Passive Acoustic Monitoring for Marine Mammals and Ambient Noise off Jacksonville

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1 Executive Summary

The U.S. Navy's Jacksonville Range Complex (JAX) is located in the South Atlantic Bight offshore northeastern Florida and southeastern Georgia. From 2009 to 2020, passive acoustic monitoring was conducted using High-frequency Acoustic Recording Packages (HARPs) deployed across a depth gradient spanning the continental shelf and slope. Three sites were located on the shallow shelf (A–C; approximately 40–90 m), and one site was located on the continental slope (D; approximately 730–800 m). These long-term acoustic data provide a comprehensive assessment of marine mammal occurrence and ambient sound conditions across the region.

Odontocete occurrence in the Jacksonville region was strongly structured by depth. Deep-diving species, including sperm whales, beaked whales, and *Kogia* spp., were detected exclusively at the slope site (D), while delphinids occurred across the shelf-to-slope gradient. Sperm whales were the most consistently detected deep-diving species, exhibiting sustained weekly presence at the slope site with clear seasonal increases during winter and spring months. Beaked whale detections were less frequent and primarily represented by goose-beaked whales , with occasional detections of True's, Gervais', and Blainville's beaked whales and rare detections of Sowerby's beaked whales. *Kogia* spp. were detected intermittently beginning in 2014 and remained at relatively low levels.

Delphinids were widely distributed but differed by presumed size class. Smaller-bodied delphinids (UD HF & 47) were detected at all sites and were most prominent at the shallow shelf site (A), where detections occurred regularly throughout the year and exhibited nocturnal diel patterns. In contrast, larger-bodied delphinids (UD LF) were concentrated at the slope site (D), where they exhibited higher overall presence relative to shelf sites. Risso's dolphins were also primarily associated with the slope site and exhibited increased nighttime detections. Overall, odontocete results indicate pronounced habitat partitioning, with slope waters supporting deep-diving and larger-bodied species, and shelf waters supporting more consistent activity from smaller-bodied delphinids.

Baleen whale detections were seasonal and generally most pronounced during fall through early spring months. Minke whales exhibited the strongest and most consistent presence, particularly at the slope site (D), where weekly detections frequently exceeded several days per week during peak winter months. Fin whales were detected at all sites and demonstrated clear winter seasonality, with more consistent offshore detections at the slope site and intermittent detections on the shelf. Sei whales were detected primarily at the slope site during fall and winter at relatively low levels. Humpback whales were rarely detected and were limited to brief late winter and early spring occurrences at shelf sites (B and C). No blue whale detections were recorded during the monitoring period. North Atlantic right whales only occurred in March of 2014 at site B and in December of 2014 at site D, indicating limited acoustic presence in the Jacksonville region during the study timeframe.

Although the Jacksonville sites were all located within the same regional study area, their placement across a depth gradient from the continental shelf to the slope exposed them to distinct oceanographic regimes. Shelf sites (A–C) were more strongly influenced by local surface processes and shallow bathymetry characteristic of the South Atlantic Bight, while the slope site (D) was subject to deeper-water conditions and the influence of the Gulf Stream. These differences were reflected in the species composition and acoustic presence observed at each site, underscoring how depth and bathymetry shape marine mammal occurrence in the region. The Jacksonville study area functions as a transition between continental shelf and offshore slope environments, and these results illustrate that patterns of presence can shift markedly across relatively short horizontal and vertical scales. Acoustic monitoring studies in such settings should therefore be interpreted with careful attention to local depth and oceanographic context. Variability in presence across sites does not necessarily indicate strict habitat boundaries but instead reflects the fluid and dynamic nature of the ecosystem. Moreover, while these data provide exceptional temporal resolution at fixed locations within the Jacksonville study area, they do not capture the full spatial heterogeneity of the broader western North Atlantic. As comparative work has shown, species' apparent regional presence varies depending on the bathymetric and oceanographic setting of monitoring sites (DeAngelis et al. 2025).

Long-term spectral averages indicate that low-frequency ambient sound was dominated by vessel noise and environmental contributions across all sites. Persistent energy below 100 Hz was consistent with commercial shipping activity. Elevated levels below 30 Hz at multiple sites were associated with current-driven mooring cable strumming. At the slope site, seasonal increases in mid-frequency energy were consistent with minke whale pulse train activity during winter months, demonstrating a biological contribution to the seasonal soundscape. Higher frequency variability reflected changes in wind and sea state conditions. Together, these results highlight how depth and oceanographic setting mediate the acoustic environment in the study area, with implications for both marine mammal detectability and long-term soundscape monitoring.

These findings contribute to the long-term understanding of species distribution and acoustic habitat use in a highly variable oceanographic setting and provide a valuable baseline for future studies assessing environmental change and anthropogenic impacts in the western North Atlantic.

2 Introduction

2.1 Project Background

The U.S. Navy's Jacksonville Range Complex (JAX) is situated within the South Atlantic Bight that extends from Cape Hatteras, North Carolina to the Florida Straits. The seafloor is relatively smooth and features a broad continental shelf, with an inner zone of less than 200 m water depth, and an outer zone extending to depths of 2000 m. The Jacksonville study area supports a diverse array of marine mammals, including both baleen and toothed whales, which rely on these habitats for foraging, migration, and other life history functions.

From 2009 to 2019, a comprehensive acoustic monitoring effort was conducted within the Jacksonville study area to study marine mammal presence and ambient noise levels. The objective was to characterize the vocalizations of marine mammal species in the area, identify their seasonal presence patterns, and assess the potential impacts of naval operations on these species. This report presents the findings from the analysis of data collected using High-frequency Acoustic Recording Packages (HARPs; Wiggins & Hildebrand 2007), which were strategically deployed within the study area across a shelf-to-slope gradient (Figure 1 & Table 1). For clarity throughout this report, sites A-C will be referred to as the shallow shelf sites and site D as the slope site.

Table 1: Recording effort for Jacksonville study area deployments.

Site	Deployment	Start Date	End Date	Depth (m)	Recording Duration (Days)	Duty Cycle (Min)
A	01	04/02/2009	05/25/2009	82	57	5/15
	02	09/16/2009	12/27/2009	83	102	5/15
	03	02/22/2010	07/30/2010	89	158	5/15
	05	08/26/2010	01/25/2011	91	152	5/15
	06	02/01/2011	07/14/2011	91	163	5/15
B	01	04/02/2009	09/05/2009	37	156	5/15
	04	03/09/2010	08/19/2010	38	163	5/15
	05	08/27/2010	02/01/2011	37	158	5/15
	06	02/02/2011	07/14/2011	37	162	5/15
C	09	05/13/2013	06/20/2013	94	38	Continuous
	10	02/17/2014	08/23/2014	88	187	Continuous
D	11	08/23/2014	05/29/2015	800	279	Continuous
	12	07/03/2015	11/04/2015	750	125	Continuous
	13	04/26/2016	06/25/2017	736	425	Continuous
	14	06/25/2017	10/28/2017	740	125	Continuous
	15	06/27/2018	06/15/2019	740	354	Continuous
	16	06/15/2019	05/31/2020	735	351	Continuous

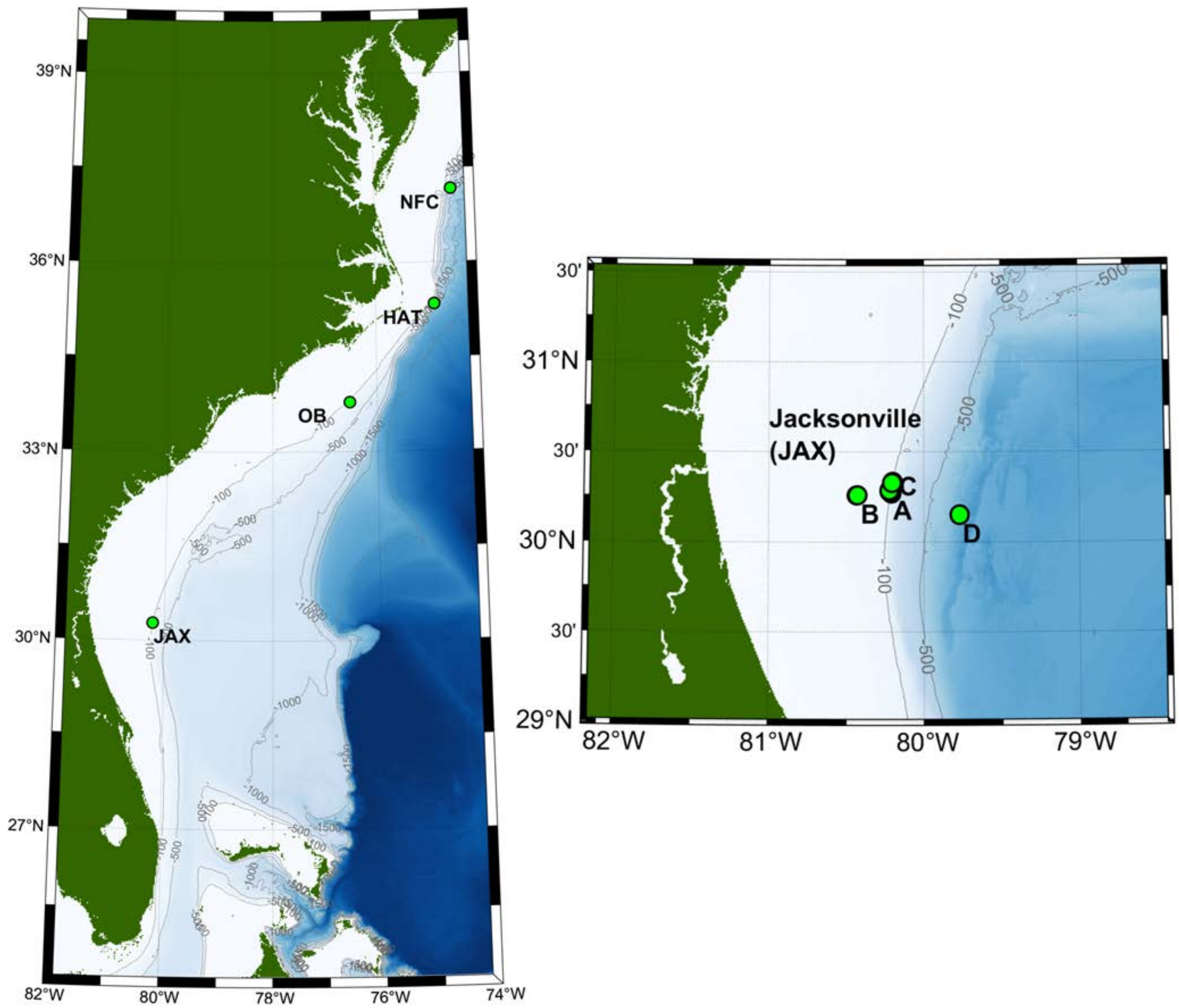

Figure 1: Location of the High-frequency Acoustic Recording Packages (HARPs) at the Jacksonville site (JAX). Left: Large-scale view of the JAX project location along the U.S. East Coast. Right: Zoomed-in view showing the positions of individual deployments at the A-D sites.

3 Data Collection & Quality

High-frequency Acoustic Recording Packages (HARPs) are autonomous underwater acoustic recording devices that, depending on configuration, can record sounds over a bandwidth from 10 Hz to 100 kHz and are capable of approximately one year of continuous recording. The HARPs were deployed in a large mooring configuration with the hydrophone suspended approximately 10 m above the seafloor. Each HARP was calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative dataloggers and hydrophones were also calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations (Wiggins & Hildebrand 2007).

A total of 17 deployments were conducted in the Jacksonville study area between 2009 and 2020 across four subsites spanning a depth gradient: three shallow shelf sites (A-C, 40-90 m) and one slope site (D, 730-800 m).

The vast majority of the data collected were found to be error free. Some deployments experienced issues with instrument strumming and flow noise which intermittently elevated low-frequency noise levels (<30 Hz) and reduced the signal-to-noise ratio for baleen whale calls.

Intermittent data gaps occurred in three shelf deployments (1A, 5A, and 9C) due to datalogger and disk write issues. One slope deployment (D12) experienced a loss of low-frequency sensitivity shortly after deployment, limiting detectability in the lowest frequency bands for part of the record. All remaining deployments maintained high data recovery, with most achieving greater than 95% usable coverage across the recording period.

Problematic segments were identified and either excluded or flagged during analysis. Although strumming noise and coverage gaps likely reduced the detectability of certain signals, particularly at low frequencies, the overall dataset remains sufficient to assess long-term patterns in marine mammal occurrence and ambient sound levels.

4 Data Analysis

The data analysis process is described below for the major classes of odontocete and mysticete vocalizations and low-frequency ambient soundscape at the Jacksonville study area, detailing the detection and characterization methods.

These datasets were analyzed individually as part of the data collection effort. During the span of data collection, both analytical methods and recording devices evolved. Here, we have reanalyzed all of the datasets using the latest and best available methods at the time of writing, to improve comparability. However, some differences between successive deployments remain, particularly due to changes in hydrophone designs aimed at improving and optimizing high frequency recordings. Current machine learning methods greatly improve comparability but may lack robustness to instrument-specific acoustic features not well represented in their training data (Roch et al. 2015). We have expended effort to ensure that the data is as comparable as possible over this timeseries, and have aimed for a level of granularity in our results that is relatively robust to these differences.

Analyses here describe temporal patterns at the Jacksonville sites, not spatial gradients across the western North Atlantic. Comparisons to other studies that include the Jacksonville study area are provided for context rather than extrapolation beyond the study area. Species presence and temporal patterns can differ even at nearby locations with varying bathymetry, distance from the slope, and Gulf Stream proximity (DeAngelis et al. 2025).

4.1 Odontocete Analyses

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 1 and 150 kHz, dependent upon the species. Buzzes or burst pulses are rapidly repeated clicks that have a creak, squeal, screech, or buzz-like sound quality; they are often lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in a long-term spectral average (LTSA) as well as in the spectrogram.

Analyses in this report focus only on echolocation clicks as a proxy for odontocete presence because they are currently the most promising call type for species classification in the region. Deep-diving odontocete species (beaked whales, sperm whales, and Kogia spp.) were only analyzed at the slope site (D), while analyses for the shallow shelf sites (A–C) were limited to Risso’s dolphins and unidentified delphinids.

Many odontocete species in the western North Atlantic show a pronounced north–south division in occurrence. Cape Hatteras is often used as a biogeographic boundary because the Gulf Stream’s influence creates strong environmental gradients along the slope and shelf break. The Jacksonville study area lies south of this boundary in Gulf Stream–influenced waters. We provide this context to frame interpretation of the odontocete analyses below.

List of odontocete species analyzed:

- Goose-beaked whale (*Ziphius cavirostris*)
- Gervais’ beaked whale (*Mesoplodon europaeus*)
- True’s beaked whale (*Mesoplodon mirus*)
- Blainville’s beaked whale (*Mesoplodon densirostris*)
- Sowerby’s beaked whale (*Mesoplodon bidens*)
- Beaked Whale of the Gulf (BWG)
- Sperm whale (*Physeter macrocephalus*)
- *Kogia* spp.
- Risso’s dolphin (*Grampus griseus*)
- Unidentified delphinids – presumed smaller-bodied delphinids (UD HF & 47)
- Unidentified delphinids – presumed larger-bodied delphinids (UD LF)

4.1.1 Beaked Whale Click Classification

Potential beaked whale echolocation clicks were detected automatically using a generic pulse detector, publicly available in the SPICE Detector remora package in Triton (Frasier 2021). Detection parameters included a fifth-order Butterworth filter with a high-passband between 5 and 100 kHz and a minimum received sound pressure level (SPL) of 118 dB peak-to-peak re 1μPa^2.

For deployments 11D and 13-15D, following the generic pulse detector, an unsupervised clustering method, accessible in the Cluster-Tool remora package (Frasier 2021), was applied. Detections were clustered within successive 5-min windows and dominant click types were identified in each window using spectral features, inter-click intervals, and waveform envelopes. A minimum for 10 clicks per cluster bin was set to include ephemeral beaked whale encounters (Solsona-Berga et al. 2024). For deployment 16D, a targeted species classification method was applied prior to the unsupervised clustering (Solsona-Berga et al. 2024). A hard negative filter based on commonly used rules for identifying beaked whale click characteristics (peak and center frequency, click duration, sweep rate) was applied to exclude non-beaked whale-like clicks prior to clustering (Solsona-Berga et al. 2024). From there, the same unsupervised clustering method was applied. A deep neural network was trained to classify these signal types with an overall accuracy of 97.7% on a balanced test set (Solsona-Berga et al. 2024). A trained analyst then manually verified the neural network labels for all deployments, using DetEdit, an open-source software for visualizing events within large acoustic datasets (Solsona-Berga et al. 2020).

4.1.2 Sperm Whale Click Detection

Sperm whale echolocation clicks were detected using the multi-step approach described in Solsona-Berga et al. 2020 (appendix). These clicks have multiple pulses (Backus & Schevill 1966), 2–9 ms apart, depending upon the size of the animal (Norris & Harvey 1972). As a result, the detector had a lockout for clicks separated by less than 30 ms to avoid multiple detections of a single click. Band-pass filtering the data (5–95 kHz) minimized the effects of low-frequency noise from vessels, weather, or instrument self-noise on detections, but allowed for detection of the echolocation clicks of toothed whales. The Power Spectral Density (PSD) of detected signals was calculated with the Pwelch method using 4 ms of the waveform and a 512-point Hann window with 50% overlap (Welch 1967). Instrument-specific full-system transfer functions were applied to account for the hydrophone sensor response, signal conditioning electronics, and analog-to-digital conversion. To provide a consistent detection threshold, only clicks exceeding peak-to-peak (pp) sound pressure level (RL) of at least 125 dBpp re 1 μPa were analyzed. This threshold was chosen to eliminate noise signals and the echolocation clicks of other odontocetes, while retaining sperm whale clicks.

Sperm whale echolocation clicks can be confused with the impulsive signals from ship propeller cavitation. An automated classifier developed by Solsona-Berga et al. 2020 (appendix) was used to exclude periods of ship passages. The classifier identified potential ship passages from long-term spectral averages (LTSA), which are long-duration spectrograms (Wiggins & Hildebrand 2007). Further averaging was calculated as Average Power Spectral Densities (APSD) per 2-hour blocks over low (1-5 kHz), medium (5-10 kHz), and high (10-50 kHz) frequency bands with 100 Hz bins and 50% overlap. Using received sound levels, transient ship passage signals were separated from odontocete echolocation clicks and weather events. A trained analyst manually reviewed identified ship passages using the MATLAB-based custom software program Triton (Wiggins & Hildebrand 2007). Ship passage times were removed from further analysis and considered time periods with no effort.

Instrument self-noise and the echolocation clicks of other odontocetes were also removed to reduce the number of false positive detections. A classifier using spectral click shape was implemented, taking advantage of a sperm whale click's distinct low-frequency spectral shape to remove dissimilar clicks by delphinid and beaked whales, which typically have higher frequencies (Solsona-Berga et al. 2020). The remaining acoustic encounters containing putative sperm whale echolocation clicks were manually reviewed with DetEdit, a custom, MATLAB-based graphical user interface (GUI) software program used to view, evaluate, and edit automatic detections (Solsona-Berga et al. 2020).

4.1.3 *Kogia* Spp., Risso's Dolphin, and Unidentified Delphinid Click Classification

Odontocete echolocation clicks were detected automatically using an energy detector with a minimum received level threshold of 120 dBpp re: 1 μPa (Roch et al. 2011; Frasier et al. 2016). To classify detected clicks to putative taxonomic groups, dominant click types and false positive categories at these sites were identified using automated unsupervised clustering methods (Frasier 2021). Detections were clustered within successive 5-min windows, and dominant click types were identified in each window using spectral features, inter-click intervals (ICI), and waveform envelopes. Regular clicks were the focus of this analysis; therefore, clicks with an ICI less than 0.001 s were excluded to limit the inclusion of buzz clicks. An automated clustering algorithm was then used to identify recurrent types based on spectral features, ICI, and waveform distributions at each site (Frasier et al. 2017). Common click types were manually aggregated across all western North Atlantic sites to form classifier training and testing datasets for 13 signal types, including nine odontocete signal classes and four sources of false positives.

Click types were attributed to a specific species when acoustically identifiable (e.g., *Kogia* spp. and Risso's dolphin) or assigned to unidentified categories when species-level identification was not possible (e.g., delphinids). A deep neural network was trained to classify these signal types, achieving at least 93% classification accuracy on a balanced test set. This trained network was then used to classify all 5-min windows across all sites. Classifications were retained if the classification probability exceeded 95% and the classified bin contained at least 100 clicks.

Only five odontocete signal categories are presented in this report: *Kogia* spp., Risso's dolphin, unidentified presumed smaller-bodied delphinids (UD HF & 47), which were combined due to their similar acoustic characteristics), and unidentified presumed larger-bodied delphinids (UD LF). The classifier achieved high accuracy on an independent test set, with 100% accuracy for *Kogia* spp., 97.3% for Risso's dolphins, 93.2% for the combined smaller-bodied delphinid classes, and 97.6% for larger-bodied delphinids (UD LF). Some misclassification occurred among acoustically similar delphinid classes, reflecting overlapping click characteristics; however, cross-class confusion was generally low, and overall model performance was consistent with the spectro-temporal distinctiveness of each class.

4.2 Odontocete Species Call Descriptions

Several odontocetes are resident to the Onslow Bay study area. A description of the identifying features of each species' call types follows. For all odontocete species (except sperm whales), the following figures are presented:

- Average spectrum of an acoustic signal type with associated variance
- Histogram of average ICIs for an acoustic signal type
- Envelope of the signal waveform
- Long-term average spectrogram (LTSA) of an acoustic encounter over 1-hour
- Standard spectrogram of acoustic signals over 5 seconds

4.2.1 Goose-Beaked Whale

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering et al. 2014). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features. Identifiable signals are described for all beaked whales known to occur in the region, namely Blainville's, goose, and Gervais' beaked whales.

Goose-beaked whale's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figures 2 & 3), and uniform inter-click interval (ICI) of about 0.5 s (Johnson et al. 2004) (Zimmer et al. 2005). An additional feature that helps with the identification of goose-beaked whale FM pulses is that they have three characteristic spectral peaks around 17, 23, and 70 kHz.

Previous studies have shown that goose-beaked whales are among the most frequently detected beaked whales in the western North Atlantic, with high acoustic presence along the shelf break and slope from Cape Hatteras north through the Mid-Atlantic (Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025). They are less frequently detected south of Cape Hatteras, while detections at Hatteras and farther north occur year-round, with increased prevalence in winter and spring (Haver et al. 2025; Stanistreet et al. 2022; Cohen et al. 2023).

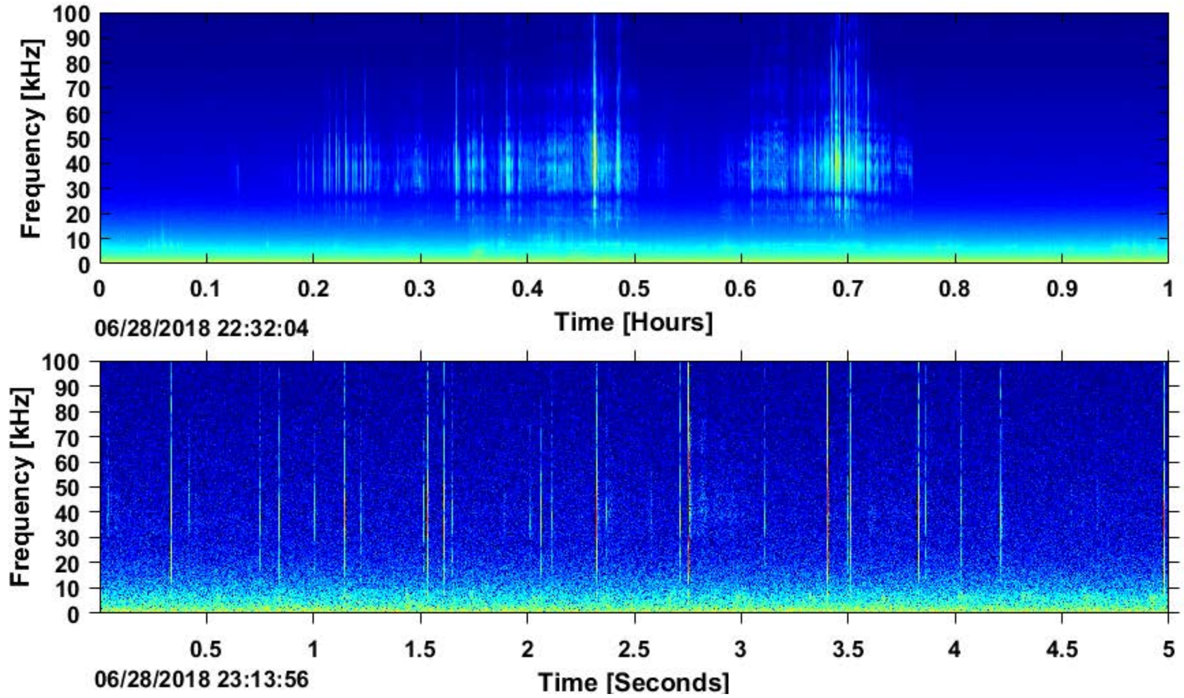

Figure 2: Goose-beaked whale signal in LTSA (top) and spectrogram (bottom).

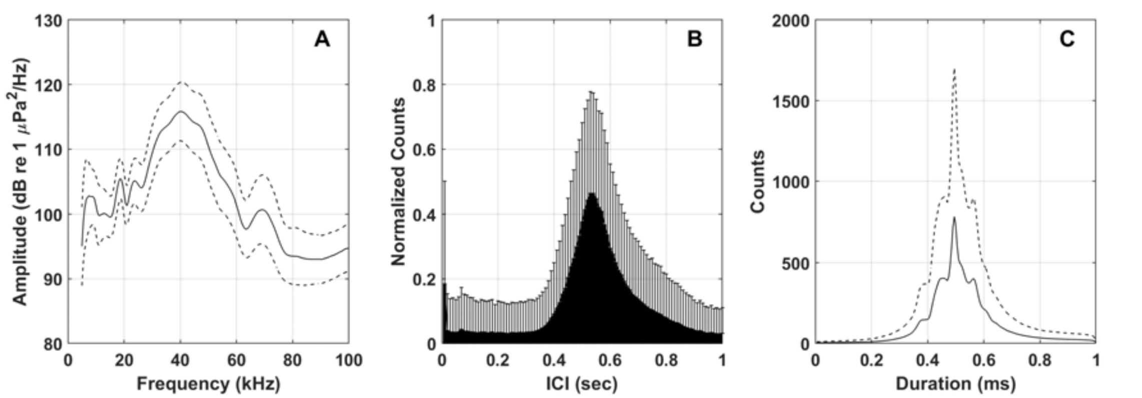

Figure 3: Left: Mean frequency spectrum of goose-beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.5 s; Right: Mean waveform envelope (solid line) and standard deviation (dashed line) of representative clicks.

4.2.2 Gervais' Beaked Whale

Gervais' beaked whale echolocation signals have energy concentrated in the 30-50 kHz band (Gillespie et al. 2009b), with a peak at 44 kHz (Baumann-Pickering et al. 2013) (Figures 4 & 5). While Gervais' beaked whale signals are similar to those of True's and Blainville's beaked whales, the Gervais' beaked whale FM pulses have a slightly longer ICI (near 0.3 s compared to 0.2 s) than True's and are at a slightly higher frequency than Blainville's. Similar to all beaked whales, Gervais' beaked whale FM pulses sweep up in frequency. The ICI for Gervais' beaked whale signals is typically around 0.28 s (Baumann-Pickering et al. 2013; Gillespie et al. 2009a).

Previous studies have shown that Gervais' beaked whales are concentrated from Cape Hatteras southward along the western North Atlantic slope (1000m contour), with limited presence north of Hatteras (Cohen et al. 2022; Haver et al. 2025; Cohen et al. 2023; DeAngelis et al. 2025). They occur year-round in these southern regions, with increased detections from late summer through winter (Stanistreet et al. 2022; Cohen et al. 2023). These patterns indicate that Cape Hatteras and waters to the south represent important foraging hotspots for this species within the U.S. EEZ (Haver et al. 2025; Cohen et al. 2023). Broad-scale surveys further show that Gervais' presence is closely tied to warm, low-chlorophyll Gulf Stream waters, distinguishing them from True's beaked whales, which occur more often in cooler slope and abyssal habitats (DeAngelis et al. 2025).

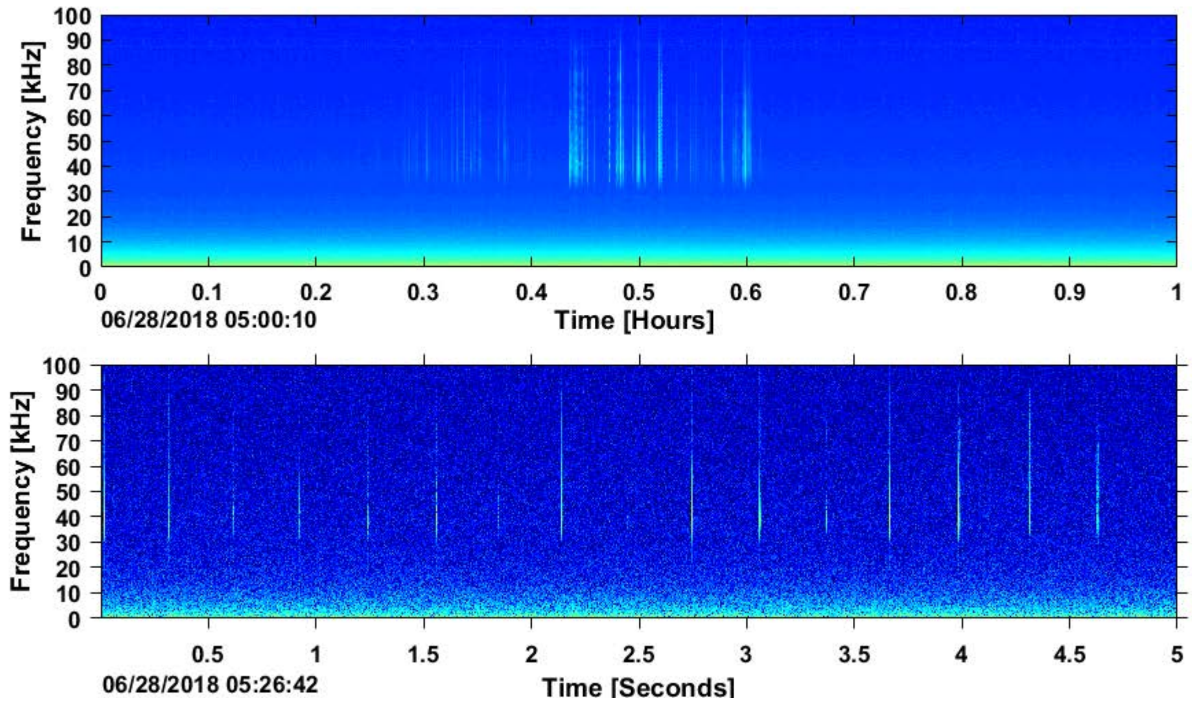

Figure 4: Gervais' beaked whale signal in LTSA (top) and spectrogram (bottom).

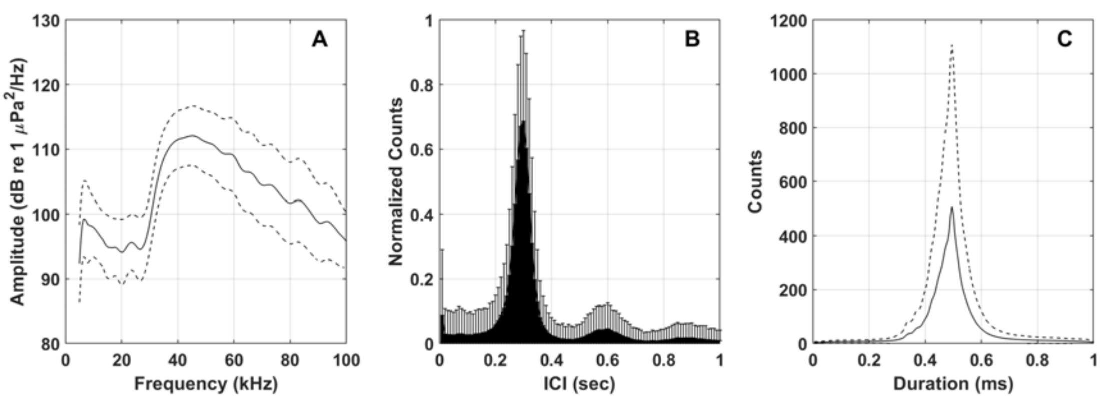

Figure 5: Left: Mean frequency spectrum of Gervais' beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.3 s. Smaller peaks can occur at multiples of the main peak, and represent cases where a subset of clicks in a click train have been missed by the detector or classifier; Right: Mean waveform envelope of representative clicks.

4.2.3 True's Beaked Whale

True's beaked whale echolocation signals are FM upsweep pulses, with a peak frequency around 46 kHz and an inter-pulse interval of about 0.18 s. The spectral features of True's beaked whale FM pulses closely resemble those produced by Gervais' beaked whales (DeAngelis et al. 2018) (Figures 6 & 7).

Previous studies have shown that True's beaked whales are primarily associated with deep slope and canyon habitats along the western North Atlantic slope (1000 m contour), with presence concentrated from Cape Hatteras north through the Mid-Atlantic canyons (Stanistreet et al. 2022; Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025). They are infrequently reported south of Cape Hatteras, and acoustic detections indicate year-round presence with increased prevalence from winter through summer at northern sites (Stanistreet et al. 2022; Cohen et al. 2022; Cohen et al. 2023). Broad-scale surveys further indicate that True's detections are more frequent in cooler slope and abyssal habitats, distinguishing them from Gervais' beaked whales that are more closely tied to Gulf Stream waters (DeAngelis et al. 2025). These patterns suggest that slope waters north of Cape Hatteras, including the canyon regions, represent important foraging hotspots for this species within the U.S. EEZ (Haver et al. 2025; Cohen et al. 2023).

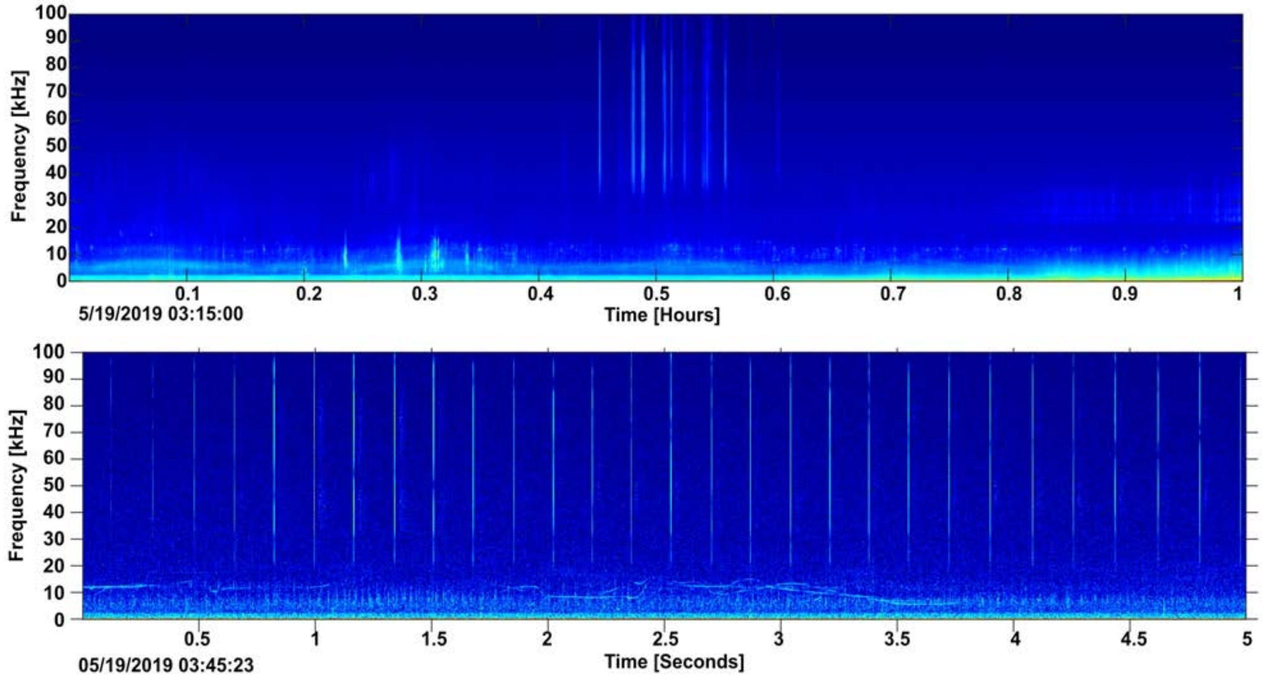

Figure 6: True's beaked whale signal in LTSA (top) and spectrogram (bottom).

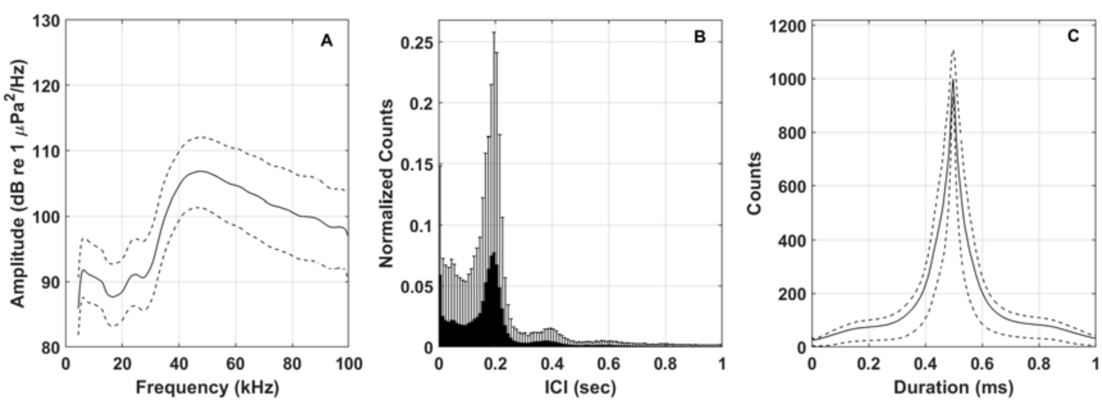

Figure 7: Left: Mean frequency spectrum of True's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.18 s; Right: Mean waveform envelope of representative clicks.

4.2.4 Blainville's Beaked Whale

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic with a characteristic frequency-modulated upsweep, and are identifiable by a peak frequency around 34 kHz and uniform ICI of about 0.28 s (Johnson et al. 2004; Baumann-Pickering et al. 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figures 8 & 9).

Previous studies have shown that Blainville's beaked whales are rarely encountered in the western North Atlantic slope (1000 m contour), with only occasional detections along the slope and shelf break of the U.S. EEZ (Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025). When present, they are generally restricted to southern regions near and south of Cape Hatteras, and detections occur sporadically throughout the year without clear seasonality (Stanistreet et al. 2022; Cohen et al. 2023). Broad-scale surveys further indicate that Blainville's detections are primarily associated with Gulf Stream waters, distinguishing them from goose-beaked whales, which are more broadly distributed across slope habitats (DeAngelis et al. 2025). These patterns suggest that Blainville's beaked whales are uncommon in the region, with only limited use of southern Mid-Atlantic waters as foragig habitat (Haver et al. 2025; Cohen et al. 2023; DeAngelis et al. 2025).

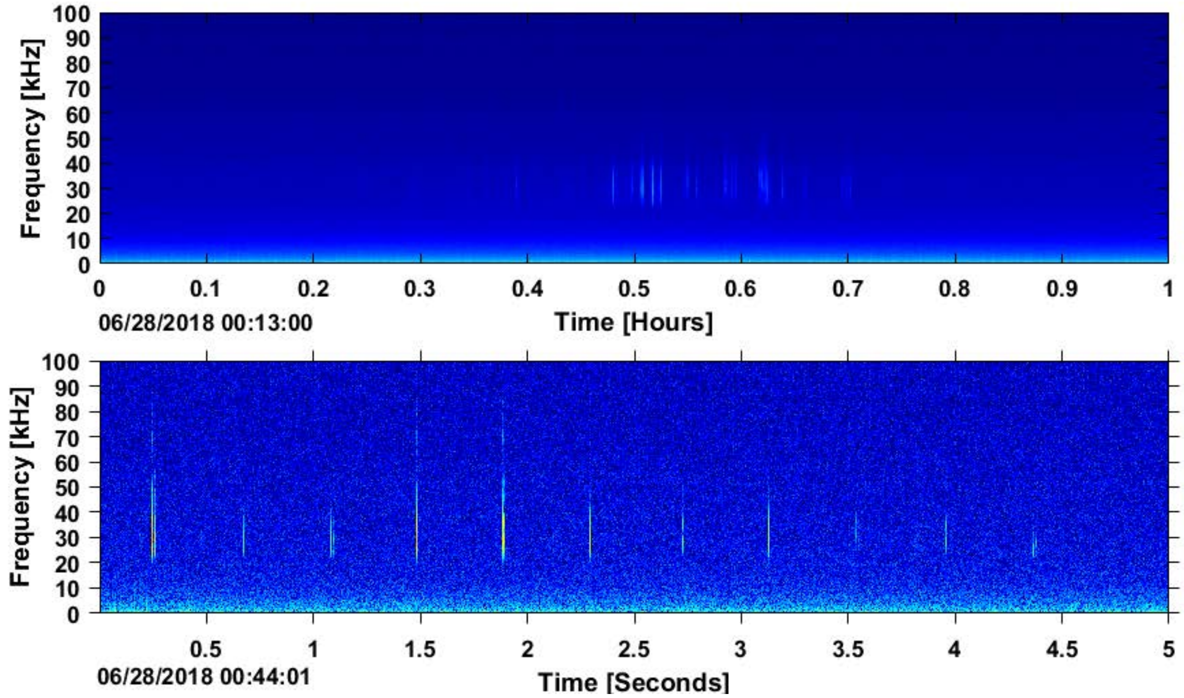

Figure 8: Blainville's beaked whale signal in LTSA (top) and spectrogram (bottom).

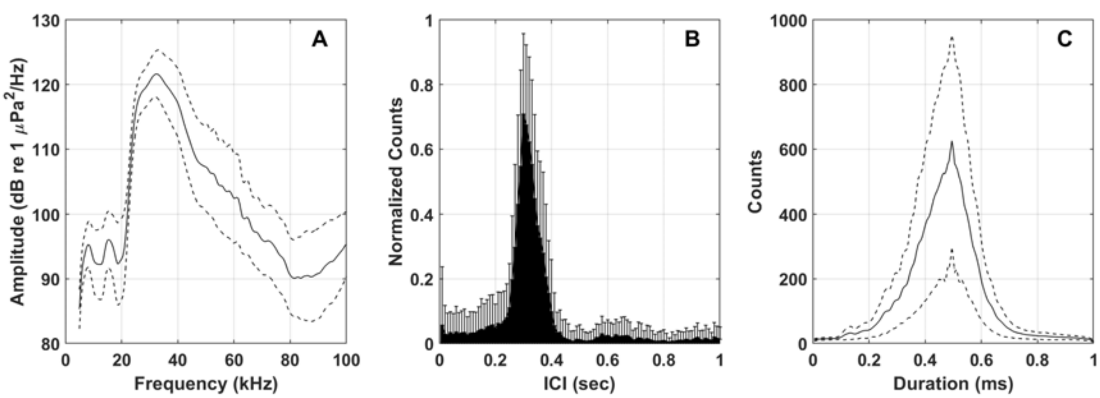

Figure 9: Left: Mean frequency spectrum of Blainville's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.3 s; Right: Mean waveform envelope of representative clicks.

4.2.5 Sowerby's Beaked Whale

Sowerby's beaked whale echolocation signals have energy concentrated in the 50-95 kHz band, with a peak at 67 kHz. Sowerby's beaked whale signals have a characteristic FM upsweep, and are distinguishable from other co-occurring beaked whale signal types by their higher frequency content and a relatively short inter-pulse interval of around 0.15 s (**Clarke2019**) (Figures 10 & 11).

Previous studies have shown that Sowerby's beaked whales are found primarily in the northern portion of the western North Atlantic slope (1000 m contour), with detections concentrated north of Norfolk Canyon and limited presence farther south (Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025). They occur year-round in these northern slope and canyon habitats, with detections peaking from summer through winter (Stanistreet et al. 2022; Cohen et al. 2023). Broad-scale surveys further show that Sowerby's detections are closely tied to the shelf-break front and continental slope waters, underscoring their predominance in more northerly habitats (DeAngelis et al. 2025). These patterns indicate that regions north of Norfolk Canyon represent the main foraging hotspots for this species within the U.S. EEZ (Haver et al. 2025; Cohen et al. 2023; DeAngelis et al. 2025).

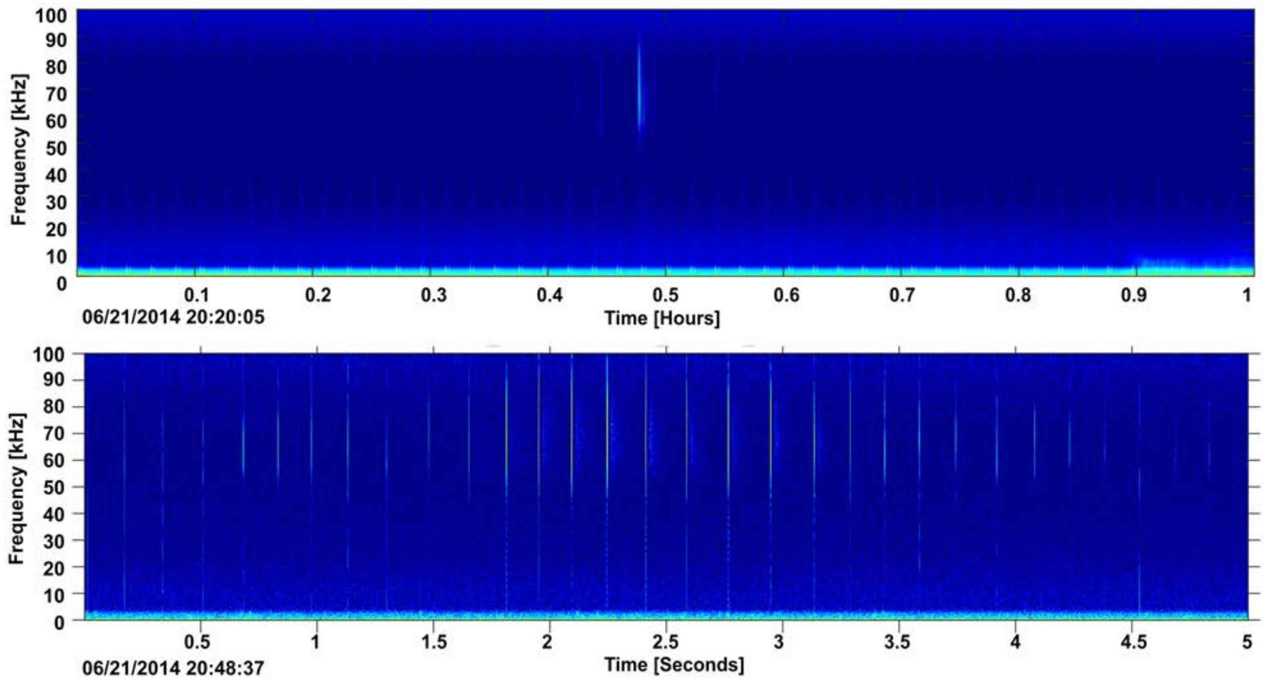

Figure 10: Sowerby's beaked whale signal in LTSA (top) and spectrogram (bottom).

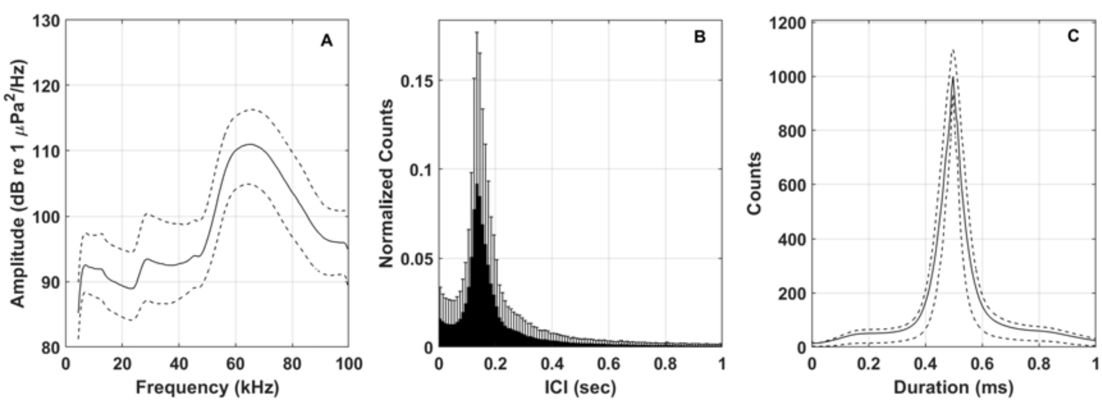

Figure 11: Left: Mean frequency spectrum of Sowerby's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.15 s; Right: Mean waveform envelope of representative clicks.

4.2.6 Beaked Whale Gulf (BWG)

The Beaked Whale Gulf (BWG) signal is believed to be produced by a beaked whale but currently of an unidentified speices. BWG echolocation signals are FM upsweep pulses, with a peak frequency around 47 kHz and an inter-pulse interval of about 133 ms (Baumann-Pickering et al. 2013). BWG pulses have a longer click duration and are greater bandwidth than other beaked whale species in this area (Hildebrand et al. 2015) (Figures 12 & 13). Although BWG was included in the neural network classifier, no encounters were detected during the analysis period, though classifier performance for BWG-like signals is lower than for other beaked whale species due to limited training and test sample sizes, which may reduce detection reliability.

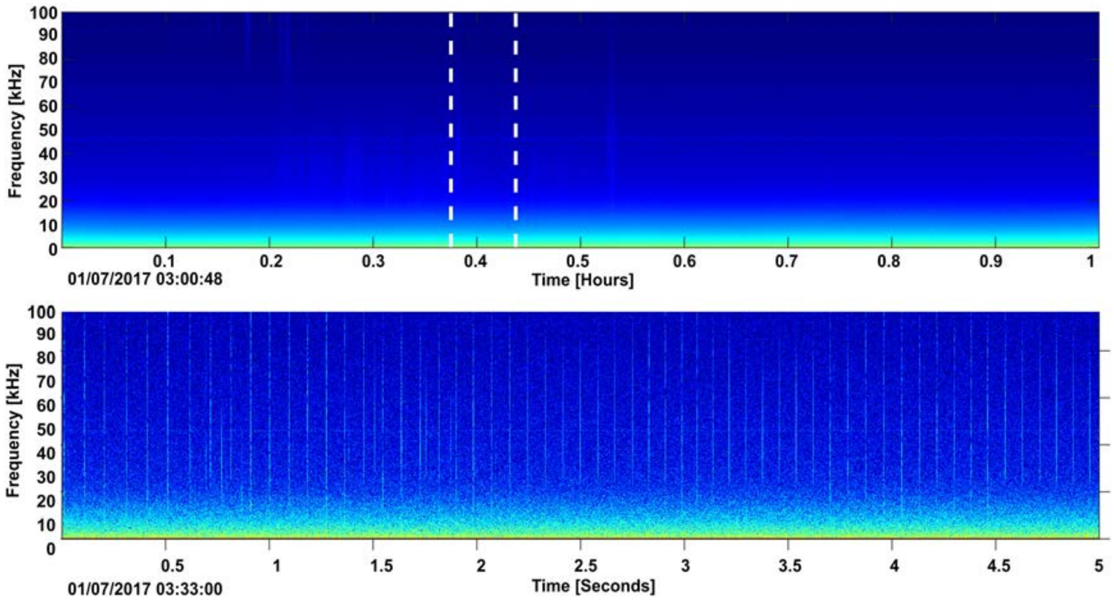

Figure 12: Beaked Whale Gulf (BWG) signal in LTSA (top) and spectrogram (bottom).

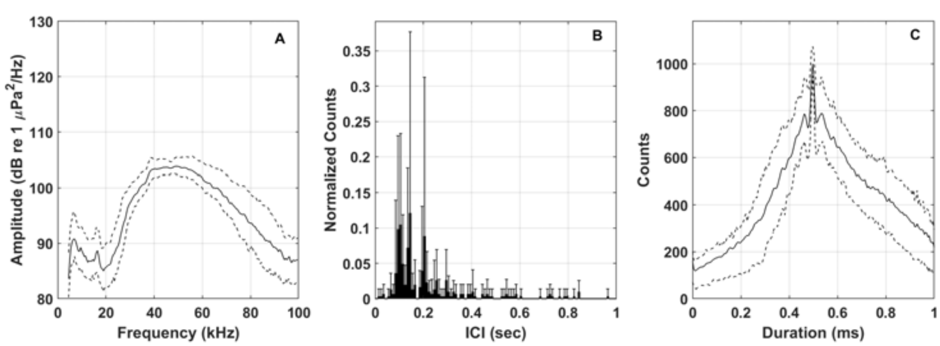

Figure 13: Left: Mean frequency spectrum of Beaked Whale Gulf (BWG) signals (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.18 s; Right: Mean waveform envelope of representative clicks.

4.2.7 Sperm Whales

Sperm whale clicks contain energy from 1-20 kHz, with the majority of energy between 10-15 kHz (Møhl et al. 2003) (Figure 14). With predominantly lower frequency energy, their echolocation clicks are highly distinguishable from those of other odontocetes. Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-2 s (Goold & Jones 1995) (Madsen et al. 2002). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Watwood et al. 2006). Effort was not expended to denote whether sperm whale detections were codas, creaks, regular or slow clicks, or to associate clicks with demographic groups (e.g. males vs. females, (Solsona-Berga et al. 2022)).

Previous studies have shown that sperm whales are distributed along the western North Atlantic slope (1000 m contour), with detections from the southeastern U.S. through Cape Hatteras and northward into New England waters (Stanistreet et al. 2018). They are present year-round, though occurrence is lower in the southern regions, with increased prevalence off Cape Hatteras in winter and farther north during spring and summer (Stanistreet et al. 2018). These patterns indicate that Cape Hatteras and slope habitats to the north represent important foraging areas for this species within the U.S. EEZ (Stanistreet et al. 2018).

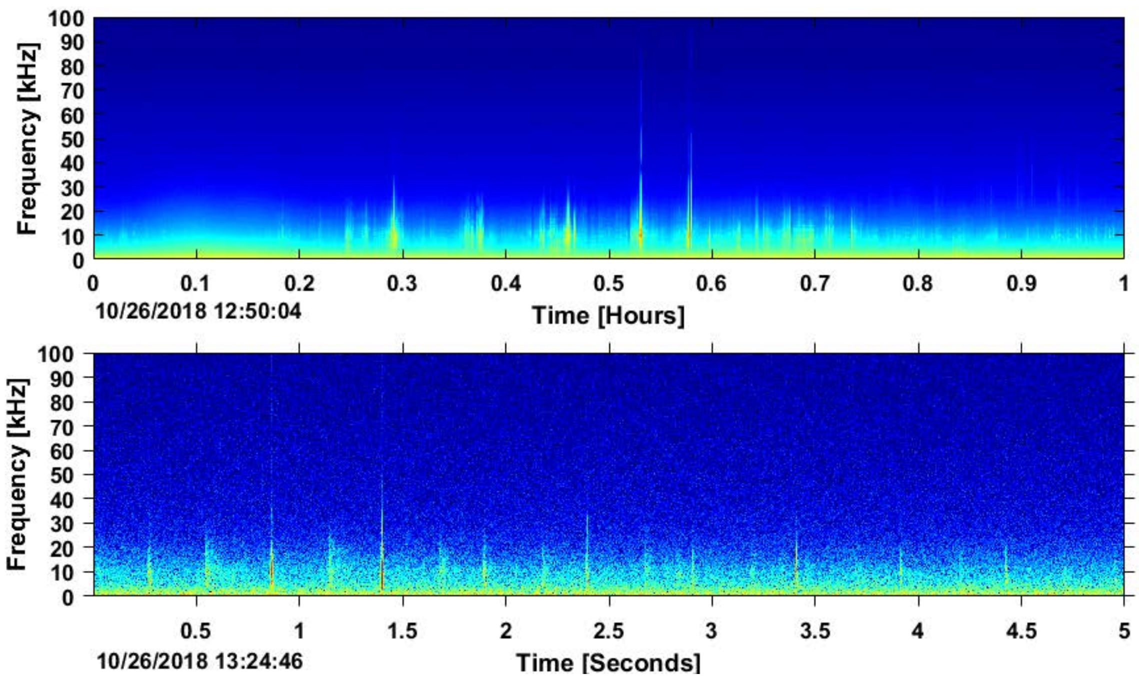

Figure 14: Sperm whale signals in LTSA (top) and spectrogram (bottom).

4.2.8 *Kogia* spp.

Dwarf and pygmy sperm whales emit echolocation signals which have peak energy at frequencies near 130 kHz (Au 1993). Their clicks can readily be distinguished from other species in the Western Atlantic, but not from each other. While the peak frequency of these clicks is above the upper frequency band recorded by the HARP during these deployments, energy from *Kogia* clicks can be recorded within the 100 kHz HARP bandwidth (Figure 15). The observed signal may result both from the low-frequency tail of the *Kogia* echolocation click spectra, and from aliasing of energy from above the Nyquist frequency of 100 kHz (Figures 15 & 16). Typical modal ICIs for *Kogia* spp. are near 0.1 s.

Previous studies have shown that Kogia spp. are broadly distributed along the western North Atlantic slope (1000 m contour), with acoustic detections from the southeastern U.S. through Cape Hatteras and into the Mid-Atlantic (Haver et al. 2025; Cohen et al. 2022). They are present year-round, but detections are generally more common in southern regions, including Cape Hatteras and southward, than in northern slope waters (Cohen et al. 2023). These patterns suggest that Cape Hatteras and adjacent southern slope habitats represent important foraging hotspots for Kogia spp. within the U.S. EEZ (Haver et al. 2025; Cohen et al. 2023).

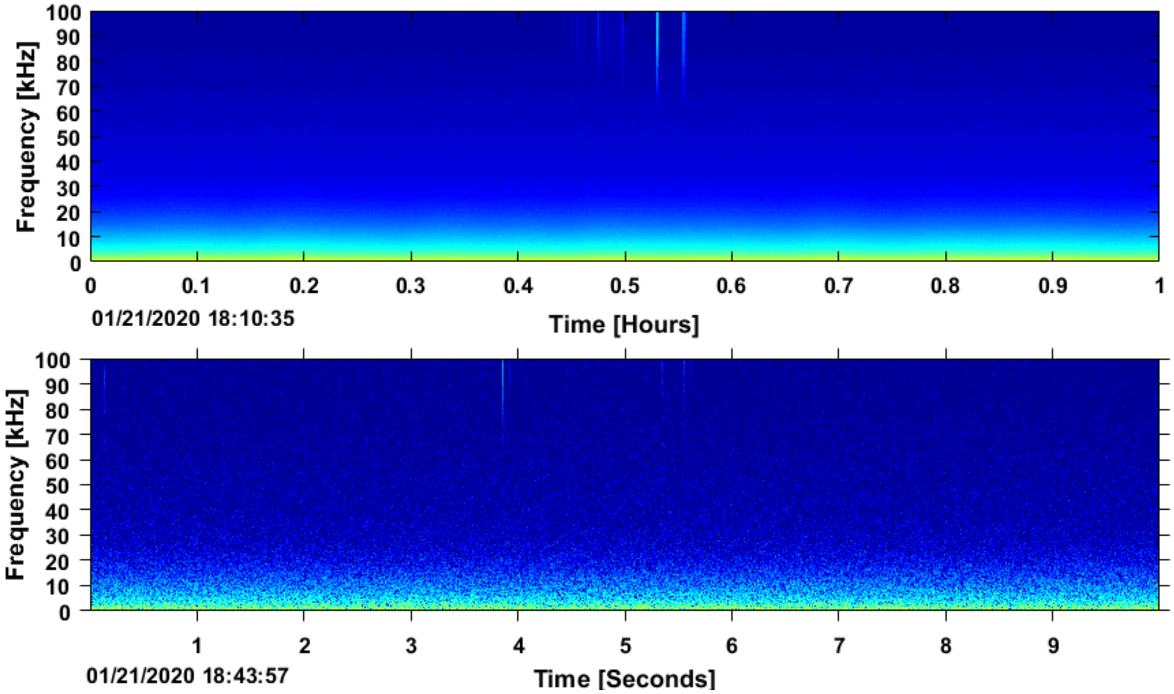

Figure 15: ***Kogia*** **spp. signals in LTSA (top) and spectrogram (bottom).**

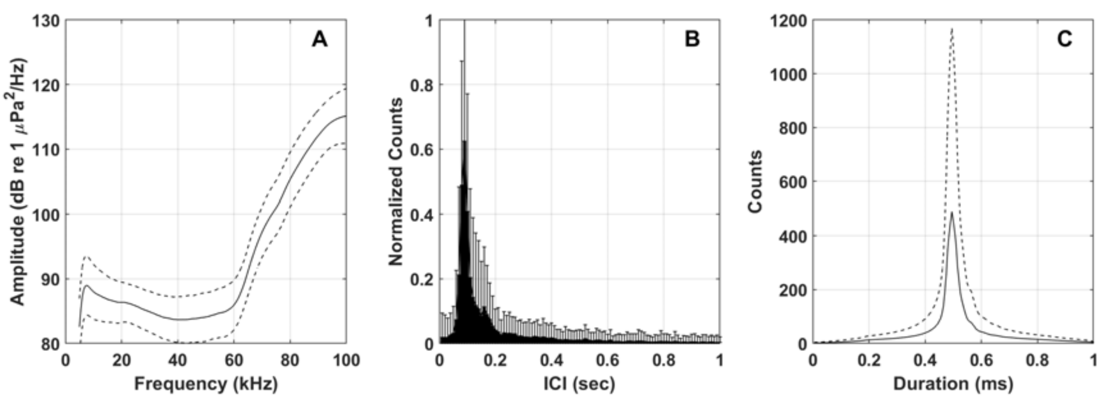

Figure 16: Left: Mean frequency spectrum of *Kogia* spp. echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.1 s; Right: Mean waveform envelope of representative clicks.

4.2.9 Risso's Dolphins

Risso's dolphin clicks (Figures 17 & 18) have frequency peaks at approximately 22, 26, and 33 kHz. These clicks have a modal ICI of approximately 0.15 seconds. Past studies have shown that spectral properties of Risso's dolphin clicks have slight variations with geographic region (Soldevilla et al. 2017), although the multiple sharp frequency peaks and average ICI found in the Gulf of Mexico are similar to what has been found elsewhere.

Previous studies have shown that Risso's dolphins are commonly distributed along the western North Atlantic slope (1000 m contour) and shelf break, with frequent occurrence from Cape Hatteras north through the Mid-Atlantic (Baumgartner & Mussoline 2011; Haver et al. 2025). They are present year-round, though detections tend to be higher in warmer months, particularly summer and fall, when they are most often associated with the slope waters of the Mid-Atlantic region (Baumgartner & Mussoline 2011; Cohen et al. 2023). These patterns indicate that Cape Hatteras and Mid-Atlantic slope habitats represent important foraging areas for this species within the U.S. EEZ (Haver et al. 2025; Cohen et al. 2023).

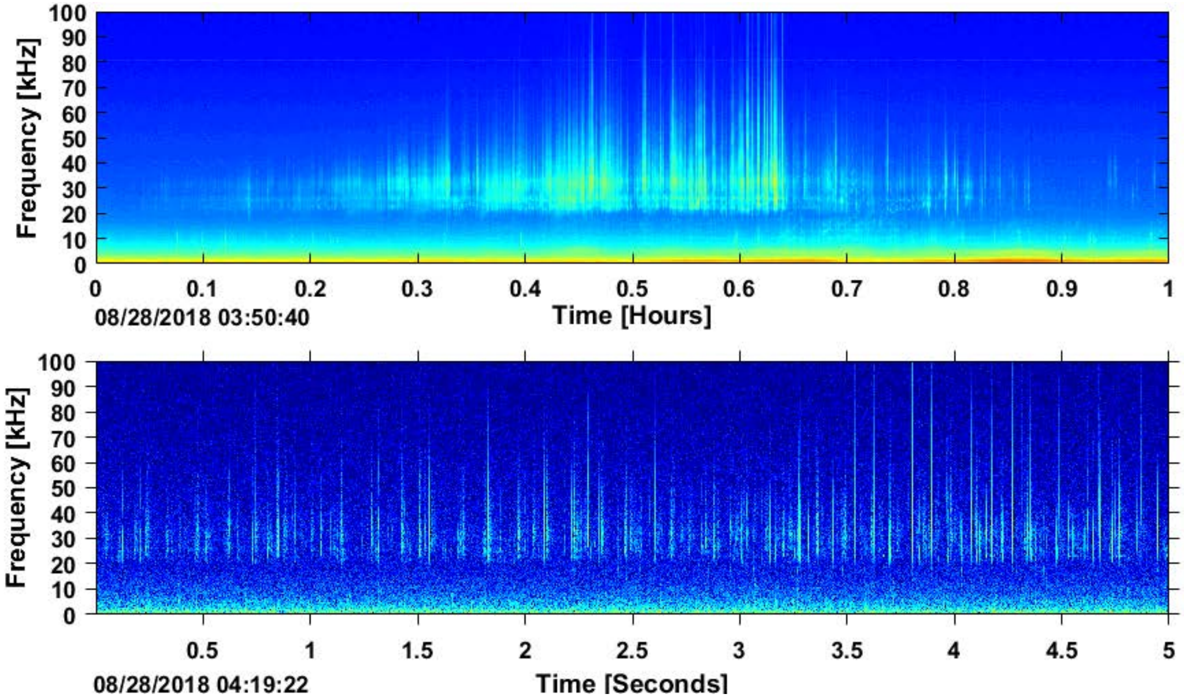

Figure 17: Risso's dolphins signals in LTSA (top) and spectrogram (bottom).

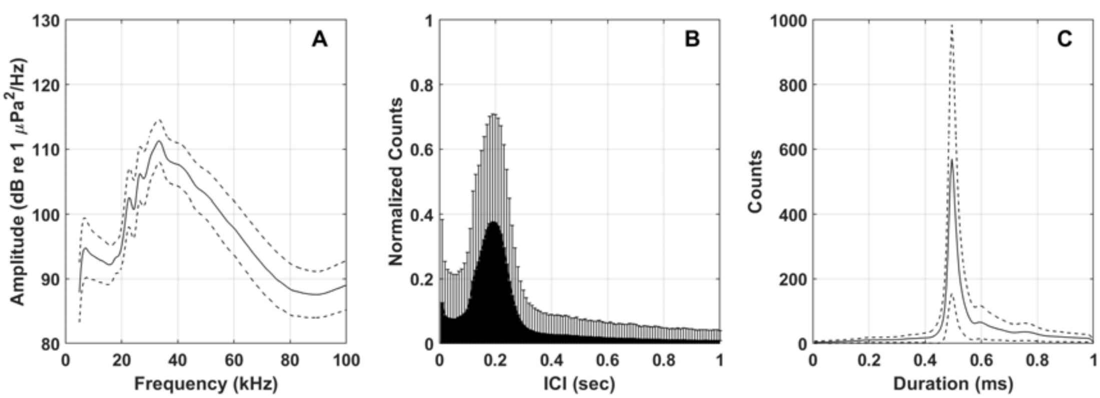

Figure 18: Left: Mean frequency spectrum of Risso's dolphins echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.2 s; Right: Mean waveform envelope of representative clicks.

4.2.10 Unidentified Dolphins – Presumed Smaller-Bodied Delphinids (UD HF)

High-frequency unidentified dolphin clicks (UD HF) were among the dominant click types identified by the unsupervised clustering algorithm. These clicks are acoustically distinctive but have not been conclusively associated with a single species. This grouping likely represents a suite of smaller-bodied delphinids known to occur in the mid-Atlantic, with dominant contributions at Onslow Bay most likely from short-beaked common dolphins (*Delphinus delphis*) and offshore bottlenose dolphins (*Tursiops truncatus*), based on regional spatiotemporal patterns reported for this site and nearby monitoring locations (Cohen et al. 2022). Cooler-water species such as Atlantic white-sided (*Lagenorhynchus acutus*) and white-beaked dolphins (*Lagenorhynchus albirostris*) may also contribute seasonally. While delphinids in the genus *Stenella* (e.g., Atlantic spotted, pantropical spotted, spinner, Clymene, and striped dolphins) are acoustically plausible contributors, these species are expected to be less prevalent at this site given their more southerly and tropical distributions.

UD HF clicks are characterized by peak frequencies primarily between 30 and 45 kHz (Figures 19 & 20). The inter-click interval (ICI) distribution exhibits two distinct modes, with a dominant peak near 0.065 s and a secondary peak near 0.1 s. The shorter ICI is consistent with click rates reported for *Stenella* species, while the longer ICI is more typical of offshore bottlenose dolphins. Further refinement of this category is anticipated, with future analyses likely to resolve this grouping into multiple click types and reduce classification confusion among acoustically similar delphinid signals.

Presumed smaller-bodied delphinids represented by the UD HF click type (hereafter referred to as smaller-bodied delphinids) occur year-round throughout the northwestern Atlantic, with higher prevalence along slope and canyon habitats off Cape Hatteras and in the mid-Atlantic (Haver et al. 2025; Cohen et al. 2023).

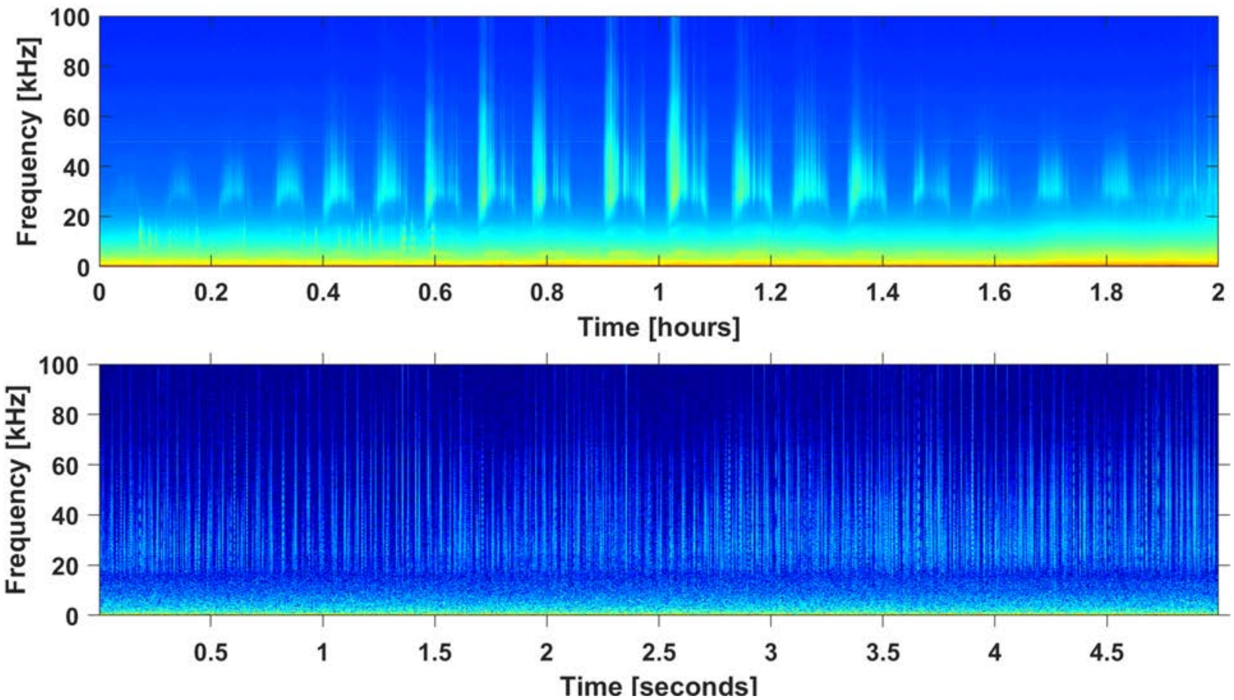

Figure 19: Unidentified dolphin high-frequency (UD HF) echolocation signals in LTSA (top) and spectrogram (bottom).

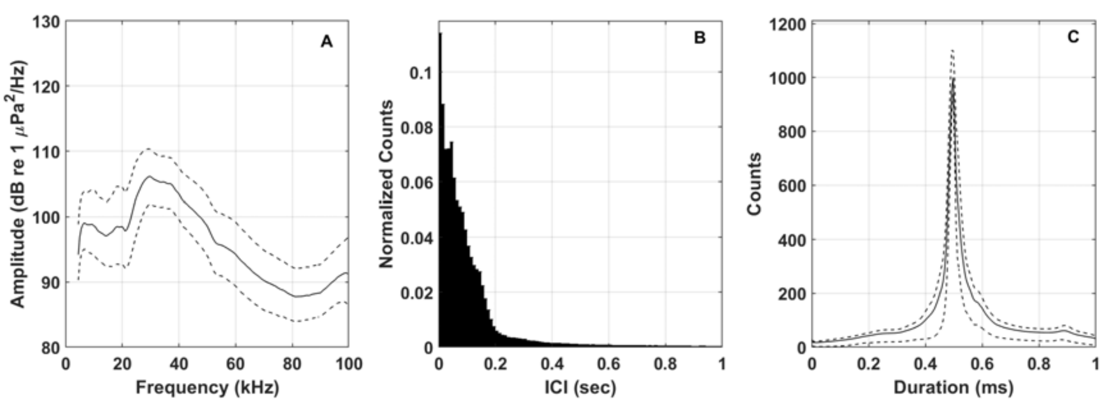

Figure 20: Left: Mean frequency spectrum of unidentified dolphin mid-frequency (UD HF) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.065 s and 0.1 s; Right: Mean waveform envelope of representative clicks.

4.2.11 Unidentified Dolphins – Presumed Smaller-Bodied Delphinids (UD47)

A second, acoustically distinct unidentified dolphin click type characterized by multiple low-frequency spectral peaks and a broader band of higher-frequency energy (UD47) was among the dominant click types identified by the unsupervised clustering algorithm. This click type was classified seperately due to its unique and recognizable spectral features and has not been conclusively linked to a specific species. UD47 clicks exhibit small spectral peaks near 13 and 19 kHz, with a broader region of elevated energy between approximately 30 and 50 kHz (Figures 21 & 22). The inter-click interval distribution for this click type shows a modal peak near 0.1 s, consistent with click rates reported for smaller-bodied delphinids and similar to those observed for the UD HF click type.

Presumed larger-bodied delphinids represented by the UD47 click type (hereafter referred to as smaller-bodied delphinids) are widely distributed along the western North Atlantic shelf break and slope, particularly near the 1000 m isobath (Cohen et al. 2022; Haver et al. 2025). Detections occur year-round across the U.S. Exclusive Economic Zone, with relatively higher prevalence off Cape Hatteras and into the mid-Atlantic slope waters (Haver et al. 2025; Cohen et al. 2023). Seasonal increases have been reported during summer and fall, consistent with broader patterns of delphinid occurrence in the region (Cohen et al. 2023). These observations suggest that mid-Atlantic slope habitats represent important foraging areas for smaller-bodied delphinids producing UD47 clicks (Haver et al. 2025; Cohen et al. 2023).

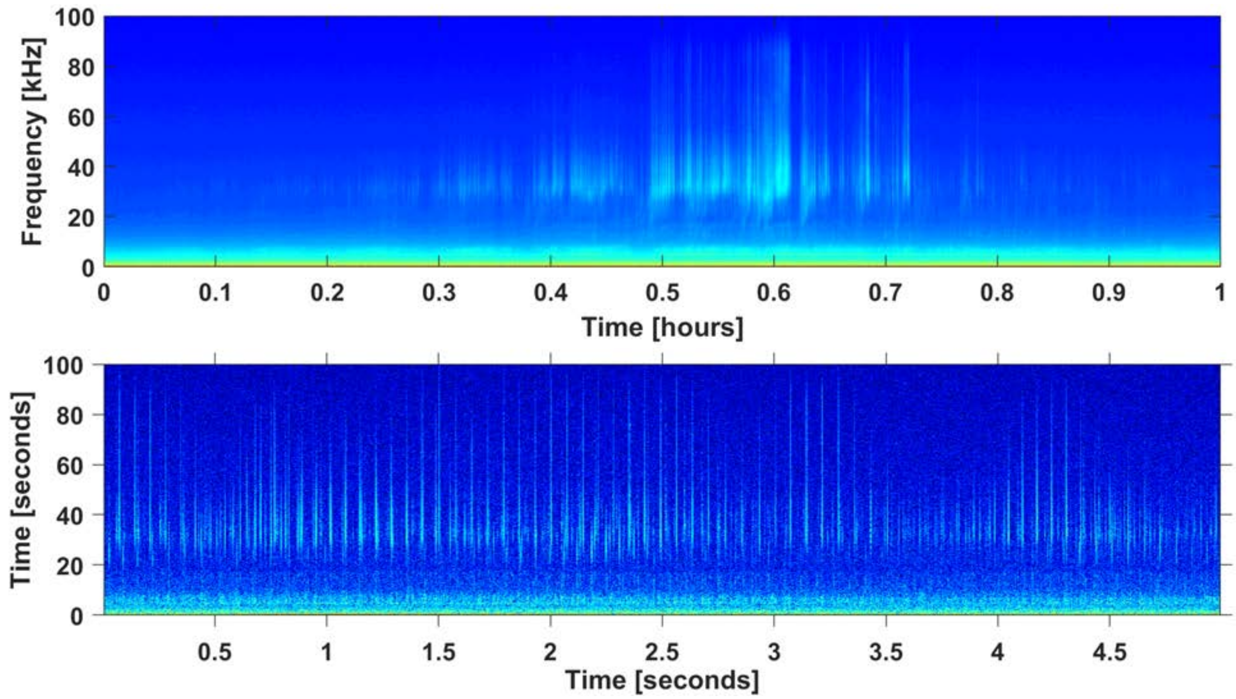

Figure 21: Unidentified dolphin 47 (UD47) echolocation signals in LTSA (top) and spectrogram (bottom).

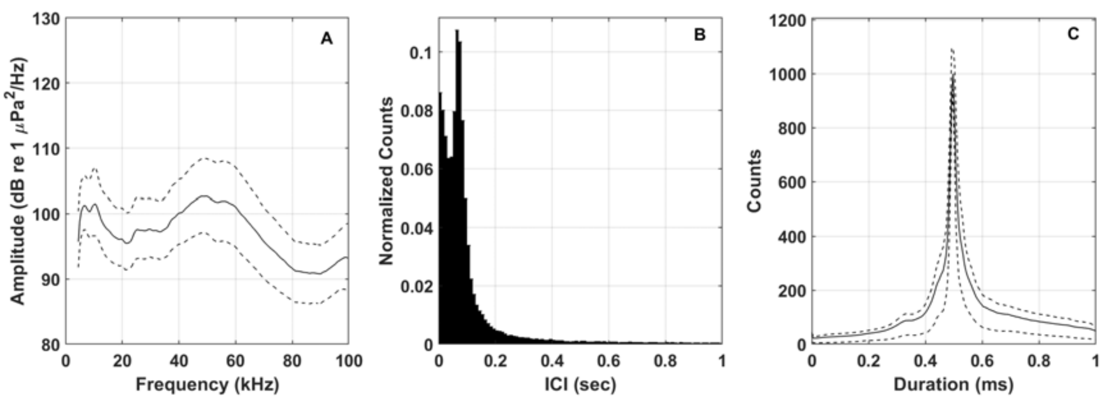

Figure 22: Left: Mean frequency spectrum of unidentified dolphin 47 (UD47) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.1 s; Right: Mean waveform envelope of representative clicks.

4.2.12 Unidentified Dolphins – Presumed Larger-Bodied Delphinids (UD LF)

A low-frequency unidentified dolphin click category (UD LF) was another dominant click type identified by the unsupervised clustering algorithm. This category likely represents several larger-bodied delphinid species, listed in order of expected abundance, including short-finned pilot whales (*Globicephala macrorhynchus*; Cohen et al. 2022), long-finned pilot whales (*Globicephala melas*), melon-headed whales (*Peponocephala electra*), false killer whales (*Pseudorca crassidens*), and killer whales (*Orcinus orca*; Leu et al. 2022). UD LF clicks are characterized by peak frequencies below 30 kHz and a variable modal inter-click interval near 0.2 s (Figures 23 & 24). This is a diverse category, and ongoing analyses are expected to further resolve this grouping into multiple subtypes that may be attributable to individual species.

Presumed larger-bodied delphinids producing UD LF clicks (hereafter referred to as larger-bodied delphinids) are consistently detected along the western North Atlantic slope, particularly near the 1000 m isobath (Cohen et al. 2022). These signals occur year-round within the U.S. Exclusive Economic Zone, with concentrations along the slope near Cape Hatteras and extending into the mid-Atlantic region (Haver et al. 2025; Cohen et al. 2023). Seasonal variation has been reported, with detections generally increasing during winter near Cape Hatteras and during fall in more northern regions (Cohen et al. 2023). These patterns indicate that Cape Hatteras and the mid-Atlantic slope represent important foraging areas for larger-bodied delphinids producing UD LF clicks (Cohen et al. 2023).

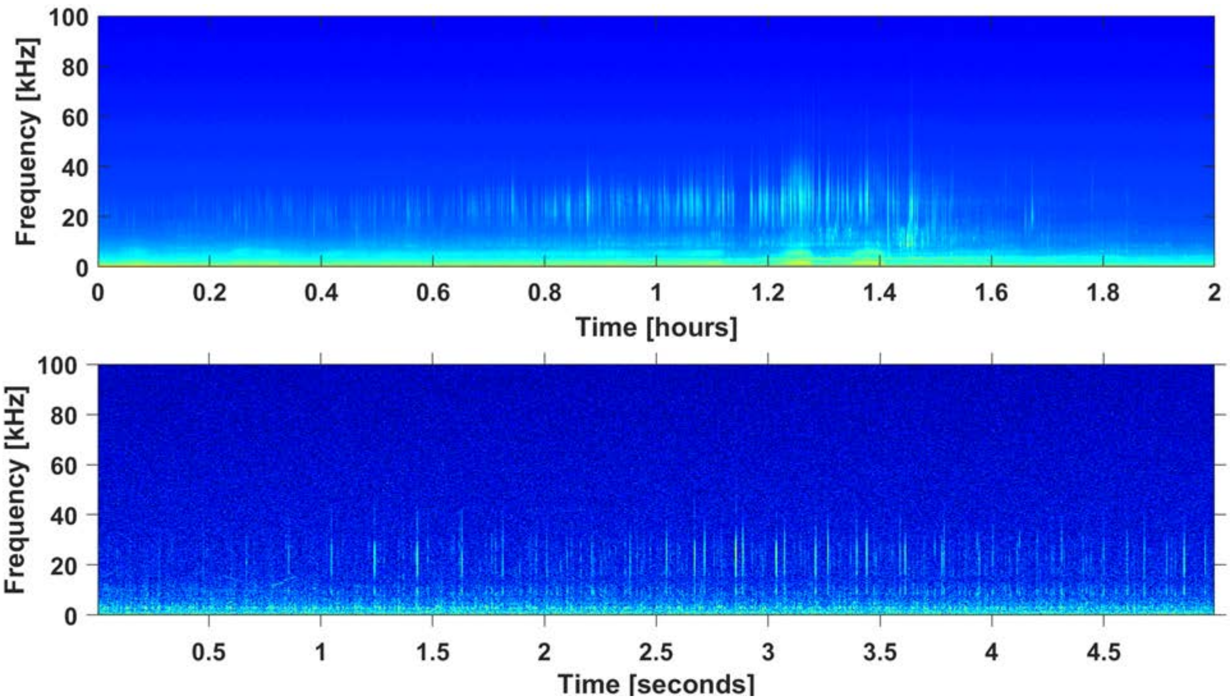

Figure 23: Unidentified dolphin low-frequency (UD LF) echolocation signals in LTSA (top) and spectrogram (bottom).

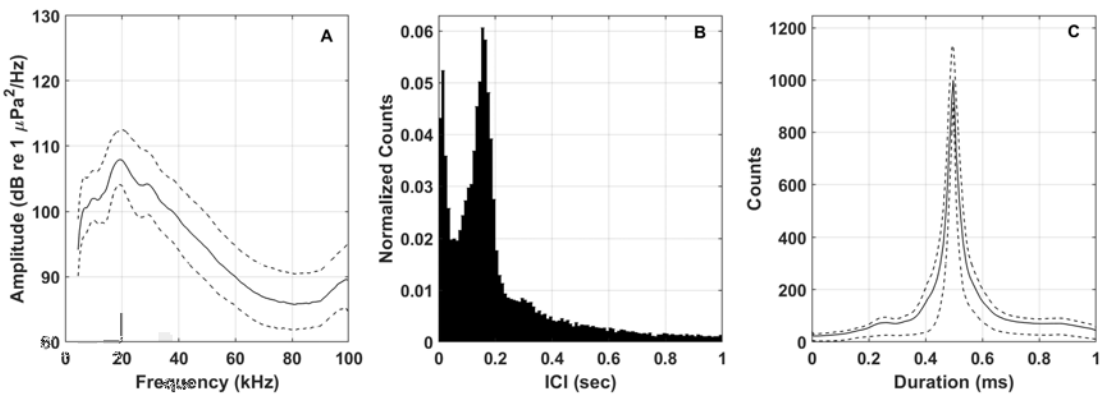

Figure 24: Left: Mean frequency spectrum unidentified dolphin low-frequency (UD LF) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.2 s; Right: Mean waveform envelope of representative clicks.

4.3 Mysticete Whale Analyses and Species Call Description

All mysticete species in this analysis, with the exception of minke whales, were detected using the Low Frequency Detection and Classification System (LFDCS; Baumgartner & Mussoline 2011). Minke whales were analyzed separately using a combination of manual logging and a custom detector, described below.

LFDCS creates conditioned spectrograms using a short-time Fourier transform with a data frame of 512 samples and 75% overlap, resulting in a time step of 64 ms and frequency resolution of 3.9 Hz. After tracing contour lines, or "pitch tracks," through tonal sounds, the program uses multivariate discriminant function analysis to classify the pitch tracks into species-specific call types based on a call library. Each detection is assigned a Mahalanobis distance (MD), which measures the deviation of a sound's pitch track from the assigned call type (Baumgartner & Mussoline 2011). A lower MD indicates a closer match to the assigned call type. For a well-developed call type in the LFDCS (i.e., the seven attributes used in the discriminant function analysis are multivariate normal), 75% of pitch tracks for the call type will have an MD of 3.0 or less (Baumgartner et al. 2013). Setting an MD threshold is necessary to minimize false detection rates, but in doing so, some true detections may be missed. The MD threshold of 3.0 was chosen for all call types detected and classified in the North Atlantic right whale, humpback, sei, and fin whale call library. However, for blue whales, false detection rates were lower than for any of the other species, and thus an MD threshold of 5.0 was originally chosen to reduce the probability of missing true detections; this threshold has since been increased to 6.0 for the current analysis.

All vocalizations were classified based on a user-developed call library (expanded from (Davis et al. 2017); Table S1). The library used for the 2 kHz sampled data included three of the target species, North Atlantic right, humpback, and sei whales. Due to the low-frequency characteristics of fin and blue whale vocalizations, an additional call library was created for these two species that matched the decimated 120 Hz sampled data.

All LFDCS detections were manually reviewed by trained acoustic analysts to determine daily presence of each of the five mysticetes species. A true detection was defined as a pitch track that correctly classified a call or song unit to the species that produced it (Bonnell et al. 2016). Given the variability of each species' vocalizations, the specific methodology to determine daily acoustic presence varied by species, as described below.

Although mysticetes are known to produce a broad repertoire of calls, only specific, consistently detectable call types were targeted for analysis and are described below.

4.3.1 Blue Whales

Daily presence for blue whales was confirmed if three song phrases were visible, including at least one true detection. Given the low false detection rate for this species, the MD threshold was increased from 5.0 to 6.0 in the current analysis to reduce the likelihood of missing true detections (Davis et al. 2020).

Blue whales in the western North Atlantic produce a well-characterized paired call known as the A-B call (Figure 25). The A call is a tonal signal at 18-19 Hz lasting approximately 8 seconds. It is often followed by a B call, which is a downsweep from 18 to 15 Hz and lasts around 11 seconds. This A-B sequence is typical of North Atlantic blue whale vocal behavior and is used in studies to monitor seasonal occurrence and distribution (Mellinger & Clark 2003).

Blue whales are infrequently observed within the U.S. EEZ compared to Canadian waters, but acoustic monitoring confirms their presence in offshore regions. They have been detected in the New York Bight (Muirhead et al. 2018), Mid-Atlantic Ridge (Nieukirk et al. 2004), and around the New England Seamounts (Lesage et al. 2017), as well as farther south near Cape Hatteras and Blake's Plateau (Davis et al. 2020). These detections are generally low in number, suggesting that U.S. waters function more as a migratory corridor and occasional foraging area rather than a primary feeding ground. Seasonal occurrence indicates that blue whales are mostly absent in summer, when they concentrate in northern feeding habitats, but they are detected in winter and during transitional periods, reflecting movement through the Mid-Atlantic and southeastern shelf regions (Davis et al. 2020).

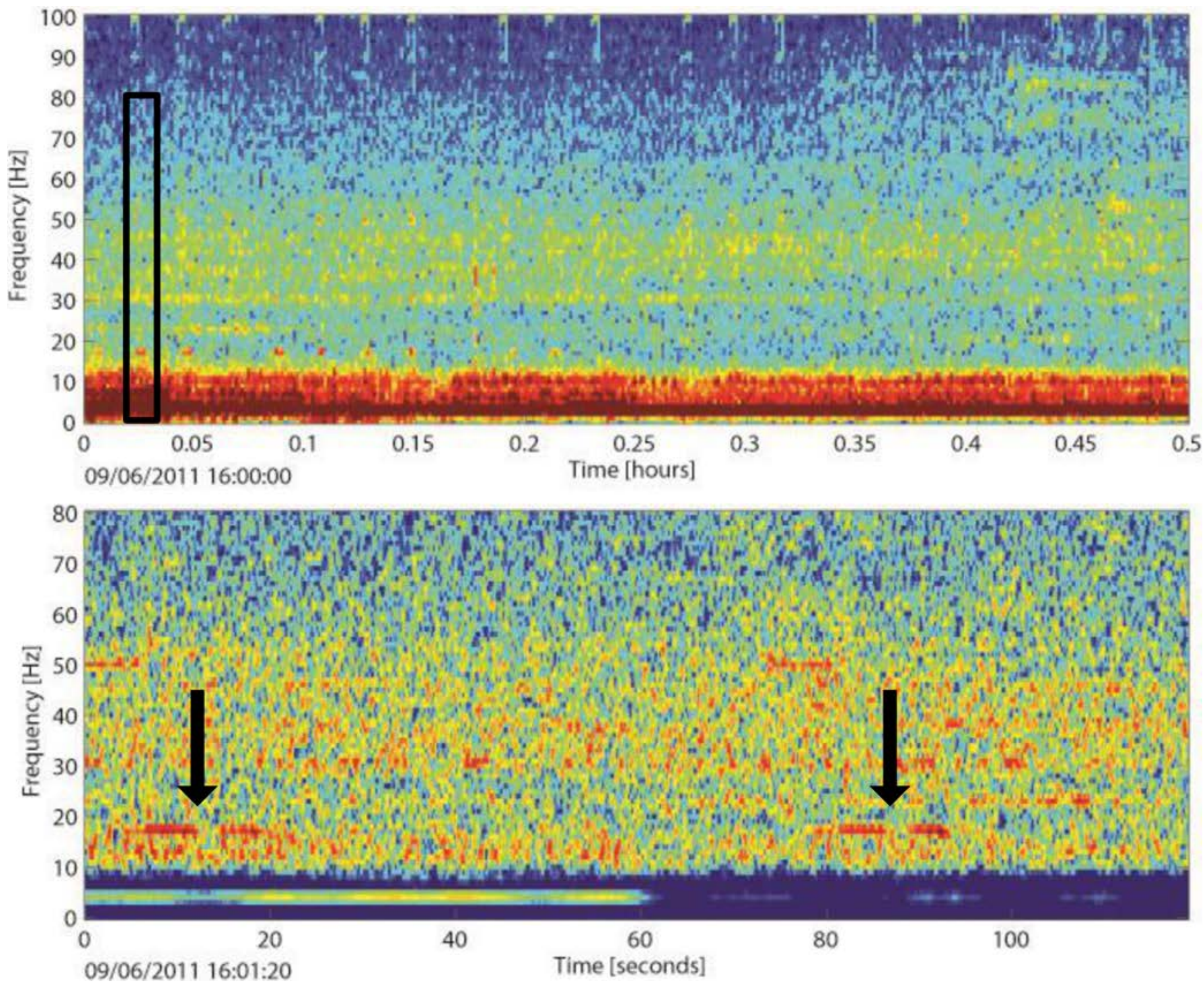

Figure 25: North Atlantic blue whale calls in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by black arrows.

4.3.2 Fin Whales

To confirm true fin whale presence across the full dataset, all hours with at least 29 detections were first identified based on a previous manual logistic regression analysis. Those hours were then manually reviewed, and fin whales were considered present for that day if a true detection was found within a regular interpulse interval pattern of at least three other 20 Hz pulses (Davis et al. 2020).

Fin whales produce a short, low-frequency call known as the 20 Hz pulse, which is a frequency-modulated downsweep from approximately 30 to 15 Hz and lasts around 1 second (Figure 26). These pulses are often produced at regular intervals in the form of song, particularly by males during the breeding season (Thompson et al. 1992), or irregularly as counter-calls among traveling animals (McDonald et al. 1995). The 20 Hz call is one of the most commonly detected fin whale vocalizations worldwide and is highly suitable for passive acoustic monitoring (Watkins 1981).

Fin whales are among the most frequently detected mysticetes in the U.S. EEZ of the western North Atlantic. They occur year-round from the Gulf of Maine to Cape Hatteras, with consistent acoustic detections in Massachusetts Bay, the New York Bight, and farther south near Cape Hatteras and Blake's Plateau (Morano et al. 2012; Muirhead et al. 2018; Davis et al. 2020). Offshore detections extend their seasonal range to Bermuda and the Mid-Atlantic Ridge from fall through spring (Clark & Gagnon 2004; Nieukirk et al. 2004). The Gulf of Maine and southern New England serve as important feeding areas, while Mid-Atlantic and southeastern U.S. waters provide overwintering habitat and a migratory corridor linking northern feeding grounds with more southerly habitats (Davis et al. 2020; Clapham & Mead 1999; Kennedy et al. 2014). Although neonatal strandings suggest possible calving in Mid-Atlantic latitudes (Hain et al. 1992), calving grounds have not been confirmed.

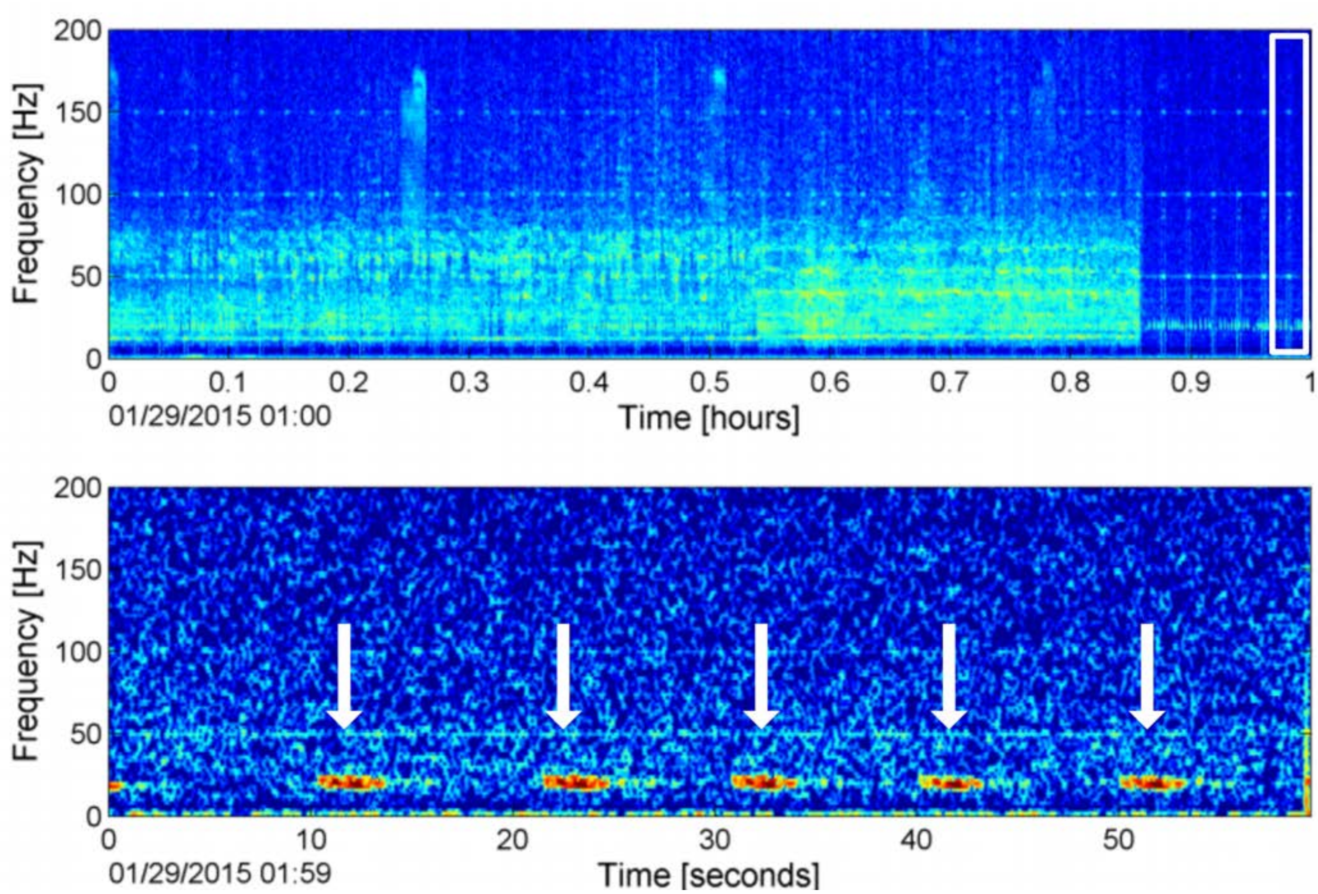

Figure 26: Fin whale 20 Hz calls in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

4.3.3 Sei Whales

Sei whales were considered present if at least one true detection of a downsweep (within a doublet or triplet) was verified for that day (Davis et al. 2020).

Sei whale vocalizations used in this study consist of low-frequency downsweeps that begin near 100 Hz and sweep downward to about 40 Hz (Figure 27). These calls, typically lasting 1 to 2 seconds, have been consistently attributed to sei whales in the western North Atlantic and are widely used in passive acoustic detection (Baumgartner & Fratantoni 2008; Baumgartner et al. 2008).

Sei whales are less frequently observed in the U.S. EEZ of the western North Atlantic, but acoustic and visual records confirm their presence along the shelf break from Georges Bank to Cape Hatteras (Davis et al. 2020; Baumgartner & Mussoline 2011). Most detections occur during spring and fall, suggesting that U.S. waters function primarily as a migratory corridor between high-latitude summer foraging grounds in the Gulf of Maine and Canadian waters, and possible wintering areas farther south (Payne et al. 1990; Davis et al. 2020). Occasional records off Cape Hatteras and the Blake Plateau indicate that these regions may serve as transitional habitats during seasonal movements (Davis et al. 2020).

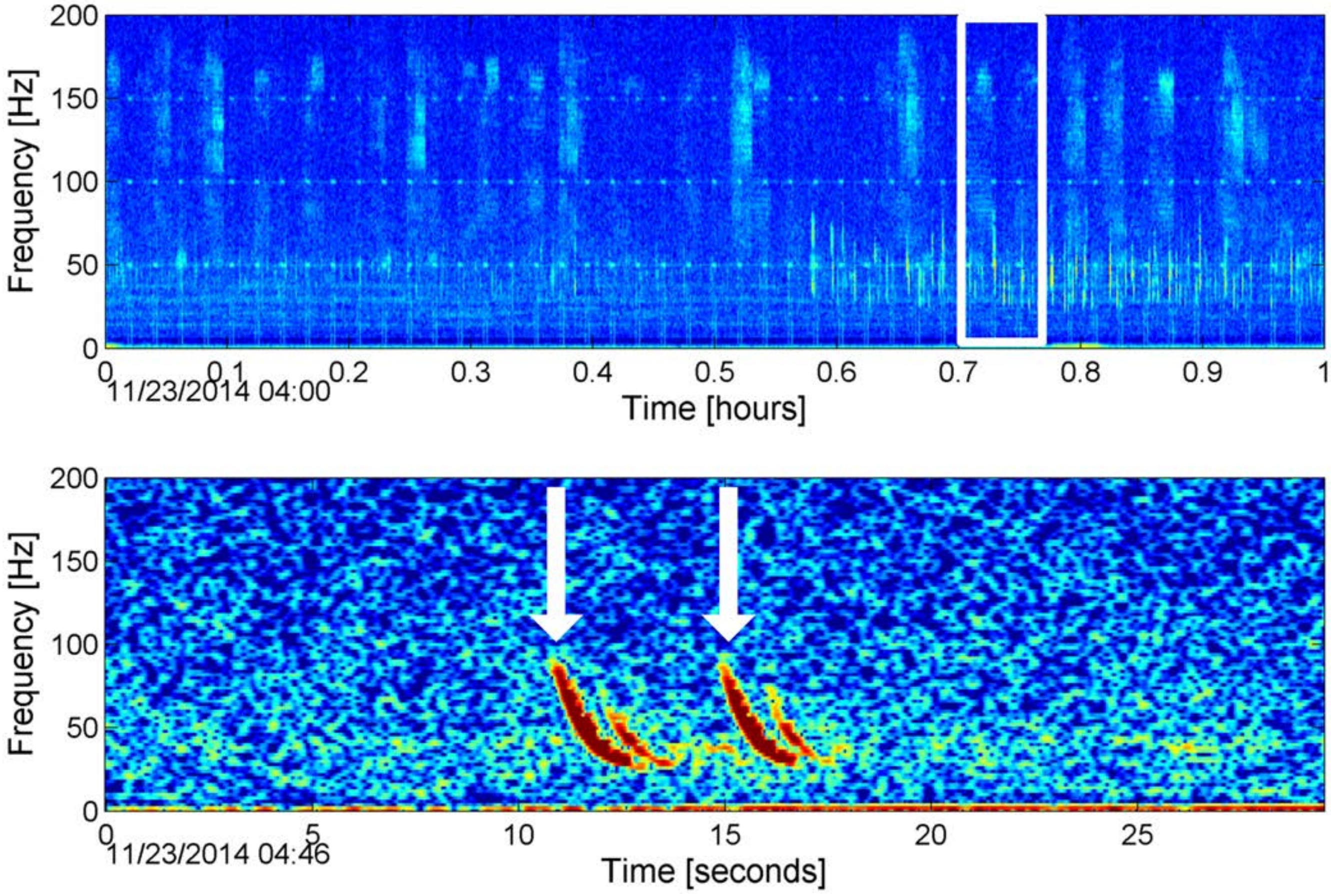

Figure 27: Sei whale downseep call in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

4.3.4 Humpback Whales

A day was marked as present for humpback whales if one true detection was found within at least three humpback whale vocalizations occurring over a 10-min window (Davis et al. 2020).

Humpback whales produce both complex songs and various non-song vocalizations (Figures 28 & 29). The vocalizations used for detection in this study fall within the 100–3,000 Hz range and may consist of either song units—repeating structures organized into phrases and themes (Payne & McVay 1971)—or social and feeding calls. These non-song vocalizations typically last between 0.15 and 2.5 seconds and exhibit variable frequency and amplitude modulation (Dunlop et al. 2007; Stimpert et al. 2011).

Humpback whales are regularly observed throughout the U.S. EEZ of the western North Atlantic, with strong seasonal patterns. They occur from the Gulf of Maine south through the Mid-Atlantic Bight and to Cape Hatteras, with detections extending onto Blake's Plateau (Davis et al. 2020; Kennedy et al. 2014). The Gulf of Maine and waters off southern New England are important feeding grounds, supporting large seasonal aggregations in spring and summer (Clapham & Mead 1999; Kenney & Winn 2001). In contrast, detections in the Mid-Atlantic and near Cape Hatteras are most frequent during migration periods in the spring and winter, indicating these regions function as a migratory corridor and transitional habitat (Davis et al. 2020; Kennedy et al. 2014). Some individuals remain in the Mid-Atlantic and southeastern U.S. waters year-round, but most migrate to the Caribbean for breeding and calving (Davis et al. 2020; Smith et al. 1999; Aschettino et al. 2020).

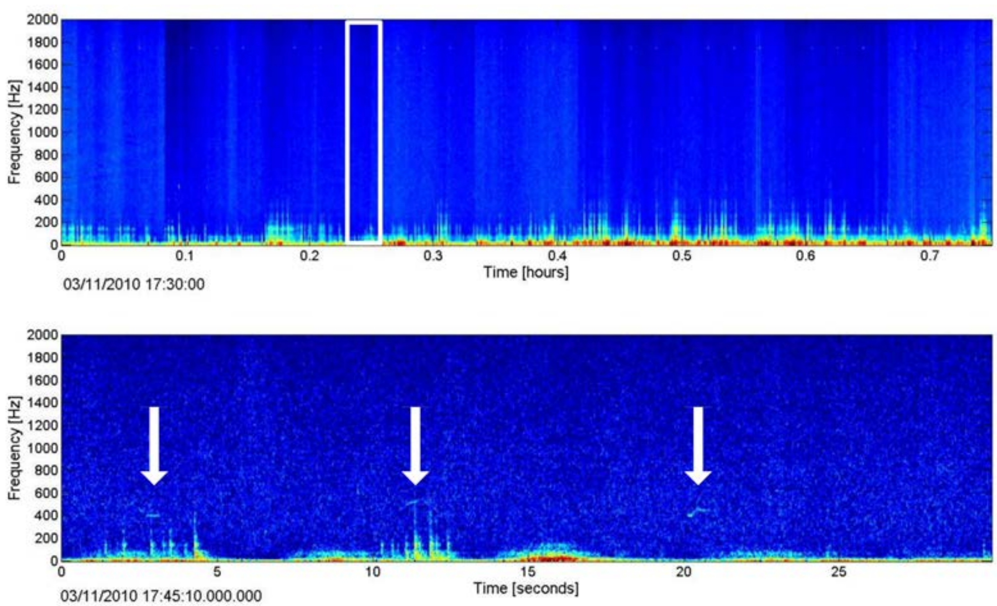

Figure 28: Humpback whale call in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the black arrows.

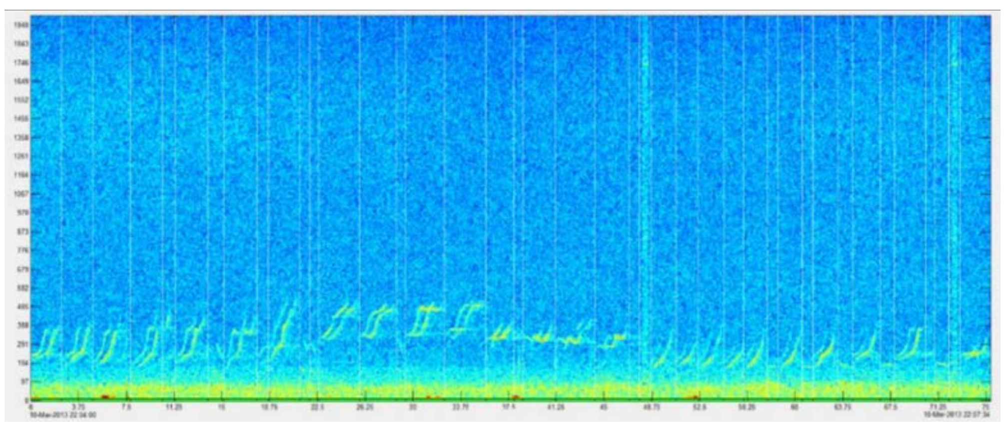

Figure 29: Concatenated humpback whale songs viewed in the software GPL review (Helble et al. 2012).

4.3.5 North Atlantic Right Whales

Three or more true upcall detections in one day were required for North Atlantic right whales to be marked as detected on that day (Davis et al. 2017).

The primary vocalization used to detect North Atlantic right whales is the upcall, a frequency-modulated tonal signal that typically sweeps upward from 80 Hz to 200 Hz over approximately 1 second (Figure 30). Harmonics may be present depending on individual variation and recording conditions. Upcalls are believed to function as contact calls and are consistently used in acoustic monitoring efforts due to their distinctiveness and frequent occurrence (Parks & Tyack 2005).

North Atlantic right whales are among the most critically endangered mysticete and have historically used U.S. waters extensively. Within the U.S. EEZ, they are most frequently observed from the Gulf of Maine to Cape Hatteras, with core foraging habitats in Cape Cod Bay, the Great South Channel, and the Gulf of Maine (Kenney & Winn 2001; Clapham & Mead 1999; Davis et al. 2020). Seasonal occurrence reflects a latitudinal migration: aggregations are common in the northeast U.S. during spring and summer, while movements southward in fall and winter bring individuals to the Mid-Atlantic, southeastern shelf waters, and the calving grounds off Florida and Georgia (Waring et al. 2010; Davis et al. 2020). Detections off Cape Hatteras and the Blake Plateau highlight their use of the Mid-Atlantic as both a migratory corridor and transitional habitat (Davis et al. 2020). Despite this, right whales now appear less frequently in historical foraging habitats and increasingly occur farther north into Canadian waters, underscoring ongoing distributional shifts (Davis et al. 2020; Record et al. 2019).

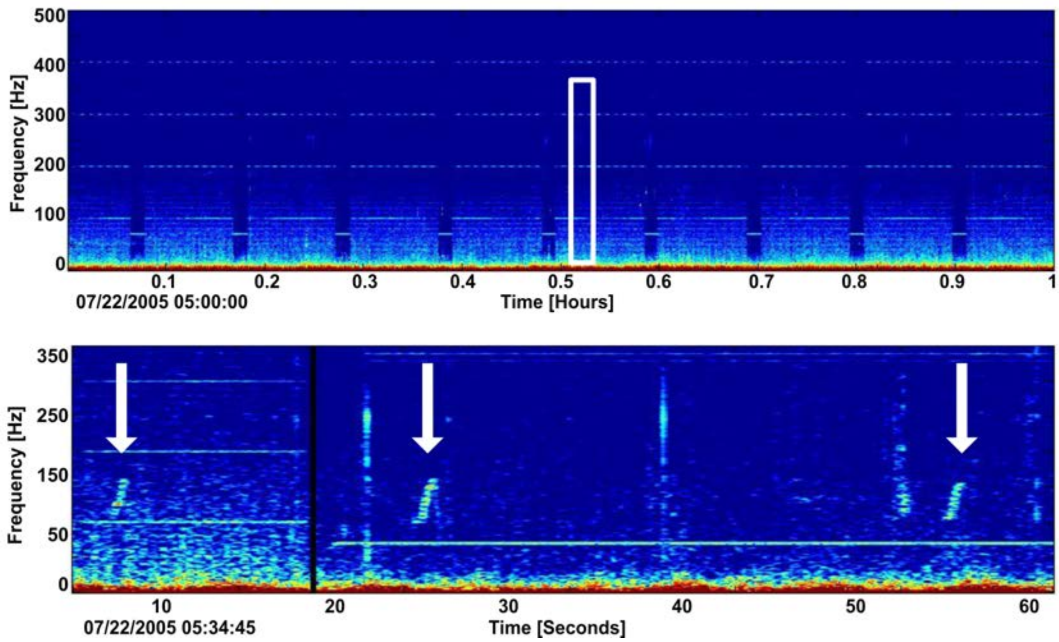

Figure 30: North Atlantic right whale upcall in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

4.3.6 Minke Whales

For sites B, C and deployments 2A-4A, 6A, 11D, and 13D, analysis of minke whale vocalizations was performed by manually scanning long-term spectral averages (LTSAs) and spectrograms. The recordings were decimated by a factor of 100 from the original 200 kHz sampling rate to obtain an effective bandwidth of 1 kHz. LTSAs were generated using the Triton software package with a 5-second time average and 1 Hz frequency bins. During visual analysis, the LTSA display range was typically set to 1-300 Hz over a 1-hour window, and the spectrogram view was set to 1-250 Hz with a 60-second duration. FFT lengths ranged from 1500 to 2000 data points, yielding approximately 1 Hz frequency resolution, with 85-95% overlap applied to enhance call visibility. When pulse trains were identified, presence was logged in hourly bins; however, analysts did not differentiate between the three known pulse train subtypes (speed-up, slow-down, constant-rate) during annotation.

For deployment 5A and 14D-16D, recordings were processed with a custom-built detector in Python to identify common North Atlantic minke whale pulse trains (Mouy et al. 2025). This detector uses a binary ResNet18 deep neural network (DNN) to detect and automatically classify minke whale pulse trains based on spectrogram images. The network was trained using manually annotated sounds from minke whale and non-minke whale sounds collected across multiple regions. All detections with a model confidence threshold exceeding or equal to 0.6 were manually reviewed on a daily basis. If one true detection was verified, that day was marked as 'detected' for minke whales. A formal performance evaluation for this detector is ongoing. Preliminary exploratory comparisons between manually logged and detector-derived detections suggest that the two approaches are not directly comparable, with the automated detector likely under-representing minke whale presence relative to manual review. Accordingly, the results presented here are interpreted conservatively.

North Atlantic minke whales produce long-duration pulse trains consisting of repeated broadband pulses (Figure 31). These have been categorized into several types: “speed-up” and “slow-down” trains, in which the pulse rate increases or decreases over time, respectively, and constant-rate pulse trains where the pulse interval remains stable. These call types were first described by (Mellinger & Clark 2000) near Puerto Rico and later expanded by (Risch et al. 2013) for use in the North Atlantic. Minke whales are the smallest and among the most frequently sighted mysticete in the U.S. EEZ of the western North Atlantic. They occur year-round from the Gulf of Maine south to Cape Hatteras, with peak sightings and acoustic detections in spring and summer when they forage in nearshore and shelf waters (Mitchell 1991; Kenney & Winn 2001; Stanistreet et al. 2018; Davis et al. 2020). The Gulf of Maine and Georges Bank are primary feeding habitats, but animals are also reported farther south along the Mid-Atlantic shelf and near Cape Hatteras, where detections indicate the southern limit of their regular range (Kenney & Winn 2001; Davis et al. 2020). Seasonal distribution suggests a migratory pattern, with individuals moving northward in summer to feed and southward in winter, though some remain in the Mid-Atlantic year-round (Mitchell 1991; Kenney & Winn 2001). Occasional records off Blake's Plateau and farther offshore suggest use of transitional habitats during migration (Davis et al. 2020).

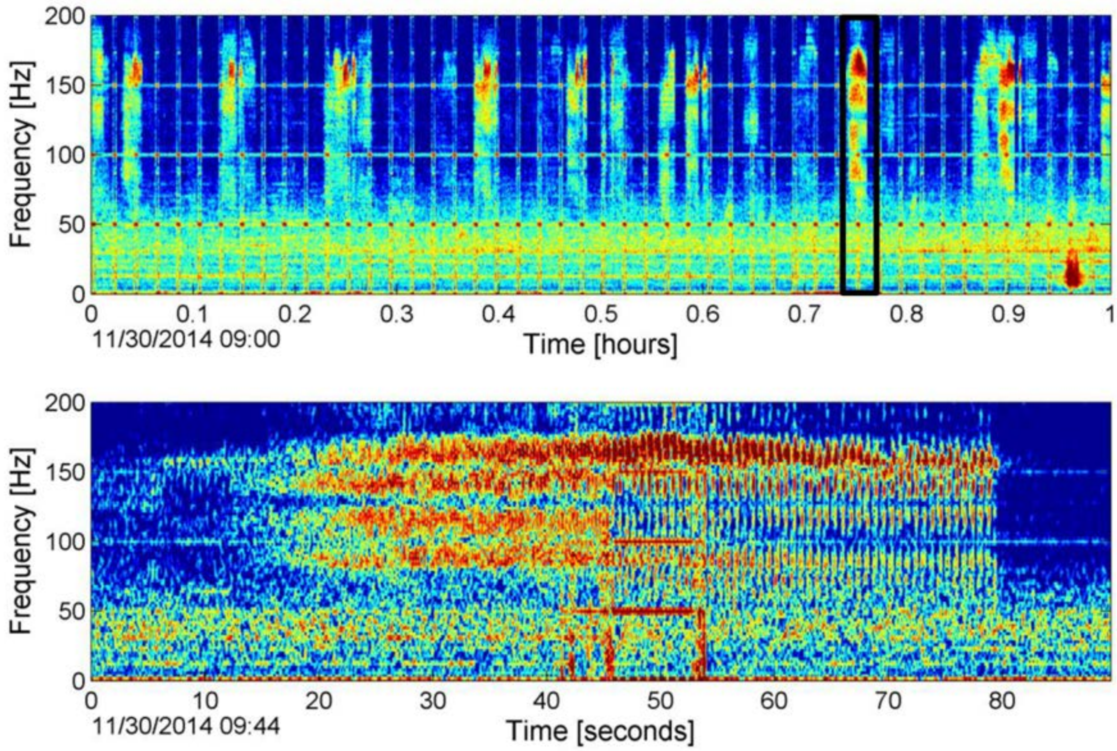

Figure 31: Minke whale pulse train in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom).

4.4 Ambient Noise Analysis

Analyses of ambient noise levels provide information on the natural and anthropogenic contributions of noise sources and how they vary over time and space. Hourly long-term spectrograms were produced at each site to document ambient noise levels over time.

Long-term spectrograms and ambient noise curves were estimated from the following methods from 2016 for low frequency, factor of 100 decimated data from 10 Hz to 1 kHz in 1 Hz bins.

In each case, consecutive, 5-second (s) waveforms were transformed into sequential sound pressure spectral density estimates with 1 Hz bin resolution using the Welch method (Welch 1967). During recording, HARPs write sequential 75 s acoustic records to standard laptop-style computer hard disk drives such that there were 15 5-s spectra for each 75 s acoustic record. However, system self-noise can be present when the HARP is writing to disk (12 s out of each 75 s record), so the first three 5-s spectra were not used for the following soundscape analyses. Statistical distributions of the noise spectra were computed per hour and per day after discarding partial days and days with deployment/recovery ships sounds or with known instrument self-noise problems. These distributions were calculated with custom MATLAB-based software to provide hourly and daily average of sound pressure spectrum levels over the monitoring period in addition to long-term spectrograms.

The data were also categorized by season, with winter represented by January, February, March; spring as April, May, June; summer as July, August, September; and fall as October, November, and December.

5 Results

Multiple odontocete and mysticete species and groups were acoustically present in the Jacksonville study area between 2009 and 2020 (Figure 32). The following results describe site-specific temporal patterns at Jacksonville sites A–D; we do not infer broader spatial gradients across the western North Atlantic, and references to other studies are provided only for context.

Among the deep divers, sperm whales exhibited the greatest and most sustained acoustic presence at the slope site (D). Beaked whales were also restricted to site D, with goose-beaked whales the most regularly occurring species. *Kogia* spp. were detected intermittently at site D, with relatively low weekly presence and modest seasonal variability. Delphinids were detected across the study area but exhibited strong depth structuring. Smaller-bodied delphinids (UD HF & 47) were present at all sites and were most pronounced at the shallow shelf site (A), with clear nocturnal diel patterns at sites A and D. In contrast, larger-bodied delphinids (UD LF) were concentrated at the slope site (D), where they exhibited sustained and comparatively high acoustic presence beginning in 2015 and clear seasonal structure, but no consistent diel pattern. Risso's dolphins were also detected primarily at site D, with relatively low overall presence and increased nighttime detections.

Mysticete detections were intermittent across the Jacksonville sites and were largely seasonal. Minke whales exhibited the strongest and most consistent presence, particularly at the slope site (D) from fall through spring, with weekly presence frequently exceeding three to five days per week during peak periods. Fin whales were detected at all sites and showed clear winter seasonality, with consistent offshore occurrence at site D. Sei whales were detected primarily at the slope site during fall and winter at low levels. Humpback whales were rarely detected and were limited to brief late winter–early spring periods at shallow shelf sites. No blue whale detections were recorded during the monitoring period. North Atlantic right whale detections were extremely limited, occurring in only March of 2014 at site B and December of 2014 at site D. Collectively, these results indicate that baleen whales use the Jacksonville region primarily as a seasonal transit and transitional habitat, with more consistent offshore use relative to shallow shelf sites.

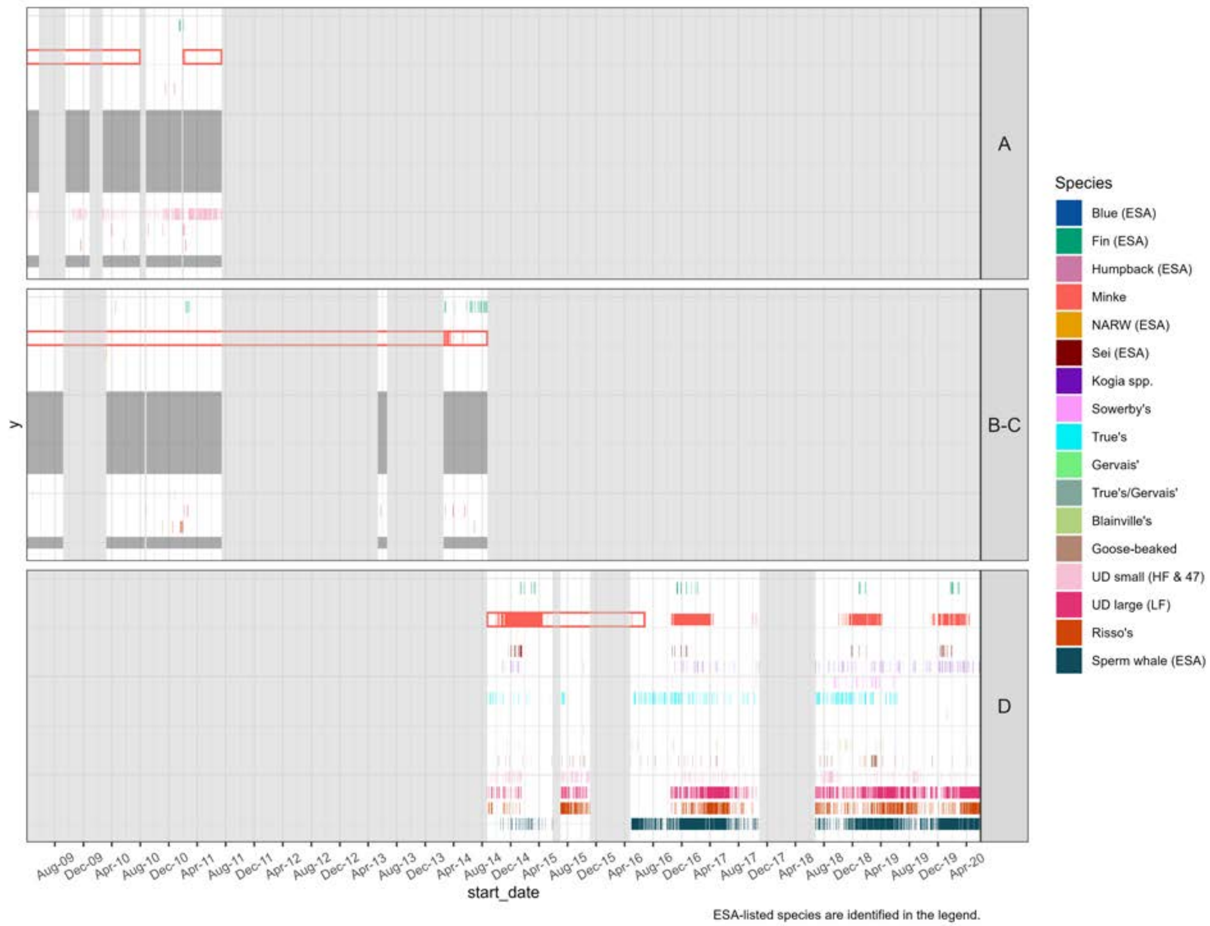

Figure 32: Daily presence of odontocetes and mysticetes at Jacksonville sites A-D from 2009 to 2020. Colored bars indicate days with confirmed acoustic presence for each species or species group. The red box around the minke time series denotes the period when presence was manually logged, with the remaining periods derived from the automated detector; manual and automated detections for minke whales are not directly comparable. Shaded gray areas denote periods of missing data due to instrument recovery or malfunction. For deep-diving species (Kogia spp., beaked whales, and sperm whales), additional gray bands denote no effort at the shallow sites (A-C). Sites are plotted vertically to illustrate overlapping deployment periods and differences in effort among subsites. Species listed under the U.S. Endangered Species Act (ESA) are identified in the legend.

5.1 Odontocetes

Multiple species and groups of odontocetes were acoustically present in the Jacksonville study area, with overall patterns strongly structured by depth (Fig. 32). Deep-diving taxa, including beaked whales, sperm whales, and *Kogia* spp., were detected only at the slope site (D), whereas Risso's dolphins and unidentified delphinids were detected across multiple sites but with clear differences in relative abundance among click-type groupings. The Beaked Whale Gulf (BWG) signal was included in the neural network classifier, but no encounters were identified during the analysis period.

Among deep divers, sperm whales showed the greatest overall acoustic presence at site D, with sustained periods of high weekly click-positive hours and highest occurrence during winter and spring. Beaked whales (goose-beaked, True's, Gervais', Blainville's, and Sowerby's) were also restricted to site D, but generally occurred at substantially lower levels than sperm whales. Goose-beaked whales were the most regularly detected beaked whale species at this site. True's, Gervais', and Blainville's beaked whales were intermittently present at low levels, and Sowerby's beaked whales were extremely rare. *Kogia* spp. were detected intermittently at site D at low levels, with increased detections in later years and modest seasonal variability.

Delphinid detections were widespread but differed markedly by presumed size class. Unidentified smaller-bodied delphinids (UD HF & 47) were detected at all sites and exhibited their greatest acoustic presence at site A, with lower overall presence at sites B and C and intermittent moderate occurrence at site D. Where sufficient detections were available to evaluate diel behavior, UD HF & 47 detections were concentrated at night, particularly at sites A and D. In contrast, unidentified larger-bodied delphinids (UD LF) were detected almost exclusively at site D, where they exhibited sustained and comparatively high acoustic presence and clear seasonal structure (highest mean presence during spring), but no distinct diel pattern. Risso's dolphins were also detected primarily at site D, with relatively low overall occurrence and a diel pattern characterized by more nighttime detections.

Together, these results highlight strong depth-stratified odontocete occurrence in the study region. Deep-diving odontocetes were concentrated at the slope site (D), while delphinids occurred more broadly across the shelf-to-slope gradient, with smaller-bodied click types most prevalent at the shallow site (A) and larger-bodied click types concentrated at the slope. Seasonal and diel variability further indicate that odontocete habitat use in the region reflects differences in foraging ecology and the oceanographic conditions associated with shelf versus slope environments.

5.1.1 Goose-Beaked Whales

Goose-beaked whales were present intermittently at site D throughout the monitoring period and was not detected at sites A-C (Figures 33–34). Acoustic presence was generally low, with most weeks exhibiting fewer than two click-positive hours, although occasional short-duration peaks were observed.

Monthly summaries indicate higher acoustic presence during winter and early spring months, with reduced presence during summer (Figure 34).

No consistent diel pattern was evident in goose-beaked whale acoustic presence (Figure 35), with activity occurring across both daytime and nighttime hours, suggesting relatively uniform acoustic activity throughout the day when animals were present.

Overall, goose-beaked whale occurrence at the Jacksonville slope site was sporadic and low, consistent with previous studies indicating more limited use of habitats south of Cape Hatteras compared to regions farther north, where higher and more sustained acoustic presence has been documented (Haver et al. 2025; Cohen et al. 2022; Stanistreet et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025).

Summary of Results – Goose-Beaked Whales

- Goose-beaked whale acoustic presence at site D was intermittent and generally low.
- Weekly presence was typically fewer than two click-positive hours, with occasional short-duration peaks.
- Acoustic presence was most common during winter and early spring months.
- No clear diel pattern in acoustic activity was observed.

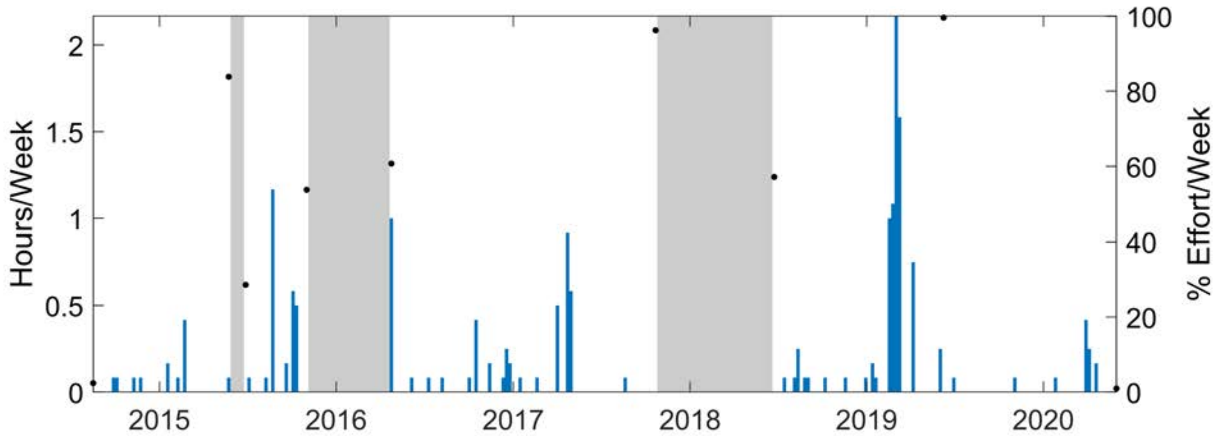

Figure 33: Cumulative hours/week of goose-beaked whale presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

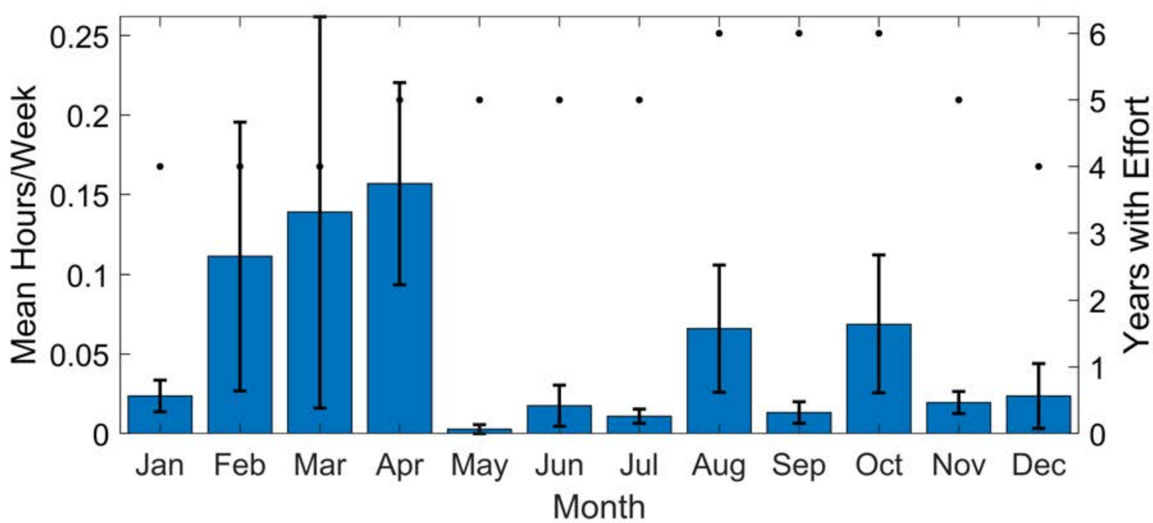

Figure 34: Monthly mean hours per week of goose-beaked whale acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

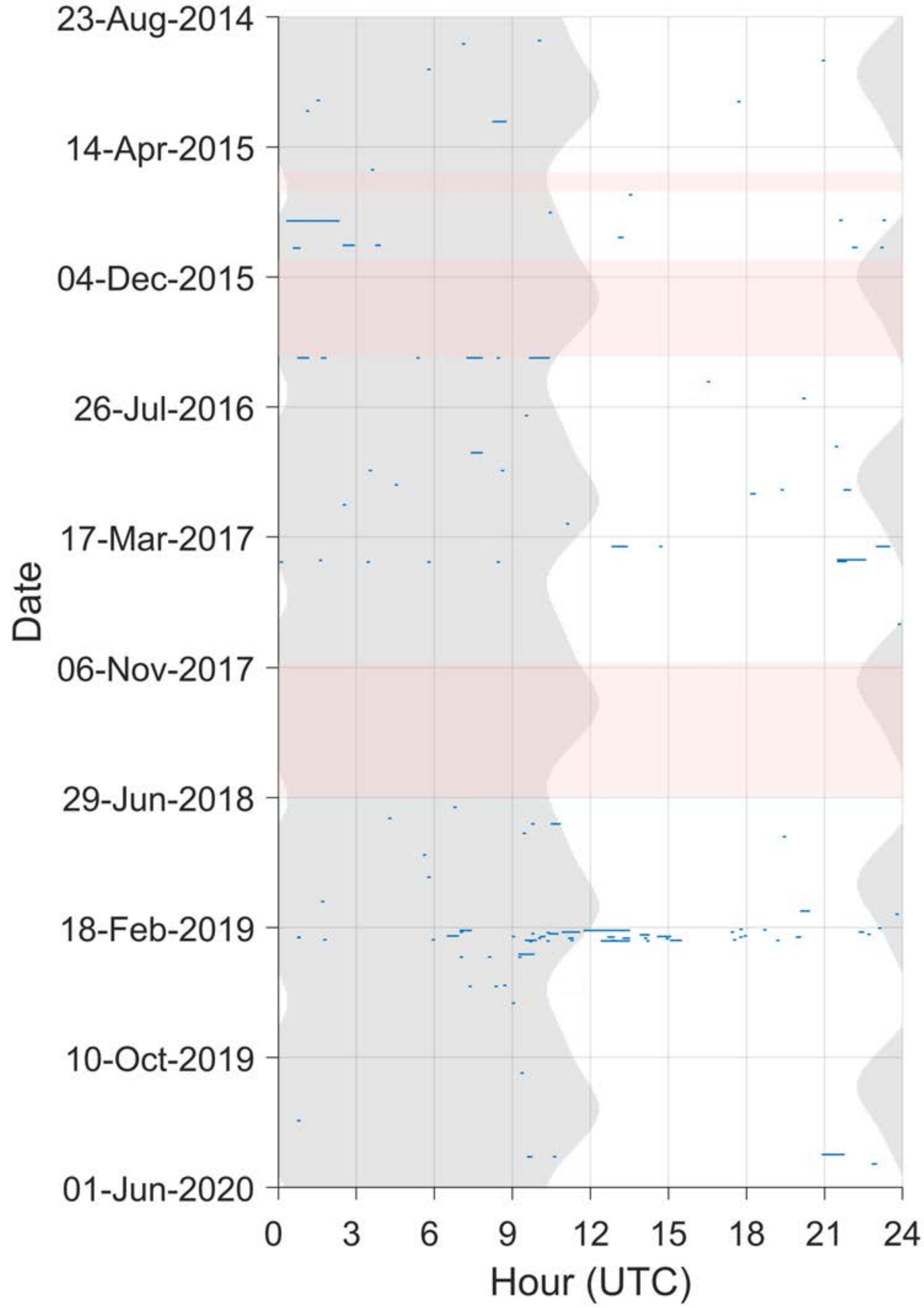

Figure 35: Goose-beaked whale acoustic presence in 5-min bins at site D. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.2 Gervais' and True's Beaked Whales

Gervais' and True's beaked whales were present at site D and were not observed at sites A–C (Figures 36–38). Among the two species, True's beaked whales exhibited higher acoustic presence relative to Gervais' beaked whales. Weekly presence of True's beaked whales frequently exceeded 0.5 hours and, during some periods, reached extended levels of up to approximately 3 hours per week (Figure 36).

Gervais' beaked whales were comparatively rare at this site. Given the acoustic similarity between Gervais' and True's echolocation clicks, some degree of misclassification cannot be ruled out; however, overall presence of Gervais' beaked whales remained low relative to True's. Combined presence of the two species occurred throughout the year, with a dip in March and April but otherwise no clear seasonal pattern was evident (Figure 37).

No consistent diel pattern was evident for either species, with acoustic presence distributed across both daytime and nighttime hours (Figure 38).

Although previous studies generally report higher Gervais' beaked whale occurrence south of Cape Hatteras, True's beaked whales exhibited greater acoustic presence at the Jacksonville slope site during this study (Haver et al. 2025; Cohen et al. 2022; Stanistreet et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025).

Summary of Results – Gervais' and True's beaked whales

- True's beaked whales exhibited higher acoustic presence than Gervais' beaked whales, with weekly presence frequently exceeding 0.5 hours and occasionally reaching up to $\sim$3 hours per week.
- Gervais' beaked whales were comparatively rare; while some misclassification is possible due to acoustic similarity, their overall presence remained low relative to True's.
- Combined presence of the two species occurred throughout the year, with a dip in March and April but otherwise no clear seasonal pattern was evident.
- No consistent diel pattern was observed, with detections distributed across both daytime and nighttime hours.

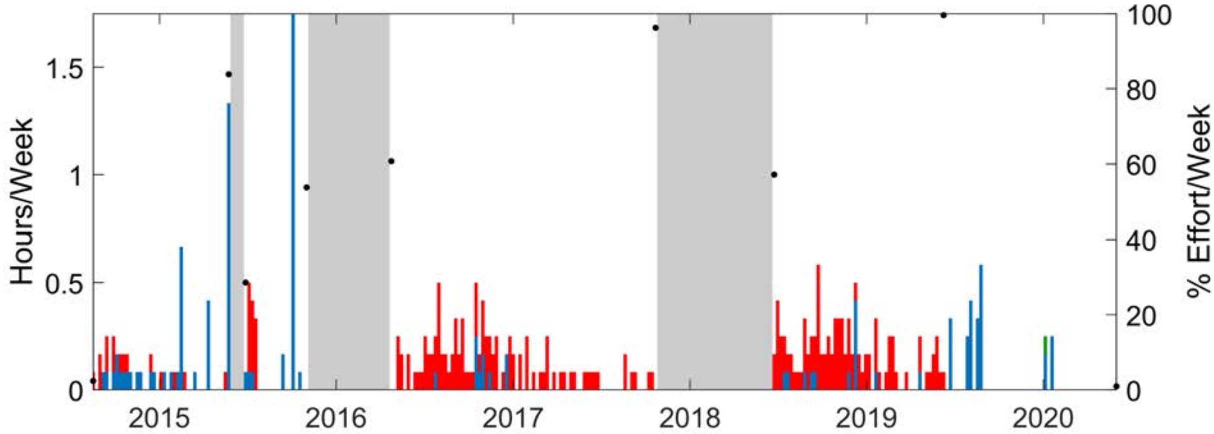

Figure 36: Cumulative hours/week of Gervais' (blue) and True's (red) beaked whale presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

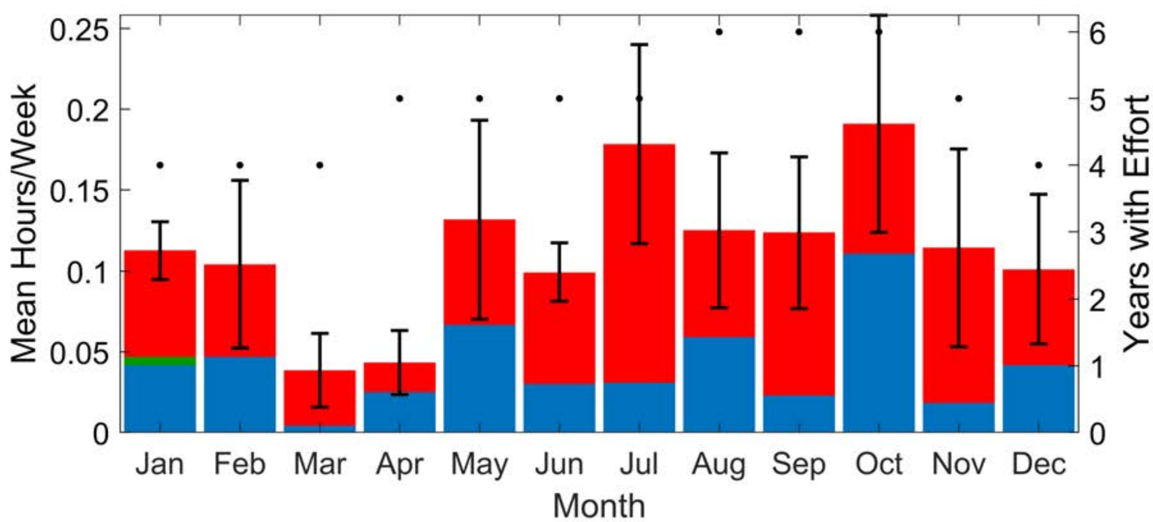

Figure 37: Monthly mean hours per week of Gervais' (blue) and True's (red) beaked whale acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

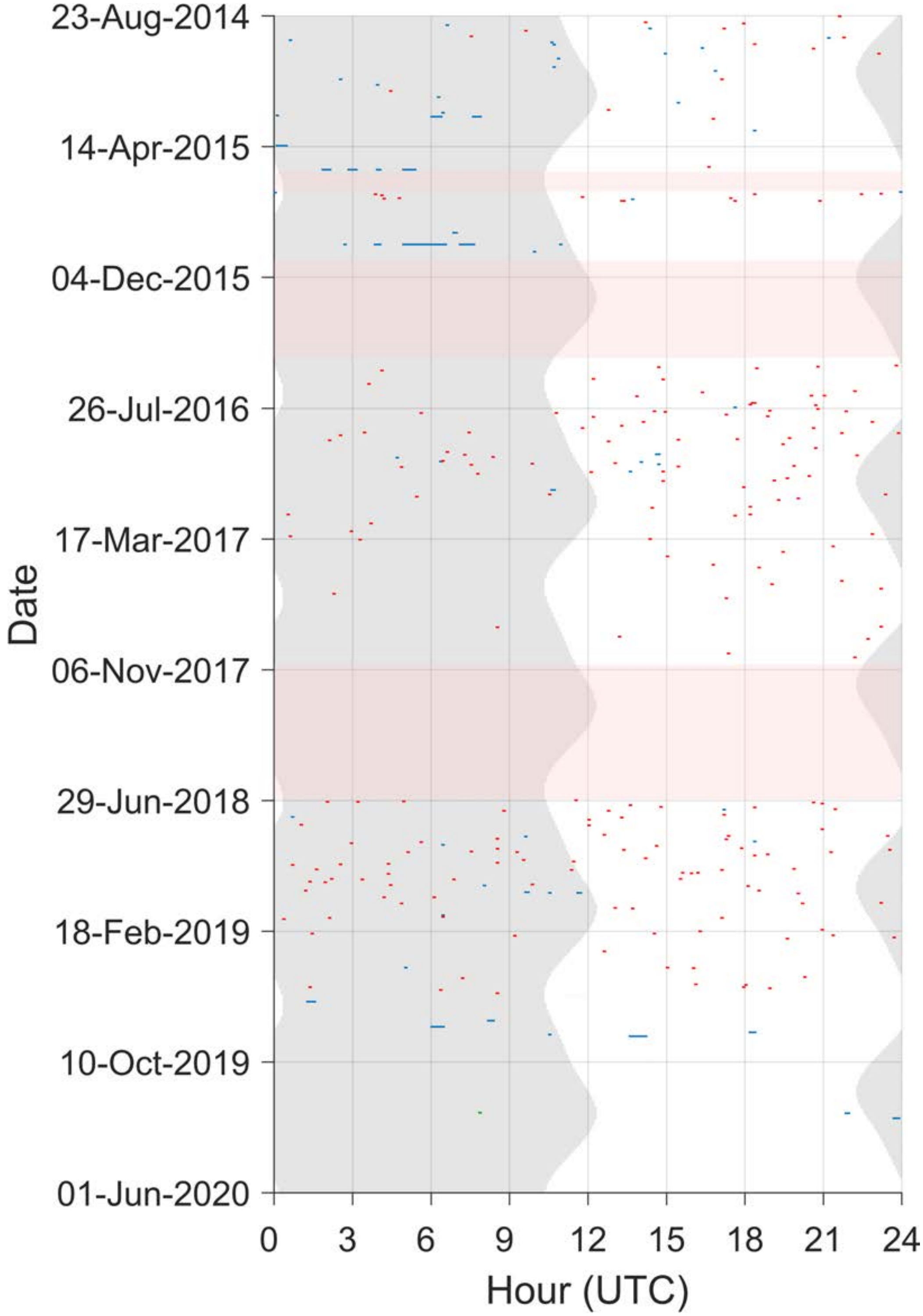

Figure 38: Gervais' (blue) and True's (red) beaked whale acoustic presence at site D in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.3 Blainville's Beaked Whales

Blainville's beaked whales were intermittently present at site D throughout the monitoring period and were not present at sites A–C (Figures 42–40). Acoustic presence was generally low, with most weeks exhibiting fewer than two click-positive hours, although occasional short-duration increases were observed.

Presence occurred across multiple months, with modest increases during spring and fall (Figure 40). While overall levels remained low, this pattern suggests recurring seasonal use of the slope site rather than random occurrence.

No pronounced diel pattern was evident in Blainville's beaked whale acoustic presence (Figure 41). Click-positive hours were distributed across both daytime and nighttime periods, indicating no clear diel preference when animals were present.

Overall, Blainville's beaked whale presence at the Jacksonville slope site was low but exhibited seasonal structure, with brief increases during spring and fall. This pattern is consistent with previous studies indicating that Blainville's beaked whales occur infrequently in this region and are not strongly associated with persistent foraging hotspots south of Cape Hatteras (Haver et al. 2025; Cohen et al. 2022; Stanistreet et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025).

Summary of Results – Blainville's Beaked Whales

- Blainville's beaked whale acoustic presence at site D was intermittent and generally low.
- Weekly presence was generally low, typically fewer than two click-positive hours, with occasional short-duration increases.
- Presence exhibited modest seasonal structure, with higher activity during spring and fall.
- No clear diel pattern in acoustic activity was observed.

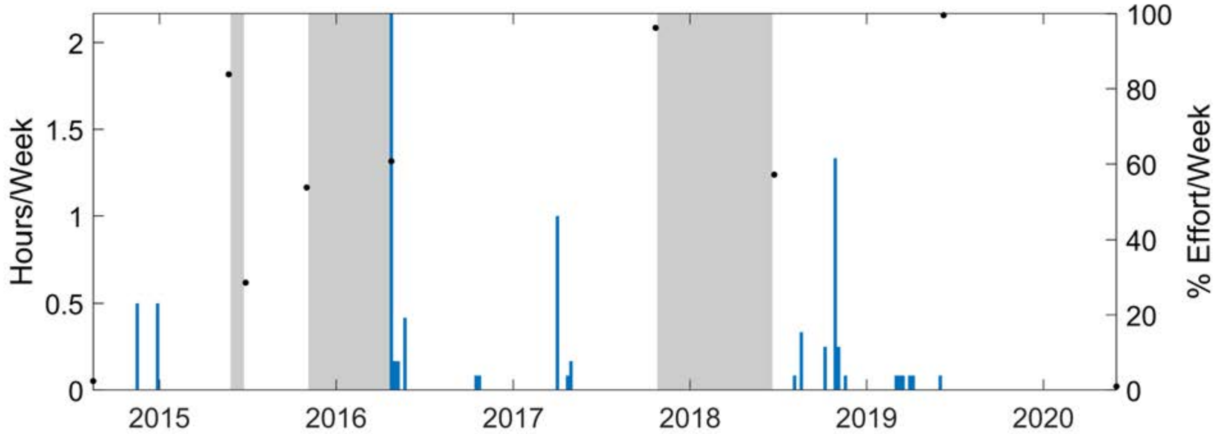

Figure 39: Cumulative hours/week of Blainville's beaked whale presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

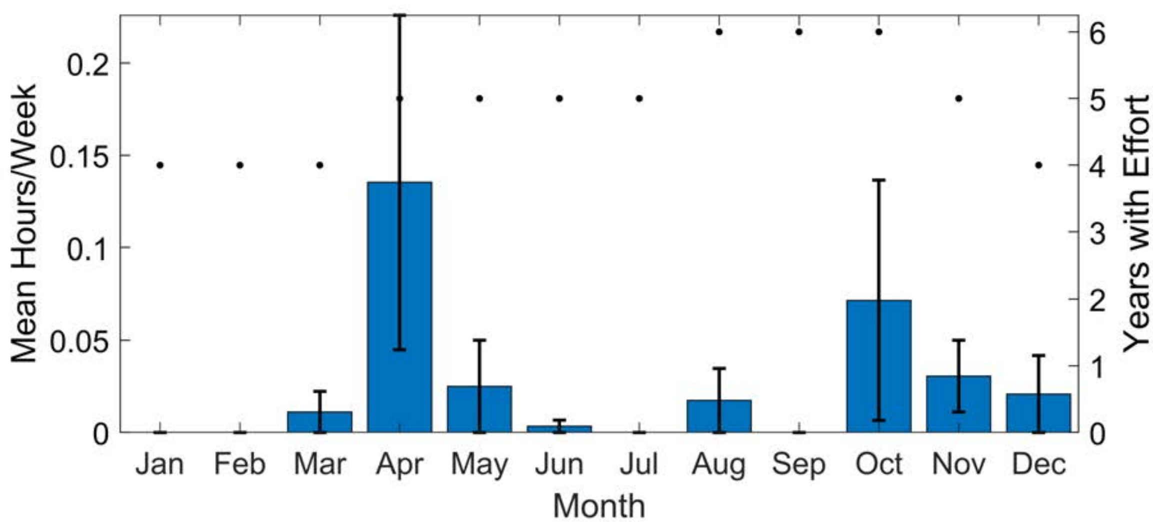

Figure 40: Monthly mean hours per week of Blainville's beaked whale acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

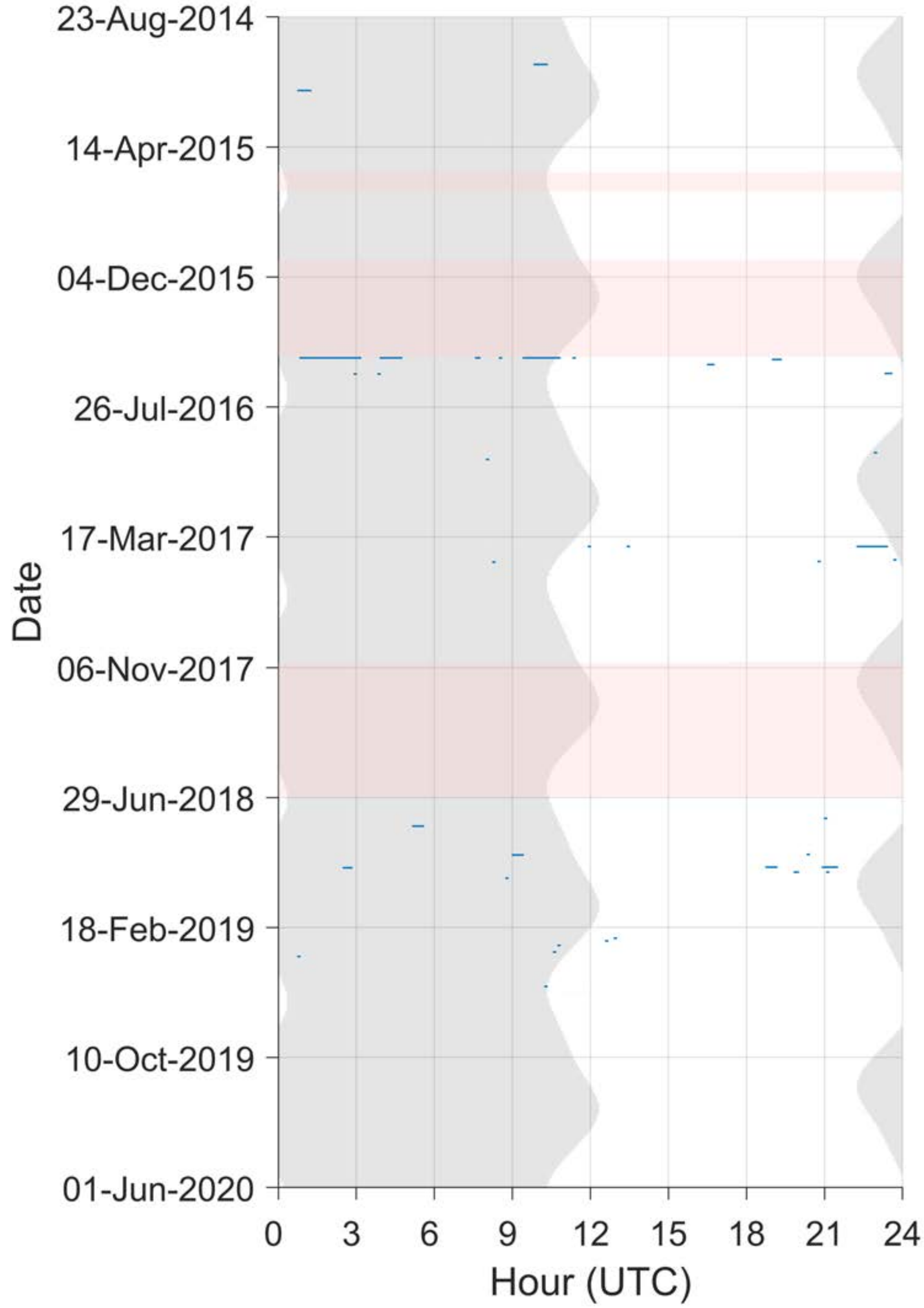

Figure 41: Blainville's beaked whale acoustic presence at site D in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.4 Sowerby's Beaked Whales

Sowerby's beaked whale acoustic presence was extremely rare at site D and was not observed at shallow shelf sites A–C (Figures 42–43). Presence was limited to brief, isolated events, typically consisting of less than an hour per week when present.

Monthly summaries indicate that presence occurred sporadically across the year, with isolated occurrences in late winter-spring, June, and September (Figure 43). Given the very low number of encounters, no consistent seasonal pattern can be confidently inferred.

No diel pattern was evident in Sowerby's beaked whale acoustic presence, as the limited events were distributed across both daytime and nighttime hours (Figure 44).

Overall, Sowerby's beaked whale presence at the Jacksonville slope site was minimal and sporadic, consistent with previous studies indicating that this species occurs infrequently south of Cape Hatteras, with primary habitat and foraging areas located farther north (Haver et al. 2025; Cohen et al. 2022; Stanistreet et al. 2022; Cohen et al. 2023; DeAngelis et al. 2025).

Summary of Results – Sowerby's Beaked Whale

- Sowerby's beaked whale acoustic presence was extremely rare at site D
- Presence consisted of brief, isolated events, typically not exceeding one hour per week.
- Occurrences were scattered across winter, spring, June, and September, with no clear seasonal pattern.
- No consistent diel pattern in acoustic presence was observed.

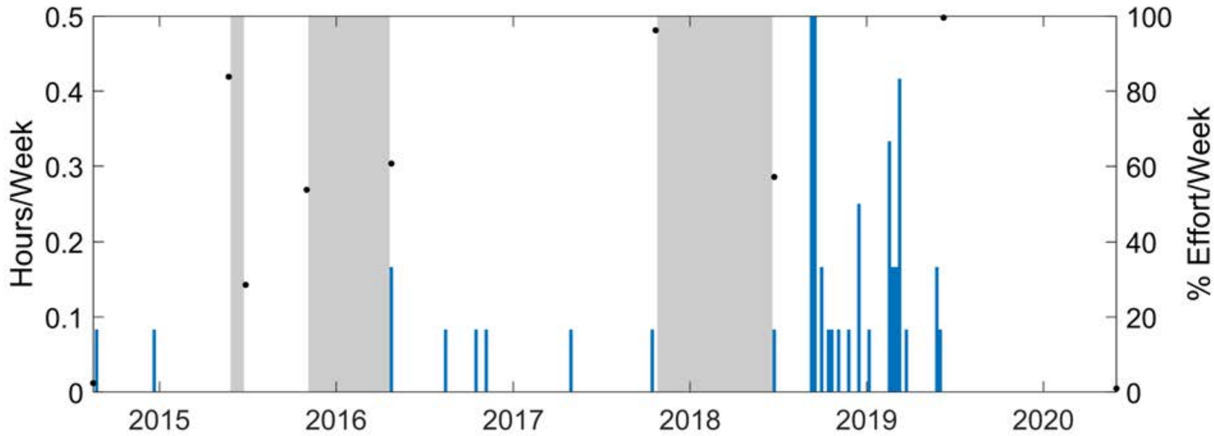

Figure 42: Cumulative hours/week of Sowerby's beaked whale presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

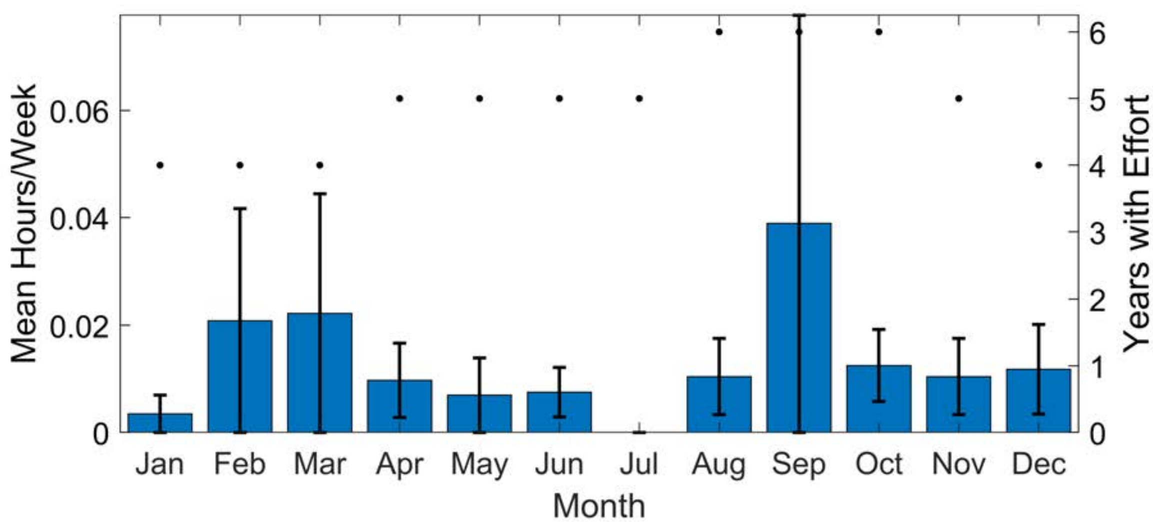

Figure 43: Monthly mean hours per week of Sowerby's beaked whale acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

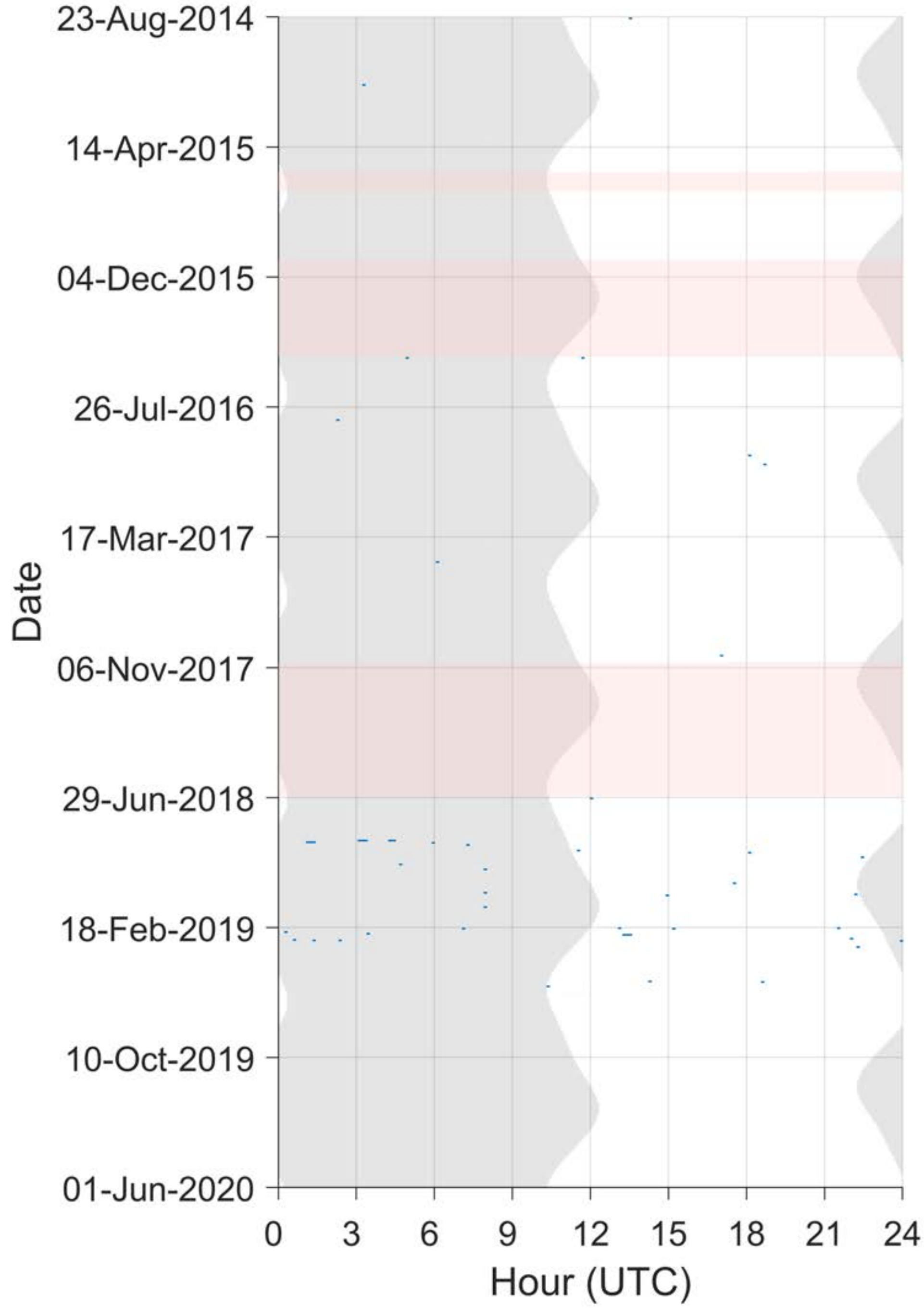

Figure 44: Sowerby's beaked whale acoustic presence at site D in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.5 Sperm Whales

Sperm whales were acoustically present at site D throughout much of the monitoring period, with no acoustic presence observed at the shallow shelf sites (A–C). Data from deployment 12D were excluded from this analysis due to data quality issues and are not included in the results presented here.

Sperm whales exhibited relatively high levels of acoustic presence compared to beaked whales at this site (Figure 45). Weekly presence frequently reached 50 hours per week. Acoustic presence was observed year-round, with lower levels during summer and fall months, and higher occurrence during winter and spring months (Figure 46).

No consistent diel pattern was evident in sperm whale acoustic presence, with click activity distributed across both daytime and nighttime hours (Figure 47).

Overall, sperm whale presence at the Jacksonville slope site was persistent and comparatively high, consistent with previous studies documenting frequent sperm whale occurrence along the western North Atlantic slope and sustained seasonal use extending south of Cape Hatteras (Stanistreet et al. 2018).

Summary of Results – Sperm Whale

- Sperm whales exhibited relatively high acoustic presence at site D.
- Weekly presence frequently reached 50 hours per week, interspersed with months of lower acoustic activity.
- Acoustic presence occurred year-round, with higher levels during winter and spring months.
- No clear diel pattern was observed, with presence distributed across day and night hours.

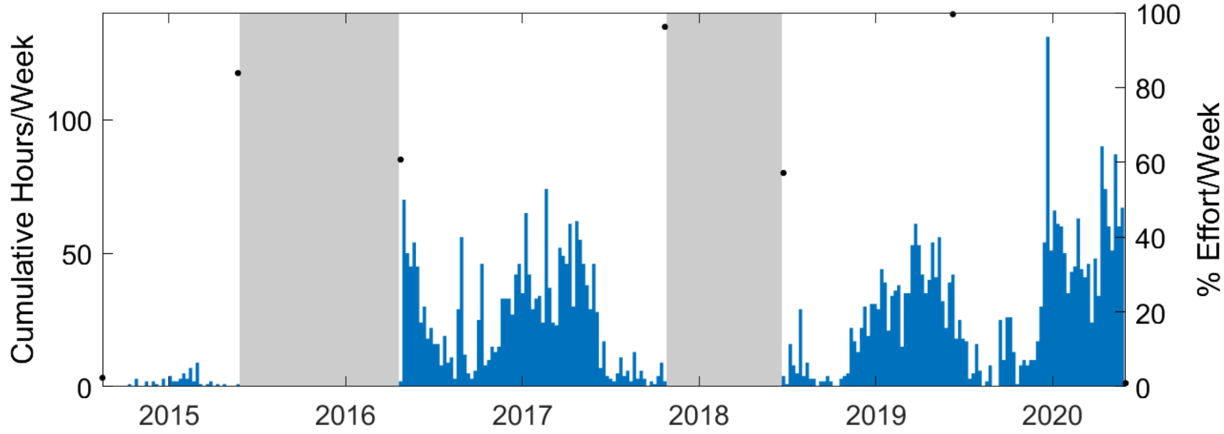

Figure 45: Cumulative hours/week of sperm whale presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

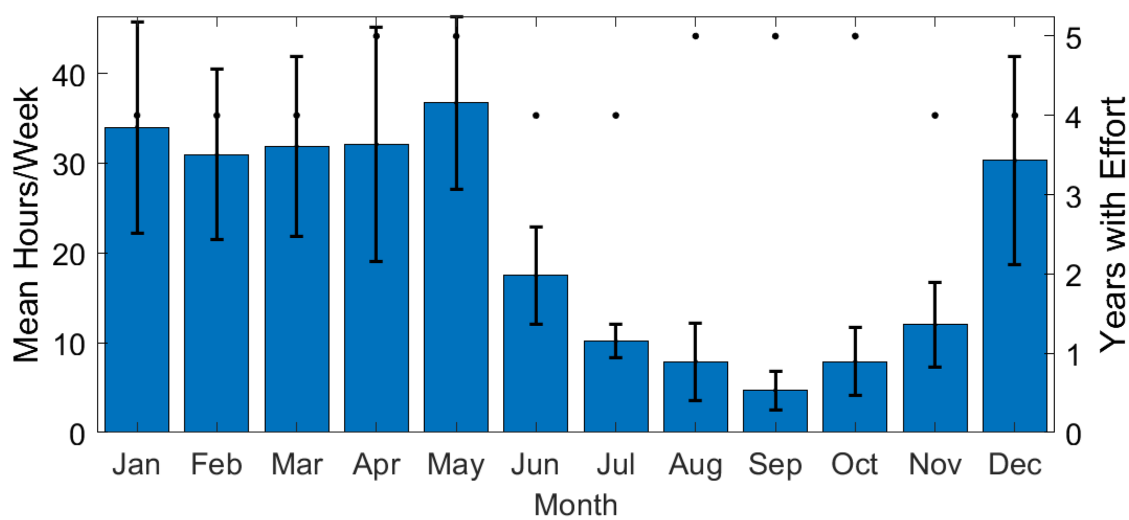

Figure 46: Monthly mean hours per week of sperm whale acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

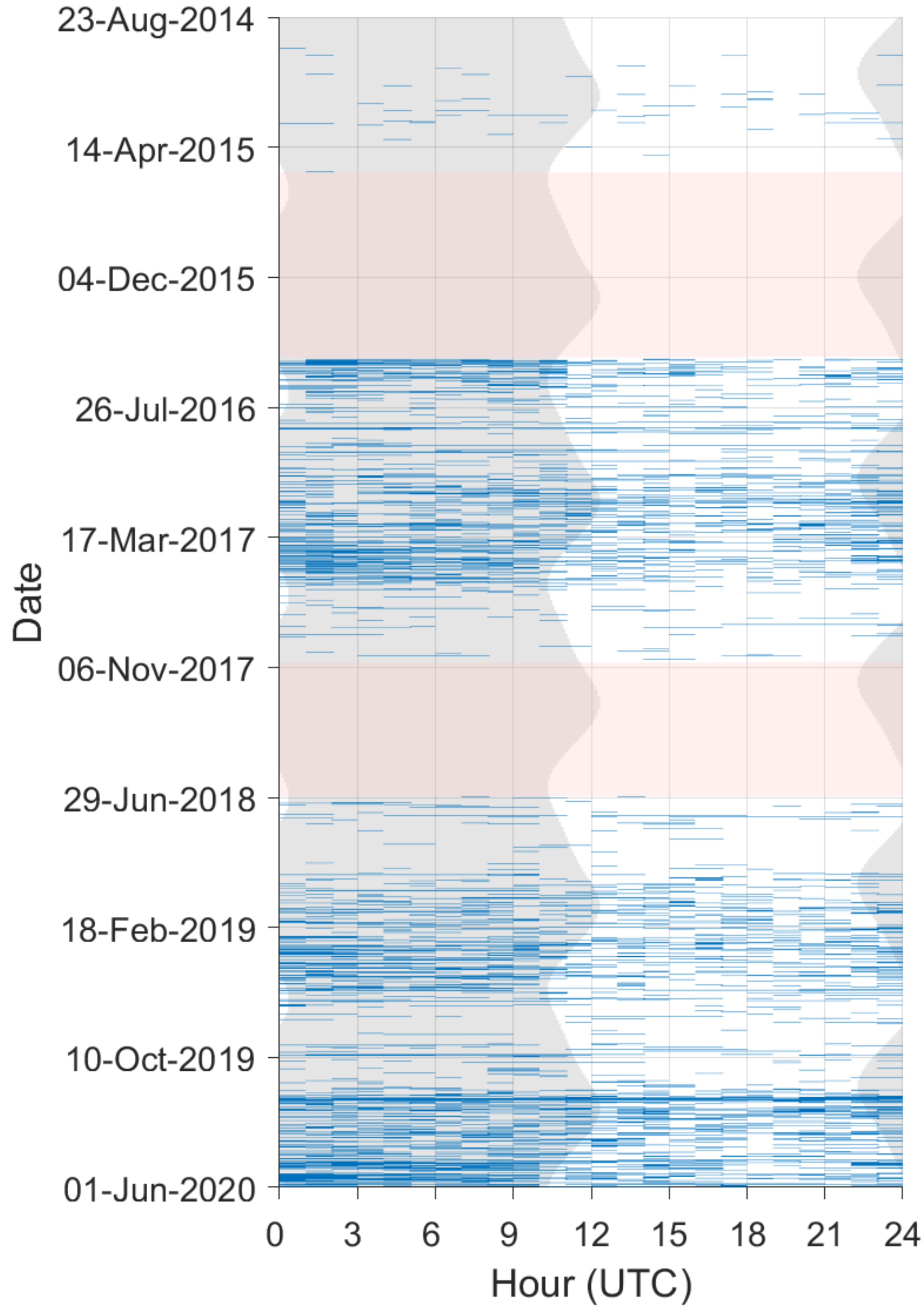

Figure 47: Sperm whale acoustic presence in 5-min bins at site D. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.6 *Kogia* spp.

Kogia spp. were detected intermittently at the site from 2014 through 2020 (Figure 48). Presence was sparse during 2014–2016 but increased beginning in 2017, with more frequent detections through 2019 and 2020. Weekly acoustic presence was generally low, typically below 0.5 hours per week, although several weeks in 2019–2020 approached 1 hour per week.

Acoustic presence occurred in most months at low levels (Figure 49). Mean weekly presence was highest in winter months (January and December) and elevated again in October. Spring months (March–April) showed moderate occurrence, while late spring and summer (May–July) had the lowest presence. However, seasonal interpretation is limited by variable effort across years and months.

No consistent diel pattern was observed, with detections distributed across both daytime and nighttime hours (Figure 50). Detections occurred throughout the 24-hour period without clear clustering.

These results are consistent with previous studies that found *Kogia* spp. occur year-round at relatively low levels at Cape Hatteras and southward, with higher occurrence in southern slope waters, indicating that the JAX region is near the northern edge of their main distribution (Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023).

Summary of Results – *Kogia* spp.

- *Kogia* spp. were intermittently detected at JAX from 2014–2020.
- Presence increased beginning in 2017, with more frequent detections through 2019–2020.
- Weekly acoustic presence was generally less than 0.5 hours per week, with occasional peaks approaching 1 hour per week.
- Highest mean presence occurred in winter (January, December) and October; lowest presence occurred in May–July.
- No clear diel pattern was evident.

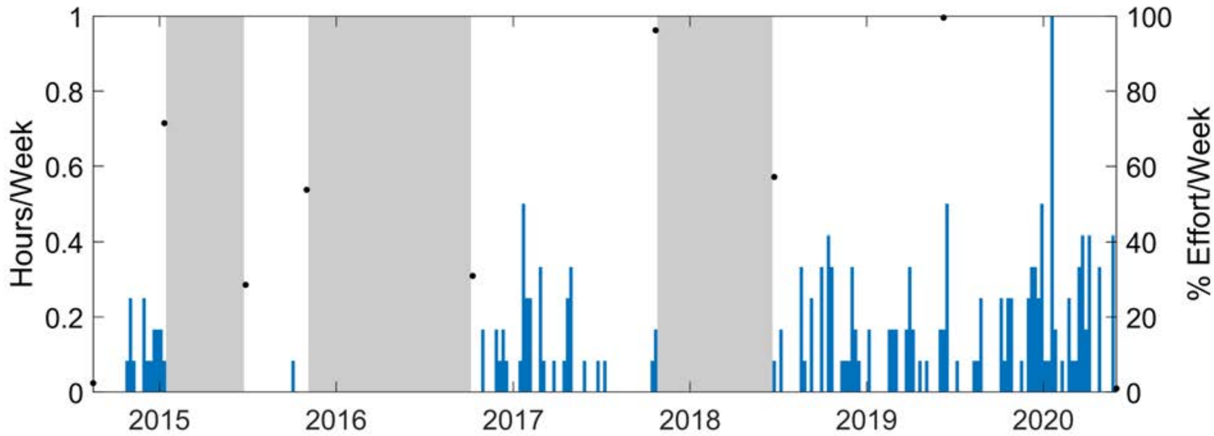

Figure 48: Cumulative hours/week of *Kogia* spp. presence at site D. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

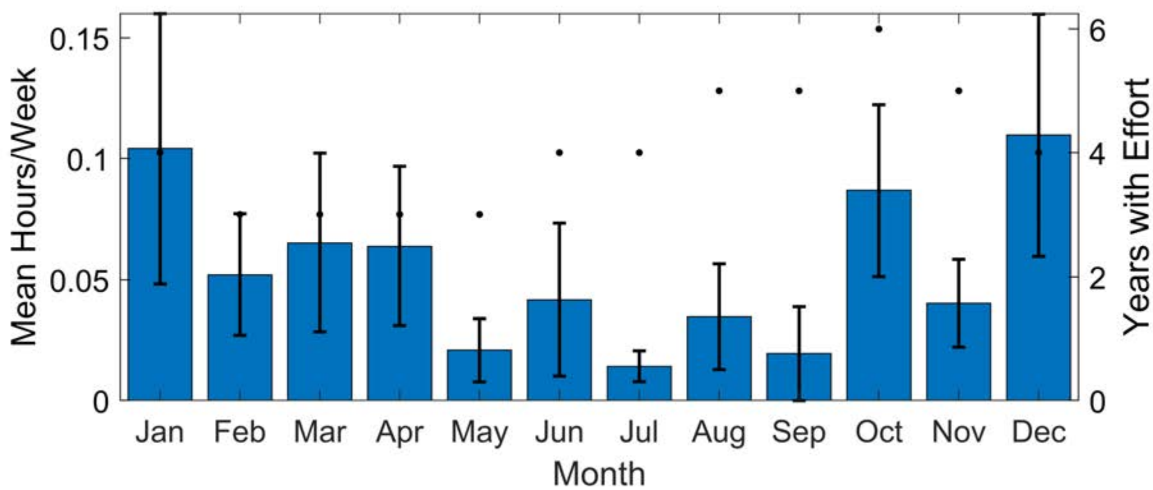

Figure 49: Monthly mean hours per week of *Kogia* spp. acoustic presence at site D. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

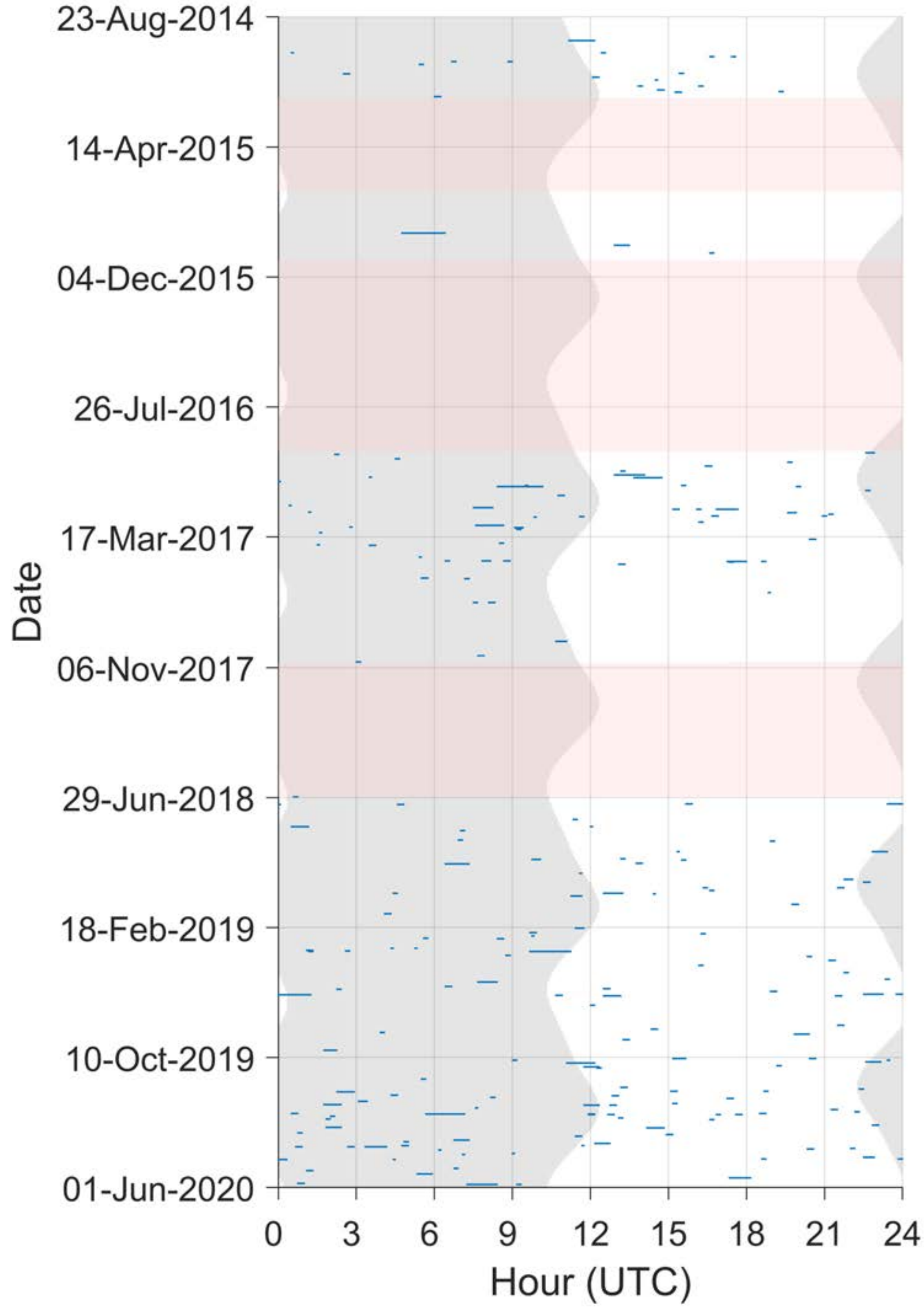

Figure 50: ***Kogia*** **spp. acoustic presence in 5-min bins at site D. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.**

5.1.7 Risso's Dolphin

Risso's dolphins were detected primarily at site D, with little to no acoustic presence at sites A–C (Figure 51). Presence at site D began in 2015 and continued intermittently through 2020, with several periods of elevated activity. Weekly acoustic presence at site D frequently exceeded 1 hour per week and, during peak periods, exceeded 5 hours per week. In contrast, detections at sites A–C were sparse and limited in duration.

At site D, mean weekly presence was highest during spring and early summer, particularly April through July, with May and July showing the greatest values (Figure 52). Presence declined in late summer and fall and was lowest during winter months (November–January). Seasonal interpretation at sites A–C is limited due to minimal detections and variable effort across years.

Diel patterns were assessed primarily at site D. Detections occurred throughout the 24-hour period but were more frequent during nighttime hours, indicating a clear diel pattern (Figure 53). In contrast, diel interpretation at sites A–C is constrained by low overall presence.

These results indicate that Risso's dolphins use the deeper JAX site (D) more regularly than the shallower sites and exhibit increased nighttime acoustic activity. This pattern is consistent with previous studies indicating that Risso's dolphins are typically associated with deeper shelf and slope habitats (Baumgartner & Mussoline 2011; Haver et al. 2025; Cohen et al. 2023).

Summary of Results – Risso's Dolphin

- Risso's dolphins were detected primarily at site D, with minimal presence at sites A–C.
- Presence at site D occurred intermittently from 2015–2020, with several periods exceeding 5 hours per week.
- Highest mean presence occurred during April–July; lowest presence occurred in winter months.
- A clear diel pattern was observed at site D, with more detections occurring at night.

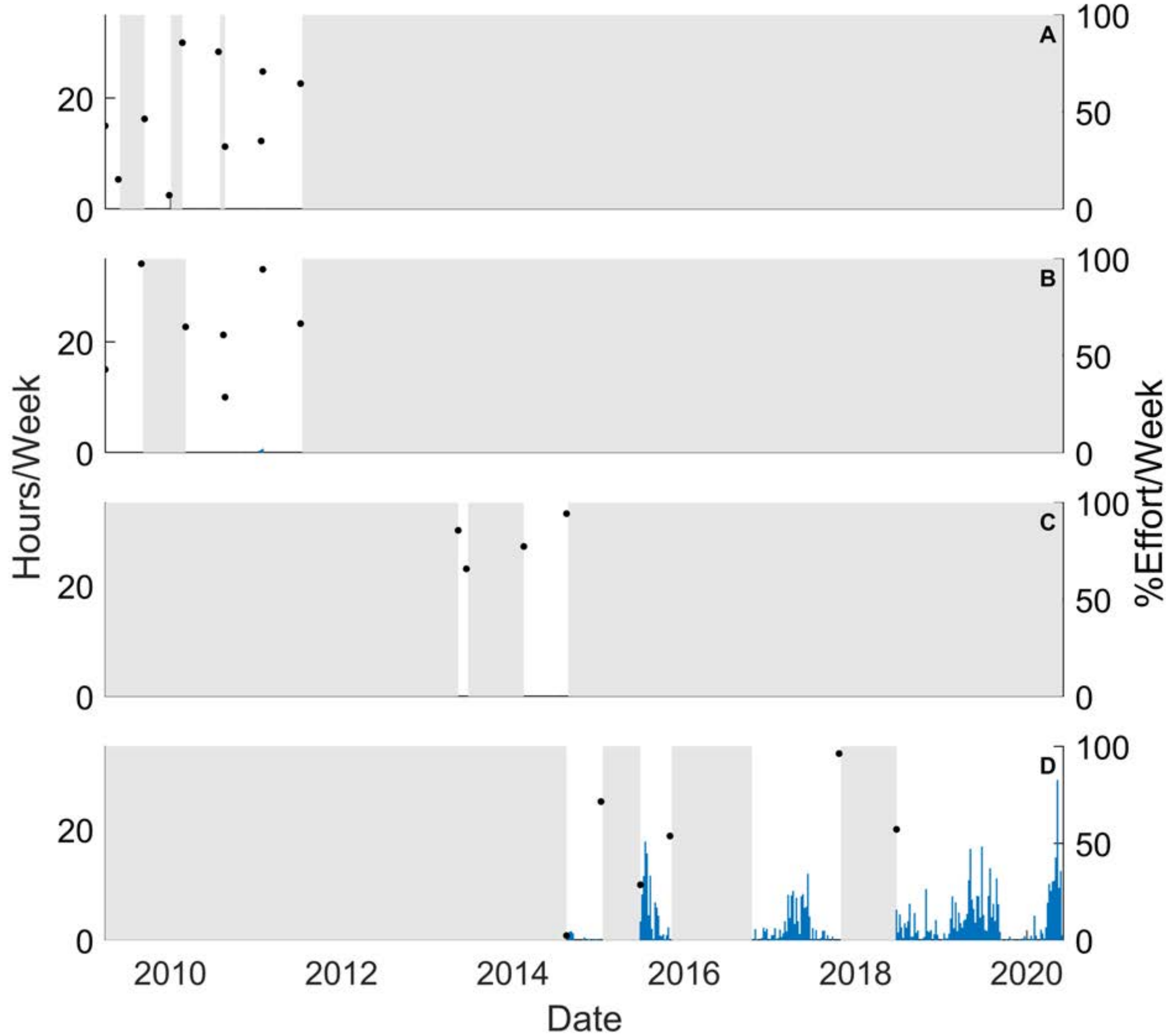

Figure 51: Cumulative hours/week of Risso's dolphin presence at all Jacksonville sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

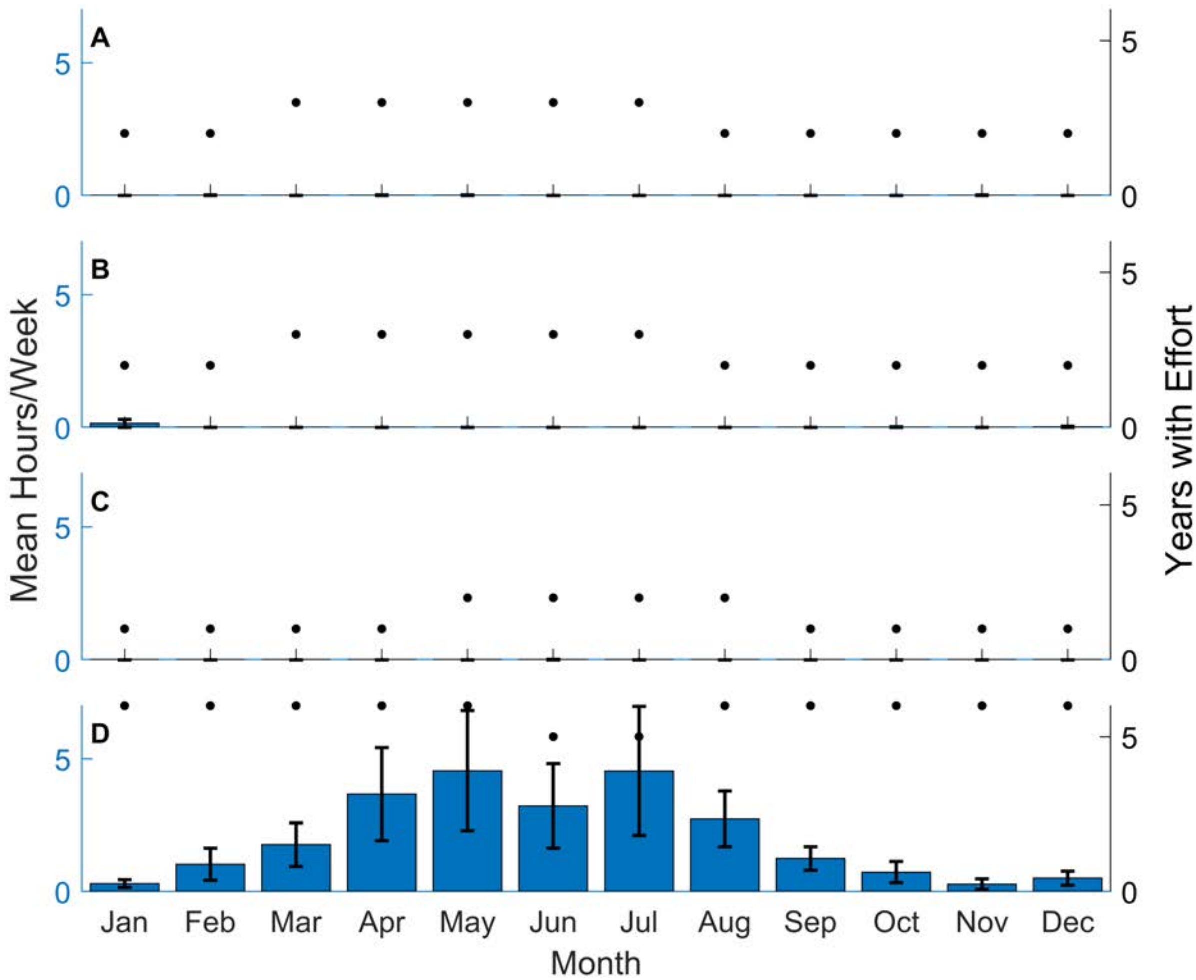

Figure 52: Monthly mean hours per week of Risso's dolphin acoustic presence at all Jacksonville sites. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

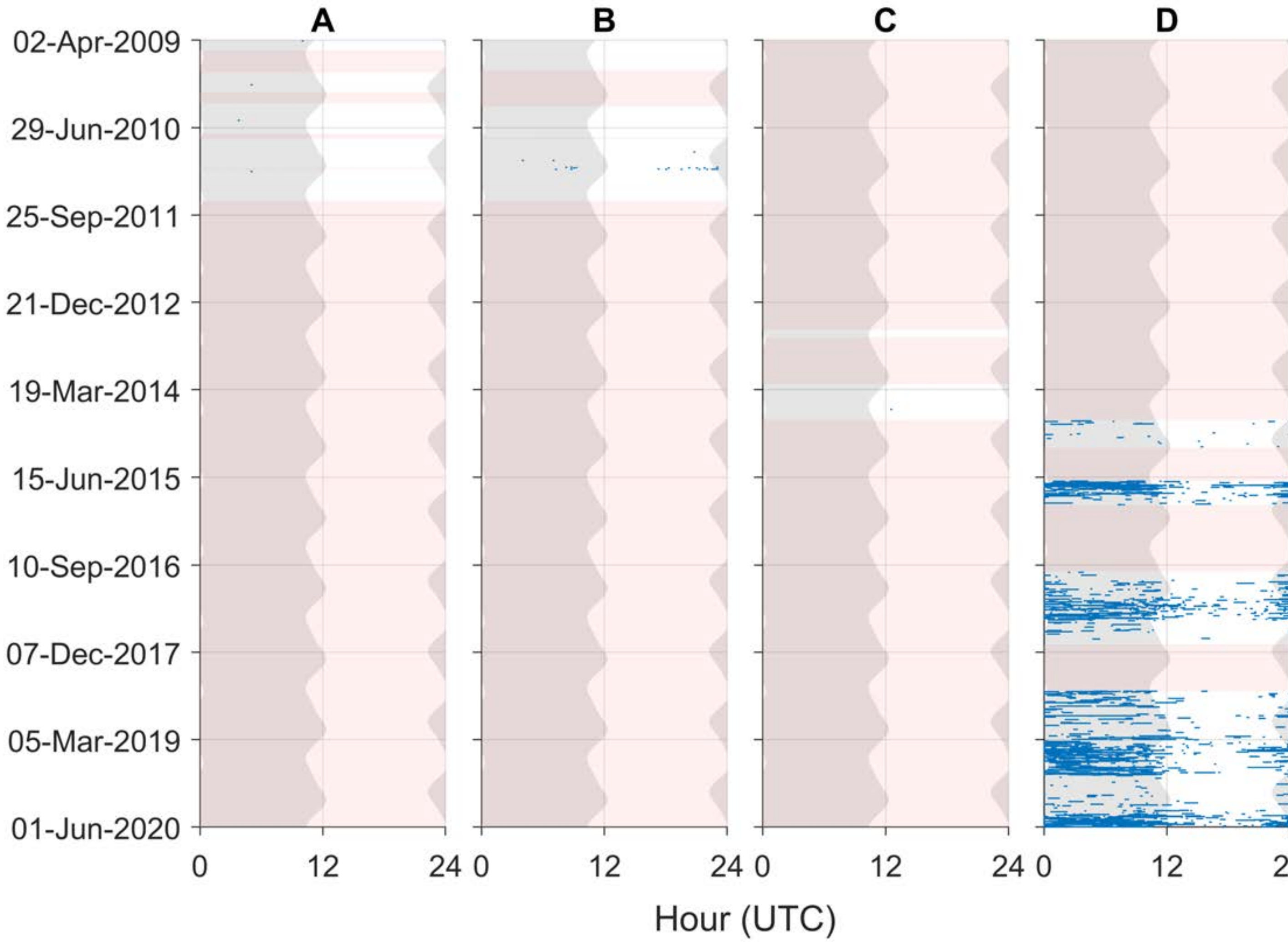

Figure 53: Risso's dolphin acoustic presence in 5-min bins at all Jacksonville sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.8 Unidentified Dolphins – Smaller-Bodied Delphinids (UD HF & 47)

Smaller-bodied delphinids (UD HF and 47 kHz click types) were detected at all sites, though overall acoustic presence varied by site (Figure 54). Site A exhibited the greatest levels of acoustic presence, with weekly values occasionally exceeding 5 hours per week. Site B showed lower overall presence, and site C exhibited only limited detections. Site D also showed intermittent presence, with weekly acoustic presence generally below 5 hours per week.

Seasonal patterns differed among sites (Figure 55). At site A, detections were most common from late winter through spring (February–May), with lower levels during summer and fall. At site D, detections occurred in multiple months, with somewhat higher presence during late summer and early fall (August–September). Seasonal interpretation at sites B and C is limited due to sparse detections and incomplete annual coverage.

Clear diel patterns were observed at sites A and D (Figure 56). At both sites, detections were concentrated during nighttime hours, indicating consistent nocturnal acoustic activity during periods of presence. In contrast, detections at sites B and C were too limited to evaluate diel trends. Differing patterns at shallow sites (A–C; more daytime echolocation activity, winter & spring presence) and the slope site (D; nocturnal activity, summer & fall presence), likely reflect behaviors and migration patterns of different species included in this category.

These results are consistent with previous studies documenting year-round occurrence of smaller-bodied delphinids in the western North Atlantic, though at relatively lower levels in the study region. High-frequency delphinid click types have been detected across shelf and slope habitats and have shown strong diel patterns characterized by increased nighttime detections, consistent with nocturnal foraging behavior (Haver et al. 2025; Cohen et al. 2022; Cohen et al. 2023).

Summary of Results – Smaller-Bodied Delphinids (UD HF & 47)

- Smaller-bodied delphinids were detected at all sites, with the highest acoustic presence at site A.
- Presence at sites B and C was limited, while site D showed intermittent moderate presence.
- Seasonal patterns varied by site, with site A showing higher presence in late winter–spring and site D showing slightly elevated presence in late summer–early fall.
- Clear nocturnal diel patterns were observed at sites A and D; detections at sites B and C were too sparse to evaluate diel trends.

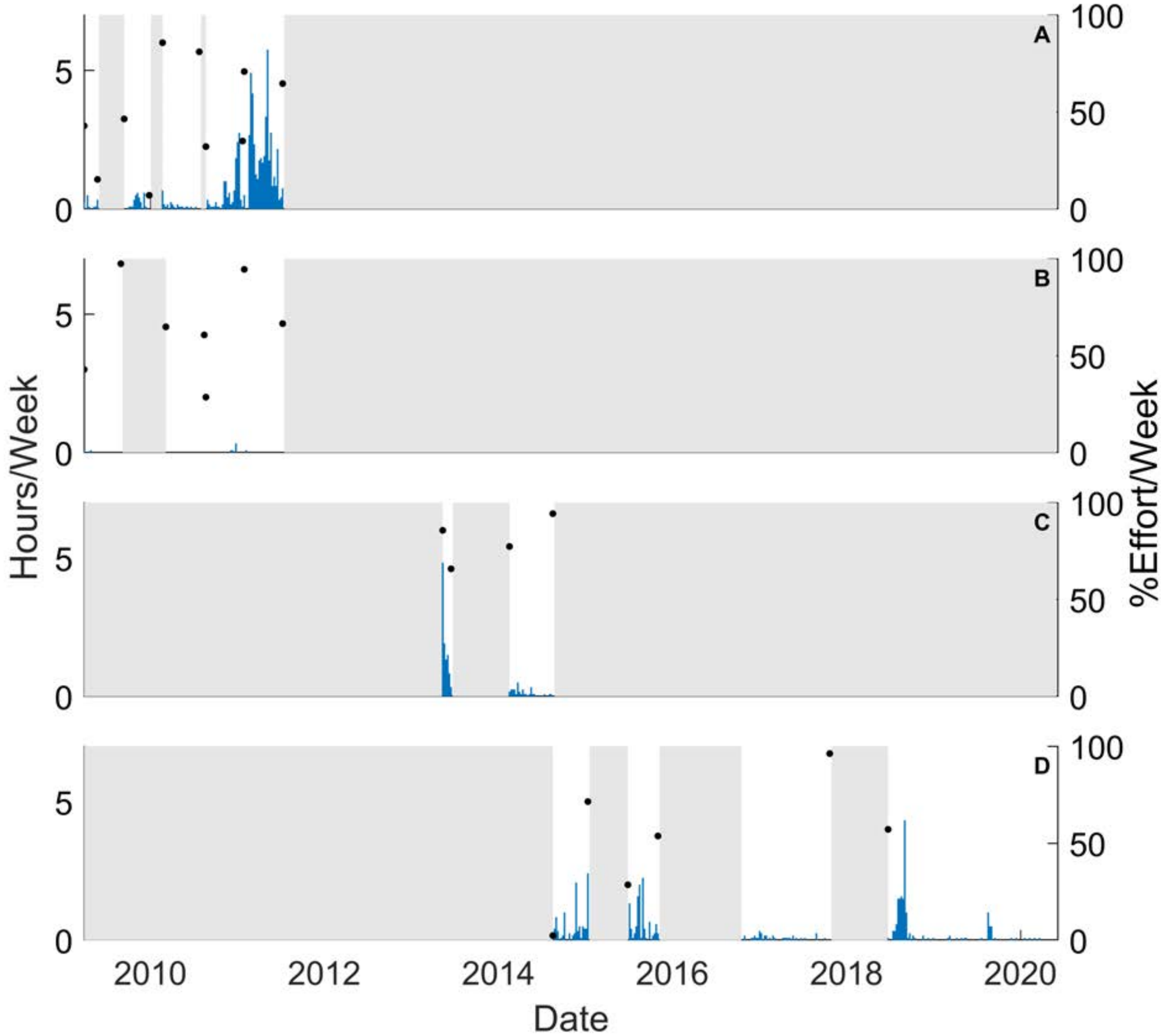

Figure 54: Cumulative hours/week of smaller-bodied delphinid (UD HF & 47) presence at all Jacksonville sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

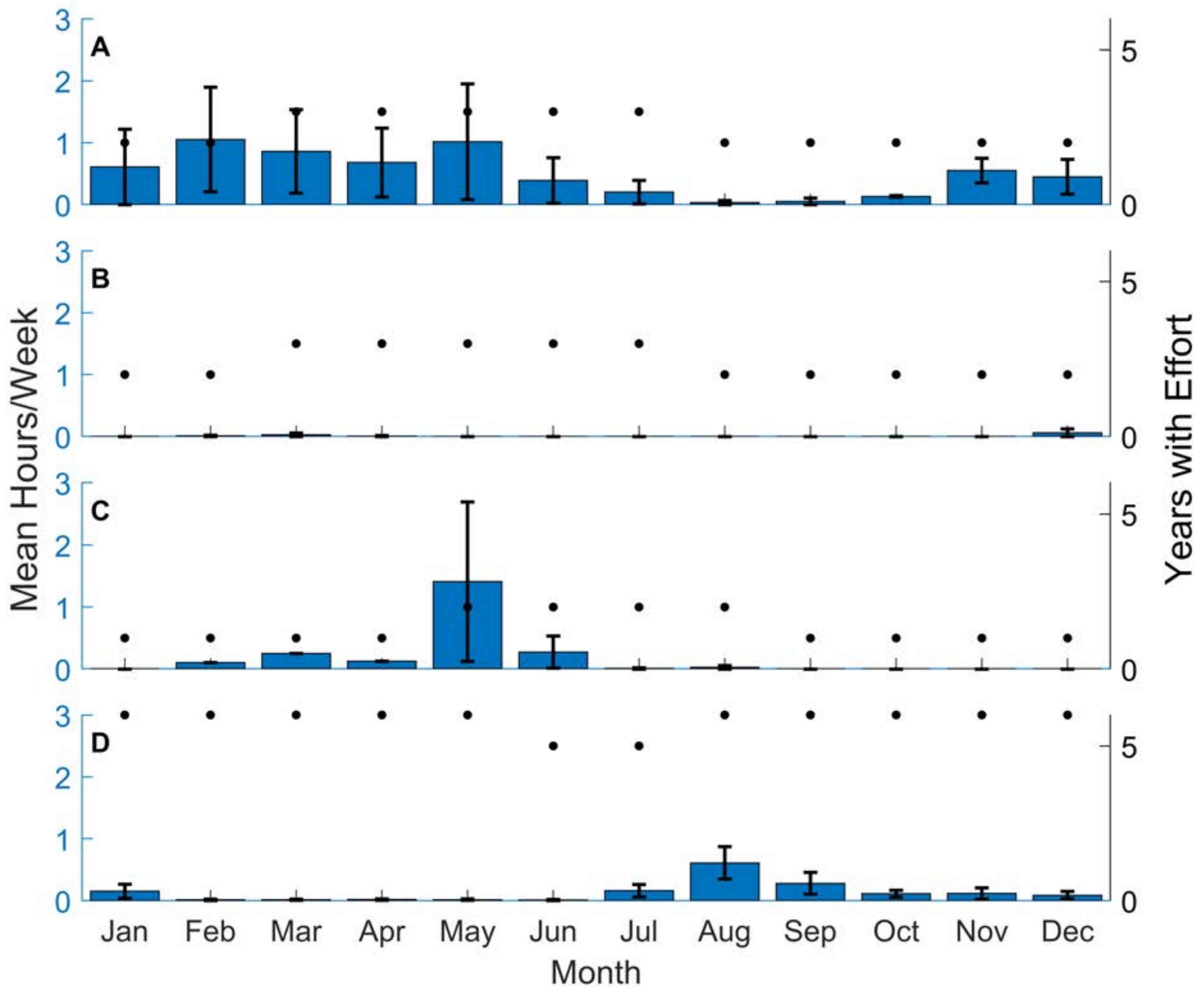

Figure 55: Monthly mean hours per week of smaller-bodied delphinid (UD HF & 47) acoustic presence at all Jacksonville sites. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

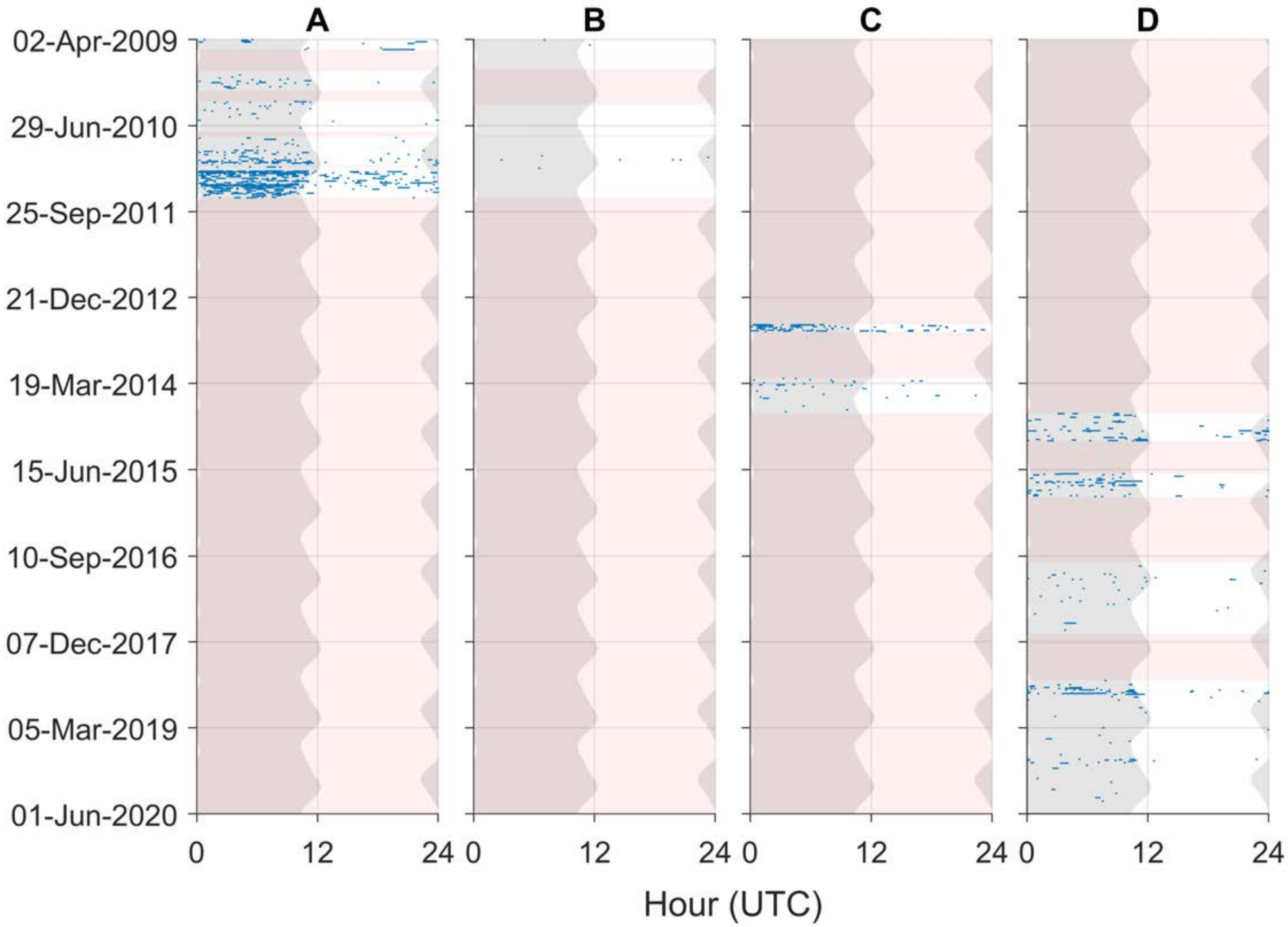

Figure 56: Smaller-bodied delphinid (UD HF & 47) acoustic presence in 5-min bins at all Jacksonville sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.9 Unidentified Dolphins – Larger-Bodied Delphinids (UD LF)

Larger-bodied delphinids, represented by the low-frequency unidentified dolphin click type (UD LF), were detected primarily at site D within the JAX region (Figure 57). Sites A, B, and C exhibited only minimal and sporadic detections throughout the monitoring period, with mean weekly acoustic presence remaining near zero.

In contrast, site D showed sustained and substantially higher acoustic presence beginning in 2015. Weekly acoustic presence frequently exceeded 40–60 hours per week during peak periods. Seasonal structure was evident at site D (Figure 58), with highest mean presence during spring (March–May), moderate levels in late summer and fall, and comparatively lower levels in winter. Seasonal interpretation at sites A–C is limited due to sparse detections.

No clear diel pattern was evident at site D, as detections occurred across both daytime and nighttime hours (Figure 59). Detections at sites A–C were too limited to evaluate diel trends.

These results are consistent with previous studies that found relatively low presence of larger-bodied delphinids in shallower portions of the study region compared to deeper slope habitats (Cohen et al. 2022; Cohen et al. 2023).

Summary of Results – Larger-Bodied Delphinids (UD LF)

- Acoustic presence was concentrated at site D.
- Sites A, B, and C exhibited minimal detections.
- Site D showed highest mean presence during spring (March–May), with moderate levels in late summer–fall.
- No clear diel trend was observed; detections at site D occurred across both day and night hours.

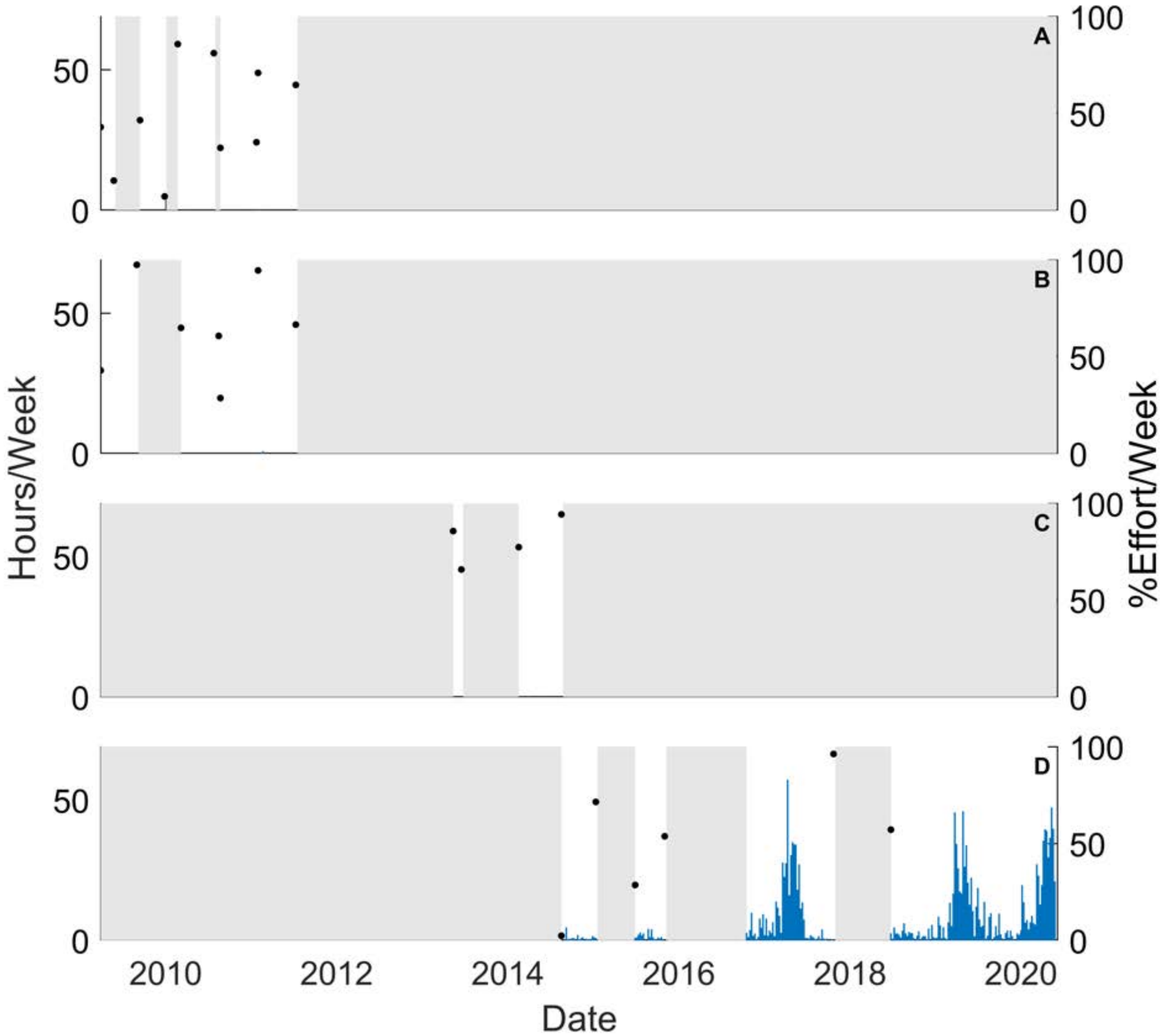

Figure 57: Cumulative hours/week of larger-bodied delphinid (UD LF) presence at all Jacksonville sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

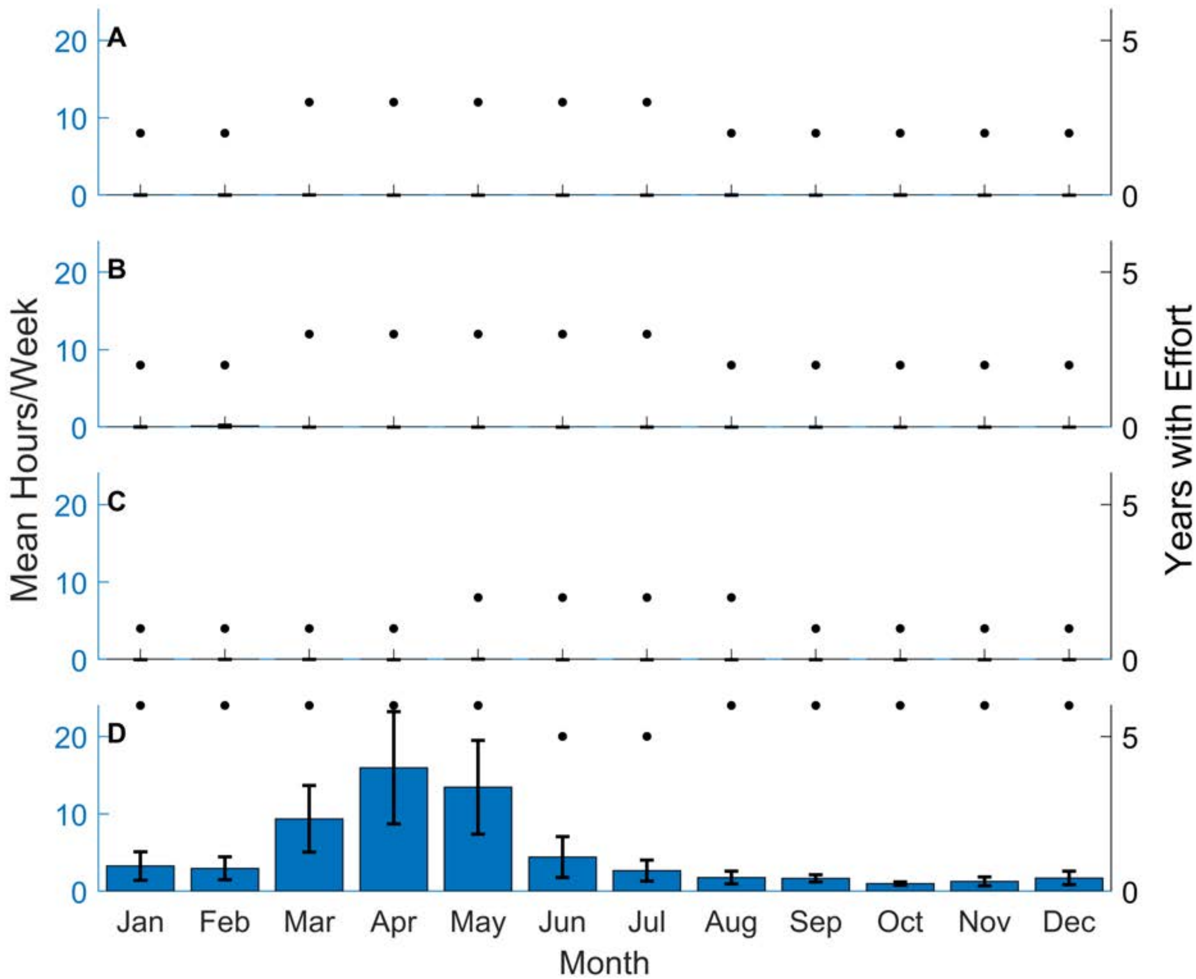

Figure 58: Monthly mean hours per week of larger-bodied delphinid (UD LF) acoustic presence at all Jacksonville sites. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

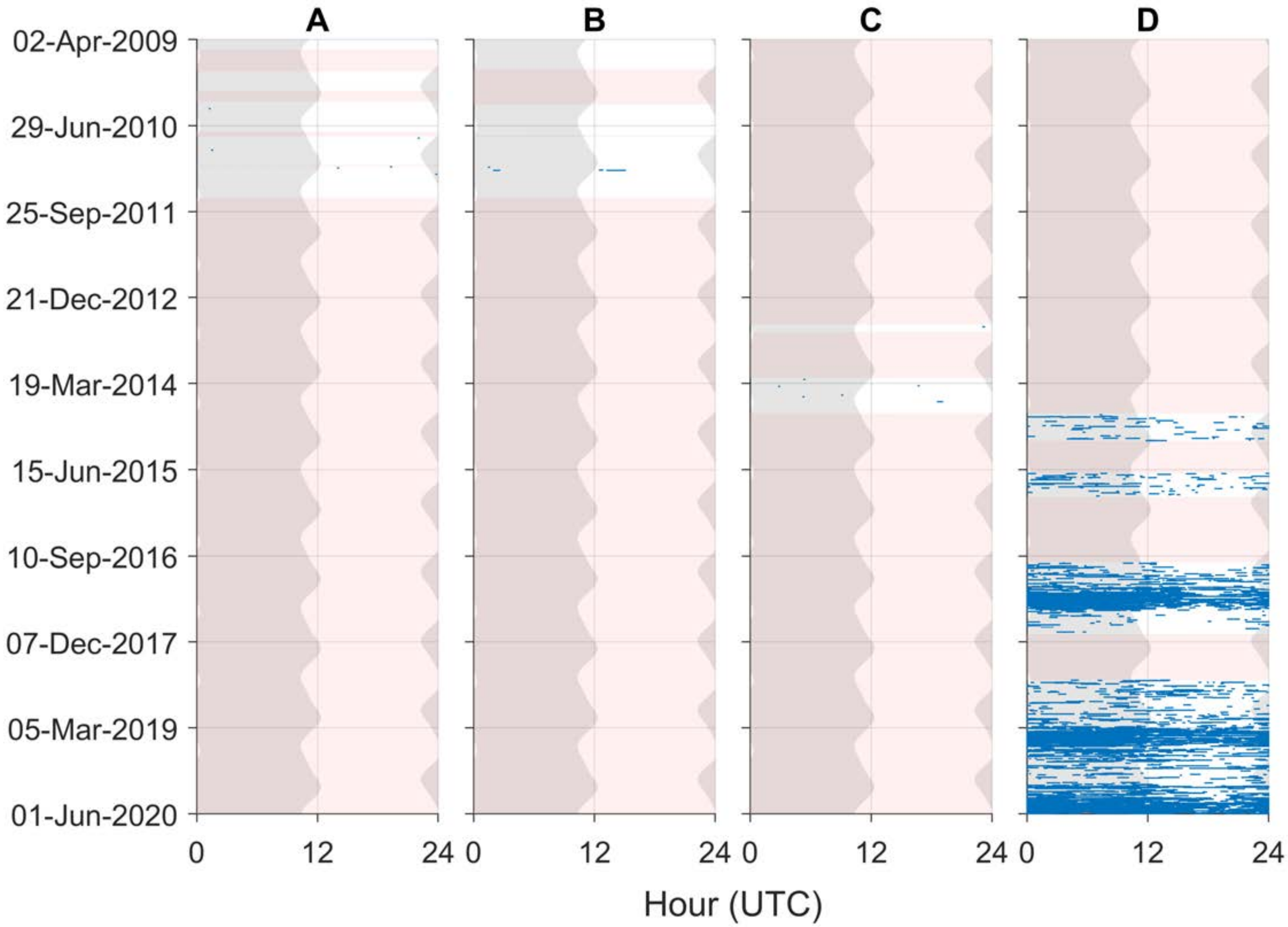

Figure 59: Larger-bodied delphinid (UD LF) acoustic presence in 5-min bins at all Jacksonville sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.2 Mysticetes

Baleen whale acoustic presence in the Jacksonville region was generally low and variable across sites and years (Figures 60 and 61). When detected, most species exhibited clear seasonal patterns, with acoustic presence concentrated during fall through early spring, consistent with migratory movements along the U.S. East Coast. Overall, detections were intermittent and typically limited in duration, indicating that the Jacksonville region is used primarily as a transient area rather than a focal habitat for sustained seasonal occupancy.

Among the species detected, minke, sei, and fin whales showed the most regular and widespread occurrence. Minke whale presence was strongly seasonal and most pronounced at the slope site, where detections frequently occurred from late fall through spring, with occasional high weekly presence during peak periods. Sei whale presence was also strongly seasonal and concentrated at the slope site, with detections occurring primarily from fall through winter. Fin whales were detected across all sites, with clear site-specific differences in the timing and duration of seasonal presence, including extended detections at the mid-depth shelf and slope sites.

No blue whale detections were recorded at any Jacksonville site despite multi-year monitoring effort across shelf and slope habitats. Humpback whales were rarely detected and limited to brief late winter–early spring periods at shallow shelf sites. North Atlantic right whale detections were extremely limited, occurring in only March of 2014 at site B and December of 2014 at site D.

Collectively, these results indicate that while several baleen whale species transit through the Jacksonville region during seasonal movements, the area is characterized by low and intermittent acoustic presence relative to regions farther north. The spatial and temporal patterns observed suggest that the Jacksonville region functions primarily as a migratory corridor with occasional offshore use, rather than a consistently occupied habitat for baleen whales.

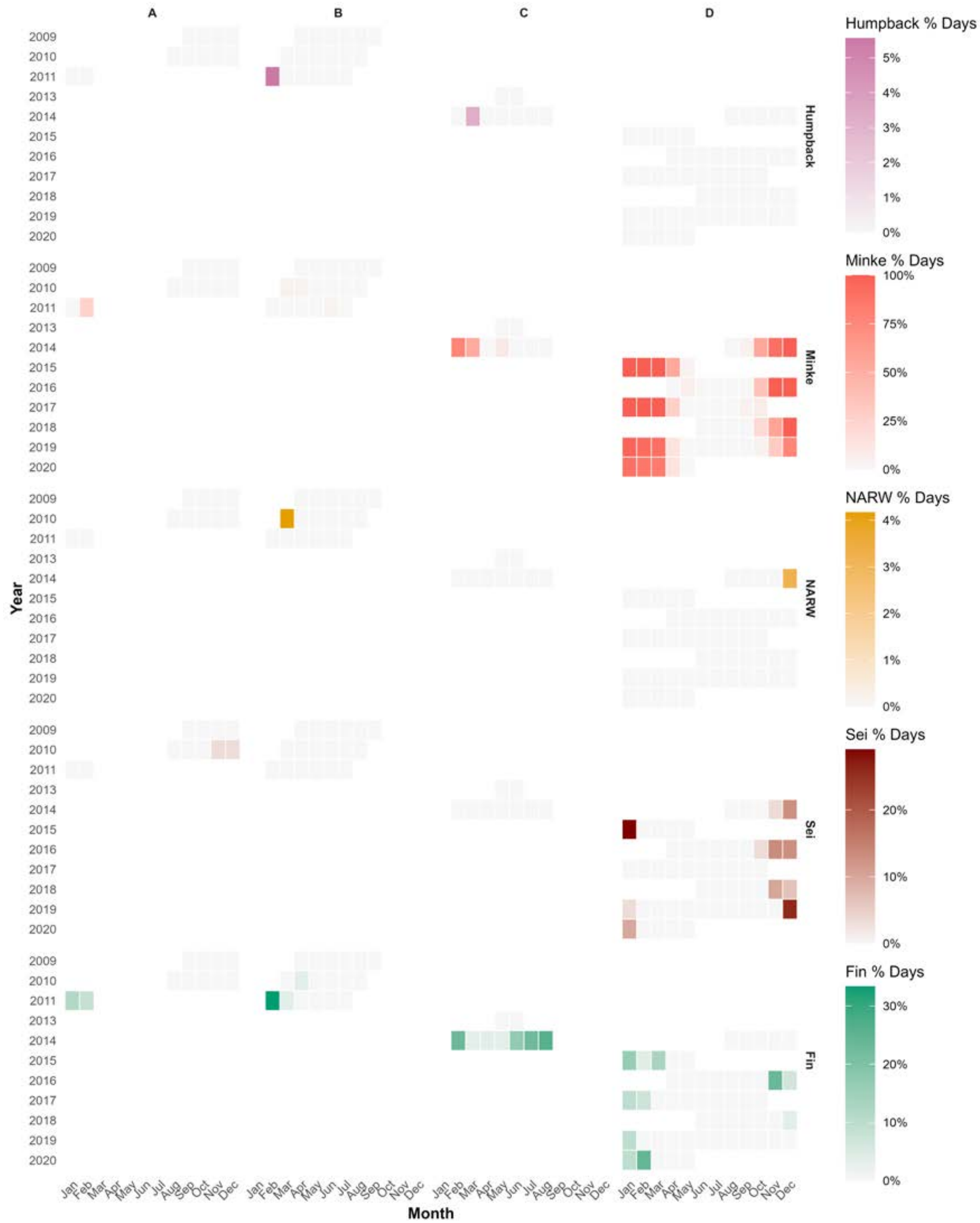

Figure 60: Annual monthly acoustic presence by species at all Jacksonville sites, represented as the percentage of days each species was detected per month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort. Note the difference in scale for each species. For minke whales only, differences between sites should be interpreted with consideration of the shift from manual review to automated detection.

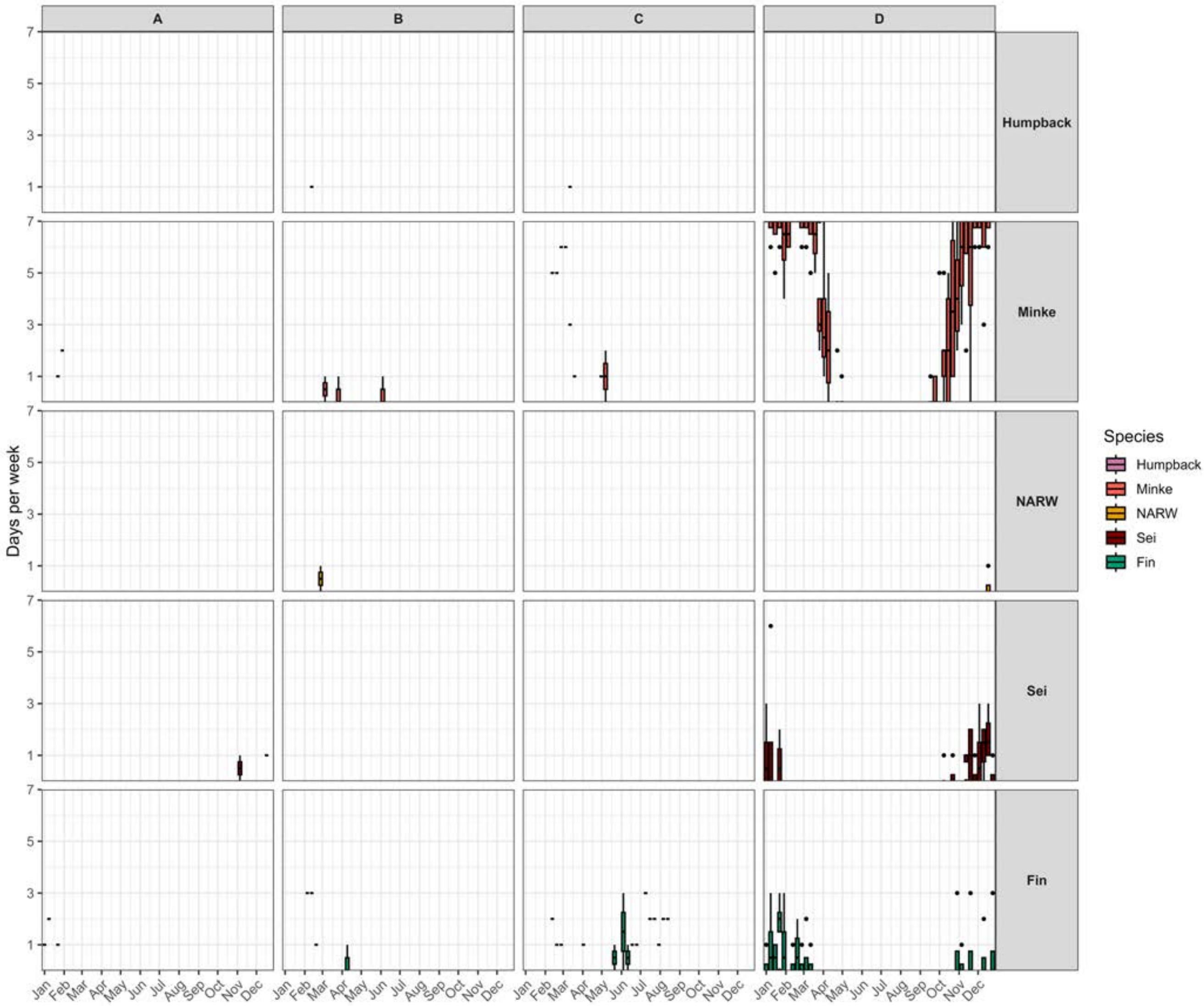

Figure 61: Average weekly acoustic presence (days per week) by species at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.2.1 Humpback Whales

Humpback whale occurrence was rare across the Jacksonville sites (Figures 62 & 63). Limited acoustic presence was detected at shallow shelf sites B and C, restricted to brief periods in late winter and early spring. Weekly presence never exceeded one day per week and was observed in only a small number of years. No humpback whale detections were recorded at site A or at the slope site (D), despite long-term recording effort.

Summary of Results – Humpback Whale

- Acoustic presence was rare and limited to shallow shelf sites B and C.
- Detections were confined to brief late winter–early spring periods and occurred intermittently across years.
- No detections were observed at site A or at the slope site (D) despite extended monitoring effort.

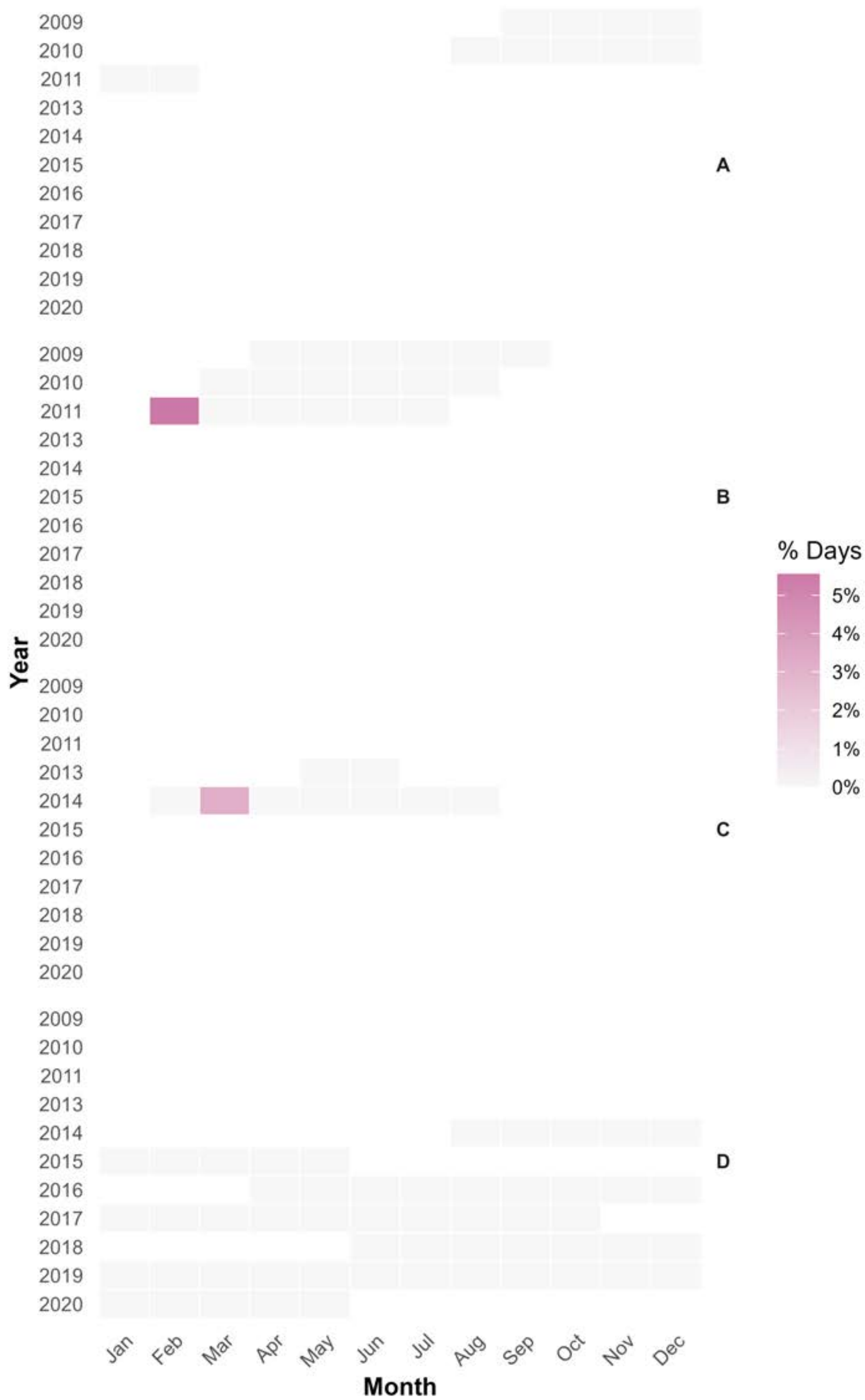

Figure 62: Annual monthly humpback whale acoustic presence at all Jacksonville sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort.

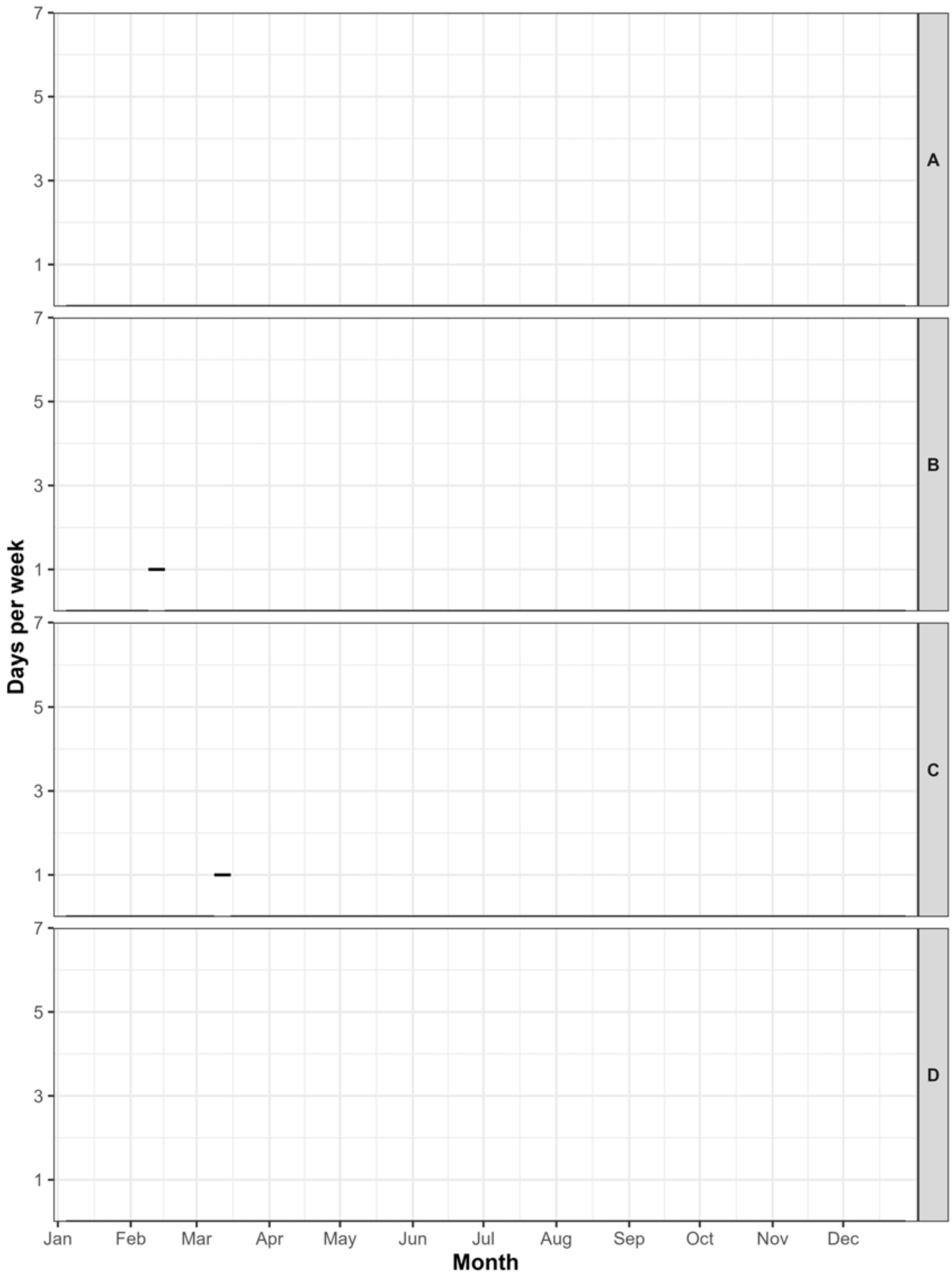

Figure 63: Average weekly acoustic presence of humpback whales (days per week) at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.2.2 Minke Whales

Minke whales were acoustically present across multiple Jacksonville sites, with pronounced seasonal and site-specific variability (Figures 64–65). The strongest and most consistent presence occurred at the slope site (D) from late fall to spring (Oct-Apr). During these periods, acoustic presence at site D was frequent, with weekly detections often exceeding three to five days per week.

Shallow shelf sites showed more limited and variable occurrence. Site C exhibited intermittent detections primarily during late winter and early spring in one deployment. At site A, minke whale detections were rare and confined to February. Minke whales were not recorded at site B.

Differences in apparent presence among sites reflect both true spatial variability and differences in monitoring effort. The slope site (D) provided the longest and most consistent year-round coverage, whereas shelf sites were monitored for shorter durations and during fewer years, limiting interannual comparisons.

Overall, the seasonal timing and distribution of detections indicate that minke whales regularly use the Jacksonville region during winter and fall months, with more consistent offshore occurrence and intermittent use of shelf habitats. Interpretation of minke whale presence should consider that different detection approaches were used during the monitoring period, and manual (sites 2A-4A, 6A, B, C, 11D, 13D) and automated detections (1A, 5A, 12D, 14-16D) are not directly comparable.

Summary of Results – Minke Whale

- Strong seasonal presence at the slope site (D) from fall to spring.
- Intermittent and lower-frequency detections at shallow shelf sites, primarily during winter and early spring.
- Weekly presence during peak periods at the slope site frequently exceeded three to five days per week, indicating regular seasonal use.
- Apparent site-level differences reflect a combination of spatial variability and differences in monitoring duration and effort.

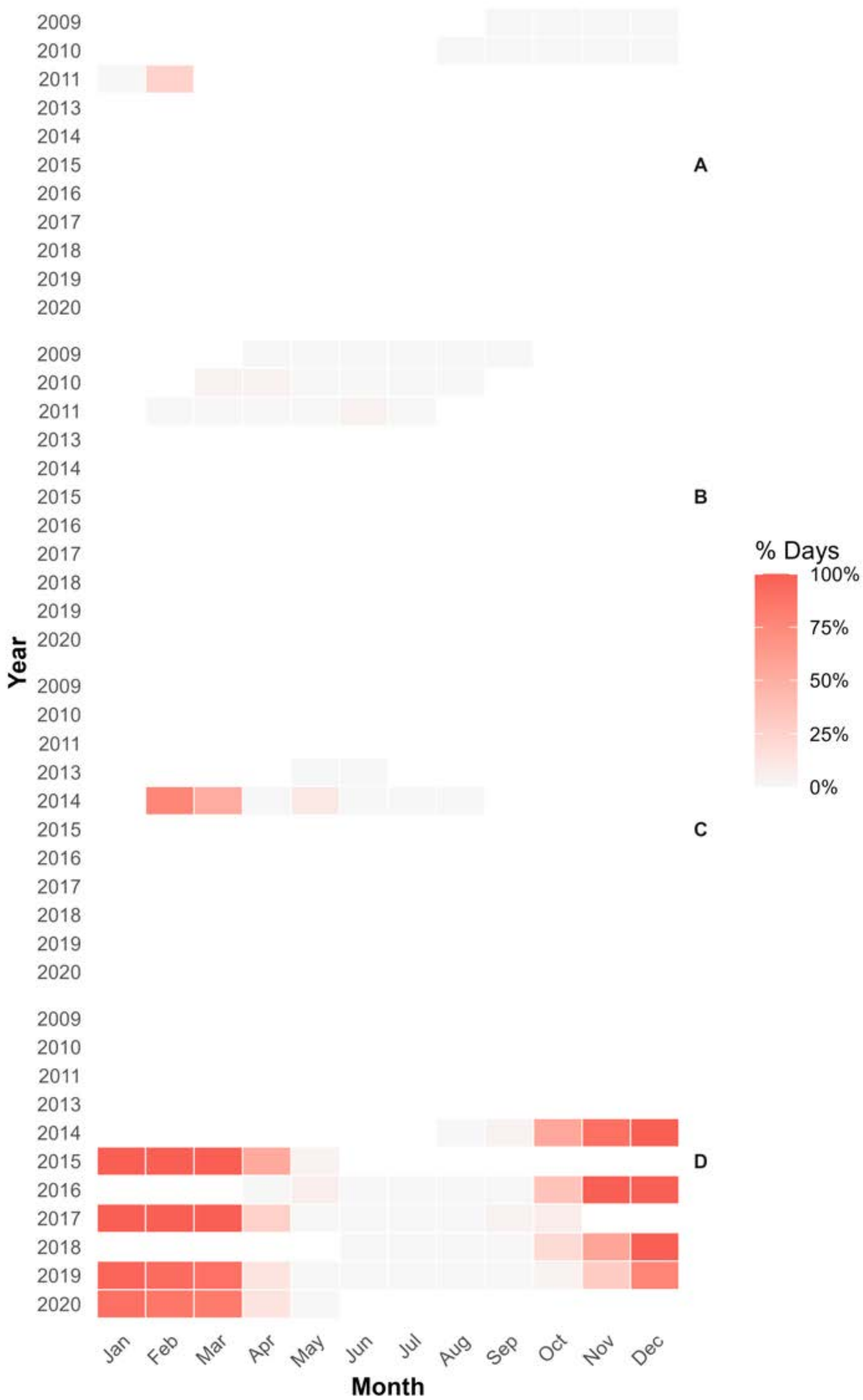

Figure 64: Annual monthly minke whale acoustic presence at all Jacksonville sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort. Manual and automated detection periods are shown together; differences between these approaches should be considered when interpreting changes in presence.

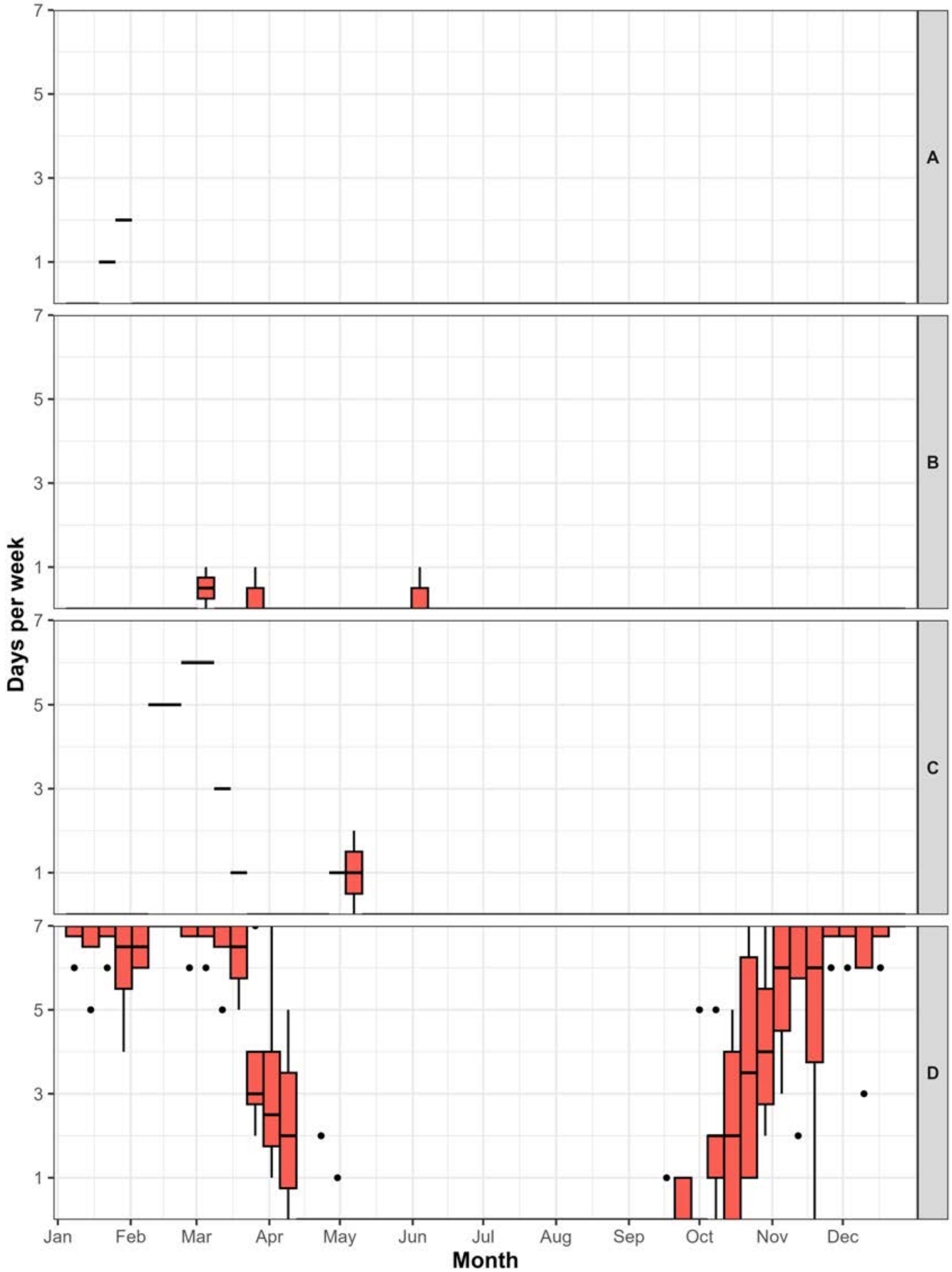

Figure 65: Average weekly acoustic presence of minke whales (days per week) at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.2.3 Blue Whales

No acoustic detections of blue whales were recorded at any of the Jacksonville sites during the monitoring period. This absence occurred despite multi-year recording effort across both shallow shelf (A–C) and slope (D) sites, including extended year-round coverage at the slope site.

5.2.4 Fin Whales

Fin whale acoustic presence at the Jacksonville sites exhibited clear seasonal variability, with detections occurring across multiple sites and years. Calling activity was most common during winter months (January–March) and again in late fall, though the timing and duration of presence varied among sites.

Detections were recorded at all sites. At sites A and B, fin whale detections were intermittent and largely confined to winter months. Site C exhibited more extended seasonal presence, with detections spanning from late winter through early fall during one deployment. At the slope site (D), fin whale detections occurred consistently across multiple years, primarily during winter and late fall months, indicating regular seasonal use of offshore habitat.

Weekly acoustic presence was generally modest, typically ranging from one to three days per week during peak periods.

Overall, the seasonal timing and distribution of detections indicate that fin whales regularly use the Jacksonville region, with site-specific differences in the duration and timing of acoustic presence.

Summary of Results – Fin Whale

- Fin whale acoustic presence exhibited clear seasonal variability across the Jacksonville sites.
- Intermittent winter detections occurred at sites A and B, while site C showed a longer seasonal window extending from late winter through early fall.
- The slope site (D) exhibited consistent seasonal detections across multiple years, particularly during winter and late fall.
- Weekly presence during peak periods generally ranged from one to three days per week.

Figure 66: Annual monthly fin whale acoustic presence at all Jacksonville sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort.

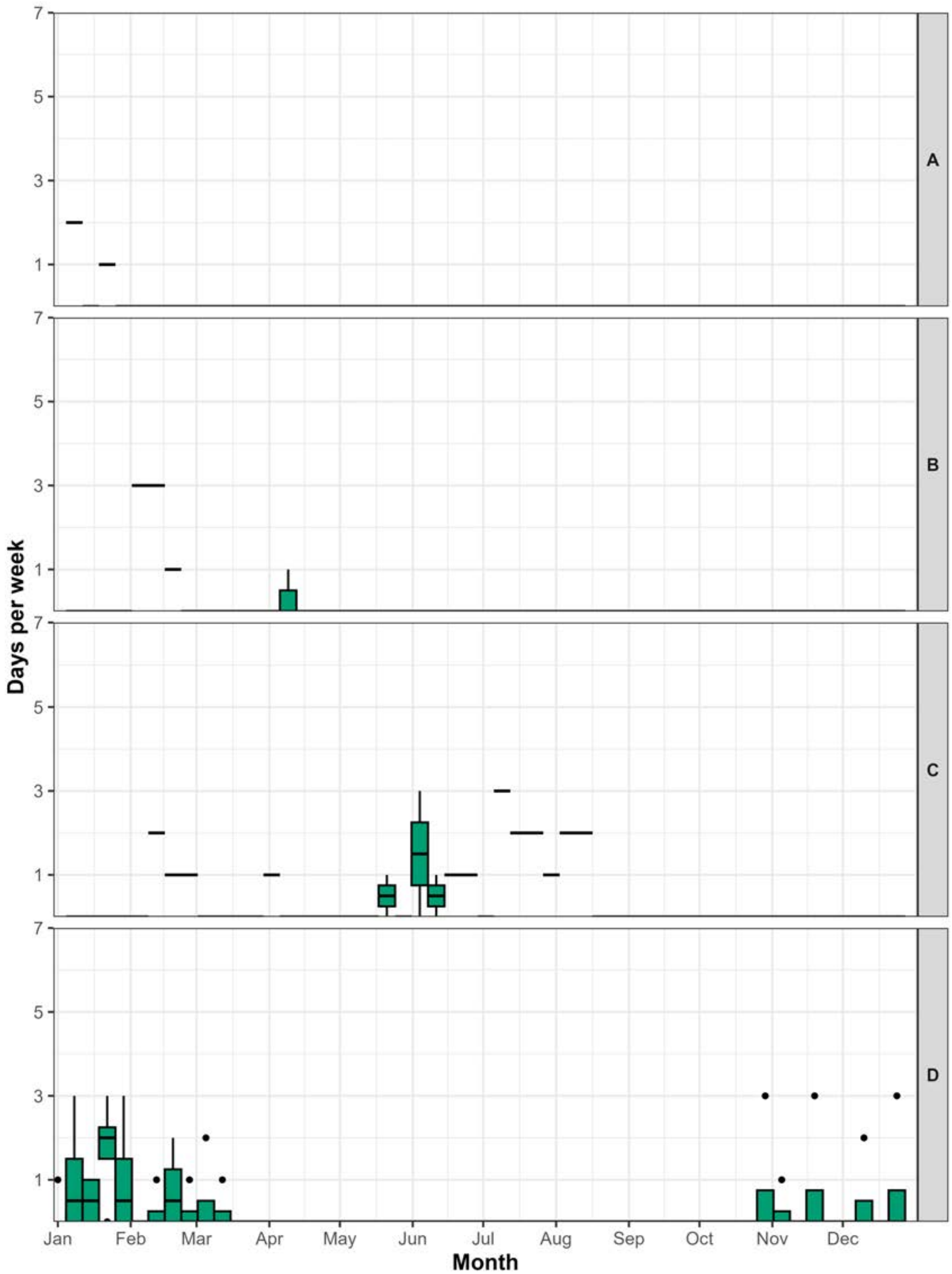

Figure 67: Average weekly acoustic presence of fin whales (days per week) at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.2.5 Sei Whales

Sei whale acoustic presence in the Jacksonville region was low overall with detections occurring from fall to winter (Oct-Jan) (Figures 68–69). Presence was not consistent across years, but the repeated timing of detections indicates recurring seasonal use of the area.

Detections were recorded predominantly at the slope site (D), with limited detections at the shallow shelf site (A) and no occurrence at site B or C. Weekly acoustic presence during periods of occurrence was generally low, typically one to two days per week.

Overall, the timing and spatial distribution of detections suggest that sei whales use the Jacksonville region intermittently during seasonal movements along the U.S. East Coast, with more consistent offshore occurrence relative to shelf habitats.

Summary of Results – Sei Whale

- Detections occurring primarily from fall through winter (October–January).
- Presence was not consistent across years, but detections occurred repeatedly during the same seasonal window.
- Detections were concentrated at the slope site (D), with limited occurrence at the shallow shelf site (A) and no detections at sites B or C.
- Weekly acoustic presence during periods of occurrence was low, typically one to two days per week, consistent with intermittent seasonal use.

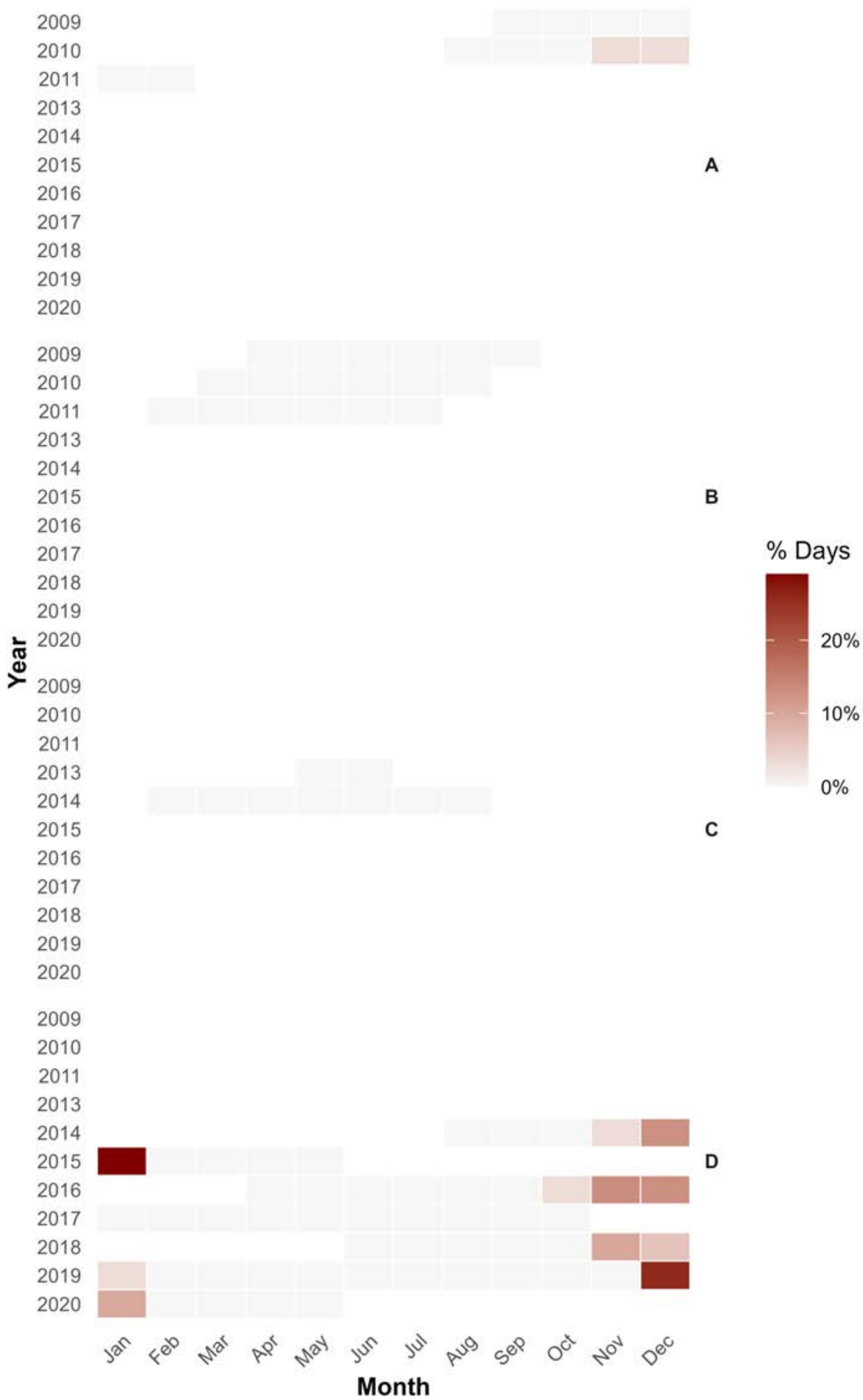

Figure 68: Annual monthly sei whale acoustic presence at all Jacksonville sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort.

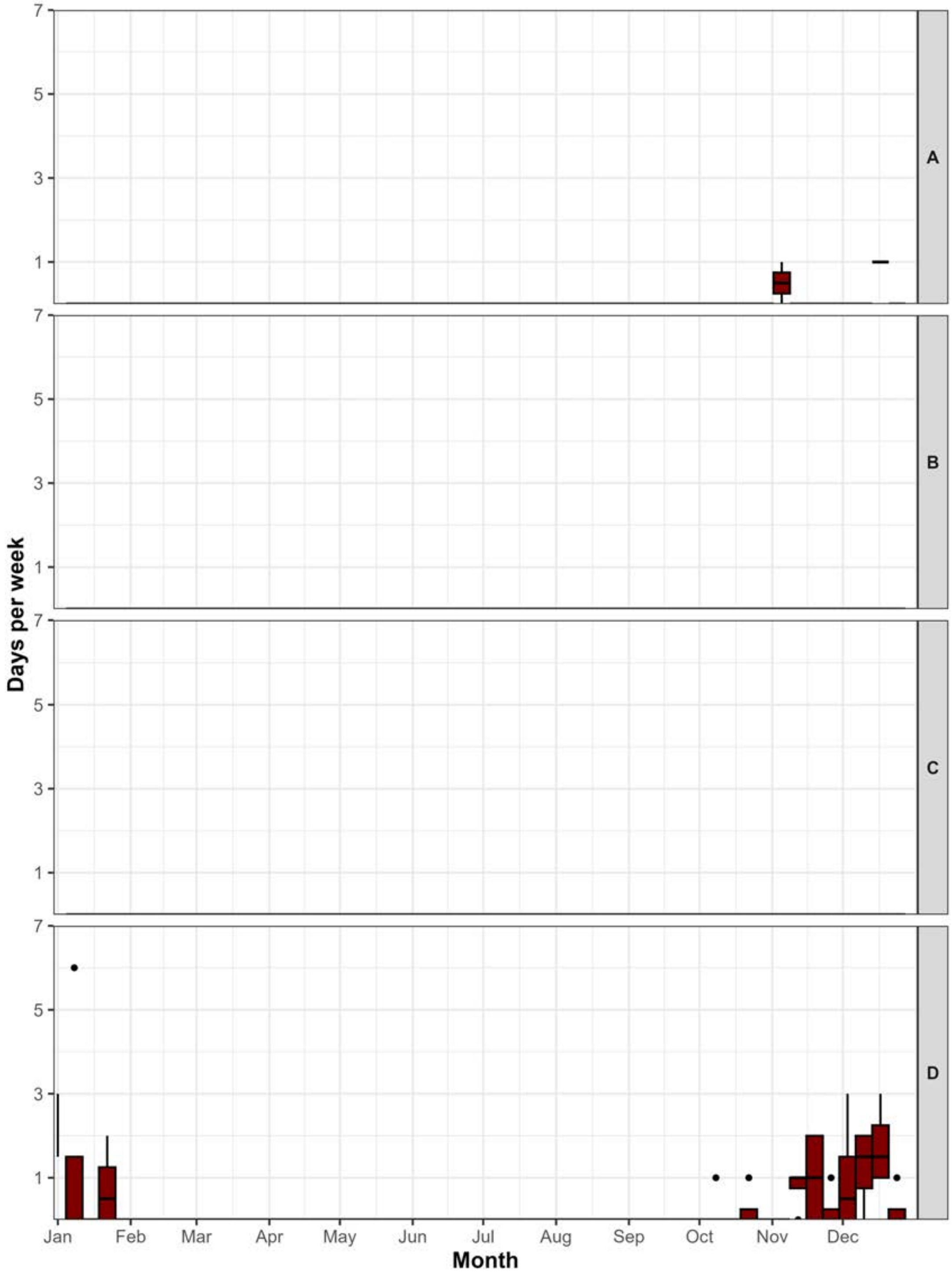

Figure 69: Average weekly acoustic presence of sei whales (days per week) at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.2.6 North Atlantic Right Whales

North Atlantic right whales were rarely detected in the Jacksonville region, with occurrence recorded in only two months during the monitoring period (Figures 70–71). This detection occurred at the shallow shelf site (B) in March 2010 and slope site (D) in December 2014. No detections were recorded at the shallow sites A and C.

Given the extremely limited number of detections, no seasonal or interannual patterns can be inferred. The absence of detections at other sites and times suggests that right whales only infrequently occur offshore Jacksonville during the study period. These results indicate that the area is not a regularly used habitat or migratory corridor for North Atlantic right whales, based on the available acoustic record, despite their only known seasonal calving area being in shallower nearshore waters immediately adjacent to the study area.

Summary of Results – North Atlantic Right Whale

- North Atlantic right whale acoustic presence was extremely limited, with detections occurring in only two months over the monitoring period.
- Detections were recorded at the shallow shelf site (B) in March 2010 and at the slope site (D) in December 2014; no detections occurred at sites A or C.
- The low number of detections precludes inference of seasonal or interannual patterns.
- Results indicate that the Jacksonville region is only infrequently used by North Atlantic right whales based on the available acoustic record.

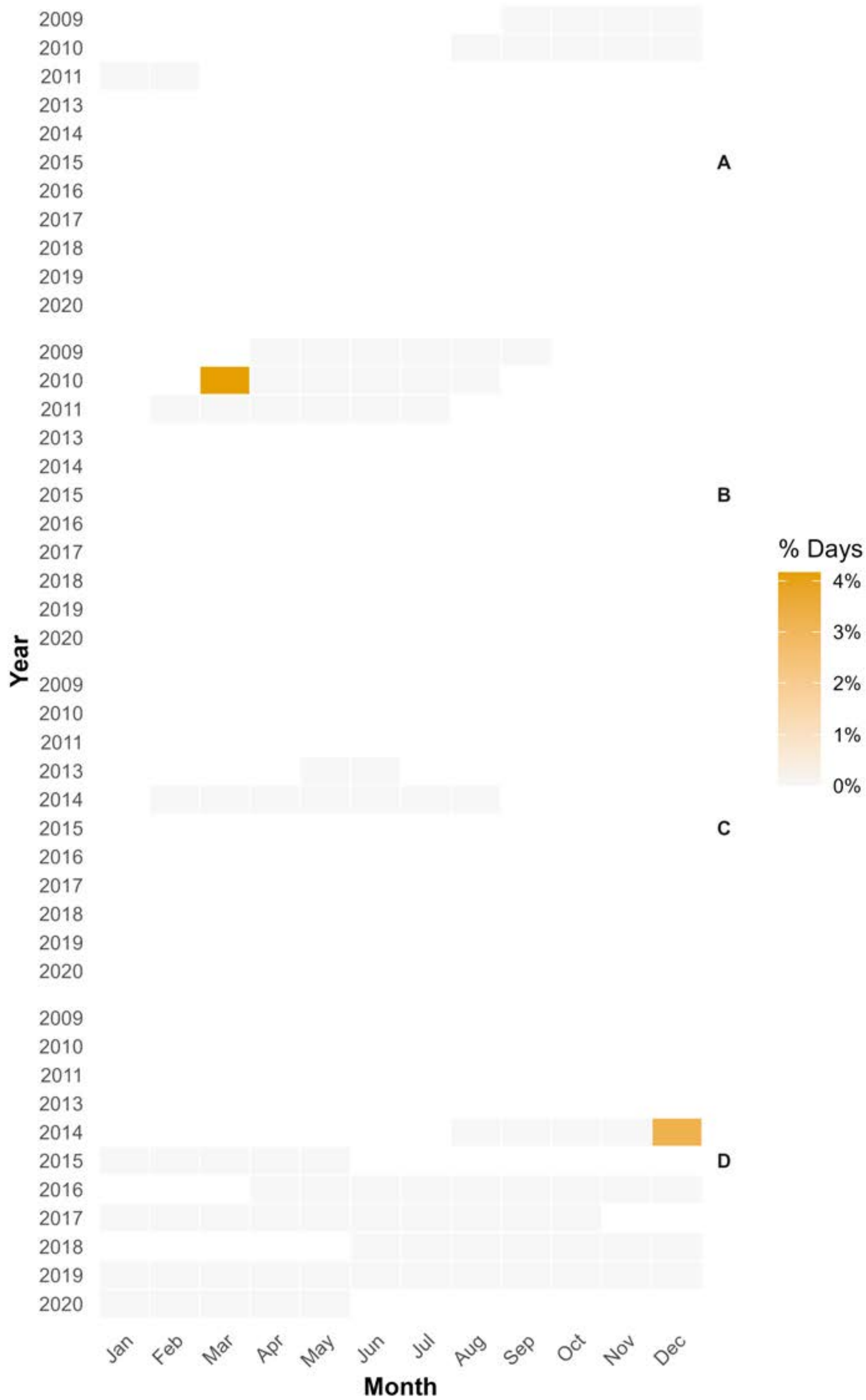

Figure 70: Annual monthly North Atlantic right whale acoustic presence at all Jacksonville sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort.

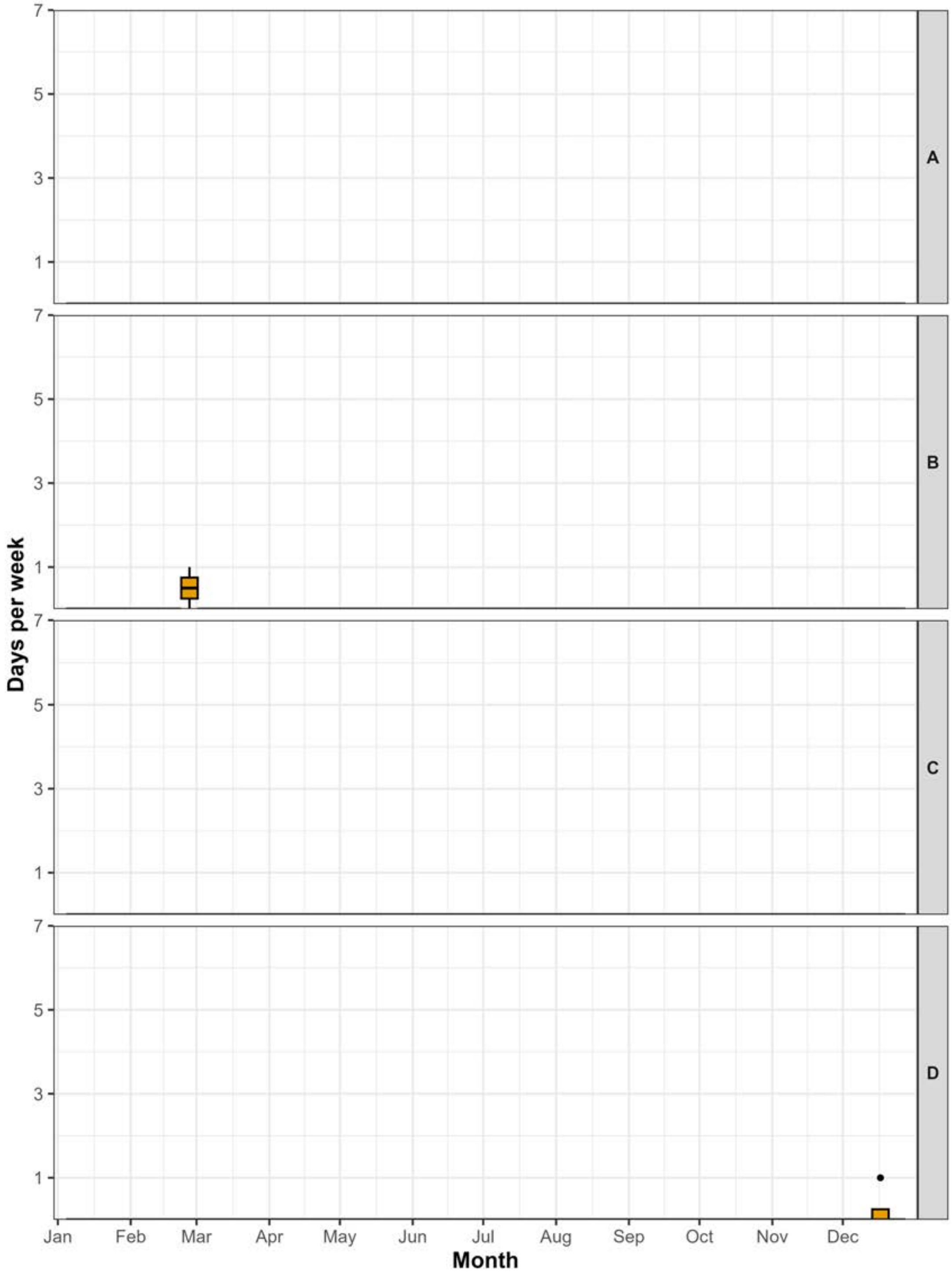

Figure 71: Average weekly acoustic presence of North Atlantic right whales (days per week) at all Jacksonville sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.3 Ambient Noise

Ambient sound levels at Jacksonville sites from 2009 to 2020 reflected a combination of shipping, biological, and environmental sources, with depth playing a key role in shaping background levels. The four subsites, spanning shallow shelf (A-C) and slope (D) waters, showed consistent gradients in spectral energy, with higher levels at the shelf sites and clearer biological contributions at the slope site (Figure 72; Figure 73).

Noise levels below 30 Hz were subject to elevated contributions from cable strumming caused by tidal currents at all sites. Flow noise and strumming were even evident at the slope site (D), likely driven by strong subsurface currents. This current-driven noise raised low-frequency spectrum levels, sometimes above 95 dB re 1 μPa^2/Hz at 10 Hz, and may have masked biological signals in that band.

At low frequencies ($<$100 Hz), shipping noise was the dominant feature across all sites. Broad peaks centered near 40–50 Hz were evident in the long-term spectral averages and seasonal plots, consistent with propulsion sounds from regional and distant commercial shipping. Seasonal increases in this band were most pronounced at the shallow shelf (A-B) and slope (D) sites, reflecting higher exposure to both local vessel traffic and propagating offshore shipping noise. Short-term variability in this band likely reflected changes in vessel traffic patterns and sea state.

Biological contributions to the soundscape were also evident at the slope site (D). Elevated spectral energy at approximately 120 Hz and 170 Hz occurred primarily during winter months and corresponded with minke whale pulse train detections, supporting the utility of these bands as biological indicators in long-term monitoring.

At higher frequencies (200–1000 Hz), seasonal increases in spectral levels during winter months at most sites were attributed to increased surface wind and wave action. Strumming may also influence variability in this band, complicating separation of wind-driven versus current-driven contributions.

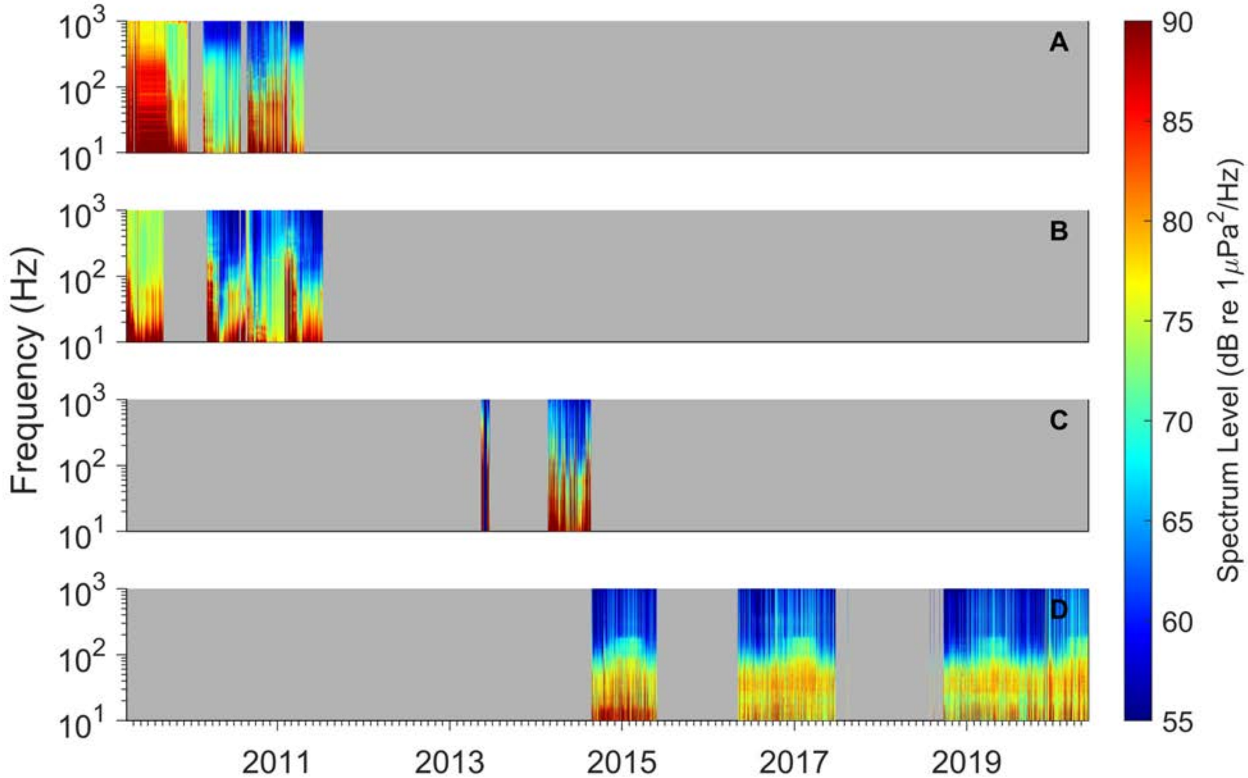

Figure 72: Long spectrograms using daily-averaged spectra for all Jacksonville sites from 2009 to 2020. Gray blocks represent periods with no effort.

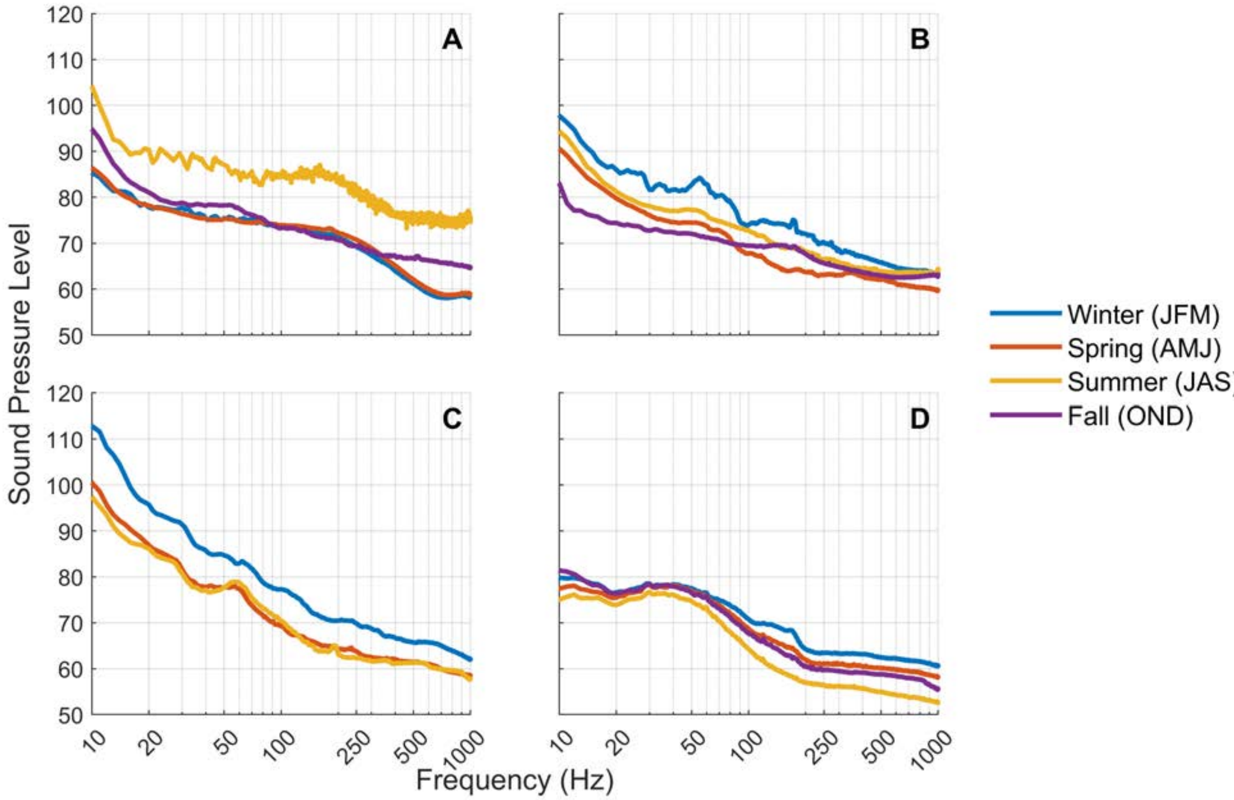

Figure 73: Full spectra averaged over each season for all Jacksonville sites from 2009 to 2020. Winter is represented by January, February, March; spring as April, May, June; summer as July, August, September; and fall as October, November, and December.

6 Applications of this Dataset

6.1 Publications

- Baumann-Pickering, S., Trickey, J.S., Solsona-Berga, A., Rice, A., Oleson, E.M., Hildebrand, J.A. and Frasier, K.E., 2023. Geographic differences in Blainville's beaked whale (*Mesoplodon densirostris*) echolocation clicks. *Diversity and Distributions*, 29(4), pp.478-491.
- Cholewiak, D., Baumann-Pickering, S. and Van Parijs, S., 2013. Description of sounds associated with Sowerby's beaked whales (*Mesoplodon bidens*) in the western North Atlantic Ocean. *The Journal of the Acoustical Society of America*, 134(5), pp.3905-3912.
- Cohen, R.E., Frasier, K.E., Baumann-Pickering, S., Wiggins, S.M., Rafter, M.A., Baggett, L.M. and Hildebrand, J.A., 2022. Identification of western North Atlantic odontocete echolocation click types using machine learning and spatiotemporal correlates. *PLoS ONE*, 17(3), p.e0264988.
- Cohen, R.E., Frasier, K.E., Baumann-Pickering, S. and Hildebrand, J.A., 2023. Spatial and temporal separation of toothed whales in the western North Atlantic. *Marine Ecology Progress Series*, 720, pp.1-24.
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