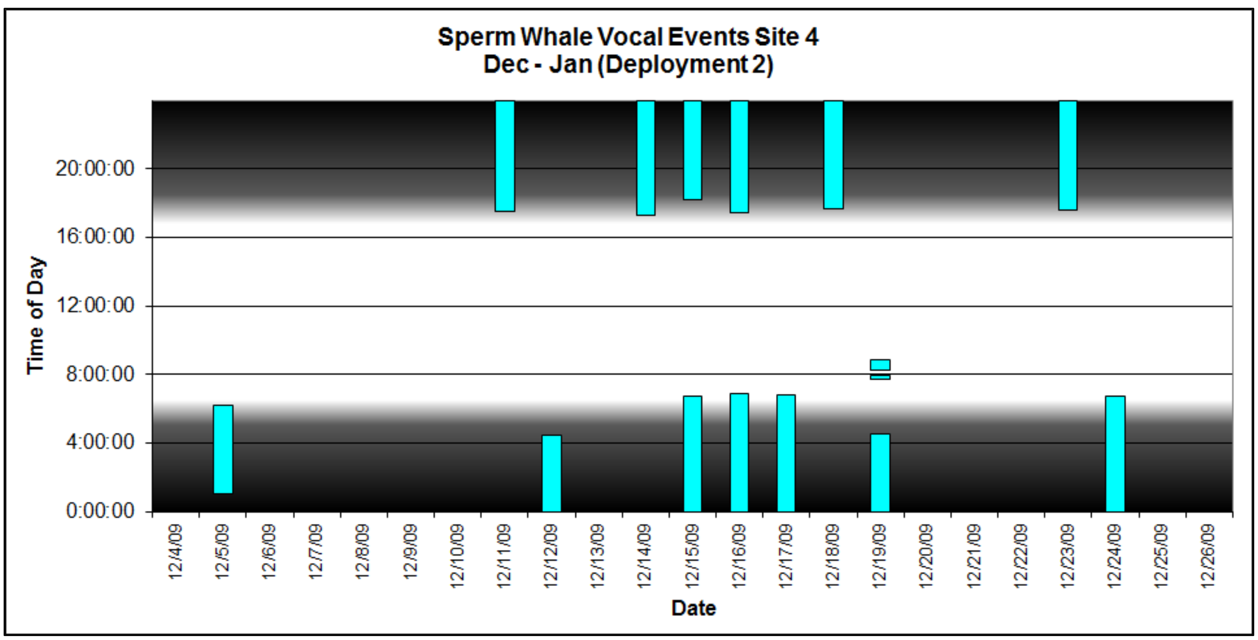

Figure 42. Deployment 2, Site 4 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

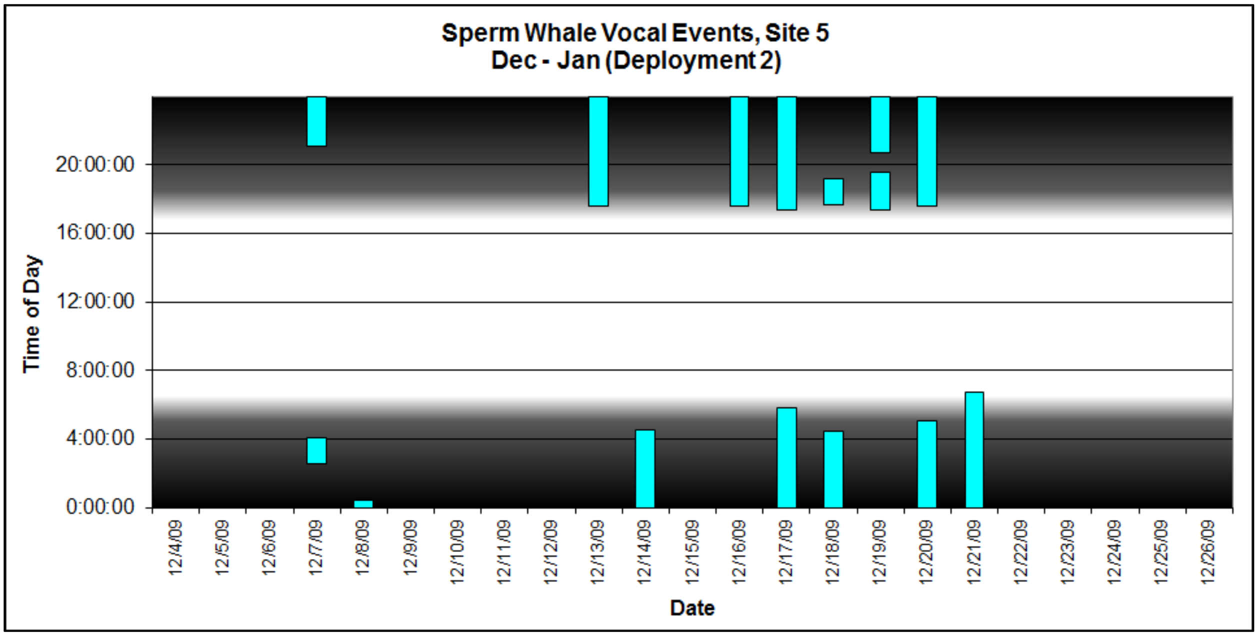

Figure 43. Deployment 2, Site 5 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

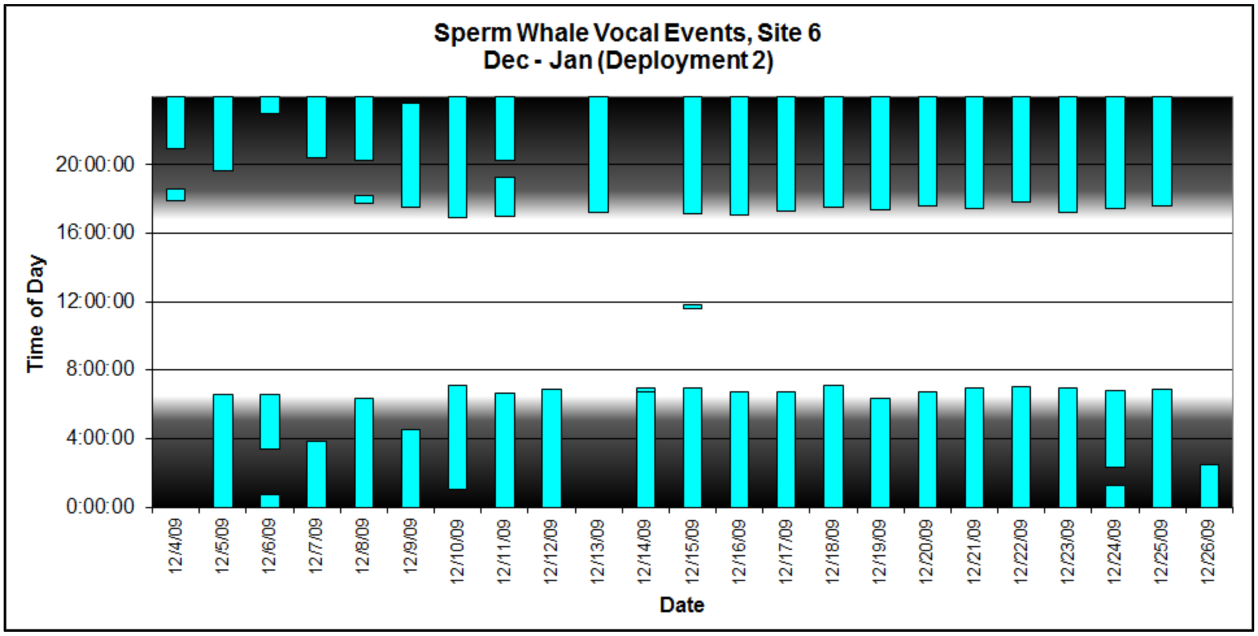

Figure 44. Deployment 2, Site 6 - Sperm Whale Vocal Events by Day and Time. Sperm whale vocal events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period.

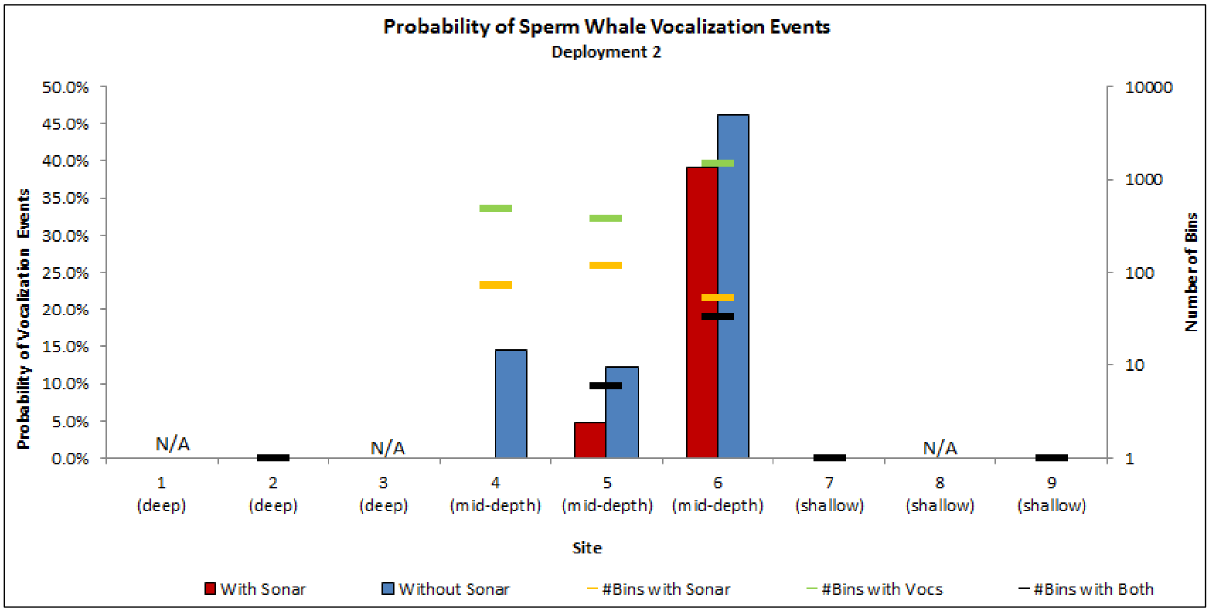

Figure 45. Probability of Occurrence of Sperm Whale Vocalizations in the Presence of Sonar (Red Bars) and in the Absence of Sonar (Blue Bars) for Deployment 2. Probabilities were calculated based on the number of 10-minute bins containing sonar only, vocalizations only, and both sonar and vocalizations. The number of 10-minute bins containing sonar only, are shown as yellow lines, the number of bins containing vocalizations only are shown as green lines, and the number of bins containing both sonar and vocalizations are shown as black lines.

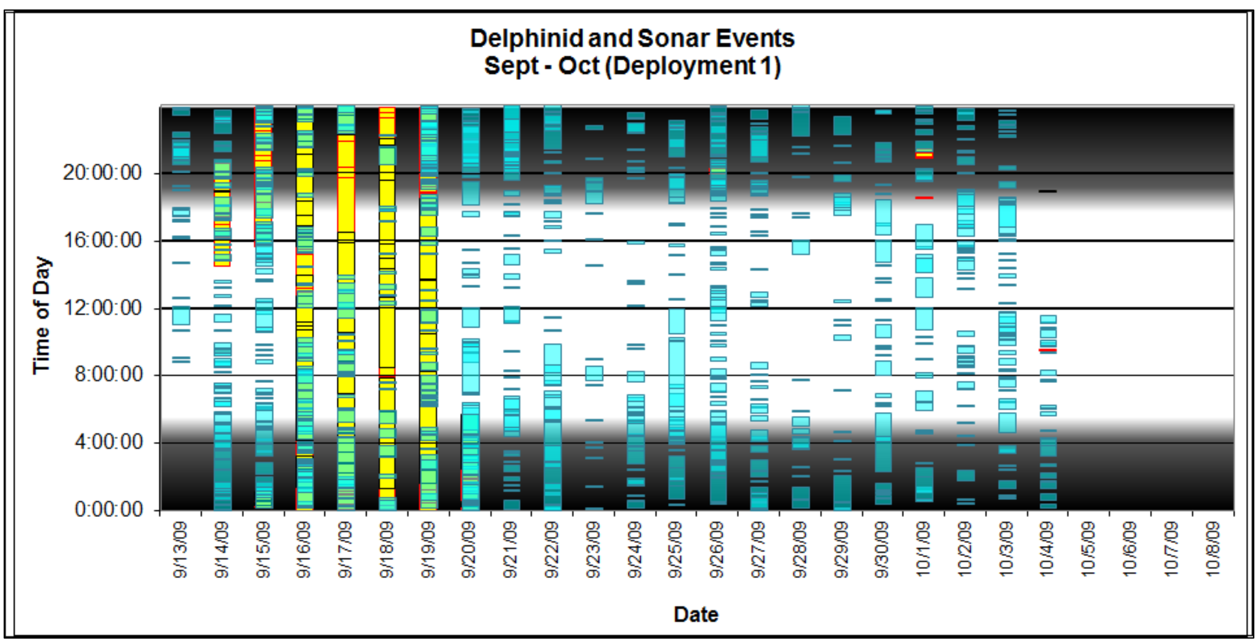

Figure 46. Deployment 1 - Delphinid Vocal Events and Sonar by Day and Time. Delphinid vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]) with time of day on the y-axis and date on the x-axis. Sonar events are shown in yellow with

the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

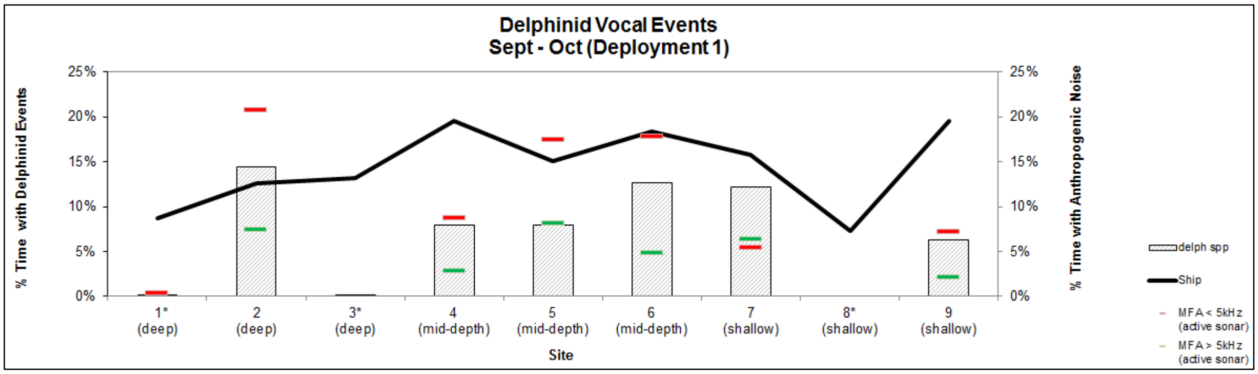

Figure 47. Deployment 1 - Delphinid Species Presence by Site. The percentage of total recording time with delphinid sp. vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

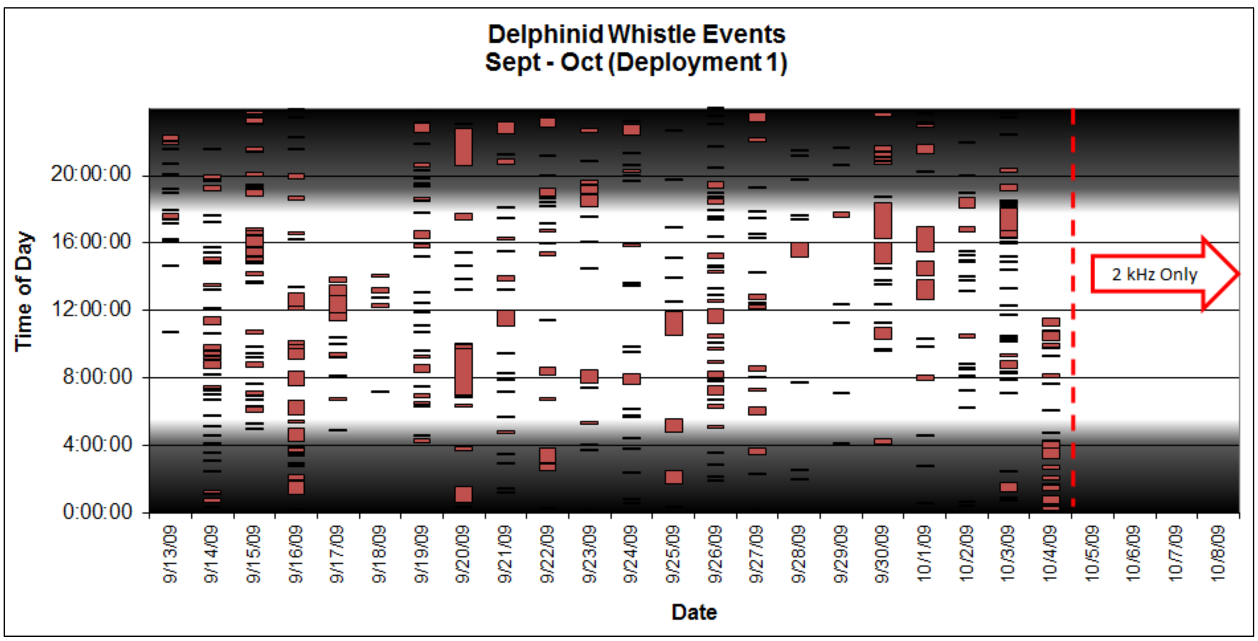

Figure 48. Deployment 1 - Delphinid Whistle Events by Day and Time. Delphinid whistle events are shown in light red with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

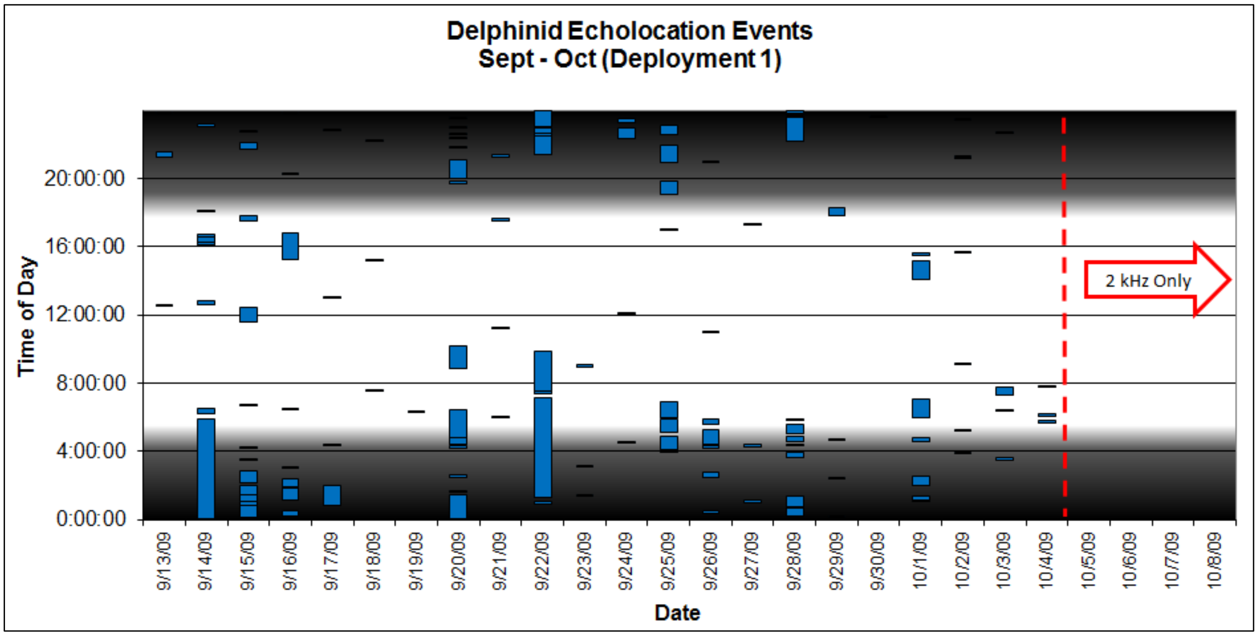

Figure 49. Deployment 1 - Delphinid Echolocation Events by Day and Time. Delphinid echolocation events are shown in blue with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

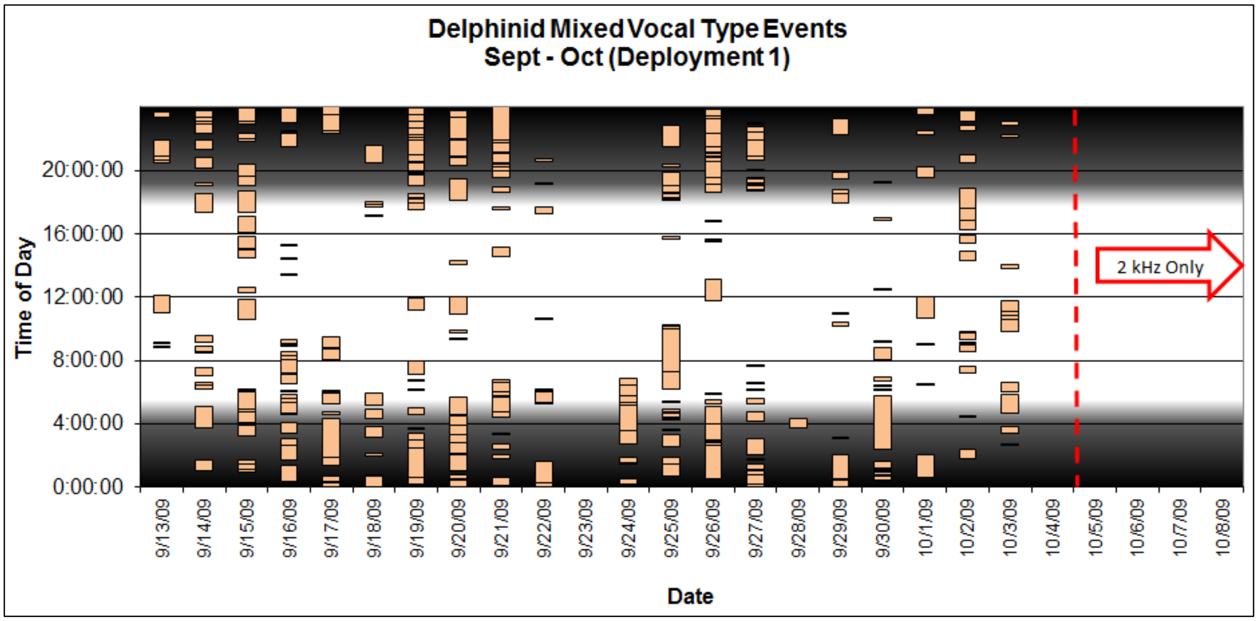

Figure 50. Deployment 1 - Delphinid Mixed-Vocal-Type Events by Day and Time. Delphinid mixed vocal type events are shown in light orange with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

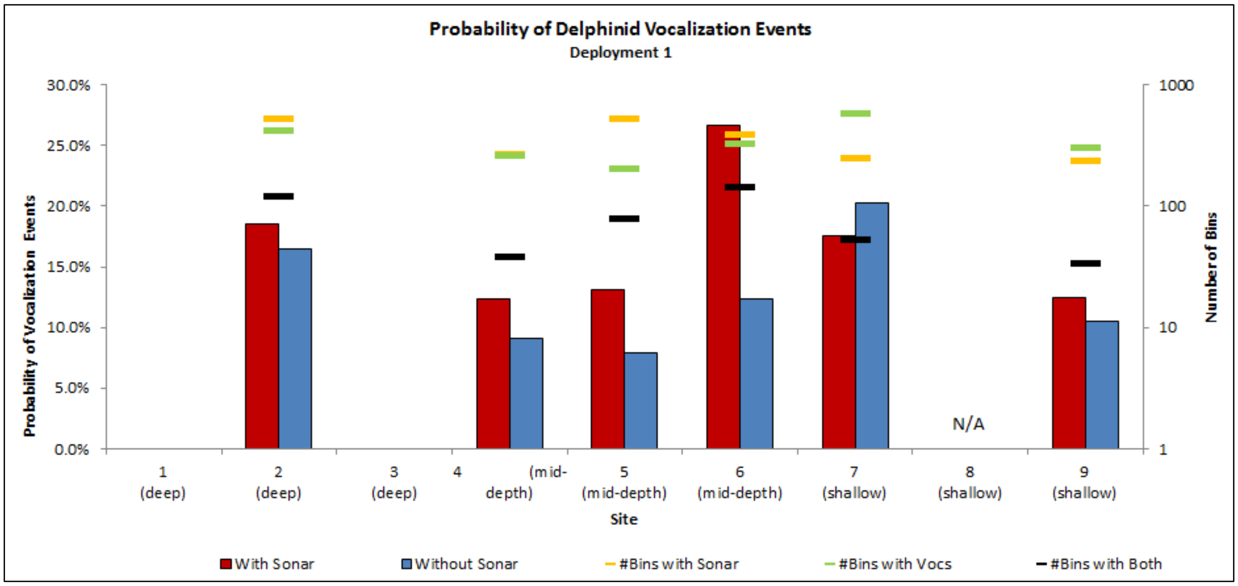

Figure 51. Probability of Occurrence of Delphinid Vocalizations in the Presence of Sonar (Red Bars) and in the Absence of Sonar (Blue Bars) for Deployment 2. Probabilities were calculated based on the number of 10-minute bins containing sonar only, vocalizations only, and both sonar and vocalizations. The number of 10-minute bins containing sonar only, are shown as yellow lines, the number of bins containing vocalizations only are shown as green lines, and the number of bins containing both sonar and vocalizations are shown as black lines

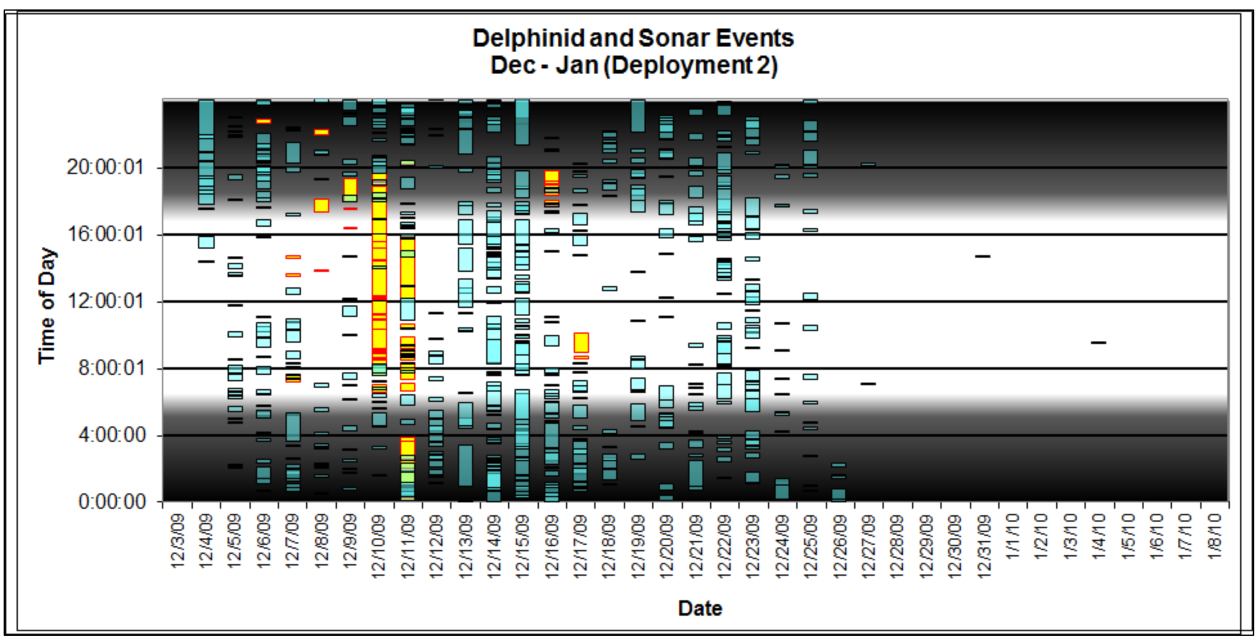

Figure 52. Deployment 2 - Delphinid Vocal Events and Sonar by Day and Time. Delphinid vocal events are shown in teal (shading is representative of event overlap, [i.e., an event occurring at multiple sites]) with time of day (y-axis) and date (x-axis). Sonar events are shown in yellow with the same axes. Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

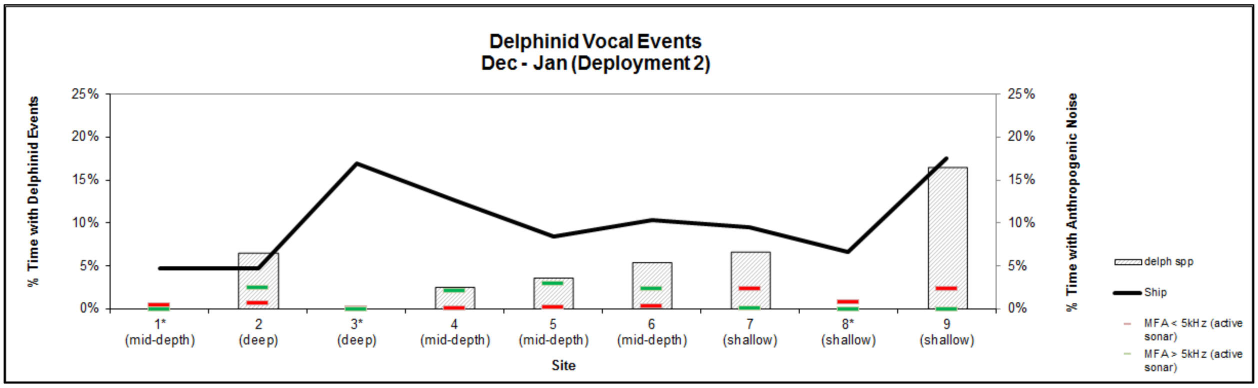

Figure 53. Deployment 2 - Delphinid Species Presence by Site. The percentage of total recording time with delphinid sp. vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

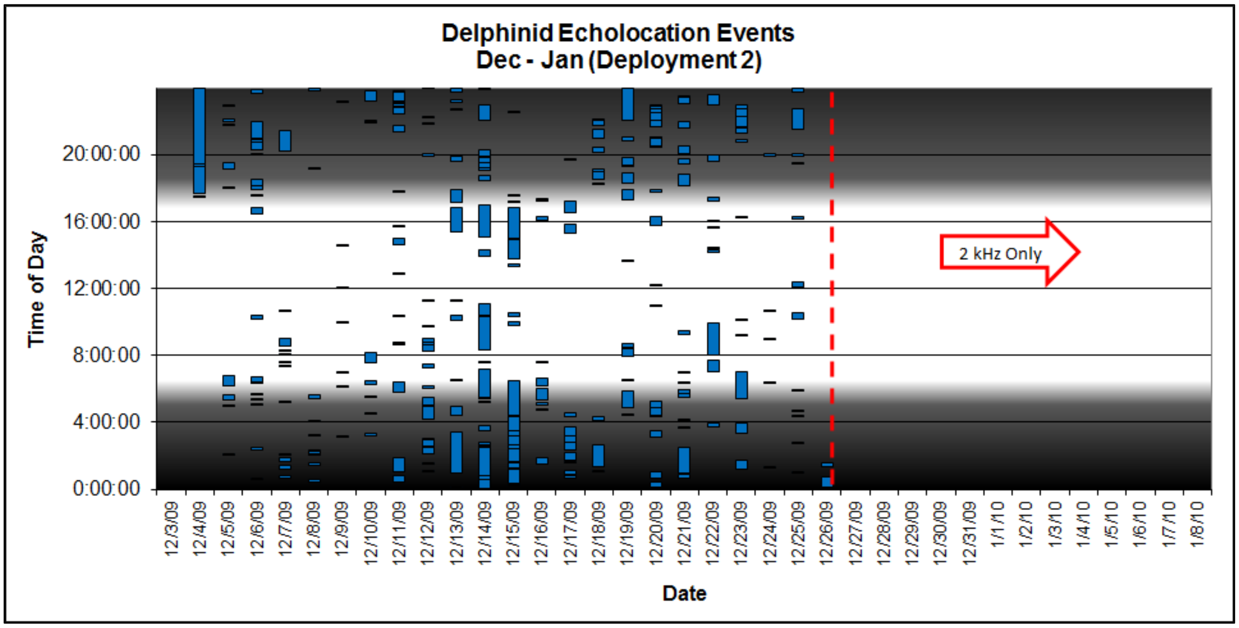

Figure 54. Deployment 2 - Delphinid Echolocation Events by Day and Time. Delphinid echolocation events are shown in blue with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

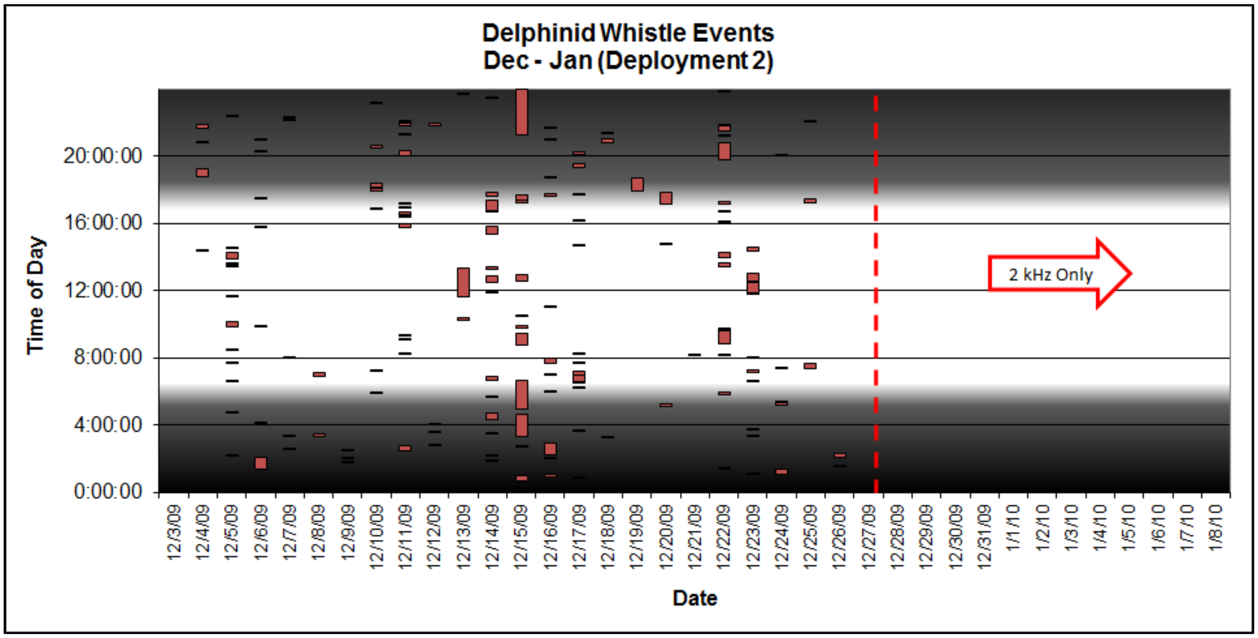

Figure 55. Deployment 2 - Delphinid Whistle Events by Day and Time. Delphinid whistle events are shown in light red with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

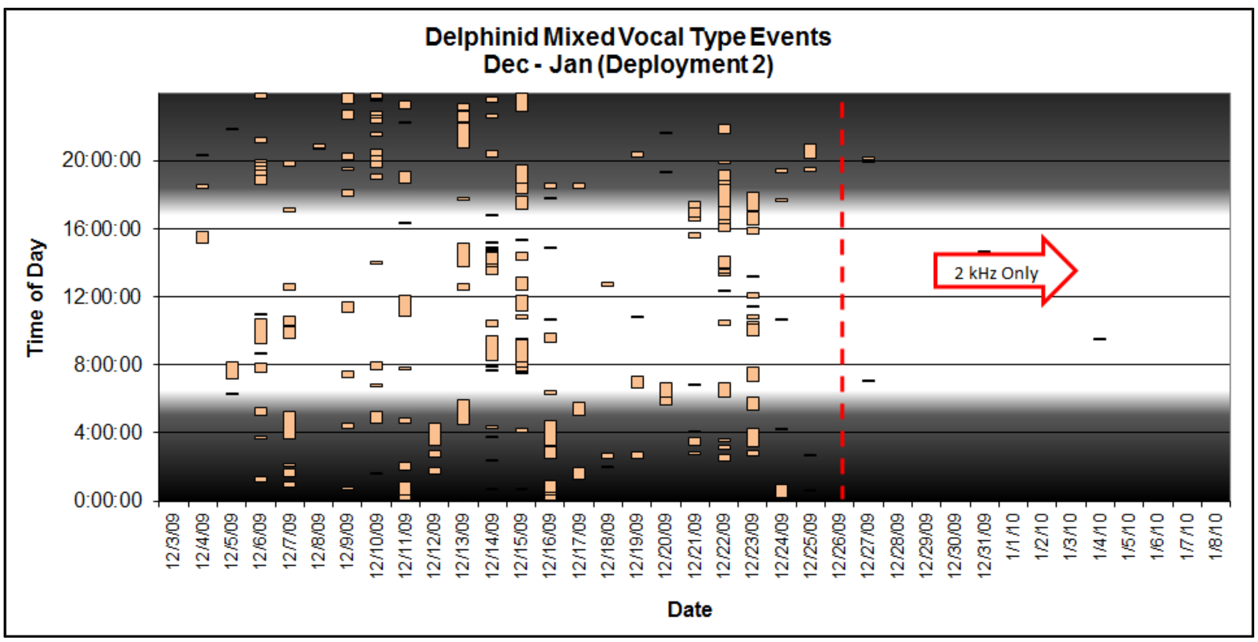

Figure 56. Deployment 2 - Delphinid Mixed-Vocal-Type Events by Day and Time. Delphinid mixed vocal type events are shown in light orange with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

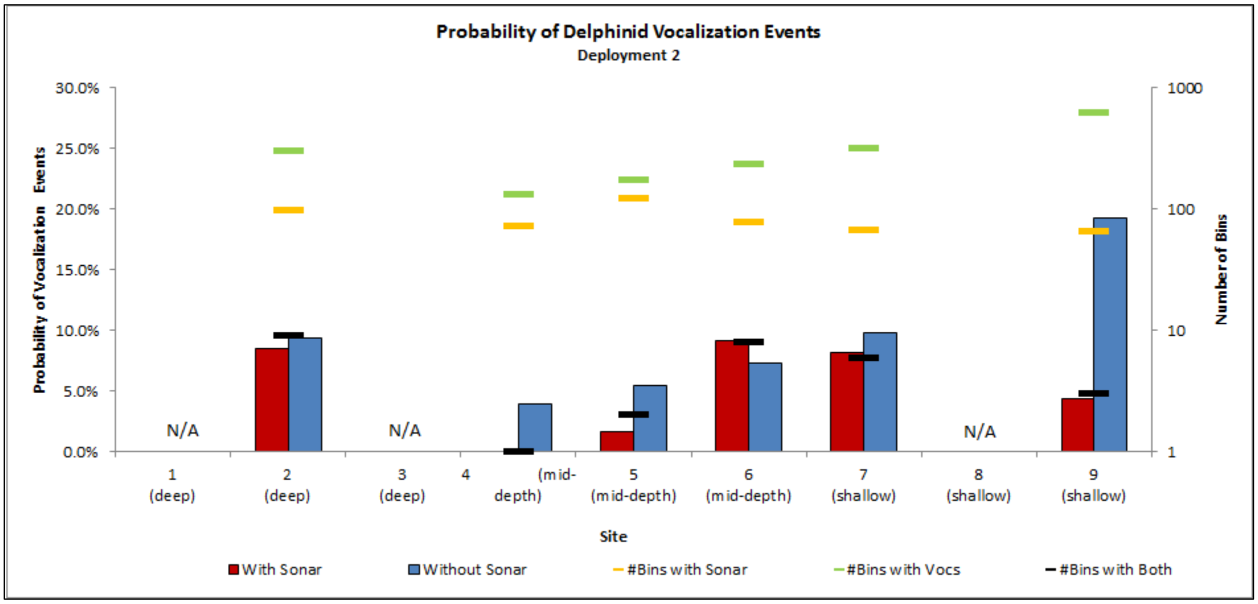

Figure 57. Probability of Occurrence of Delphinid Vocalizations in the Presence of Sonar (Red Bars) and in the Absence of Sonar (Blue Bars) for Deployment 2. Probabilities were calculated based on the number of 10-minute bins containing sonar only, vocalizations only, and both sonar and vocalizations. The number of 10-minute bins containing sonar only, are shown as yellow lines, the number of bins containing vocalizations only are shown as green lines, and the number of bins containing both sonar and vocalizations are shown as black lines.

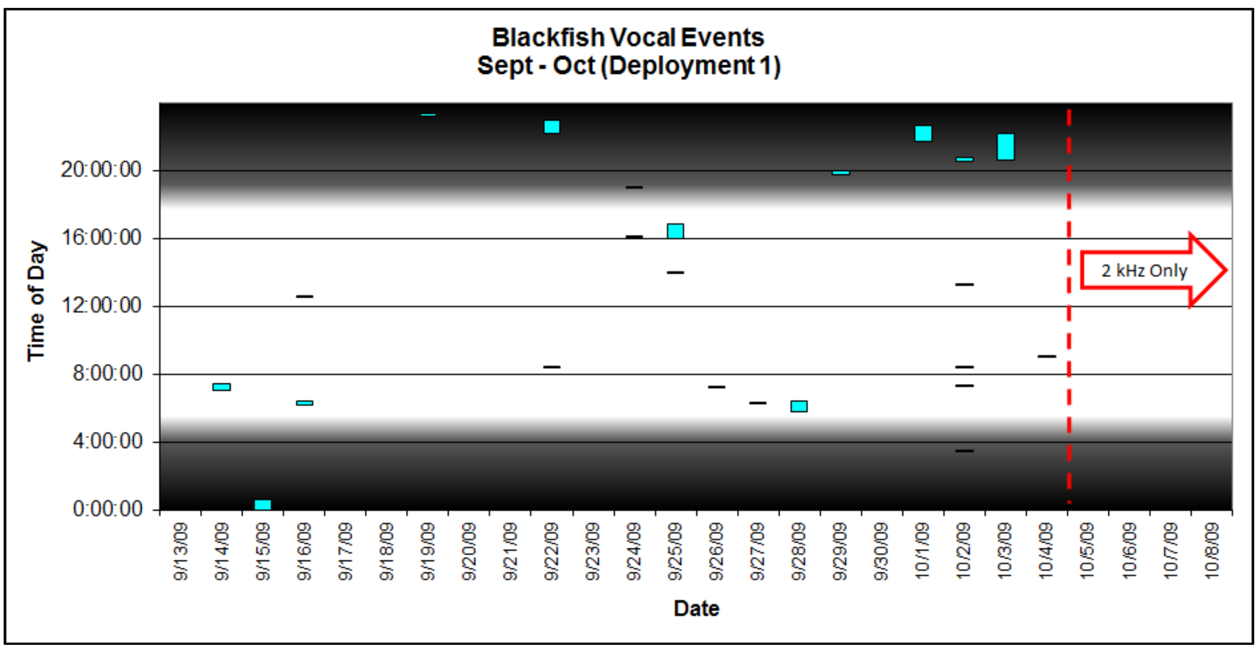

Figure 58. Deployment 1 - Blackfish Vocal Events by Day and Time. Blackfish events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

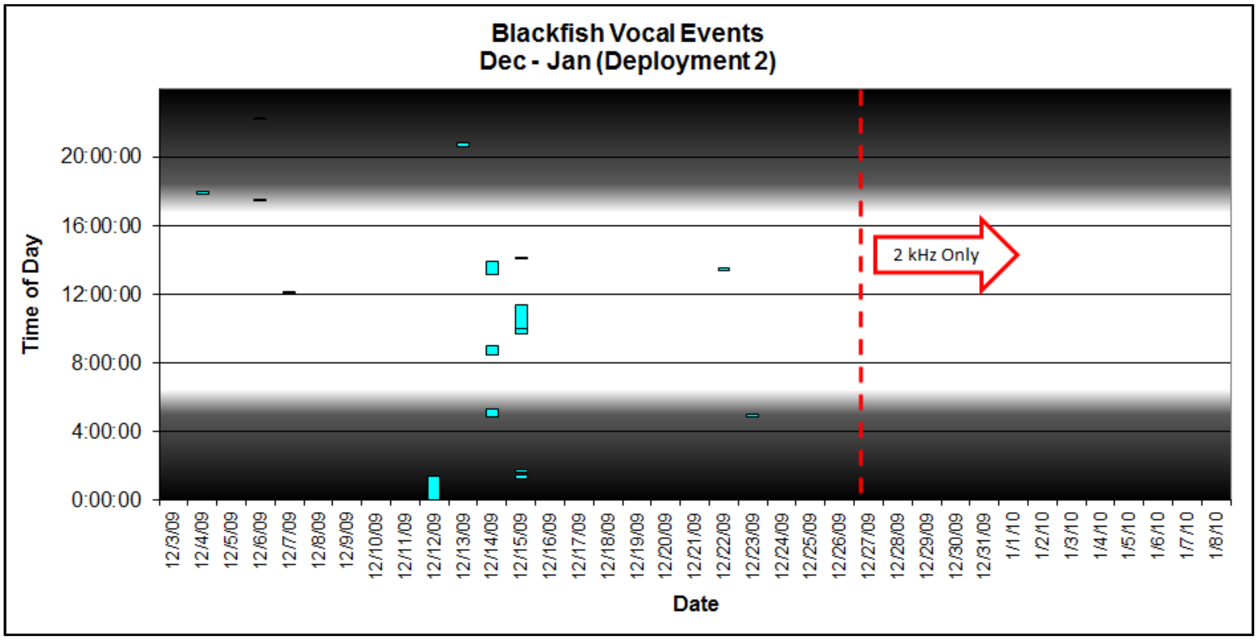

Figure 59. Deployment 2 - Blackfish Vocal Events by Day and Time. Blackfish events are shown in teal with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

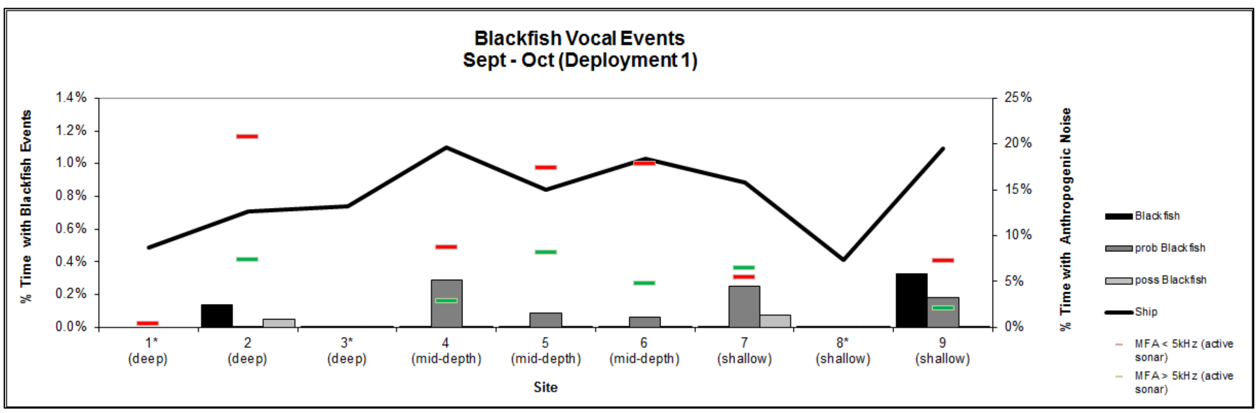

Figure 60. Deployment 1 - Blackfish Species Presence by Site. The percentage of total recording time with blackfish (‘definite’ = black; ‘probable’ = dark gray; ‘possible’ = light gray) vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

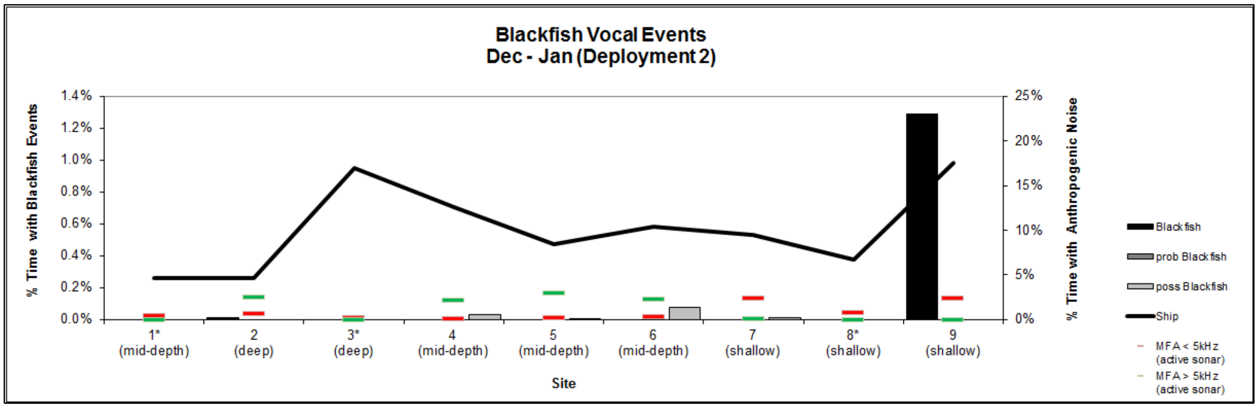

Figure 61. Deployment 2 - Blackfish Species Presence by Site. The percentage of total recording time with blackfish ('definite' = black; 'probable' = dark gray; 'possible' = light gray) vocal events is shown on the left y-axis. The percentage of total recording time with anthropogenic noise events is shown on the right y-axis (MFAS < 5 kHz = red line; MFAS > 5 kHz = green line; ship = black line). Asterisks indicate that only 2-kHz recorder data was available at these sites.

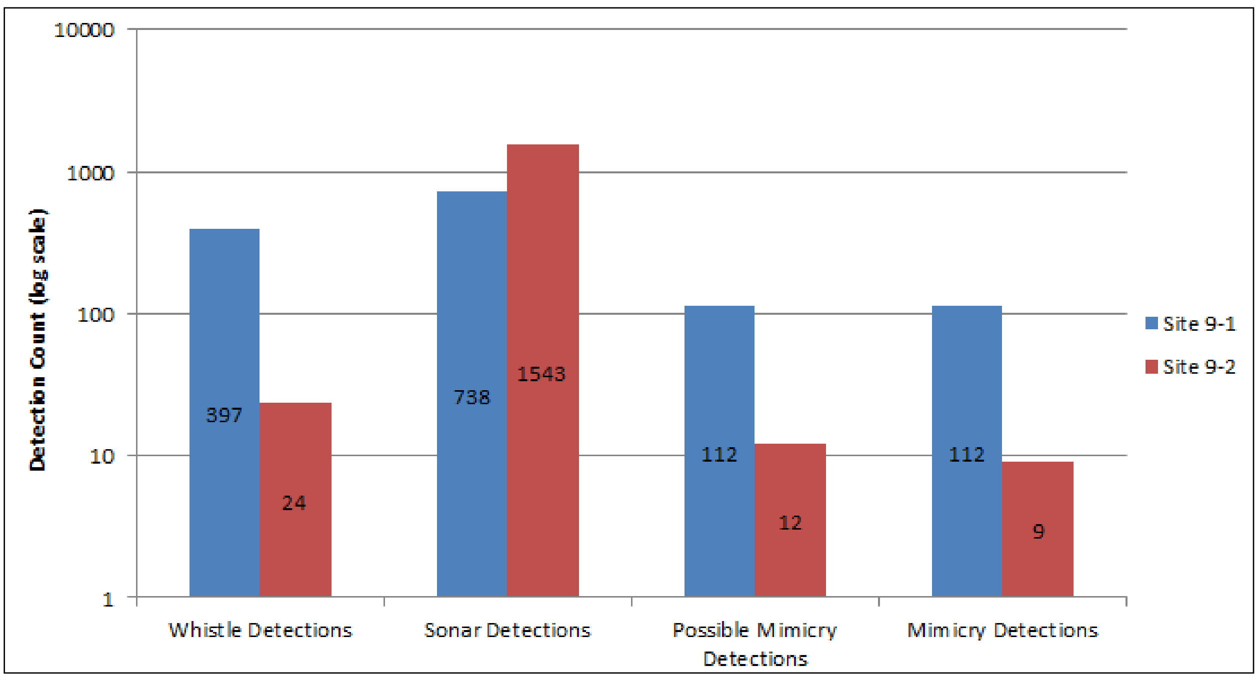

Figure 62. Occurrence of Mimicry Detections and Possible Mimicry Detections during Whistle and Sonar Events. The y-axis count values (log-scale) of individual detections of regular whistles, sonar, possible mimicry, and definite mimicry are plotted for Site 9-1 (12 September 2009) and Site 9-2 (10 December 2009).

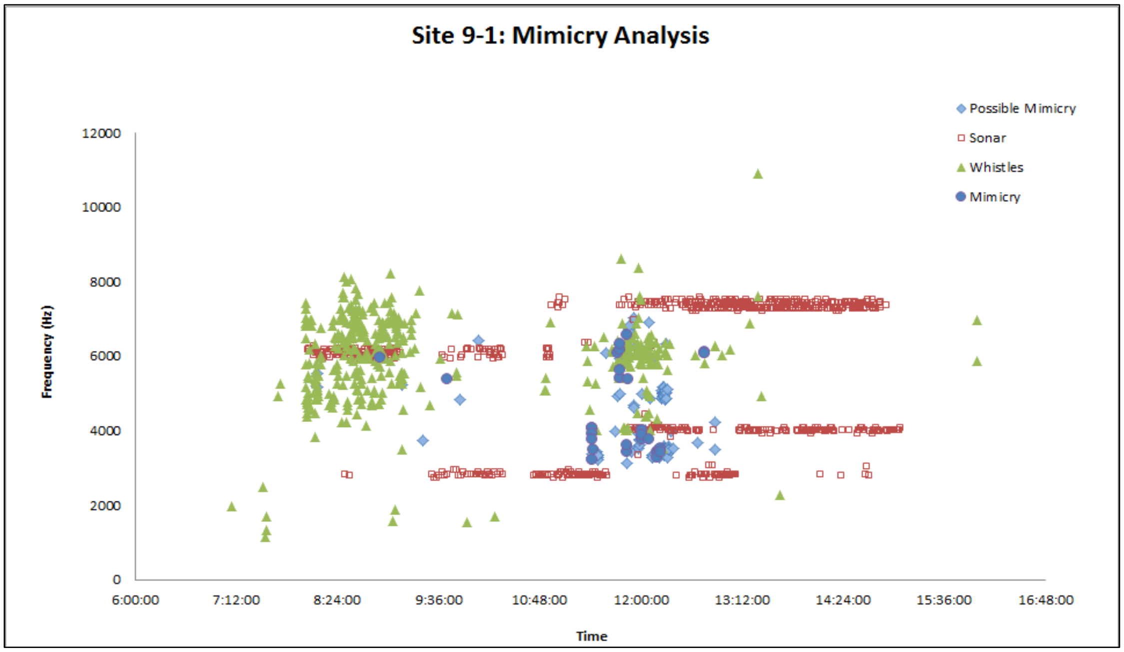

Figure 63. Occurrence of Mimicry during Whistle and Sonar Events at Site 9-1. On 12 September 2009 at Site 9-1, a 9-hr period was analyzed to look for mimicry of sonar. The instances of regular whistles (green triangles), possible mimicry (blue triangles), probable mimicry (blue circles), and sonar occurrence (red squares) are plotted by start frequency (y-axis) and time (x-axis).

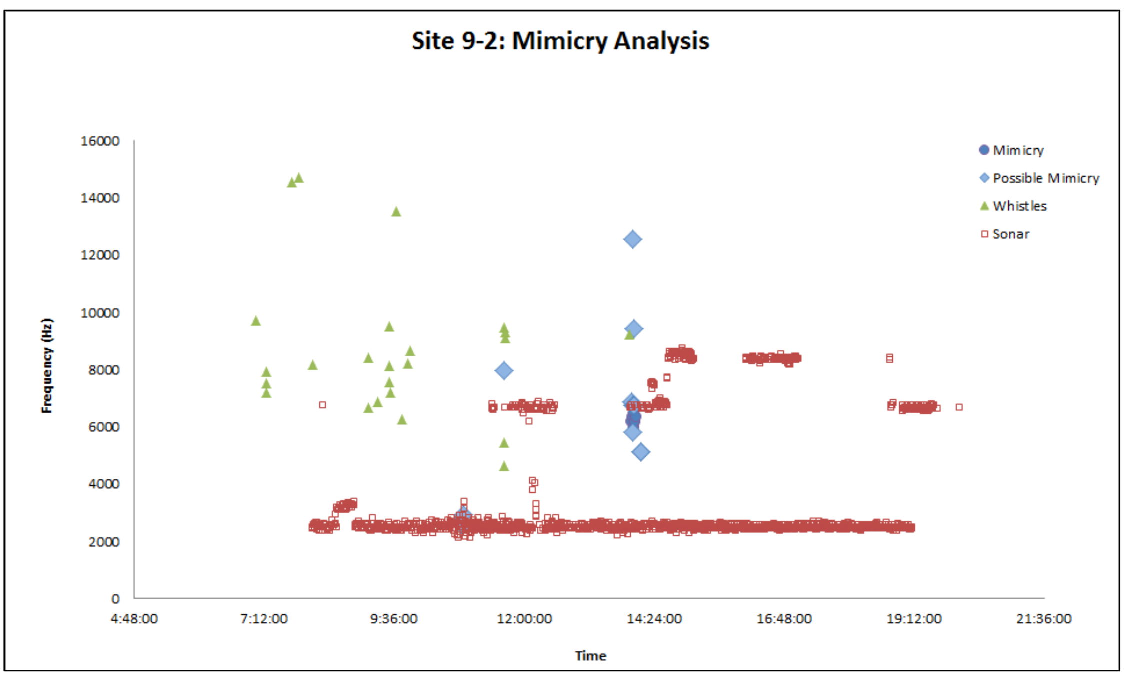

Figure 64. Occurrence of Mimicry during Whistle and Sonar Events at Site 9-2. On 10 December 2009 at Site 9, a 12-hr period was analyzed to look for mimicry of sonar. The instances of regular whistles (green triangles), possible mimicry (blue triangles), probable mimicry (blue circles), and sonar occurrence (red squares) are plotted by start frequency (y-axis) and time (x-axis).

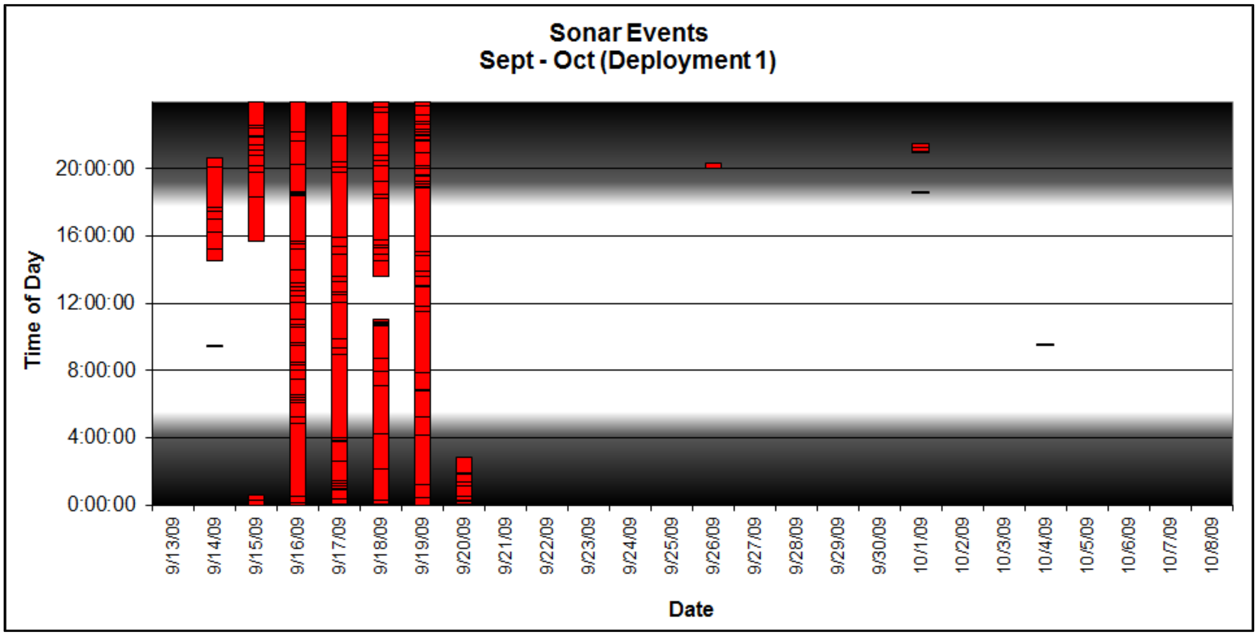

Figure 65. Deployment 1 - MFAS Events by Day and Time. Sonar events are shown in red with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

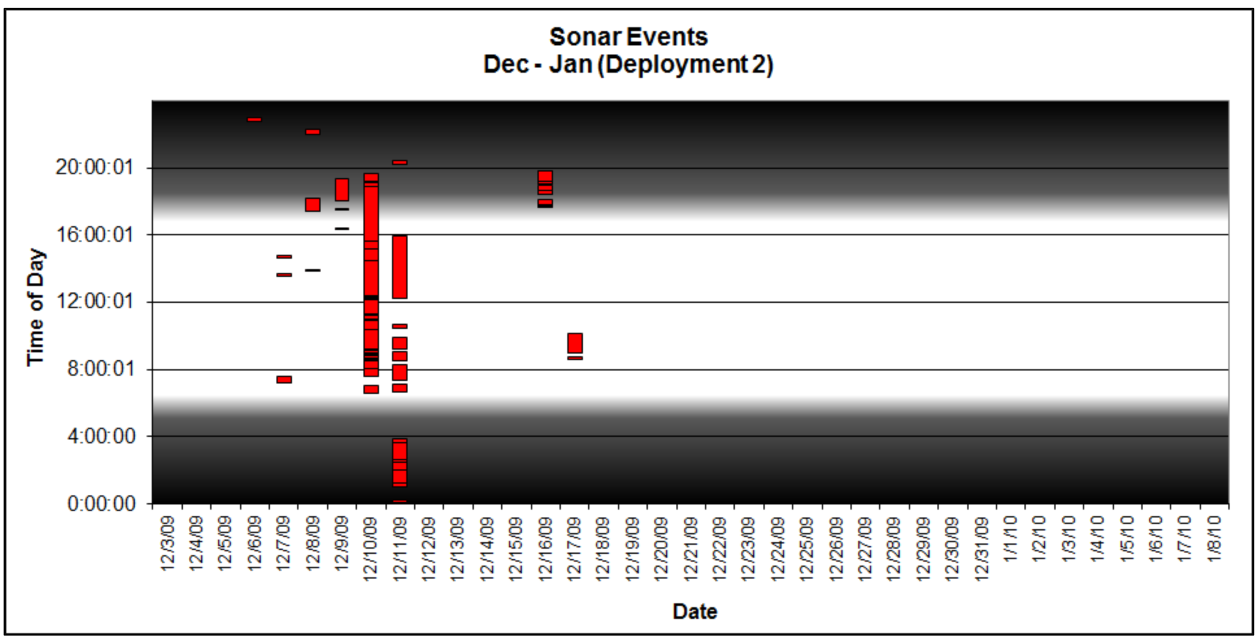

Figure 66. Deployment 2 - MFAS Events by Day and Time. Sonar events are shown in red with time of day (y-axis) and date (x-axis). Shading represents average daylight (white) and darkness (black) for the deployment period. The dotted red line indicates the date after which only 2-kHz recorders were operating.

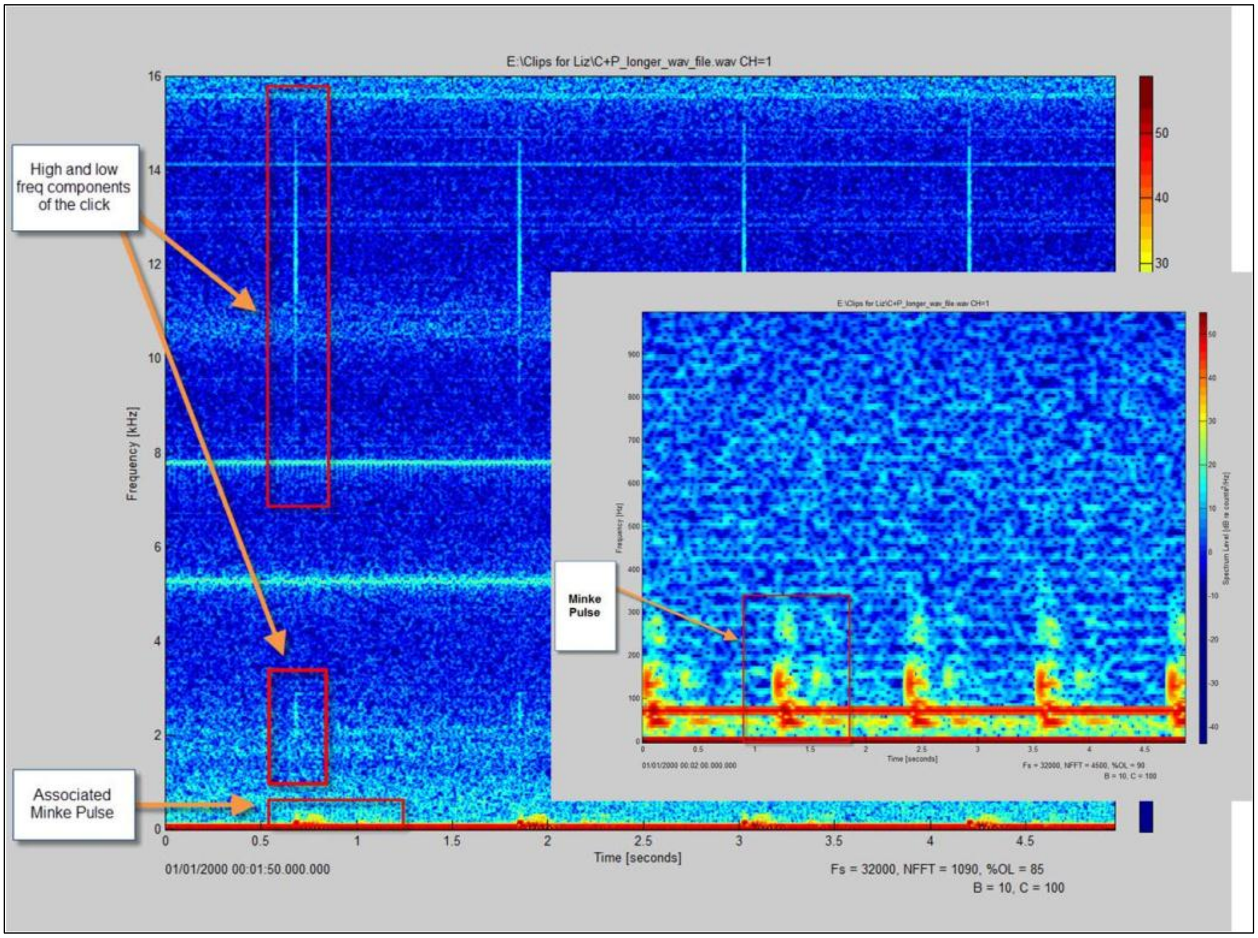

Figure 67. Example of Previously Undescribed Minke Whale Call. Spectrogram of minke whale low-frequency pulse with high-frequency click (LF pulse + HF click). The low-frequency pulse and the clicks always start at exactly the same time; therefore, we consider them to be produced by the same individual. The main energy in the low-frequency pulse was between approximately 50 Hz and 300 Hz (the lower end of was difficult to ascertain due to the tonal noise band from the MARU recorder). The pulse duration was approximately 0.25 seconds. The clicks extended from approximately 2 kHz to over 16 kHz, with stronger components at 2.2 to 3 kHz and from 5 to 16 kHz. The inter-pulse intervals were approximately 0.95 seconds for the pulses and 1.18 seconds for the clicks (due to their shorter durations). The pulses generally occurred about 2.5 minutes after a pulse-train and lasted for several minutes.

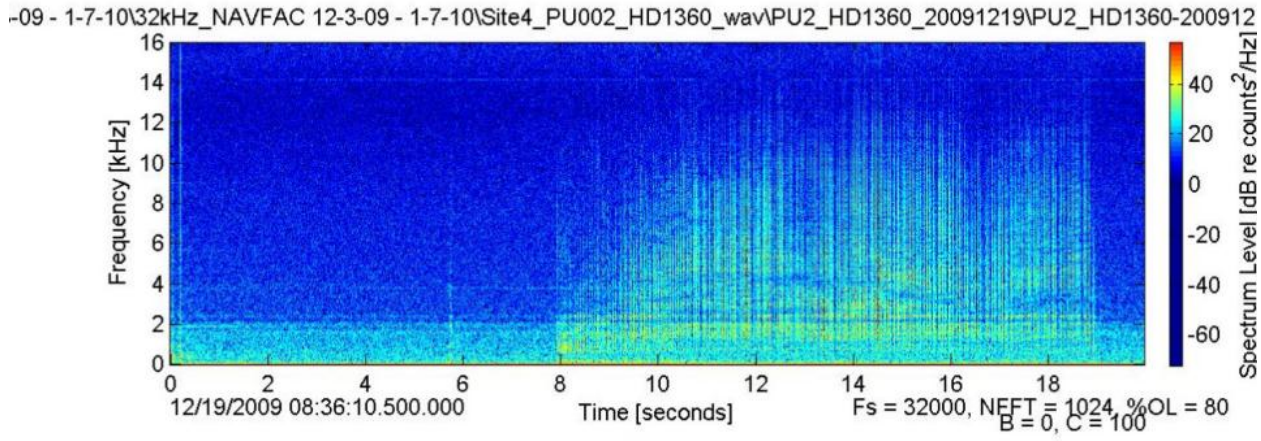

Figure 68. Example #1 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval, and occurred in a large repertoire of patterns, such as creaks, rapid clicks, etc.

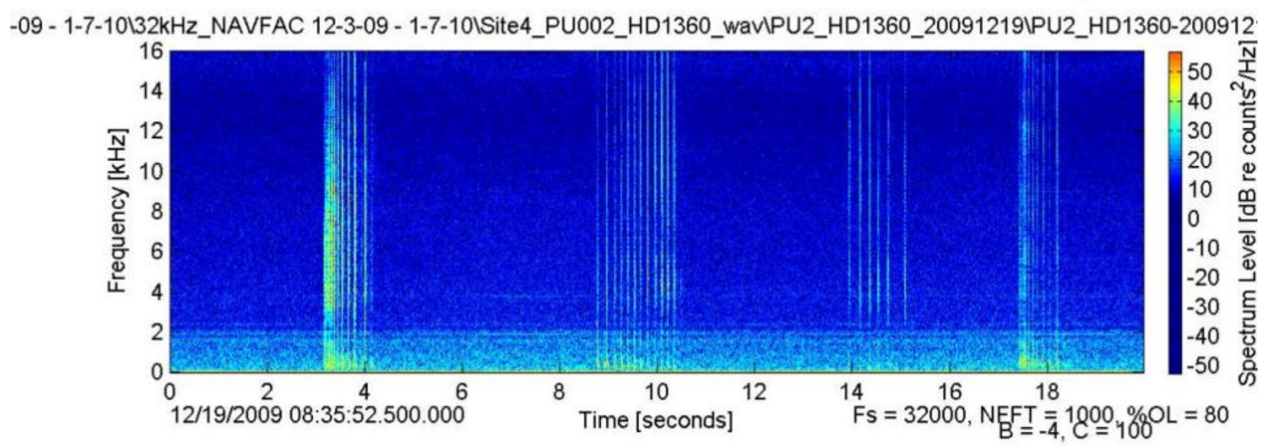

Figure 69. Example #2 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval and contains a large repertoire of patterns, such as creaks, rapid clicks, etc.

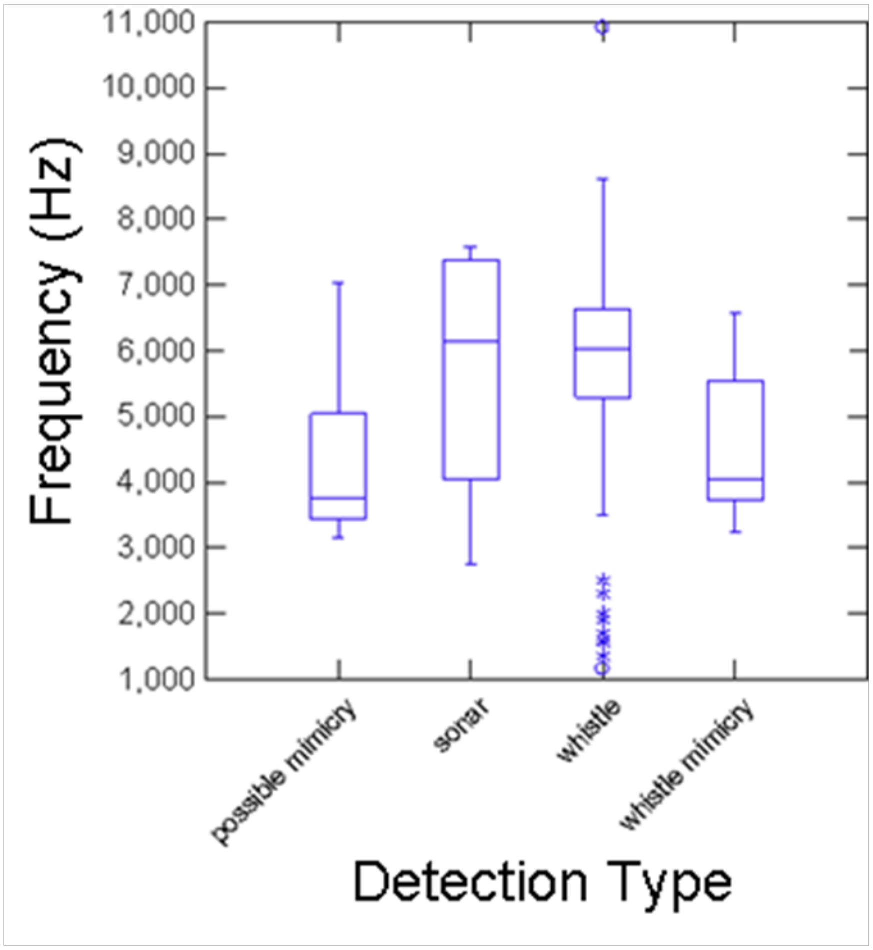

Figure 70. Frequency Ranges of Mimicry, Possible Mimicry, Whistles and, Whistle Mimicry at Site 9-1 (12 September 2009). This box plot shows frequency (y-axis) values (Hz) for each detection type (possible mimicry, sonar, whistles, and probable 'whistle mimicry'). The median of the sample is shown by the center line. The box shows the inter-quartile range (containing the central 50 percent of the values) with the edges at the first and third quartile ranges. The vertical lines show the range of values that fall within 1.5 of the interquartile range. Values between the inner and outer edges of the box are plotted with asterisks. Values beyond the outer edge are plotted with empty circles.

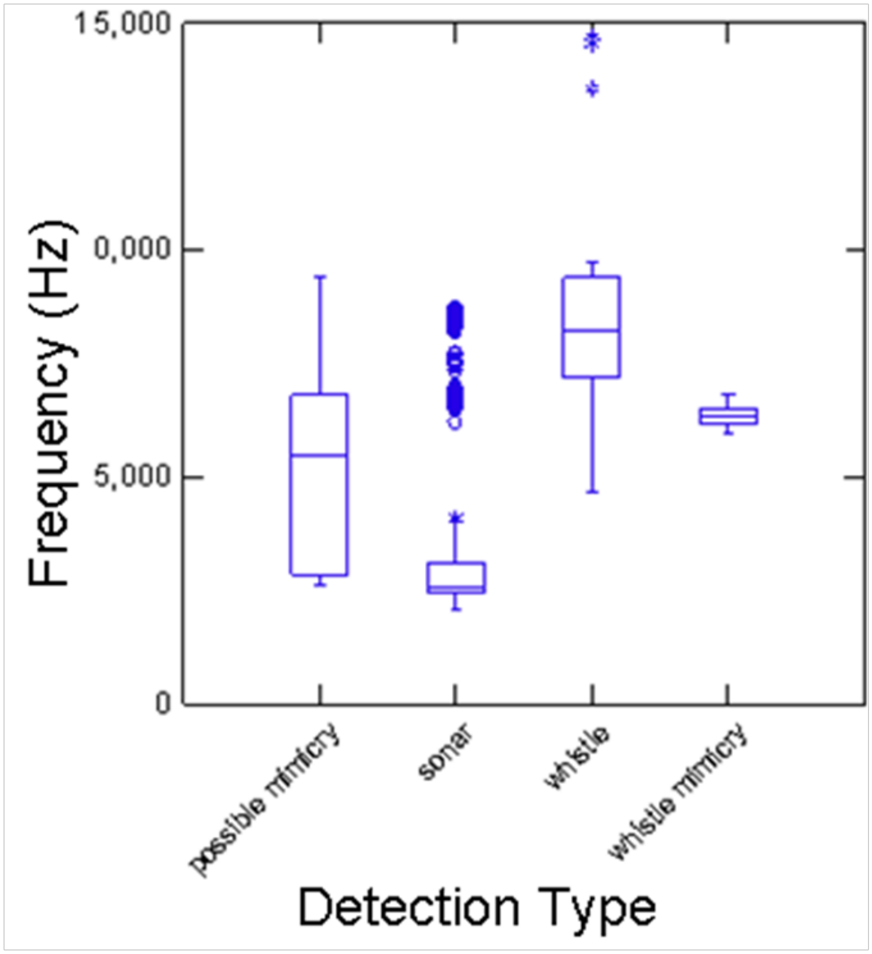

Figure 71. Frequency Range of Mimicry, Possible Mimicry, Whistles and, Whistle Mimicry at Site 9-2. This box plot shows frequency (y-axis) values (Hz) for each detection type (possible mimicry, sonar, whistles, and probable 'whistle mimicry'). The median of the sample is shown by the center line. The box shows the inter-quartile range (containing the central 50 percent of the values) with the edges at the first and third quartile ranges. The vertical lines show the range of values that fall within 1.5 of the interquartile range. Values between the inner and outer edges of the box are plotted with asterisks. Values beyond the outer edge are plotted with empty circles.

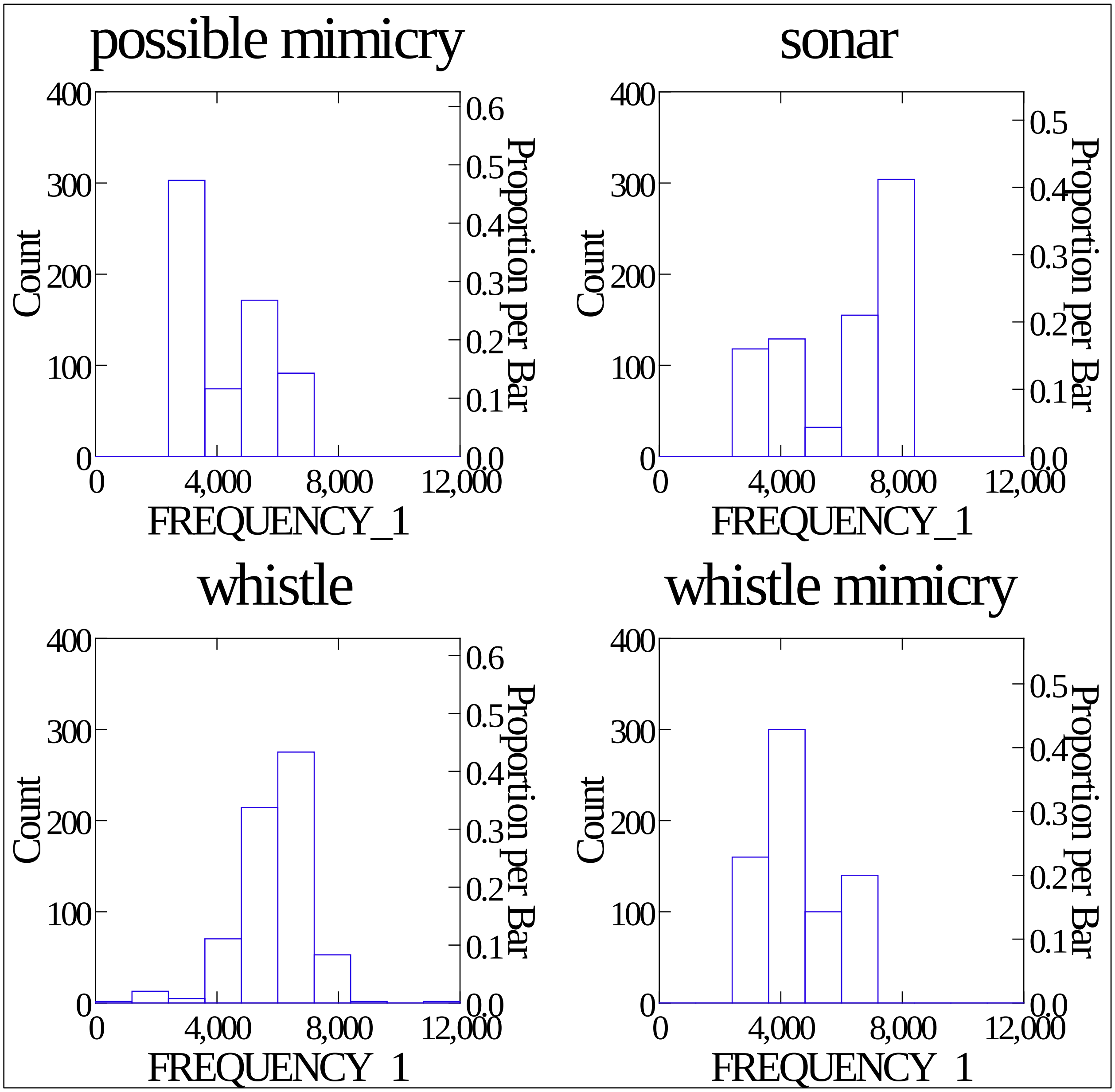

Figure 72. Mimicry Whistle Frequencies Compared to Typical Whistles and Sonar at Site 9-1. Plots show histograms of frequency (Hz) distribution (x-axis) for each detection category.

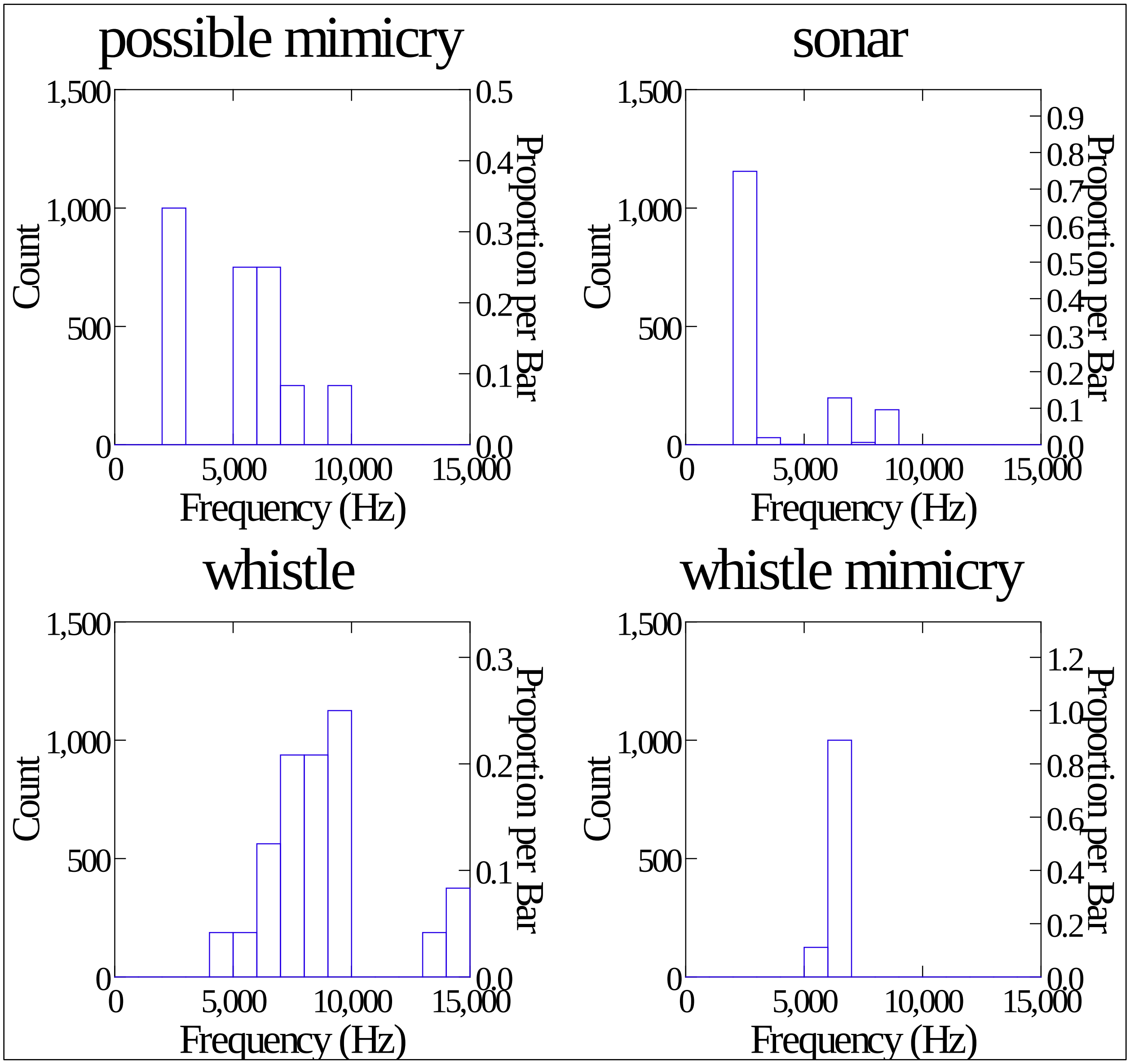

Figure 73. Mimicry Whistle Frequencies Compared to Typical Whistles and Sonar at Site 9-2. Plots show histograms of frequency (Hz) distribution (x-axis) for each detection category.

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9. TABLES

Table 1. Deployment 1 MARU Information

	Site ID 1	Site ID 2	Site ID 3	Site ID 4	Site ID 5	Site ID 6	Site ID 7	Site ID 8	Site ID 9
Popup ID	157	165	24	2	74	96	186	166	171
Deployment Date	9/13/2009	9/13/2009	9/13/2009	9/13/2009	9/13/2009	9/13/2009	9/13/2009	9/13/2009	9/13/2009
Recovery Date	10/8/2009	10/8/2009	10/8/2009	10/8/2009	10/8/2009	10/8/2009	10/8/2009	10/8/2009	10/8/2009
Target Latitude	30° 03.000 N	30° 09.816 N	30° 16.657 N	30° 21.430 N	30° 14.492 N	30° 07.600 N	30° 05.223 N	30° 12.050 N	30° 19.081 N
Target Longitude	80° 06.600 W	80° 04.980 W	80° 03.356 W	80° 09.352 W	80° 10.905 W	80° 12.500 W	80° 20.056 W	80° 18.600 W	80° 17.004 W
Actual Latitude	30° 03.015 N	30° 09.867 N	30° 16.686 N	30° 21.435 N	30° 14.505 N	30° 07.594 N	30° 05.218 N	30° 12.052 N	30° 19.092 N
Actual Longitude	80° 06.575 W	80° 04.966 W	80° 03.361 W	80° 09.331 W	80° 10.879 W	80° 12.486 W	80° 20.055 W	80° 18.585 W	80° 17.010 W
Site Depth (m)	> 300	> 300	> 300	167.6	201.4	191.7	44.5	46.3	44.5
Sampling Rate	2 kHz	32 kHz	2 kHz	32 kHz	32 kHz	32 kHz	32 kHz	2 kHz	32 kHz

Table 2. Deployment 2 MARU Information

	Site ID 1	Site ID 2	Site ID 3	Site ID 4	Site ID 5	Site ID 6	Site ID 7	Site ID 8	Site ID 9
Popup ID	157	165	24	2	74	96	186	166	171
Deployment Date	12/4/2009	12/4/2009	12/4/2009	12/4/2009	12/4/2009	12/4/2009	12/4/2009	12/4/2009	12/4/2009
Recovery Date	1/7/2010	1/7/2010	1/7/2010	1/7/2010	1/7/2010	1/7/2010	1/7/2010	1/7/2010	1/7/2010
Target Latitude	30° 03.000 N	30° 09.816 N	30° 16.657 N	30° 21.430 N	30° 14.492 N	30° 07.600 N	30° 05.223 N	30° 12.050 N	30° 19.081 N
Target Longitude	80° 06.600 W	80° 04.980 W	80° 03.356 W	80° 09.352 W	80° 10.905 W	80° 12.500 W	80° 20.056 W	80° 18.600 W	80° 17.004 W
Actual Latitude	30° 3.005 N	30° 9.854 N	30° 16.680 N	30° 21.357 N	30° 14.480 N	30° 7.609 N	30° 5.220 N	30° 12.019 N	30° 19.051 N
Actual Longitude	80° 6.508 W	80° 4.981 W	80° 3.332 W	80° 9.170 W	80° 10.843 W	80° 12.503 W	80° 20.000 W	80° 18.581 W	80° 16.984 W
Site Depth (m)	> 300	> 300	> 300	~182	~182	~182	44.2	45.7	44.2
Sampling Rate	2 kHz	32 kHz	2 kHz	32 kHz	32 kHz	32 kHz	32 kHz	2 kHz	32 kHz

Table 3. Deployment 1 Data Summary

Sample rate:	2 kHz	32 kHz
Number of buoys:	3	6
Avg. time recorded per unit*	626 hr	626 hr
Number of days recorded per site	25	21
Data recorded per site	8.3 GB	111 GB
Total time recorded (all sites)*	1,878 hr	3,756 hr
Total data recorded (all sites)	25 GB	666 GB
Total hours data reviewed - 2 kHz (all sites)	1756 hr	2,912 hr**
Total hours data reviewed - 32 kHz (all sites)	N/A	2,912 hr

* This is based on an average (per recorder) and includes time that the recorder was out of the water.

** These data were downsampled to 2 kHz.

Table 4. Deployment 2 Data Summary

Sample rate:	2 kHz	32 kHz
Number of buoys:	3	6
Avg. time recorded per unit*	827 hr	827 hr
Number of days recorded per site	34	21
Data recorded per site	11.3 GB	111 GB
Total time recorded (all sites)	2481 hr	4962 hr
Total data recorded (all sites)	34 GB	666 GB
Total hours data reviewed (2-kHz) (all sites)	2,388 hr	3,076 hr**
Total hours data reviewed (32-kHz) (all sites)	N/A	3,076 hr

* This is based on and average (per recorder) and includes time that the recorder was out of the water.

** These data were downsampled to 2 kHz.

Table 5. Event Duration by Deployment

Event Type	Deployment 1: Total Event Duration	Deployment 2: Total Event Duration	Total Event Duration
Blackfish	2:17:07	6:35:15	8:52:22
Possible Blackfish	0:36:04	0:39:30	1:15:34
Probable Blackfish	4:11:09	-	4:11:09
Delphinid Species	301:57:01	235:18:16	537:15:17
Possible Delphinid Species	2:21:25	0:27:55	2:49:20
Possible Humpback Whale	-	0:01:24	0:01:24
Minke Whale	-	1429:04:04	1429:04:04
Sperm Whale	297:29:41	395:10:54	692:40:35
Right Whale	8:35:33	2:54:43	11:30:16
Sei Whale	-	8:47:26	8:47:26
Unidentified Baleen Whale	1:55:17	1:42:58	3:38:15
Ship	659:09:51	551:41:08	1210:50:59
Echosounder (active sonar)	4:11:06	12:22:35	16:33:41
MFAS < 5kHz (active sonar)	379:41:59	43:16:42	4:22:58:41
MFAS > 5kHz (active sonar)	155:24:51	52:13:01	2:07:32:52

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APPENDIX A:

List of All MARU Recorders for Deployments 1 and 2. Deployment and Retrieval Dates Indicated in Addition to Total Recording Hours and Total Days Recorded.

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Appendix A:
List of All MARU Recorders for Deployments 1 and 2. Deployment and Retrieval Dates Indicated in Addition to Total Recording Hours and Total Days Recorded.

Sample Rate	Deployment No.	Site No.	Start Date/Time	End Date/Time	Total Recording Hours	Total Days Recorded
2kHz	1	1	9/13/2009 7:40	10/8/2009 12:44	572:33:43	23.9
2kHz	1	3	9/13/2009 9:42	10/8/2009 14:32	575:56:06	24.0
2kHz	1	8	9/13/2009 14:30	10/8/2009 19:09	607:38:45	25.3
2kHzd*	1	2	9/13/2009 8:34	10/4/2009 11:31	493:22:08	20.6
2kHzd	1	4	9/13/2009 10:38	10/4/2009 11:36	489:19:58	20.4
2kHzd	1	5	9/13/2009 11:36	10/4/2009 11:37	487:24:08	20.3
2kHzd	1	6	9/13/2009 12:32	10/4/2009 4:30	478:25:26	19.9
2kHzd	1	7	9/13/2009 13:27	10/4/2009 11:39	483:45:33	20.2
2kHzd	1	9	9/13/2009 15:37	10/4/2009 11:50	479:35:38	20.0
32kHz	1	2	9/13/2009 8:34	10/4/2009 11:31	493:22:08	20.6
32kHz	1	4	9/13/2009 10:38	10/4/2009 11:36	489:19:58	20.4
32kHz	1	5	9/13/2009 11:36	10/4/2009 11:37	487:24:08	20.3
32kHz	1	6	9/13/2009 12:32	10/4/2009 4:30	478:25:26	19.9
32kHz	1	7	9/13/2009 13:27	10/4/2009 11:39	483:45:33	20.2
32kHz	1	9	9/13/2009 15:37	10/4/2009 11:50	479:35:38	20.0
2kHz	2	1	12/5/2009 9:09	1/7/2010 12:39	781:00:32	32.5
2kHz	2	3	12/3/2009 12:16	1/6/2010 15:50	816:33:30	34.0
2kHz	2	8	12/5/2009 14:19	1/8/2010 17:21	790:02:40	32.9
2kHzd	2	2	12/4/2009 10:10	12/26/2009 2:12	520:02:40	21.7
2kHzd	2	4	12/3/2009 12:06	12/26/2009 2:17	515:22:40	21.5
2kHzd	2	5	12/4/2009 13:10	12/26/2009 2:26	513:32:50	21.4
2kHzd	2	6	12/4/2009 14:05	12/26/2009 2:32	511:55:50	21.3
2kHzd	2	7	12/4/2009 15:06	12/26/2009 2:38	508:35:45	21.2
2kHzd	2	9	12/4/2009 17:16	12/26/2009 2:46	506:00:25	21.1
32kHz	2	2	12/4/2009 10:10	12/26/2009 2:12	520:02:40	21.7
32kHz	2	4	12/4/2009 12:09	12/26/2009 2:17	515:22:40	21.5
32kHz	2	5	12/4/2009 13:10	12/26/2009 2:26	513:32:50	21.4
32kHz	2	6	12/4/2009 14:05	12/26/2009 2:32	511:55:50	21.3
32kHz	2	7	12/4/2009 15:06	12/26/2009 2:38	508:35:45	21.2
32kHz	2	9	12/4/2009 17:16	12/26/2009 2:46	506:00:25	21.1

* d represents downsampled data

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APPENDIX B:

MARINE MAMMAL ACOUSTIC EXPERT REVIEWER LIST. LIST OF EXPERT REVIEWERS WHO AIDED IN THE IDENTIFICATION OF UNKNOWN SOUNDS RECORDED BY JACKSONVILLE MARUS.

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Appendix B:
Marine Mammal Acoustic Expert Reviewer List.
List of Expert Reviewers Who Aided in the Identification of Unknown Sounds Recorded by Jacksonville MARUs.

Name	Affiliation	Area of Expertise
Chuck Gagnon	Naval Ocean Processing Facility	blue whales
Danielle Cholewiak	NMFS, Northeast Fisheries Science Center	baleen whales
David Mann	University of South Florida	fish, odontocetes
Denise Risch	NMFS, Northeast Fisheries Science Center	baleen whales
Jennifer Miksis-Olds	Pennsylvania State University	fish, baleen whales
Kathleen Stafford	Applied Physics Laboratory, University of Washington	baleen whales
Catherine Berchok	NMFS, National Marine Mammal Laboratory	baleen whales
Marc Lammers	University of Hawaii	odontocetes, fish
Ana Širović	Scripps Institution of Oceanography	fish, blue whales
Melissa Soldevilla	NMFS, Southeast Fisheries Science Center	odontocetes
Sofie Van Parijs	NMFS, Northeast Fisheries Science Center	baleen whales
Susan Parks	Pennsylvania State University	right whales
Carrie Wall	University of South Florida	fish

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APPENDIX C:

SITE SUMMARY TABLES

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Appendix C:
Site Summary Tables

		Delphinid Species	Possible Delphind Species	Possible Humpback Whale	Minke Whale	Sperm Whale	Right Whale	Possible Sei Whale	Sei Whale	Possible Baleen whale	Unidentified Baleen whale	Blackfish	Probable Blackfish	Possible Blackfish	Unknown	Ship	MFAS < 5-kHz (active sonar)	MFAS > 5-kHz (active sonar)	Echosounder (active sonar)
Deployment 1																			
1* (deep)	**Total Event Duration**	1:05:04	0:04:47	-	-	-	2:36:49	-	-	-	0:20:28	-	-	-	2:04:20	49:55:45	2:20:57	-	-
	% Total Recording Duration	0.19%	0.01%	-	-	-	0.46%	-	-	-	0.06%	-	-	-	0.36%	8.72%	0.41%	-	-
	Average Event Duration	0:05:00	0:01:12	-	-	-	0:06:49	-	-	-	0:03:25	-	-	-	0:04:17	0:49:56	0:28:11	-	-
	# Days w/Event	10	2	-	-	-	13	-	-	-	5	-	-	-	14	24	2	-	-
	# Events	13	4	-	-	-	23	-	-	-	6	-	-	-	29	60	5	-	-
2 (deep)	**Total Event Duration**	71:17:34	0:06:31	-	-	-	0:21:20	-	-	-	1:01:11	0:40:23	-	0:14:34	0:13:12	62:11:38	102:31:39	36:43:15	0:53:14
	% Total Recording Duration	14.45%	0.02%	-	-	-	0.07%	-	-	-	0.21%	0.14%	-	0.05%	0.04%	12.61%	20.78%	7.44%	0.18%
	Average Event Duration	0:37:31	0:01:18	-	-	-	0:00:44	-	-	-	0:15:18	0:06:44	-	0:14:34	0:00:44	0:53:19	7:53:12	5:14:45	0:13:18
	# Days w/Event	20	4	-	-	-	14	-	-	-	4	5	-	1	11	20	7	6	4
	# Events	114	5	-	-	-	29	-	-	-	4	6	-	1	18	70	13	7	4
3* (deep)	**Total Event Duration**	1:16:07	1:58:30	-	-	-	0:22:01	-	-	-	0:06:11	-	-	-	0:18:31	75:49:40	-	-	-
	% Total Recording Duration	0.22%	0.34%	-	-	-	0.06%	-	-	-	0.02%	-	-	-	0.05%	13.17%	-	-	-
	Average Event Duration	0:10:52	0:23:42	-	-	-	0:00:49	-	-	-	0:03:06	-	-	-	0:01:19	1:06:54	-	-	-
	# Days w/Event	7	4	-	-	-	13	-	-	-	1	-	-	-	9	25	-	-	-
	# Events	7	5	-	-	-	27	-	-	-	2	-	-	-	14	68	-	-	-
4 (mid-depth)	**Total Event Duration**	39:07:26	0:01:22	-	-	133:57:46	0:34:38	-	-	-	0:09:56	-	1:24:19	-	1:13:30	95:48:45	42:40:22	14:07:10	0:25:13
	% Total Recording Duration	8.00%	0.005%	-	-	27.38%	0.12%	-	-	-	0.03%	-	0.29%	-	0.25%	19.58%	8.72%	2.89%	0.09%
	Average Event Duration	0:37:16	0:01:22	-	-	2:37:36	0:02:10	-	-	-	0:04:58	-	0:42:09	-	0:06:08	1:23:19	2:40:01	2:01:01	0:12:36
	# Days w/Event	18	1	-	-	19	8	-	-	-	2	-	2	-	6	21	6	5	2
	# Events	63	1	-	-	51	16	-	-	-	2	-	2	-	12	69	16	7	2
5 (mid-depth)	**Total Event Duration**	39:04:03	0:10:15	-	-	52:38:00	0:22:39	-	-	-	0:01:16	-	0:24:40	-	0:08:17	71:04:25	84:58:26	39:57:53	0:29:08
	% Total Recording Duration	8.02%	0.04%	-	-	10.80%	0.08%	-	-	-	0.004%	-	0.08%	-	0.03%	14.58%	17.43%	8.20%	0.10%
	Average Event Duration	0:41:51	0:05:08	-	-	2:55:27	0:01:15	-	-	-	0:00:19	-	0:24:40	-	0:04:09	1:03:39	6:32:11	3:37:59	0:14:34
	# Days w/Event	22	1	-	-	9	11	-	-	-	3	-	1	-	1	20	7	6	1
	# Events	56	2	-	-	18	18	-	-	-	4	-	1	-	2	67	13	11	2
6 (mid-depth)	**Total Event Duration**	60:39:02	-	-	-	110:53:55	1:04:21	-	-	-	0:06:39	-	0:18:00	-	0:14:09	88:00:05	85:31:48	23:10:49	0:51:16
	% Total Recording Duration	12.68%	-	-	-	23.18%	0.22%	-	-	-	0.02%	-	0.06%	-	0.05%	18.39%	17.88%	4.85%	0.18%
	Average Event Duration	0:31:39	-	-	-	2:55:06	0:02:09	-	-	-	0:01:40	-	0:18:00	-	0:01:46	1:11:21	3:43:07	1:46:59	0:17:05
	# Days w/Event	21	-	-	-	16	13	-	-	-	3	-	1	-	6	21	8	5	2
	# Events	115	-	-	-	38	30	-	-	-	4	-	1	-	8	74	23	13	3
7 (shallow)	**Total Event Duration**	59:22:39	-	-	-	-	0:01:30	-	-	-	0:00:03	0:02:12	1:11:55	0:21:28	0:14:52	76:15:35	26:41:33	31:14:09	0:24:27
	% Total Recording Duration	12.27%	-	-	-	-	0.01%	-	-	-	0.0002%	0.01%	0.25%	0.07%	0.05%	15.76%	5.52%	6.46%	0.08%
	Average Event Duration	0:12:35	-	-	-	-	0:00:13	-	-	-	0:00:03	0:01:06	0:17:59	0:07:09	0:07:26	0:53:50	1:54:24	1:14:58	0:12:14
	# Days w/Event	21	-	-	-	-	5	-	-	-	1	2	4	3	2	21	4	6	2
	# Events	283	-	-	-	-	7	-	-	-	1	2	4	3	2	85	14	25	2
8* (shallow)	**Total Event Duration**	0:00:15	-	-	-	-	2:04:01	-	-	-	0:09:33	-	-	-	-	44:19:13	-	-	-
	% Total Recording Duration	0.001%	-	-	-	-	0.34%	-	-	-	0.03%	-	-	-	-	7.29%	-	-	-
	Average Event Duration	0:00:15	-	-	-	-	0:20:40	-	-	-	0:02:23	-	-	-	-	0:37:27	-	-	-
	# Days w/Event	1	-	-	-	-	6	-	-	-	3	-	-	-	-	23	-	-	-
	# Events	1	-	-	-	-	6	-	-	-	4	-	-	-	-	71	-	-	-
9 (shallow)	**Total Event Duration**	30:04:51	-	-	-	-	1:08:14	-	-	0:00:02	-	1:34:32	0:52:15	0:00:02	0:00:33	93:33:50	34:57:14	10:11:35	1:07:48
	% Total Recording Duration	6.27%	-	-	-	-	0.24%	-	-	0.0001%	-	0.33%	0.18%	0.0001%	0.002%	19.51%	7.29%	2.13%	0.24%
	Average Event Duration	0:11:08	-	-	-	-	0:05:41	-	-	-	-	1:34:32	0:52:15	0:00:02	0:00:11	1:07:38	2:54:46	2:32:54	0:16:57
	# Days w/Event	22	-	-	-	-	7	-	-	-	-	1	1	1	3	20	6	4	3
	# Events	162	-	-	-	-	12	-	-	1	-	1	1	1	3	83	12	4	4

		Delphinid Species	Possible Delphind Species	Possible Humpback Whale	Minke Whale	Sperm Whale	Right Whale	Possible Sei Whale	Sei Whale	Possible Baleen whale	Unidentified Baleen whale	Blackfish	Probable Blackfish	Possible Blackfish	Unknown	Ship	MFAS < 5-kHz (active sonar)	MFAS > 5-kHz (active sonar)	Echosounder (active sonar)
Deployment 2																			
1* (deep)	**Total Event Duration**	1:24:39	0:27:14	-	443:44:59	-	0:21:57	-	4:11:27	-	-	-	-	-	0:02:13	36:45:37	3:46:27	-	-
	% Total Recording Duration	0.18%	0.06%	-	56.82%	-	0.05%	-	0.54%	-	-	-	-	-	0.005%	4.71%	0.48%	-	-
	Average Event Duration	0:14:07	0:04:32	-	2:49:35	-	0:01:09	-	0:12:34	-	-	-	-	-	0:00:15	0:38:02	0:32:21	-	-
	# Days w/Event	4	5	-	34	-	8	-	4	-	-	-	-	-	5	29	1	-	-
	# Events	6	6	-	157	-	19	-	20	-	-	-	-	-	9	58	7	-	-
2 (deep)	**Total Event Duration**	33:53:32	-	-	207:56:35	-	0:58:55	-	0:03:00	-	0:33:38	0:03:45	-	-	-	24:28:10	3:39:35	13:14:13	2:23:10
	% Total Recording Duration	6.52%	-	-	39.99%	-	0.19%	-	0.01%	-	0.11%	0.01%	-	-	-	4.71%	0.70%	2.55%	0.46%
	Average Event Duration	0:18:00	-	-	1:57:42	-	0:05:21	-	0:03:00	-	0:11:13	0:03:45	-	-		0:32:38	0:54:54	1:53:28	1:11:35
	# Days w/Event	22	-	-	19	-	2	-	1	-	2	1	-	-	-	20	3	3	2
	# Events	113	-	-	106	-	11	-	1	-	3	1	-	-	-	45	4	7	2
3* (deep)	**Total Event Duration**	0:00:01	-	-	462:34:55	-	0:12:46	-	3:23:35	-	0:13:33	-	-	-	-	138:39:25	1:20:53	-	-
	% Total Recording Duration	0.00003%	-	-	56.65%	-	0.03%	-	0.42%	-	0.03%	-	-	-	-	16.98%	0.17%	-	-
	Average Event Duration	0:00:01	-	-	3:06:16	-	0:01:25	-	0:13:34	-	0:03:23	-	-	-	-	2:46:23	0:40:27	-	-
	# Days w/Event	1	-	-	34	-	9	-	8	-	3	-	-	-	-	25	1	-	-
	# Events	1	-	-	149	-	9	-	15	-	4	-	-	-	-	50	2	-	-
4 (mid-depth)	**Total Event Duration**	13:05:28	-	-	145:44:42	80:28:21	0:00:12	-	0:00:01	-	0:09:56	-	-	0:10:10	0:00:08	64:54:35	0:43:55	11:07:00	0:42:10
	% Total Recording Duration	2.54%	-	-	28.28%	15.61%	0.001%	-	0.0001%	-	0.03%	-	-	0.03%	0.0004%	12.59%	0.14%	2.16%	0.14%
	Average Event Duration	0:14:49	-	-	1:55:04	5:21:53	0:00:02		0:00:01		0:02:29			0:10:10	0:00:04	0:58:08	0:21:57	11:07:00	0:10:32
	# Days w/Event	21	-	-	18	11	5	-	1	-	3	-	-	1	2	22	1	1	2
	# Events	53	-	-	76	15	6	-	1	-	4	-	-	1	2	67	2	1	4
5 (mid-depth)	**Total Event Duration**	18:19:51	-	-	105:01:39	64:13:09	0:20:17	-	0:00:04	-	0:07:19	-	-	0:01:26	0:00:10	43:32:13	3:59:00	15:12:38	-
	% Total Recording Duration	3.57%	-	-	20.45%	12.51%	0.07%	-	0.0002%	-	0.02%	-	-	0.005%	0.001%	8.48%	0.78%	2.96%	-
	Average Event Duration	0:17:11	-	-	1:38:28	4:16:53	0:00:53		0:00:02		0:03:40	-	-	0:01:26	0:00:05	0:46:39	0:59:45	1:22:58	-
	# Days w/Event	21	-	-	13	10	13	-	2	-	1	-	-	1	2	20	4	6	-
	# Events	64	-	-	64	15	23	-	2	-	2	-	-	1	2	56	4	11	-
6 (mid-depth)	**Total Event Duration**	27:36:57	-	-	61:54:32	250:29:24	0:52:00	-	1:09:18	-	0:29:16	-	-	0:24:04	-	53:08:00	1:35:25	11:58:15	0:09:15
	% Total Recording Duration	5.39%	-	-	12.09%	48.93%	0.17%	-	0.23%	-	0.10%	-	-	0.08%	-	10.38%	0.31%	2.34%	0.03%
	Average Event Duration	0:22:06	-	-	1:01:55	5:13:07	0:02:00		0:08:40		0:07:19	-	-	0:12:02		1:09:18	0:31:48	3:59:25	0:04:37
	# Days w/Event	20	-	-	16	23	13	-	3	-	4	-	-	1	-	18	1	2	2
	# Events	75	-	-	60	48	26	-	8	-	4	-	-	2	-	46	3	3	2
7 (shallow)	**Total Event Duration**	33:55:11	0:00:32	0:01:24	1:03:53	-	0:08:07	-	-	0:02:03	0:00:03	-	-	0:03:50	0:30:30	48:28:05	12:04:50	0:40:55	4:13:30
	% Total Recording Duration	6.67%	0.002%	0.005%	0.21%	-	0.03%	-	-	0.01%	0.0002%	-	-	0.01%	0.10%	9.53%	2.38%	0.13%	0.83%
	Average Event Duration	0:16:49	0:00:16	0:01:24	1:03:53		0:02:02	-	-	0:02:03	0:00:02	-	-	0:03:50	0:04:21	0:44:44	6:02:25	0:20:27	0:31:41
	# Days w/Event	21	2	1	1	-	4	-	-	1	2	-	-	1	4	20	1	1	4
	# Events	121	2	1	1	-	4	-	-	1	2	-	-	1	7	65	2	2	8
8* (shallow)	**Total Event Duration**	0:03:29	-	-	-	-	0:00:03	-	0:00:01	-	0:08:42	-	-	-	2:28:41	52:47:05	6:29:04	-	-
	% Total Recording Duration	0.01%	-	-	-	-	0.0001%	-	0.00004%	-	0.02%	-	-	-	0.31%	6.68%	0.82%	-	-
	Average Event Duration	0:00:52	-	-	-	-	0:00:03	-	0:00:01		0:01:27	-	-	-	0:05:43	0:41:40	1:04:51	-	-
	# Days w/Event	4	-	-	-	-	1	-	1	-	5	-	-	-	10	29	1	-	-
	# Events	4	-	-	-	-	1	-	1	-	6	-	-	-	26	76	6	-	-
9 (shallow)	**Total Event Duration**	82:59:08	0:00:09	-	1:02:49	-	0:00:26	-	-	-	0:00:31	6:31:30	-	-	0:00:37	88:57:58	12:13:43	-	4:54:30
	% Total Recording Duration	16.40%	0.00%	-	0.21%	-	0.001%	-	-	-	0.002%	1.29%	-	-	0.00%	17.58%	2.42%	-	0.97%
	Average Event Duration	0:32:45	0:00:09	-	0:20:56		0:00:13	-	-	-	0:00:16	0:39:09	-	-	0:00:09	0:52:51	1:13:22	-	0:49:05
	# Days w/Event	22	1	-	1	-	2	-	-	-	2	7	-	-	1	21	1	-	3
	# Events	152	1	-	3	-	2	-	-	-	2	28	-	-	4	101	10	-	6

APPENDIX D:

IDENTIFIED EVENTS

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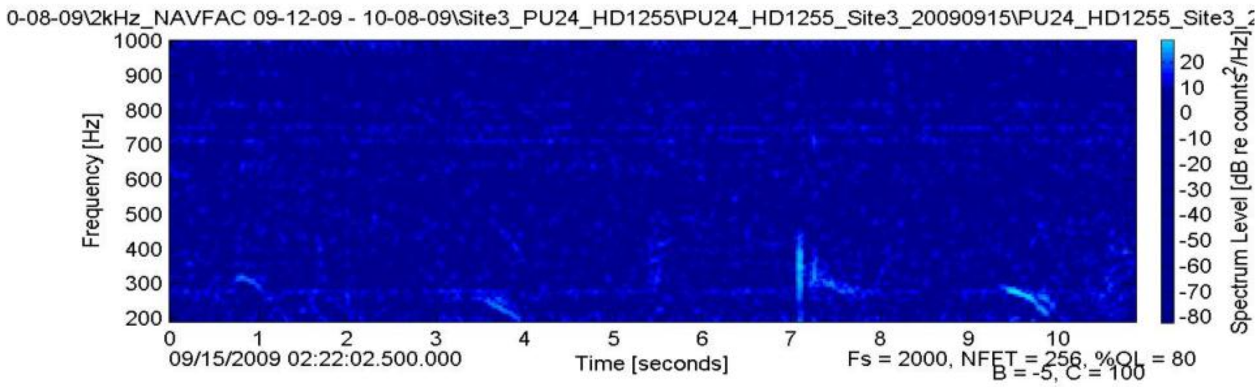
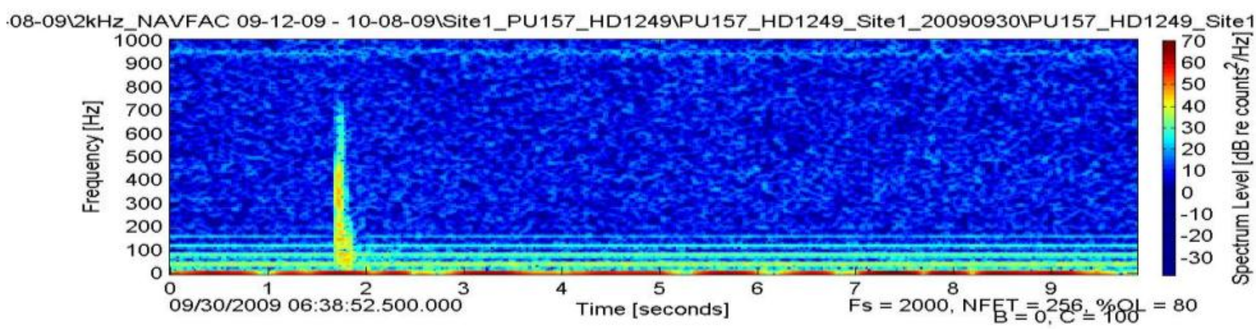
Appendix D:
Identified Events

Example Spectrograms of Identified Acoustic Events

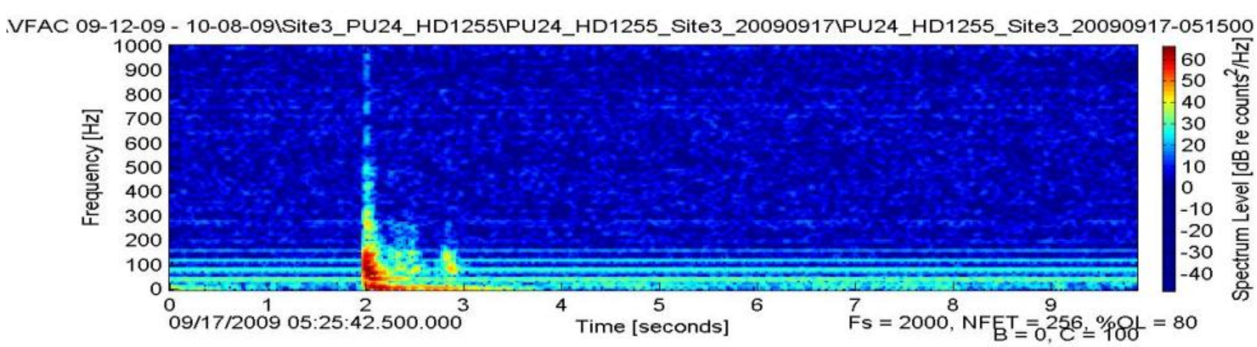
Right Whale



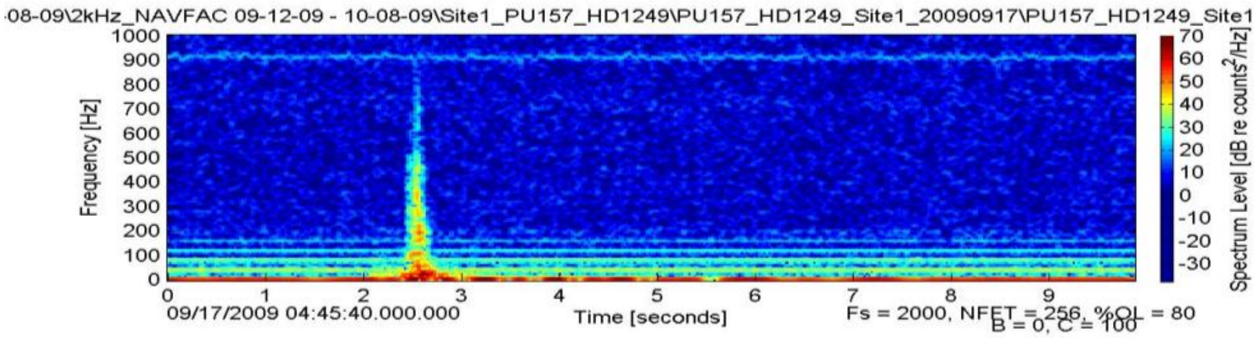
Original Code: C6. Species ID: Right Whale



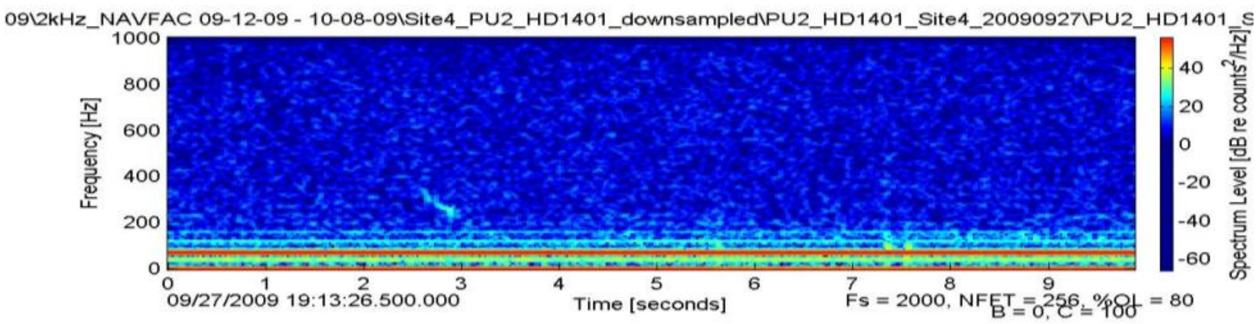
Original Code: LTH. New Code: LTHa. Species ID: RWGS- Right whale gunshot



Original Code: LTH. New Code: LTHc. Species ID: RWGS

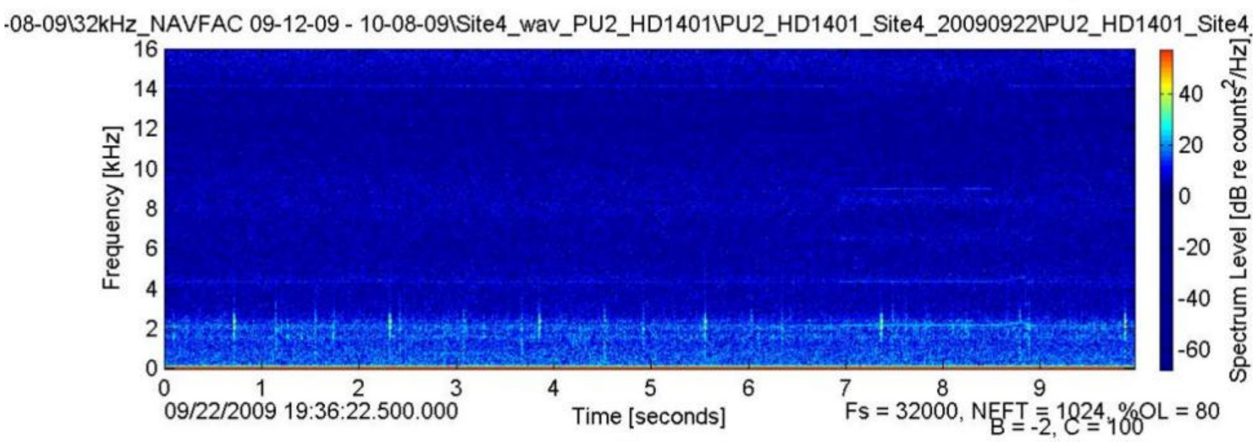


Original Code: LTH. New Code: LTHd. Species ID: Poss RWGS

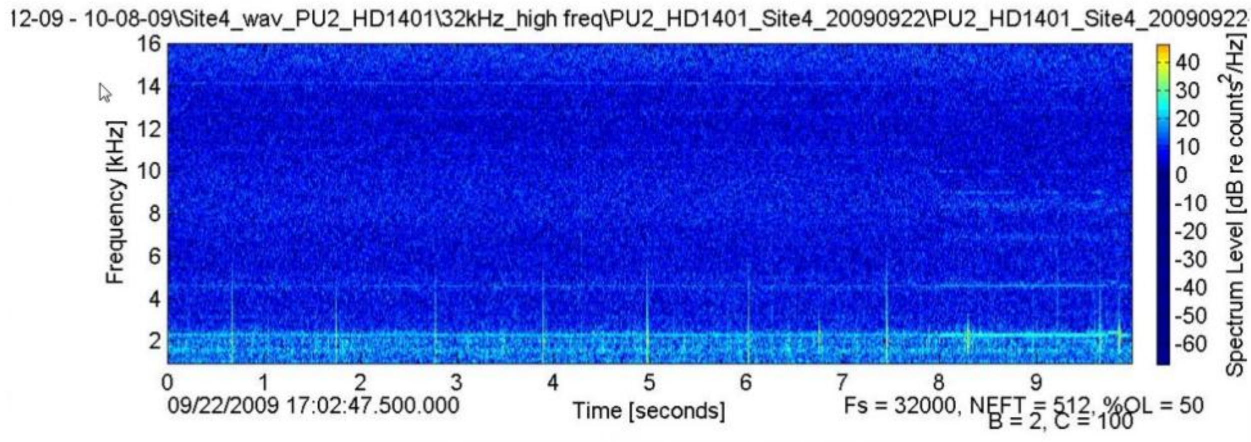


Original Code: MO. New Code: MOdc. Species ID: RW Downcall

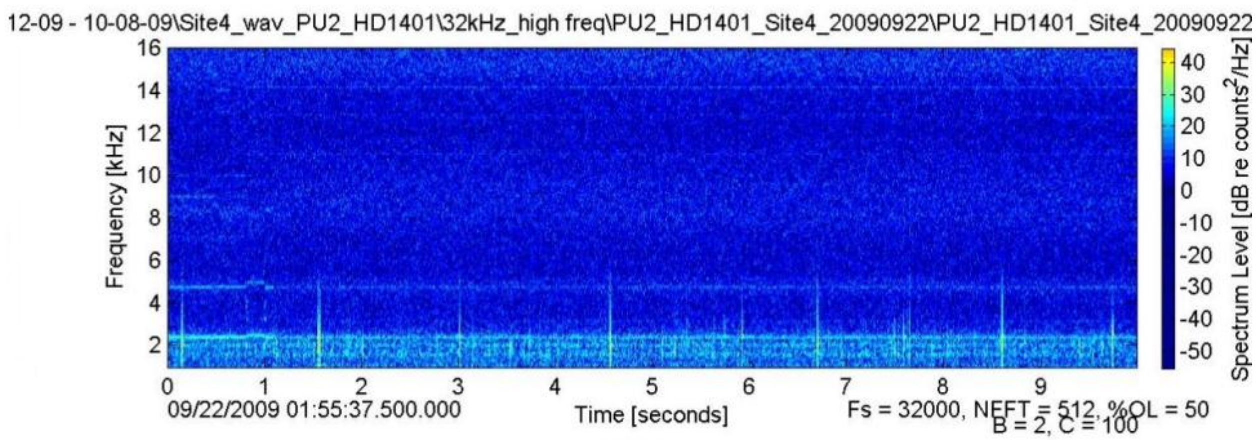
Sperm Whale



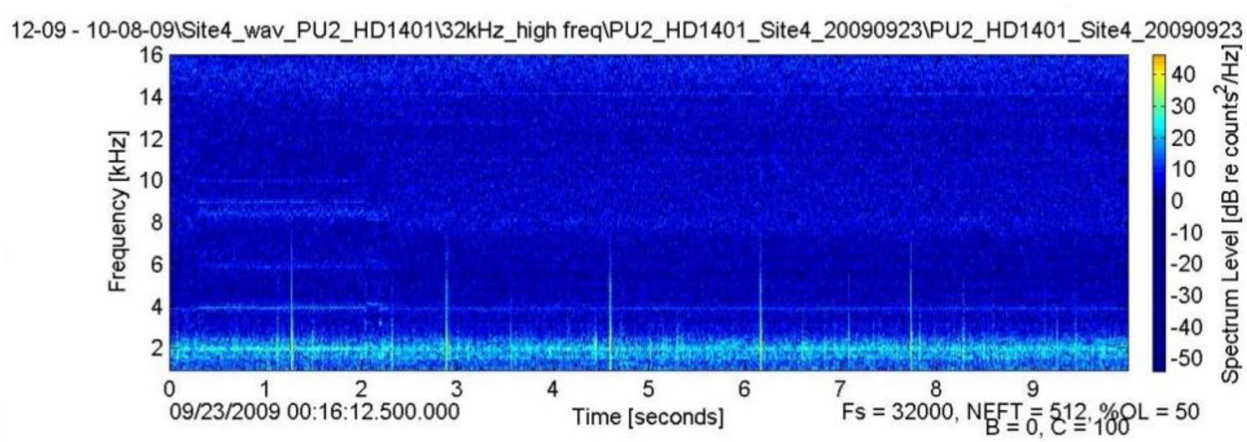
Original Code: PM. Species: Sperm Whale



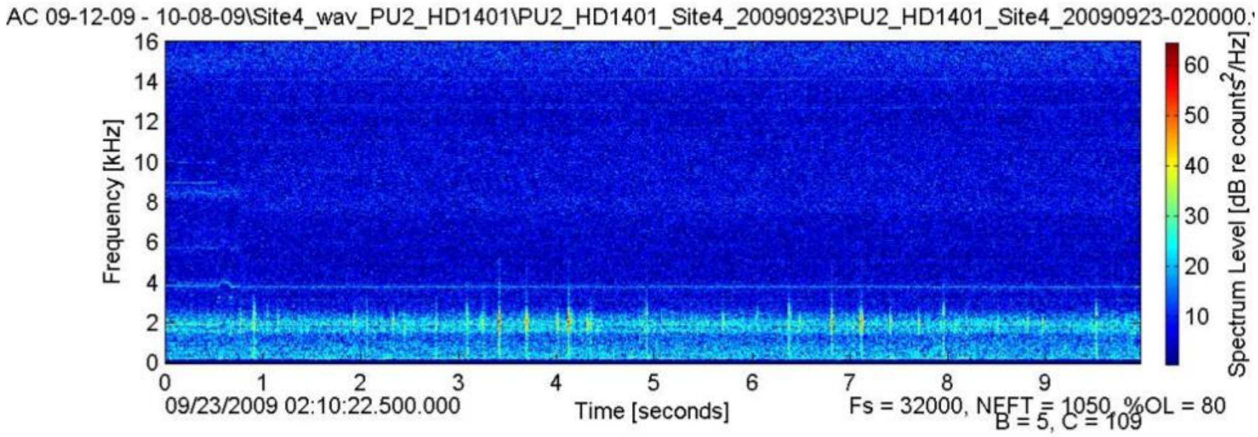
Original Code: PM. Species: Sperm Whale



Original Code: PM. Species: Sperm Whale

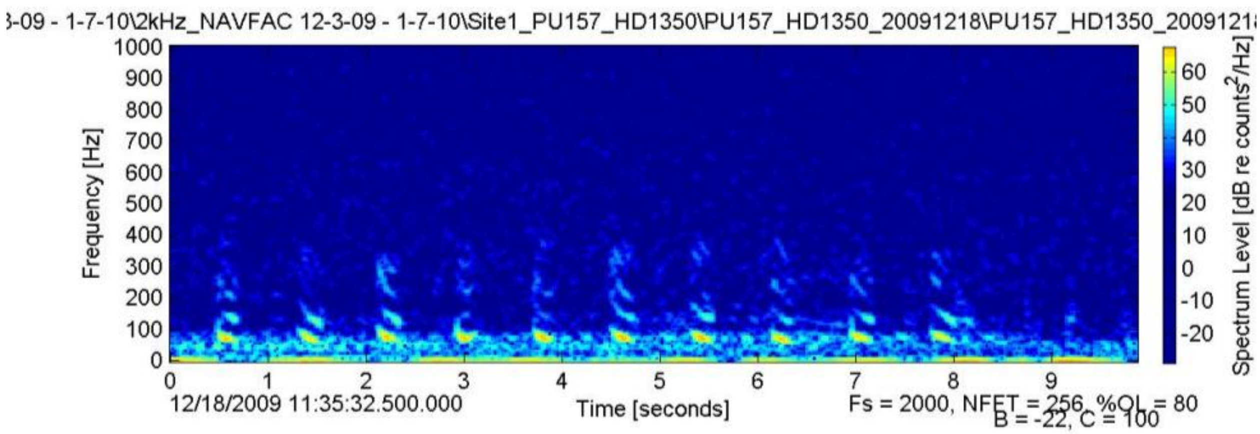


Original Code: PM. Species: Sperm Whale

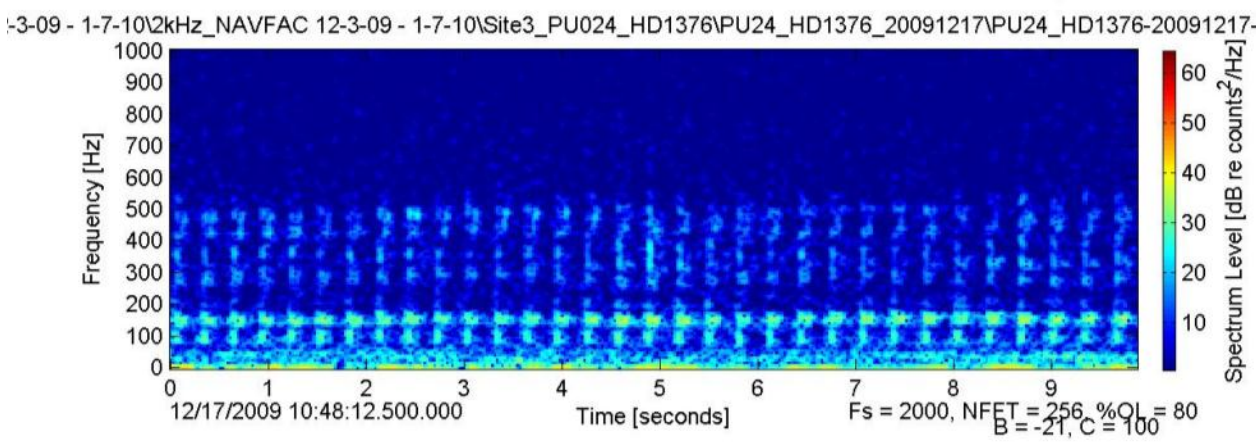


Original Code: PM. Species: Sperm Whale

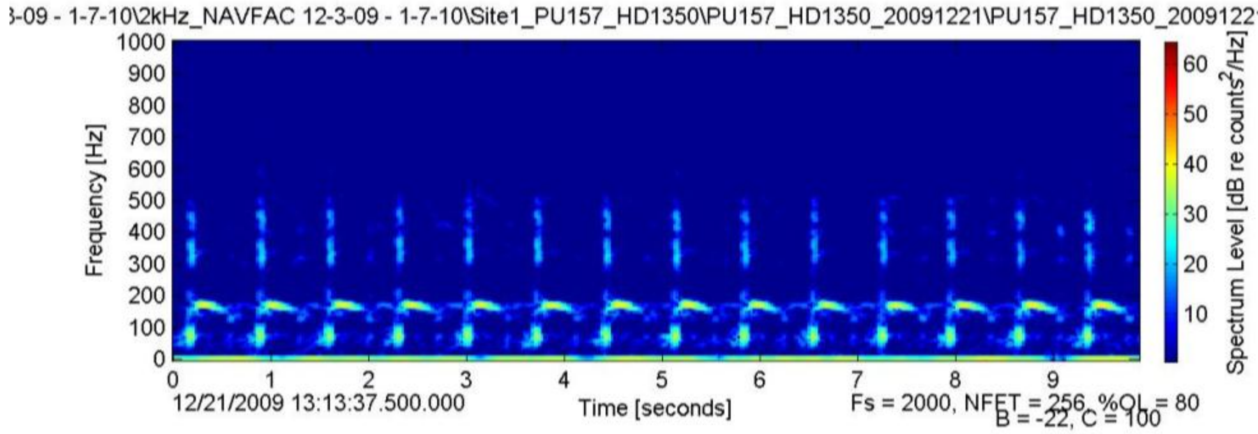
<u>Minke Whale</u>



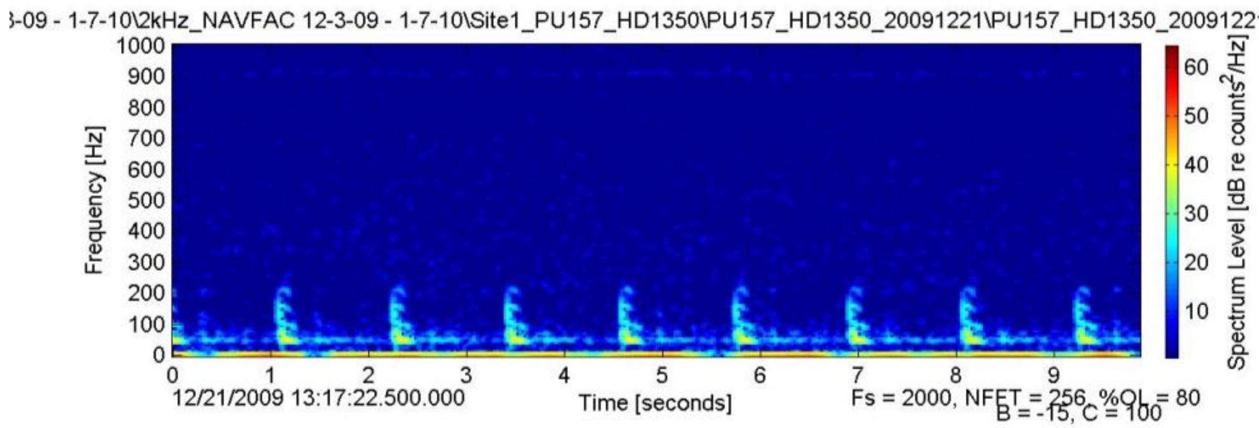
Original Code: C4. Species ID: Minke



Original Code: Minke. Species : Minke Pulse train

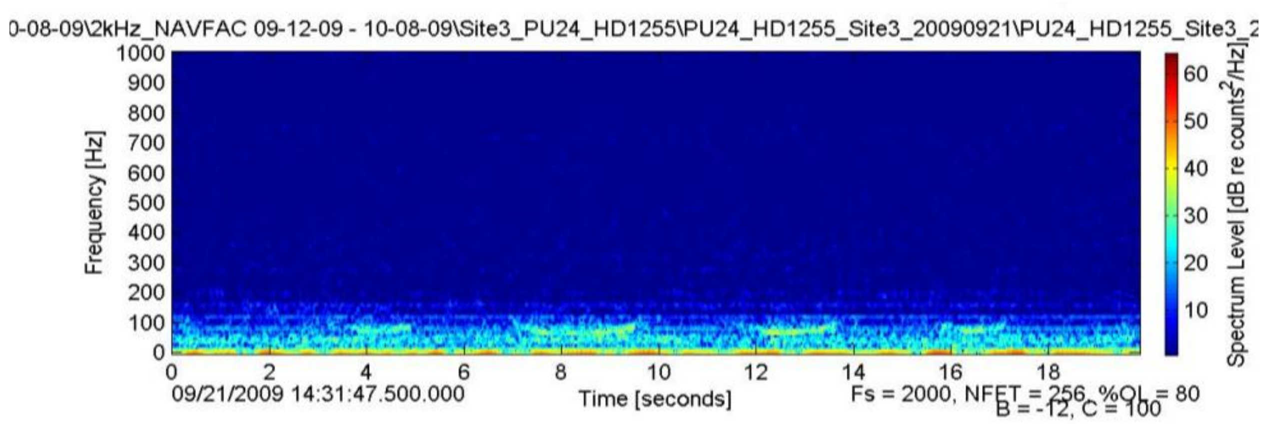


Original Code: Minke. Species : Minke Pulse train

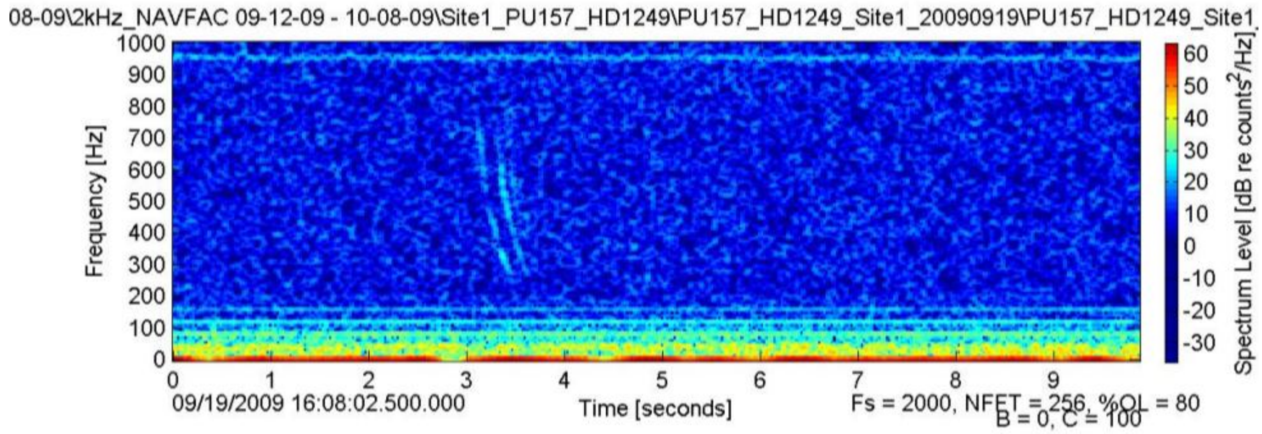


Original Code: MN follow. Species: Minke

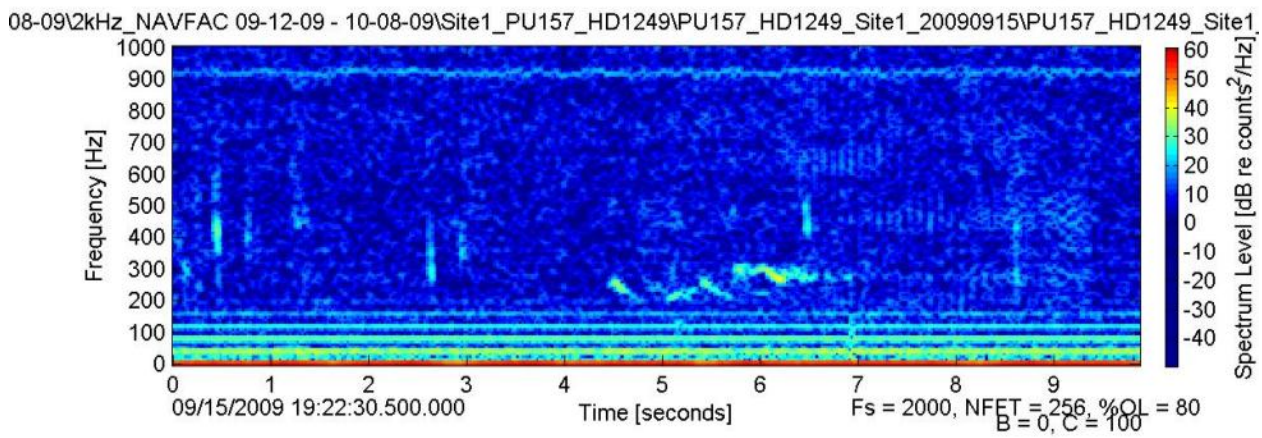
Unidentified Baleen Whale



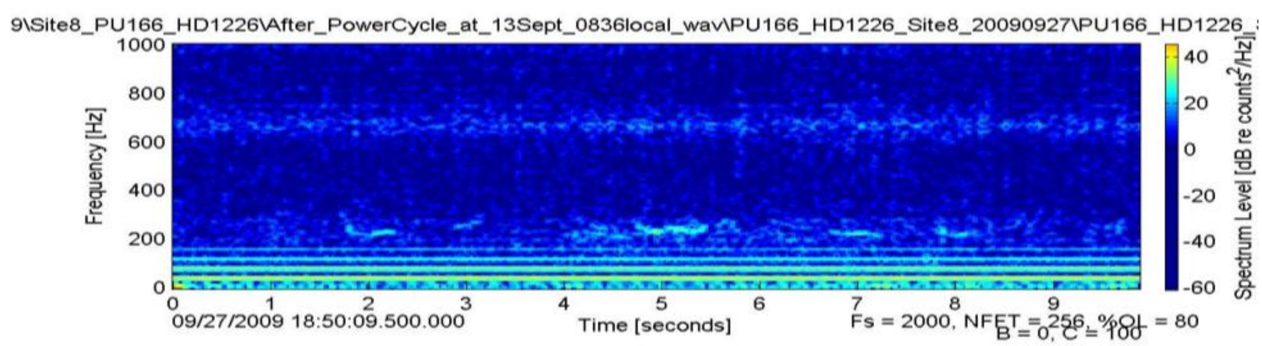
Original Code: C9 . Species ID: Unid baleen whale



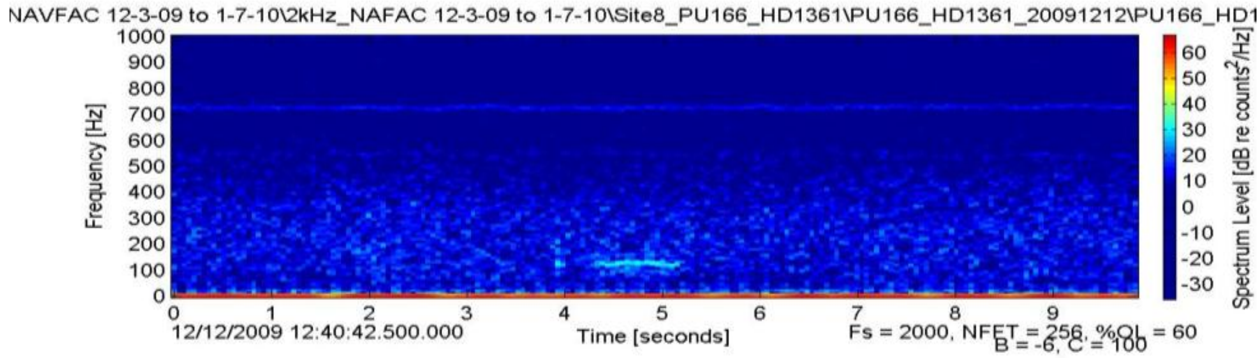
Original Code: DC. Species ID: Unid baleen whale



Original Code: MO CLC. Species ID: Unid baleen whale

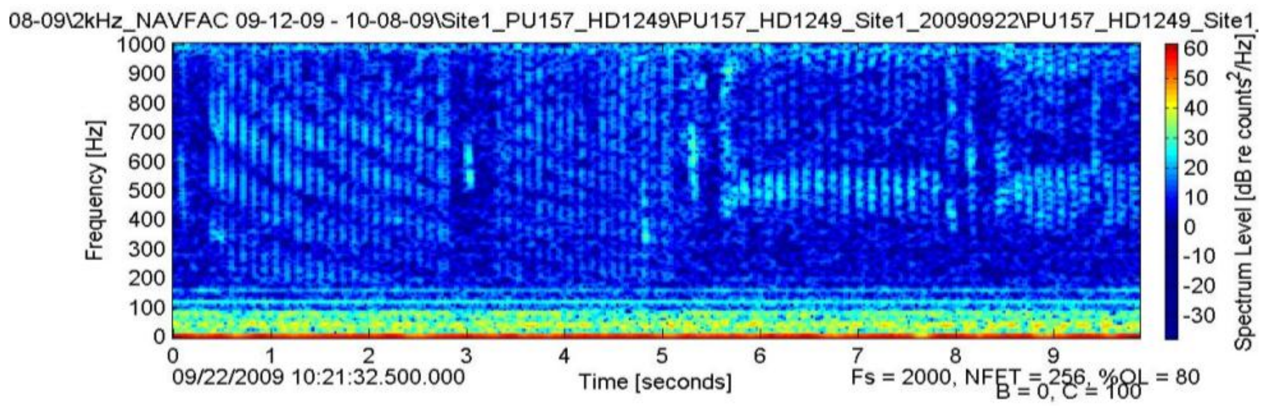


Original Code: MO. New Code: Moa. Species ID: Unid Baleen whale

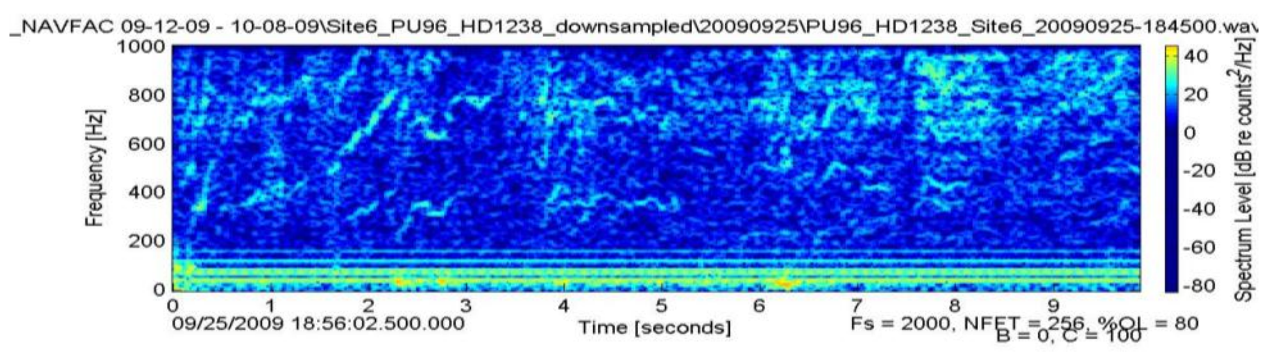


Original Code: MO. New Code: MOm. Species ID: Unid Baleen whale

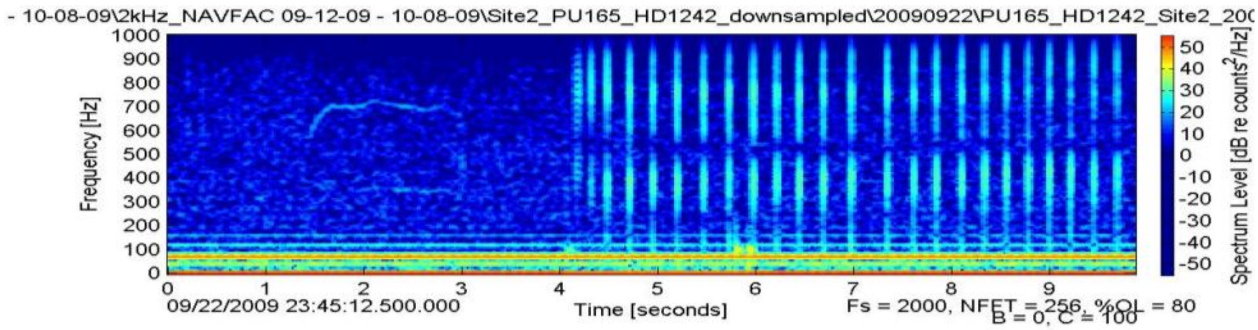
Delphinid Species



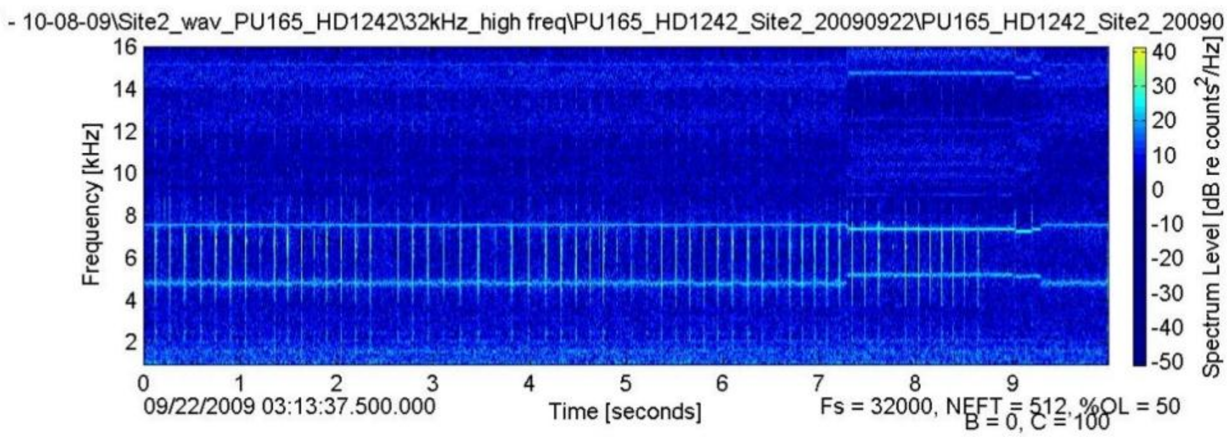
Original Code: Cl. Species ID: Delph spp



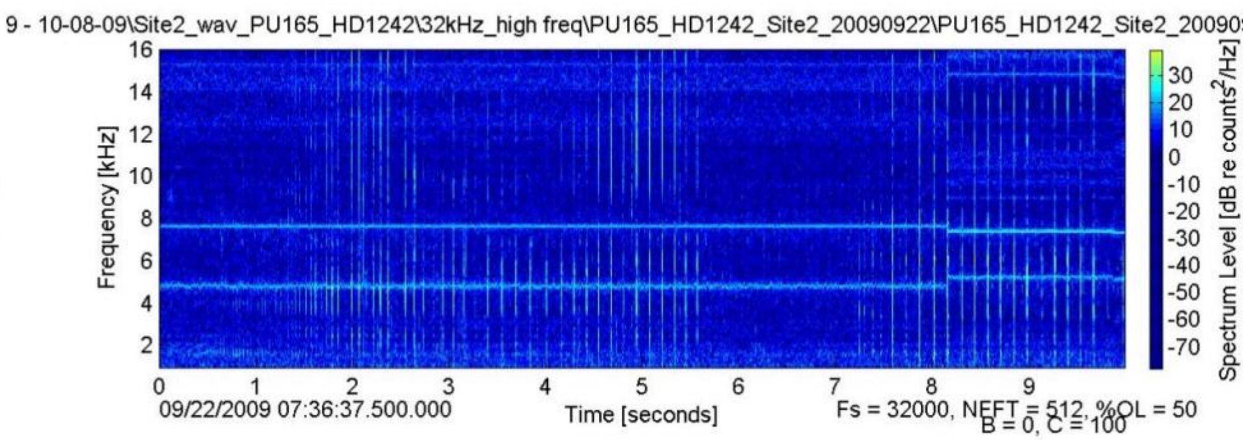
Original Code: MO. New Code: MOc. Species ID: Delph spp



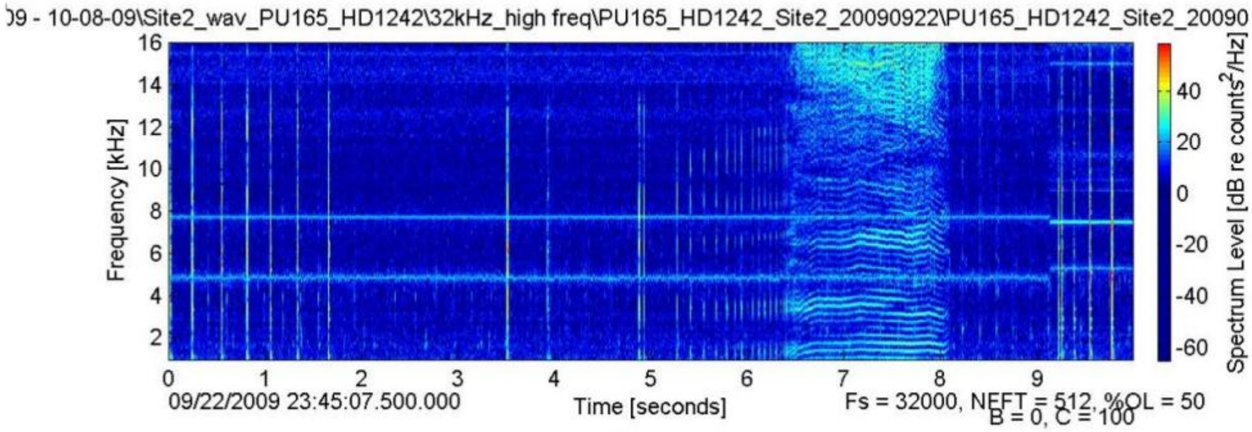
Original Code: MO. New Code: MOf- long MO with CL. Species ID: Delph spp



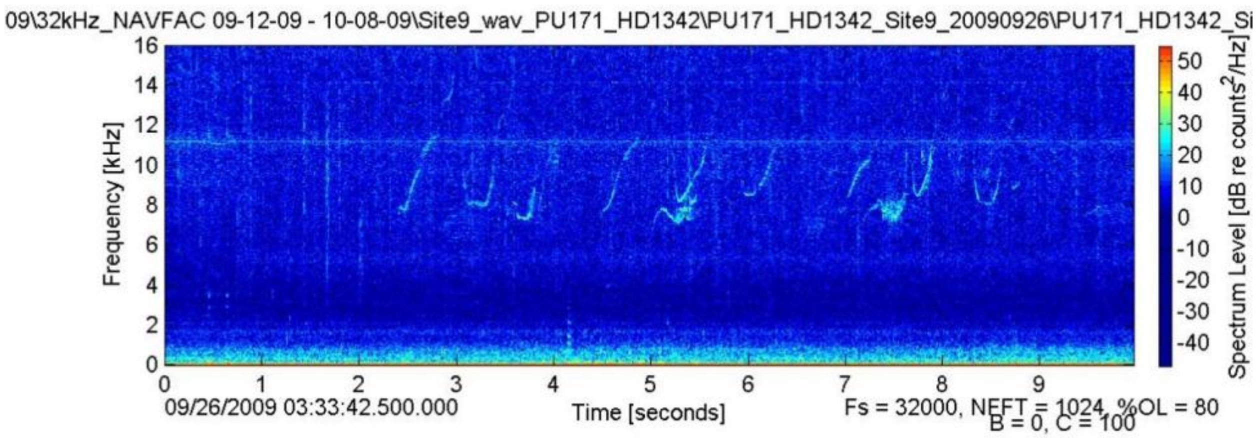
Original Code: Unid Odont. Species ID: Delph spp



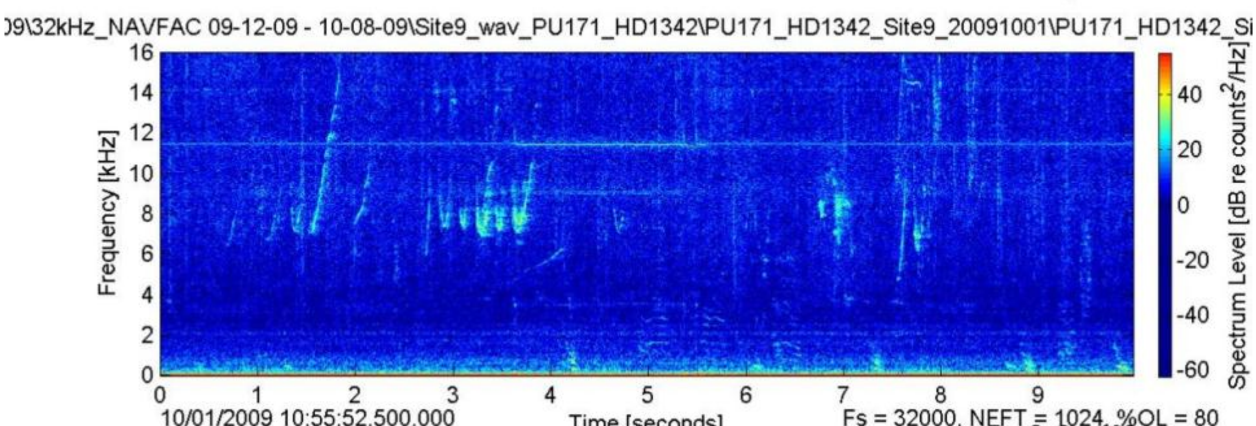
Original Code: Unid Odont. Species ID: Delph spp



Original Code: Unid Odont. Species ID: Delph spp

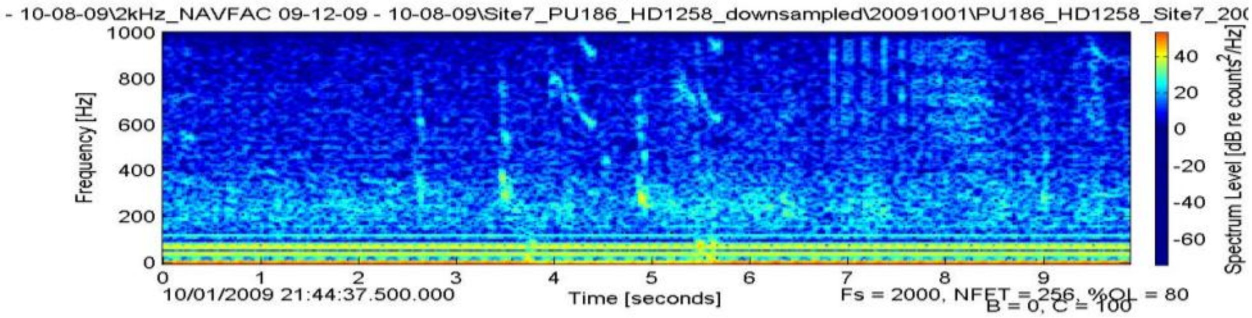


Original Code: Unid Odont. Species ID: Delph spp

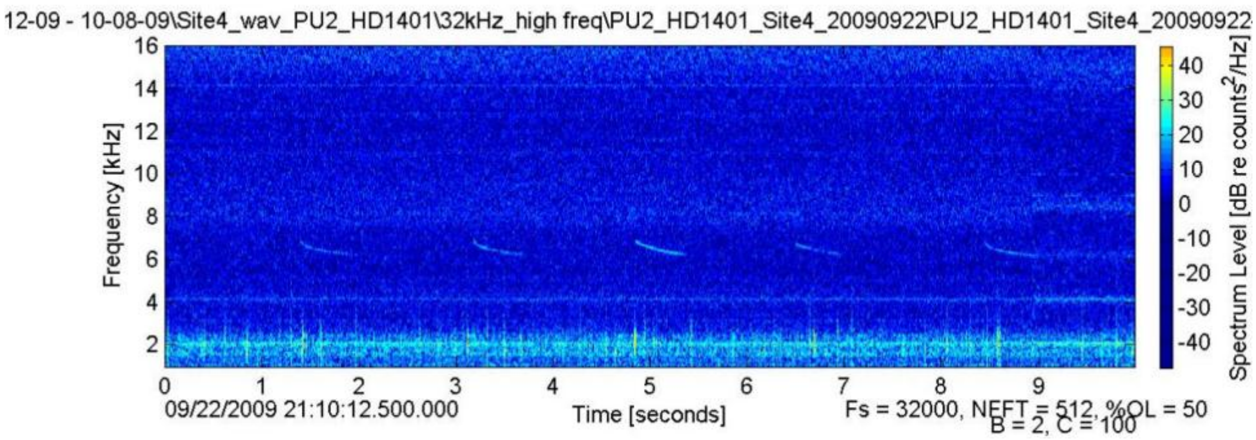


Original Code: Unid Odont. Species ID: Delph spp

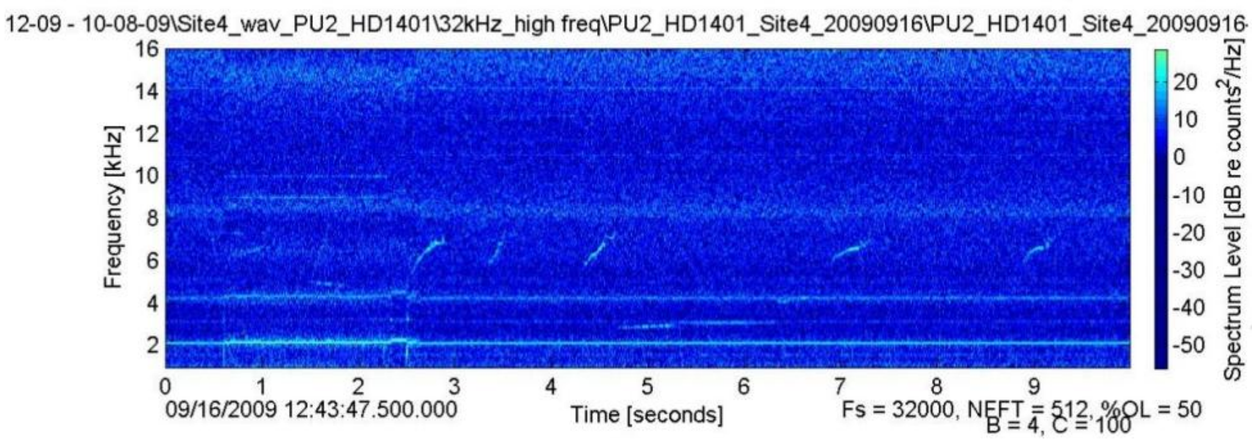
Blackfish



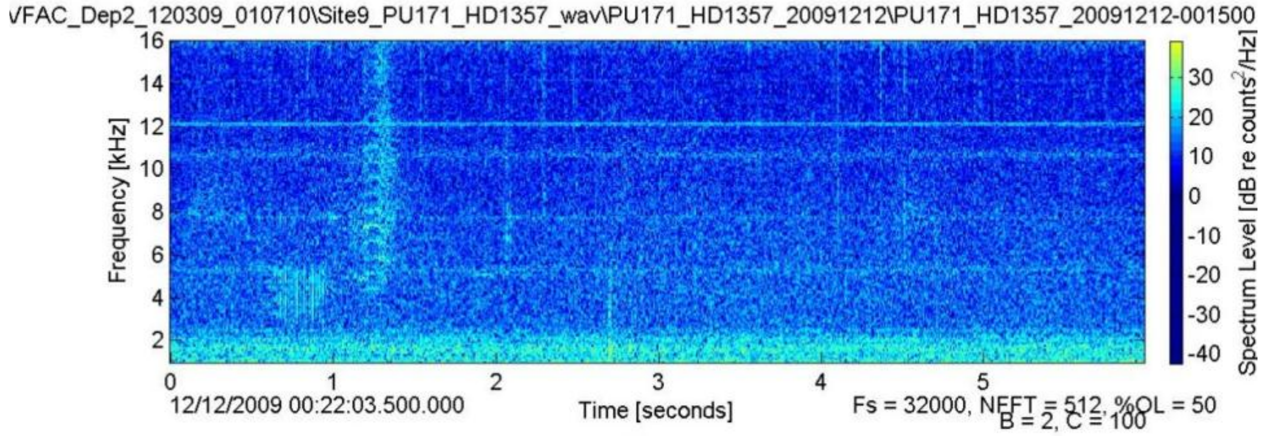
Original Code:C1-Variable calls. New code: C1d. Species ID : Blackfish



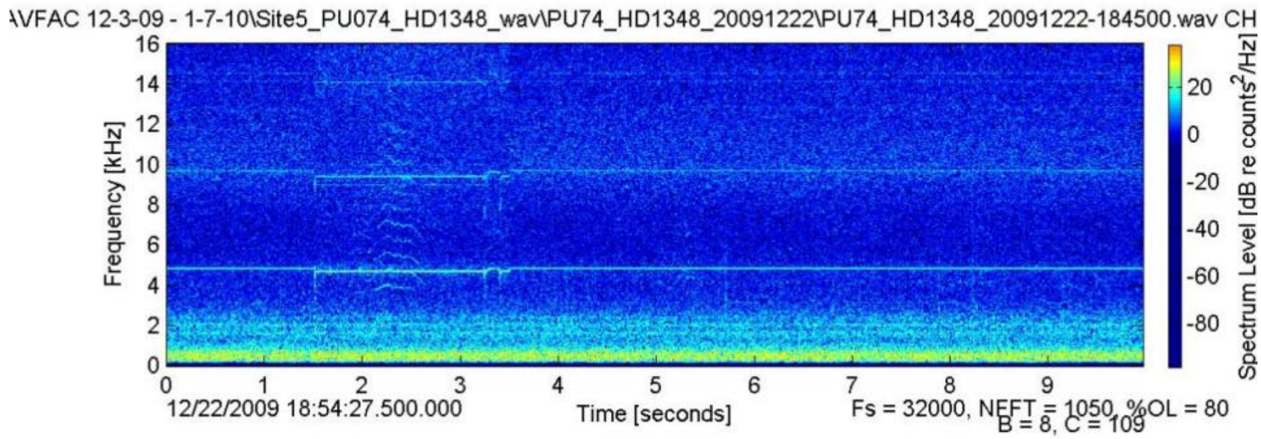
Original Code: poss BF. Species ID : Blackfish



Original Code: poss BF. Species ID : Blackfish

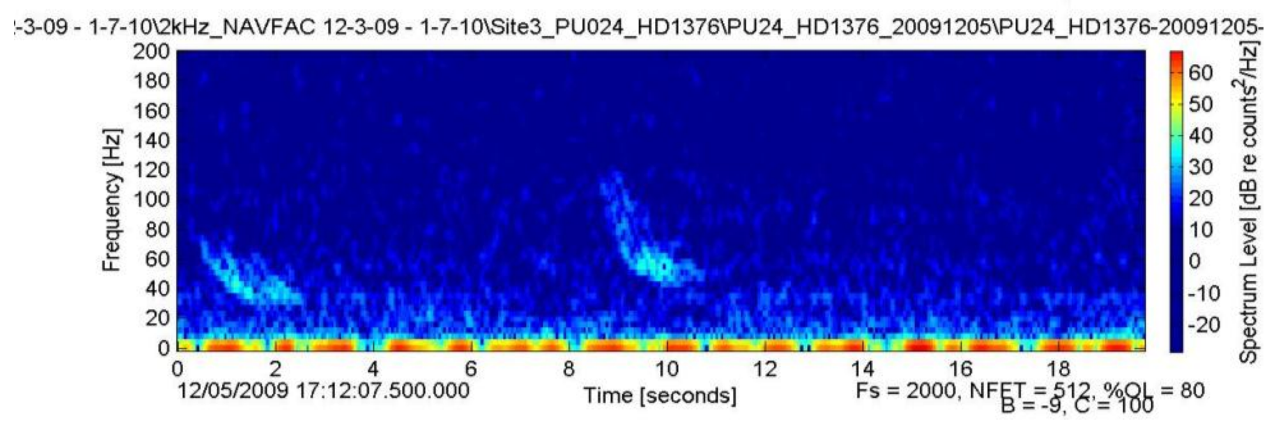


Original Code: poss BF. Species ID : Blackfish

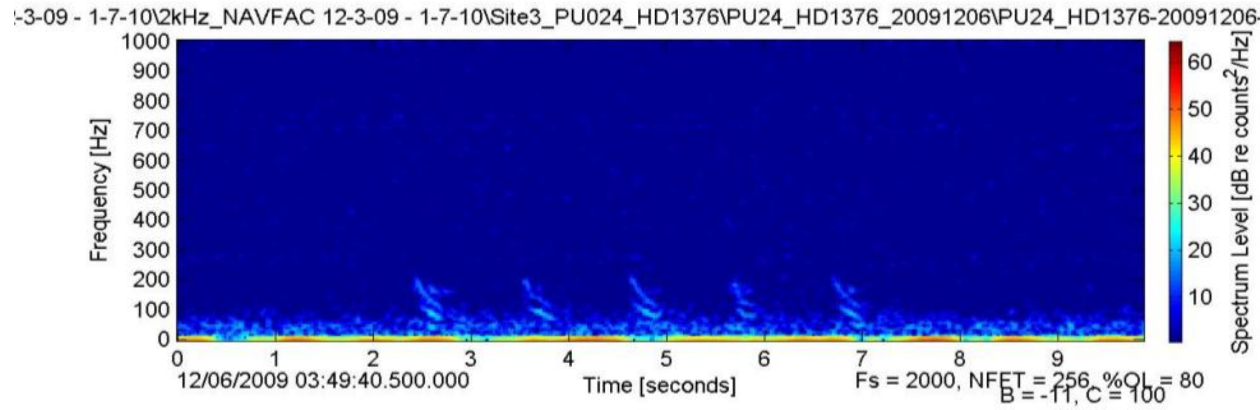


Original Code: poss BF. Species ID : Blackfish

Sei Whale

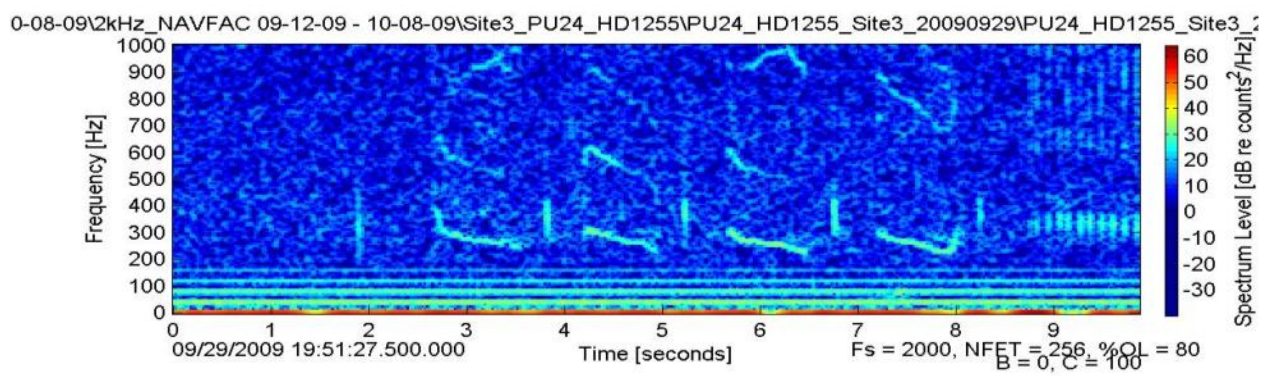


Original Code: DS 100-25hz. Species ID: Sei Whale

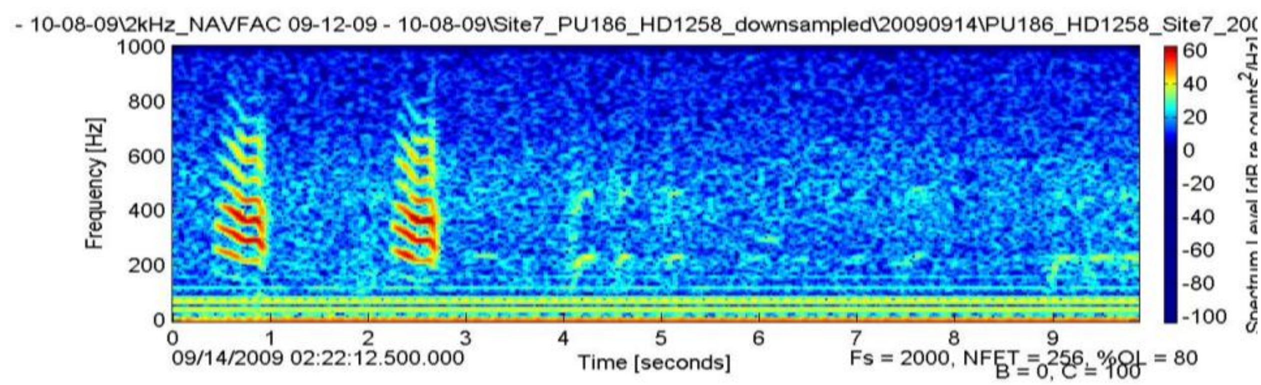


Original Code: DS 200-50hz. Species ID: Sei whale

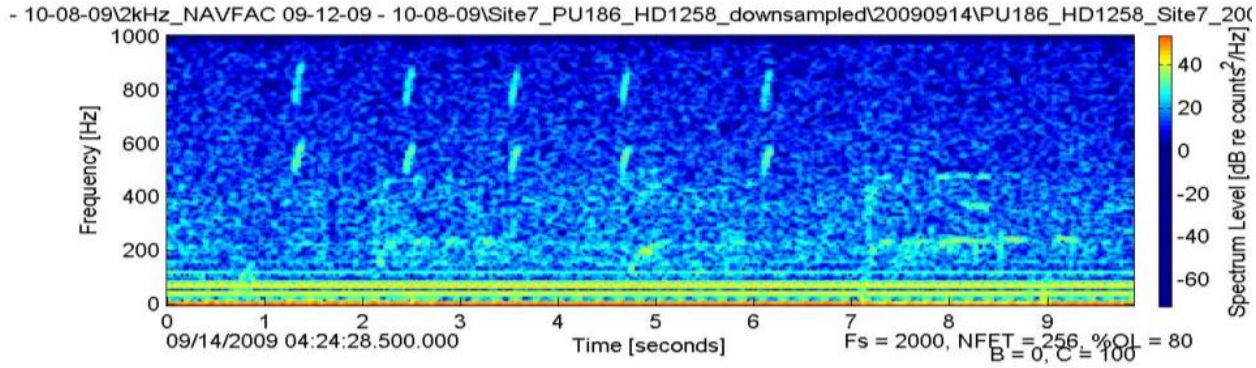
Fish



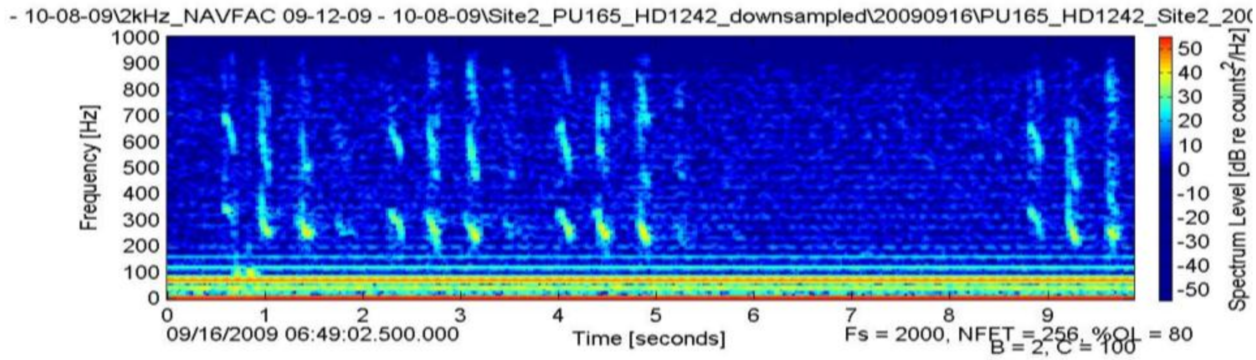
Original Code: C10(downs calls with short call in middle). Species ID: Fish



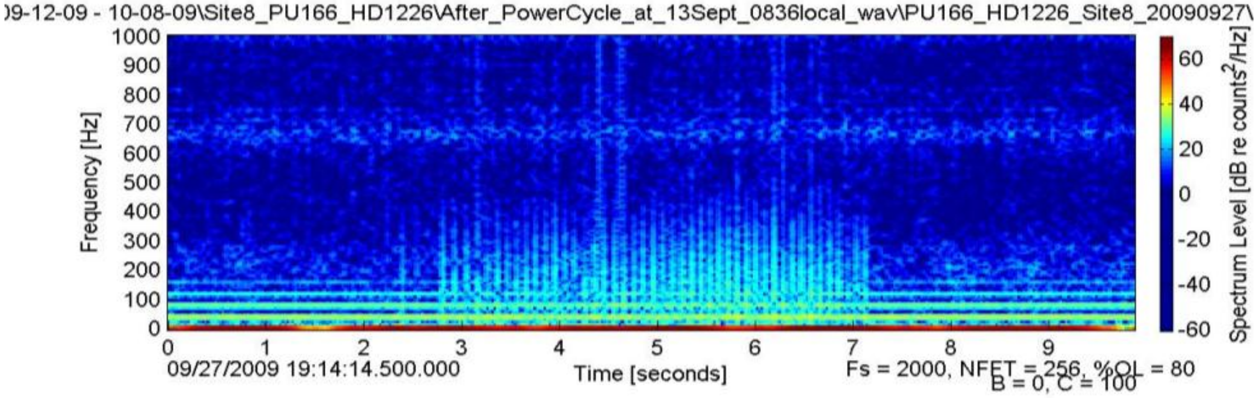
Original Code: C11. Species ID: Fish



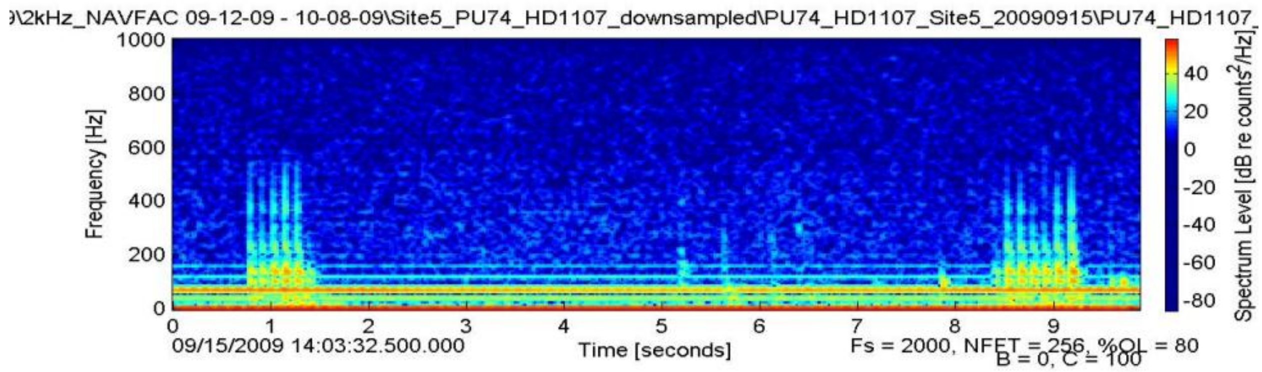
Original Code: C12. Species ID: Fish



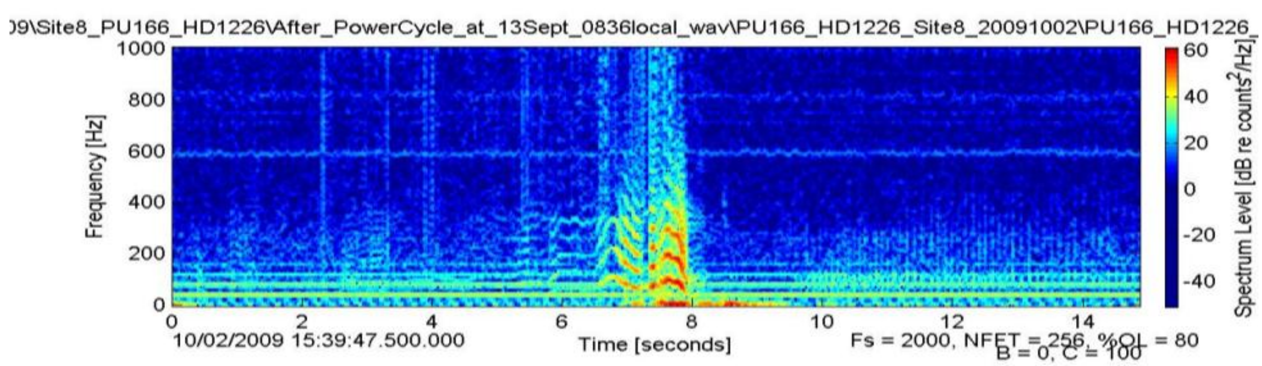
Original Code: C2. Species ID: Poss fish



Original Code: CL. New Code: CLa. Species ID: Fish

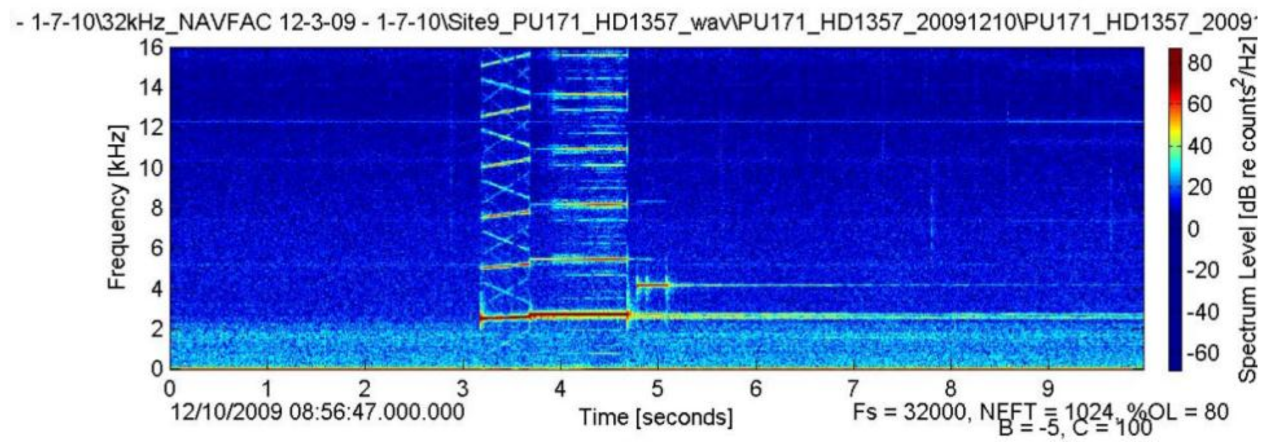


Original Code: TH5. Species ID: Fish

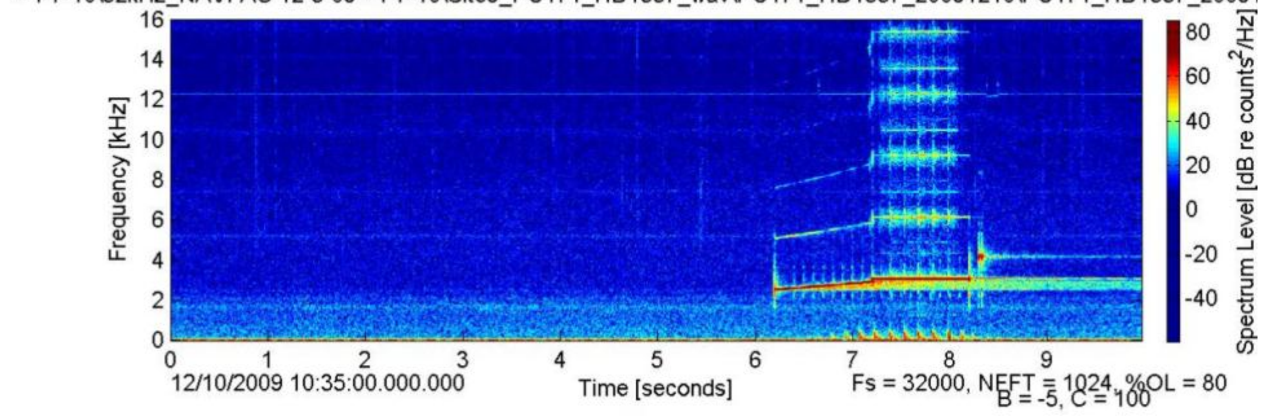


Original code: Very strange noise. Species ID: Fish

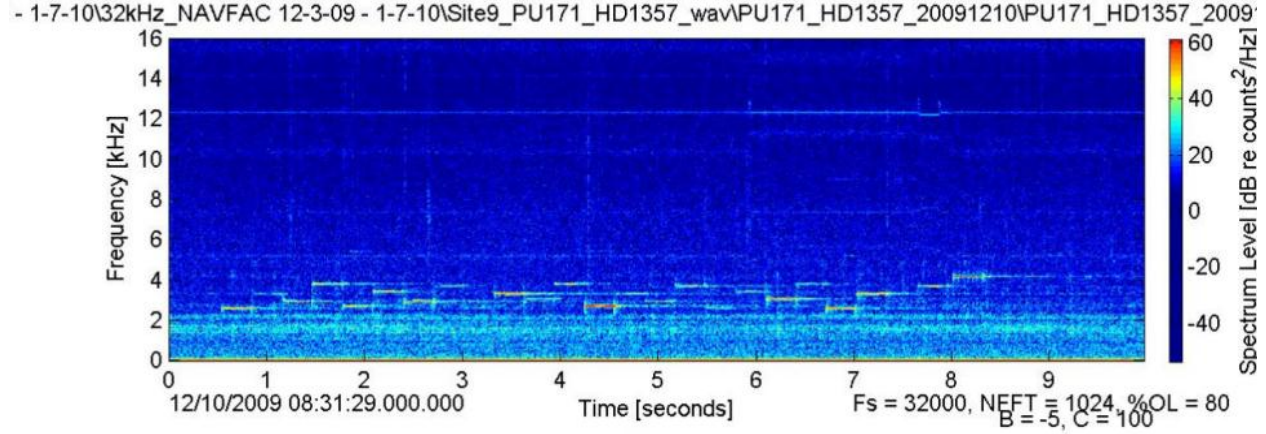
Sonar



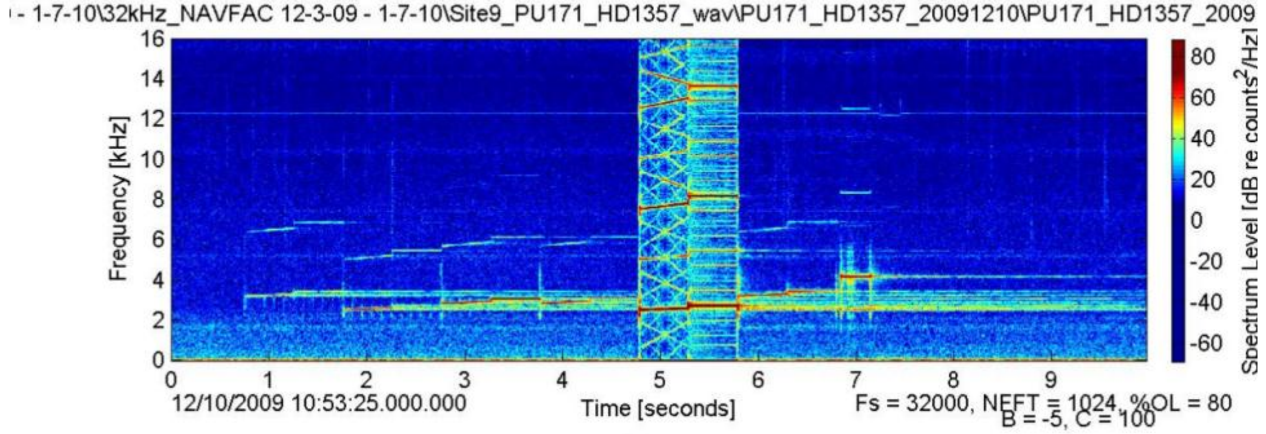
Original code: CSO. Species ID: Sonar



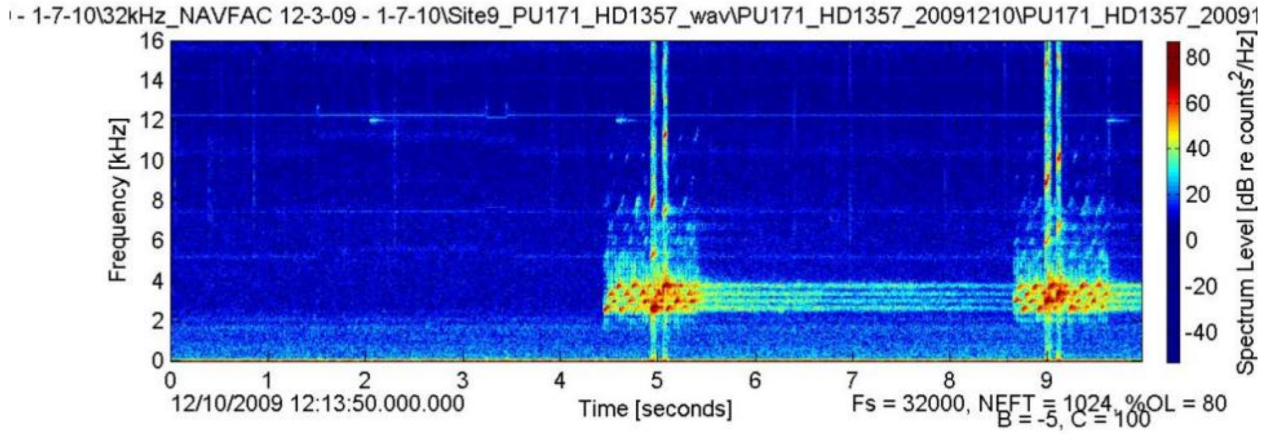
Original code: CSO. Species ID: Sonar



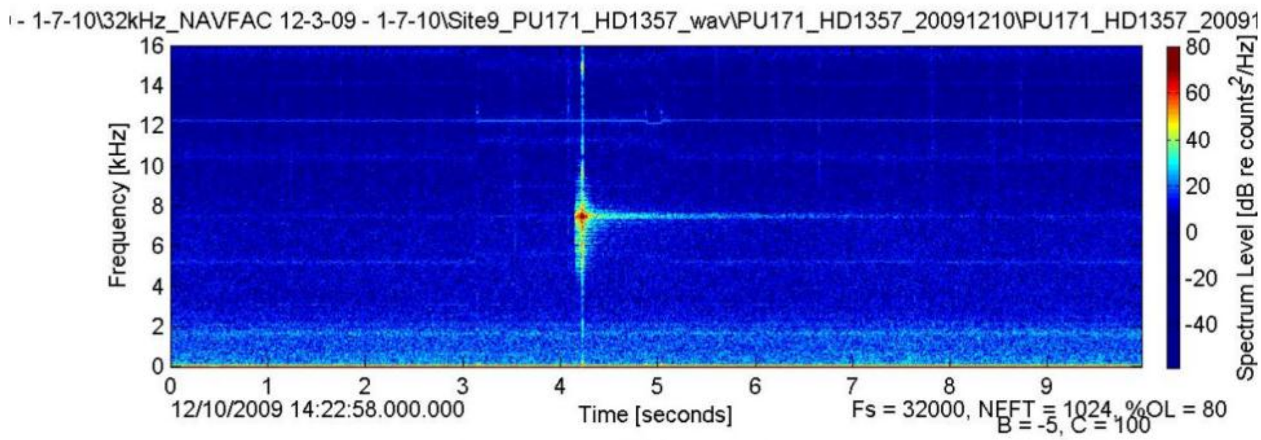
Original code: CSO. Species ID: Sonar



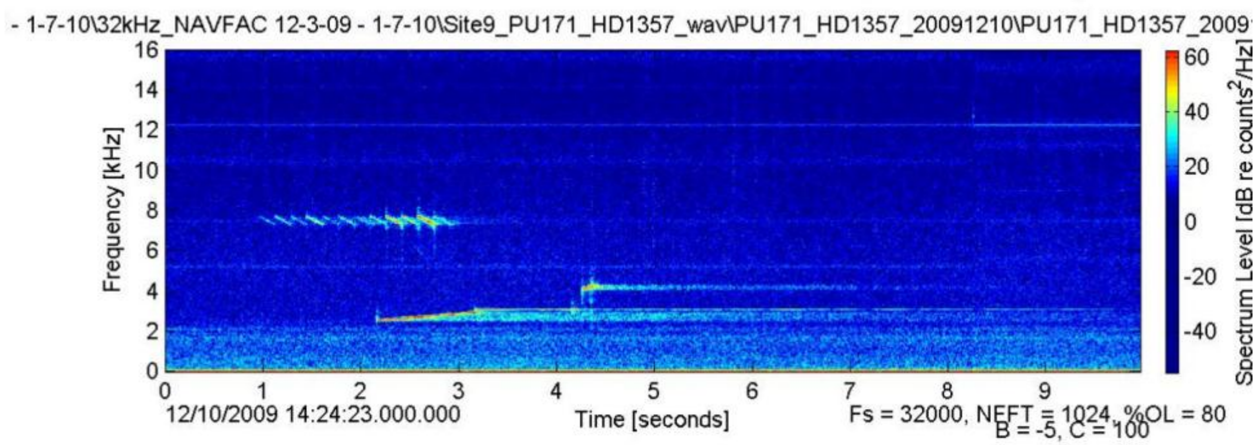
Original code: CSO. Species ID: Sonar



Original code: CSO. Species ID: Sonar

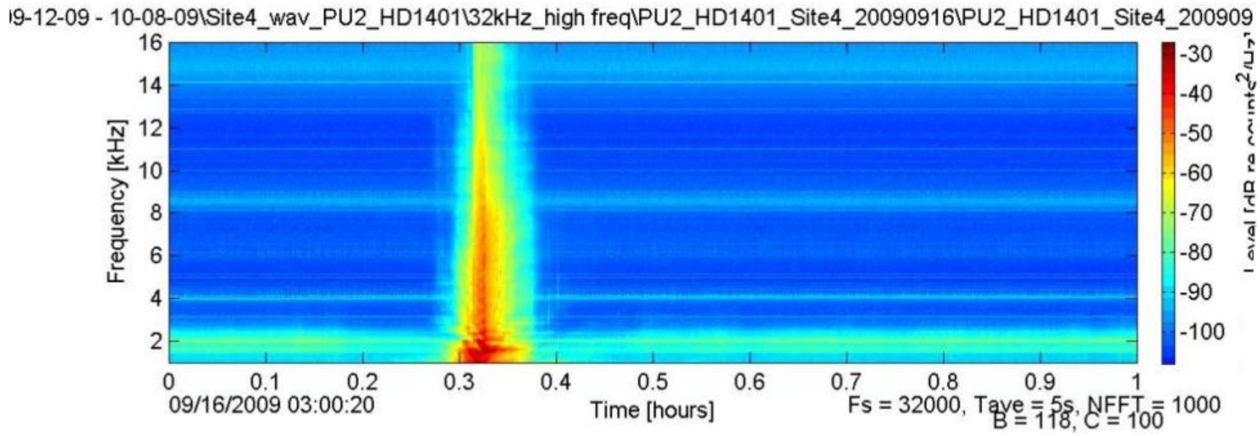


Original code: CSO. Species ID: Sonar

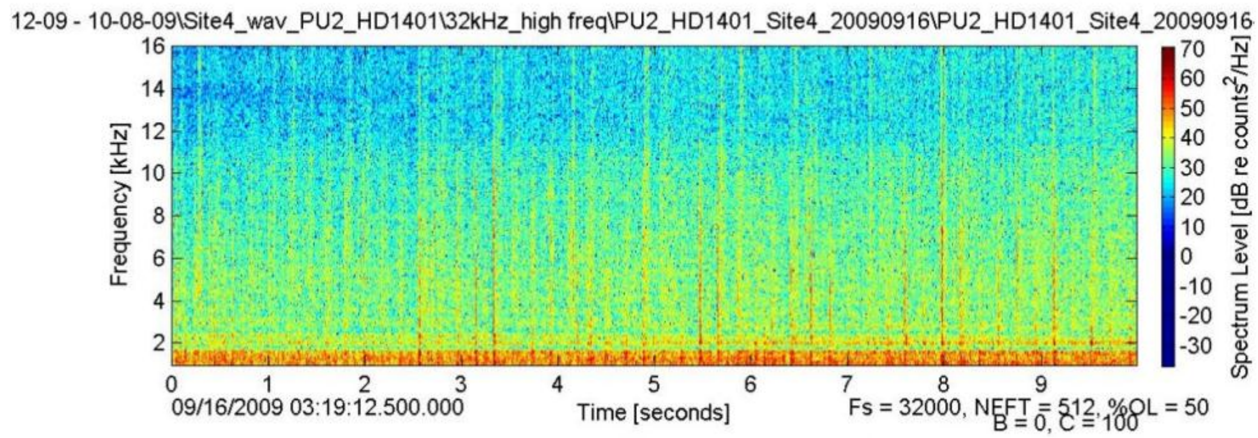


Original code: CSO. Species ID: Sonar

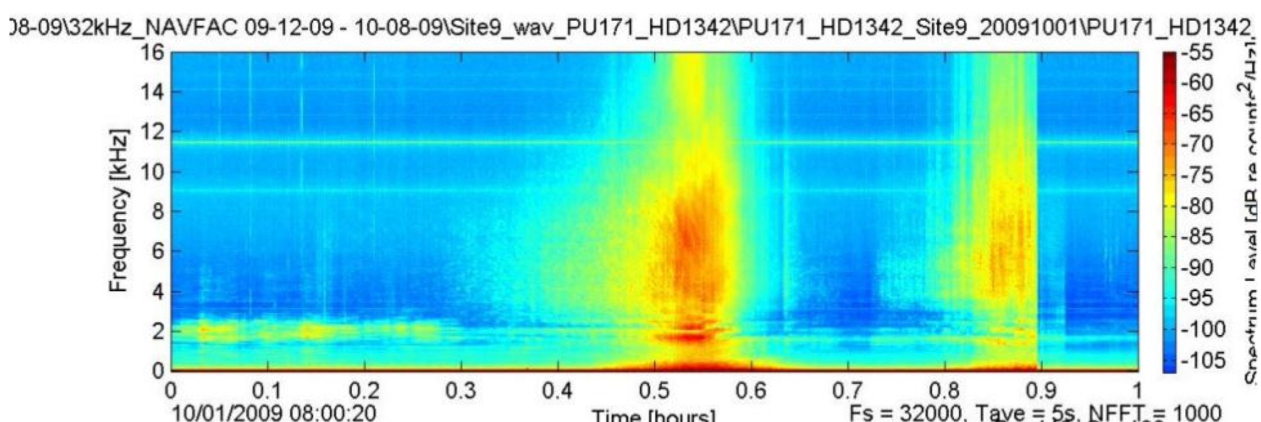
Ship



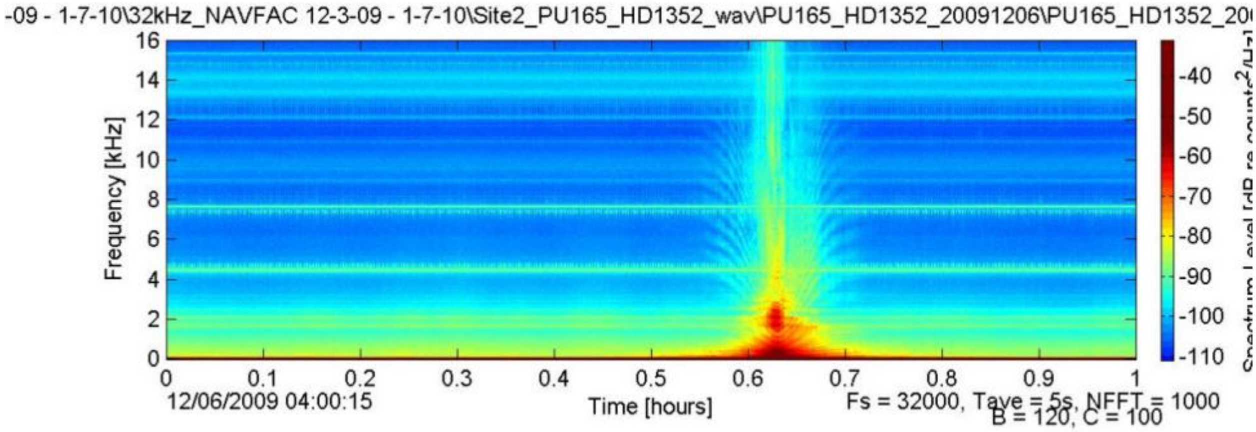
Original code: Ship/broadband. Species ID: Ship



Original code: Ship/broadband. Species ID: Ship



Original code: Ship/broadband. Species ID: Ship



Original code: Ship/broadband. Species ID: Ship

APPENDIX E:

EVENT LOG

(Provided as a separate file due to its very large size.)

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