Passive Acoustic Monitoring for Marine Mammals and Ambient Noise Near Onslow Bay

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Table of Contents

1 Executive Summary

The U.S. Navy's Cherry Point Operating Area (OPAREA) is located offshore of Onslow Bay, North Carolina, within the South Atlantic Bight. From 2007 to 2013, High-frequency Acoustic Recording Packages (HARPs) were deployed at five sites across a depth gradient from the continental shelf to the slope, providing a unique long-term record of marine mammal occurrence and ambient noise conditions in the region. These data allow for the assessment of temporal patterns in species presence and the potential influence of environmental and anthropogenic drivers.

This report presents analyses of odontocete echolocation clicks, baleen whale low-frequency calls, and long-term spectral averages of ambient sound. Odontocete analyses were divided by ecological group: deep-diving species (beaked whales, sperm whales, and *Kogia* spp.) were analyzed at the deep slope site (E), while delphinids were analyzed across the full shelf-to-slope gradient (sites A–E). Mysticete results are presented for species producing identifiable low-frequency calls, and ambient noise analyses characterize patterns across frequencies relevant to both biological and anthropogenic sources.

Among odontocetes, sperm whales and Gervais' beaked whales were the most consistently present deep-diving species at the slope site (E), with sperm whale occurrence often exceeding 10 hours per week in fall and early winter between 2011 and 2013, and Gervais' detections peaking in winter and spring. Other beaked whales (goose-beaked, True's, Blainville's, and Sowerby's) and *Kogia* spp. were detected only intermittently and at low levels, with too few encounters to describe clear temporal patterns. BWG ("Beaked Whale Gulf"), an unidentified beaked whale signal discovered in the Gulf of Mexico, was included in the classifier but was not detected during this study.

Delphinids occurred across the full shelf-to-slope gradient (sites A–E), with distinctions between presumed small-bodied and large-bodied types. Presumed smaller-bodied delphinids (UD HF & 47) were most common at the shallow shelf site (A) and also present at the slope site (E), with seasonal peaks in fall and winter and diel patterns that were primarily crepuscular at the shelf sites and more nocturnal at depth. Presumed larger-bodied delphinids (UD LF) were less common overall but showed increased presence at the slope site in 2013. Risso's dolphins were also present throughout the study at relatively low levels, with brief seasonal increases in spring and summer, most pronounced at site E.

Together, these results highlight a depth-stratified pattern of odontocete presence in Onslow Bay. While sperm whales and Gervais' beaked whales were the most regularly occurring deep divers at slope waters, delphinids occurred across all depths, with contrasting spatial, seasonal, and diel patterns between presumed small-bodied and large-bodied types.

Baleen whale detections were intermittent across the Onslow Bay sites, with most species occurring seasonally between fall and early spring. Minke and fin whales were the most regularly detected, with presence spanning multiple seasons and occasional detections in summer. Blue and sei whales showed more defined peaks in fall and early winter, while humpback whales were detected only briefly in early spring. North Atlantic right whales were detected only once during the monitoring period. These results indicate that baleen whales transit through Onslow Bay primarily during migratory movements, with limited evidence of prolonged or consistent seasonal residency.

Although the Onslow Bay 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–D) were more strongly influenced by local surface processes and shallower bathymetry, while the slope site (E) was subject to Gulf Stream influence and deeper-water conditions. These differences were reflected in the species composition and acoustic presence observed at each site, underscoring how depth and bathymetry shape marine mammal occurrence. The Onslow Bay region functions as a transition zone between shelf and slope waters, 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 in Onslow Bay, they do not capture the full spatial heterogeneity of the 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).

Ambient noise analyses revealed distinct contributions from environmental, biological, and anthropogenic sources across the Onslow Bay study area. Persistent peaks in the 30–60 Hz band reflected commercial shipping, while seasonal enhancements near 20 Hz corresponded with fin whale calls. Additional peaks around 120 and 170 Hz in winter months were attributed to minke whale activity. At higher frequencies (>200 Hz), spectral levels increased during periods of elevated sea state. Recordings at the slope site (E) were particularly influenced by Gulf Stream-driven currents, with cable strumming and flow noise elevating low-frequency levels at times. In contrast, shelf sites (A–D) were more affected by local surface noise, including wind-driven variability and fish chorusing. Together, these results highlight how depth and oceanographic setting mediate the acoustic environment in Onslow Bay, 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 Cherry Point Operating Area (OPAREA) is situated in the coastal and offshore waters of Onslow Bay, North Carolina, within the South Atlantic Bight. This area encompasses a broad continental shelf, ranging from 40 to 140 km in width, with an inner zone of less than 200 meters in depth and an outer zone extending across the slope to depths approaching 2,000 meters. The Onslow Bay 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 2007 to 2013, a comprehensive acoustic monitoring effort was conducted within the boundaries of the Onslow Bay 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 Onslow Bay study area across a shelf-to-slope gradient (Figure 1 & Table 1). For clarity throughout this report, site A is referred to as the shallow shelf site, sites B–D as the mid-depth shelf sites, and site E as the slope site.

Table 1: table

Recording effort for deployments at the Onslow Bay study area.

Site	Deployment	Start Date	End Date	Depth (m)	Recording Duration (Days)	Duty Cycle (Min)
A	01	10/10/2007	01/16/2008	160	99	5/10
	03	04/24/2009	08/09/2009	170	108	5/10
	04	11/08/2009	02/24/2010	170	109	5/15
	05	07/30/2010	03/03/2011	170	217	5/10
B	02	05/20/2008	09/10/2008	230	114	5/10
C	04	11/08/2009	04/20/2010	330	164	5/15
D	05	07/30/2010	02/04/2011	340	190	5/10
E	06	08/19/2011	12/01/2011	950	105	5/10
	07	07/14/2012	10/02/2012	900	81	5/10
	08	10/24/2012	06/30/2013	850	250	5/10

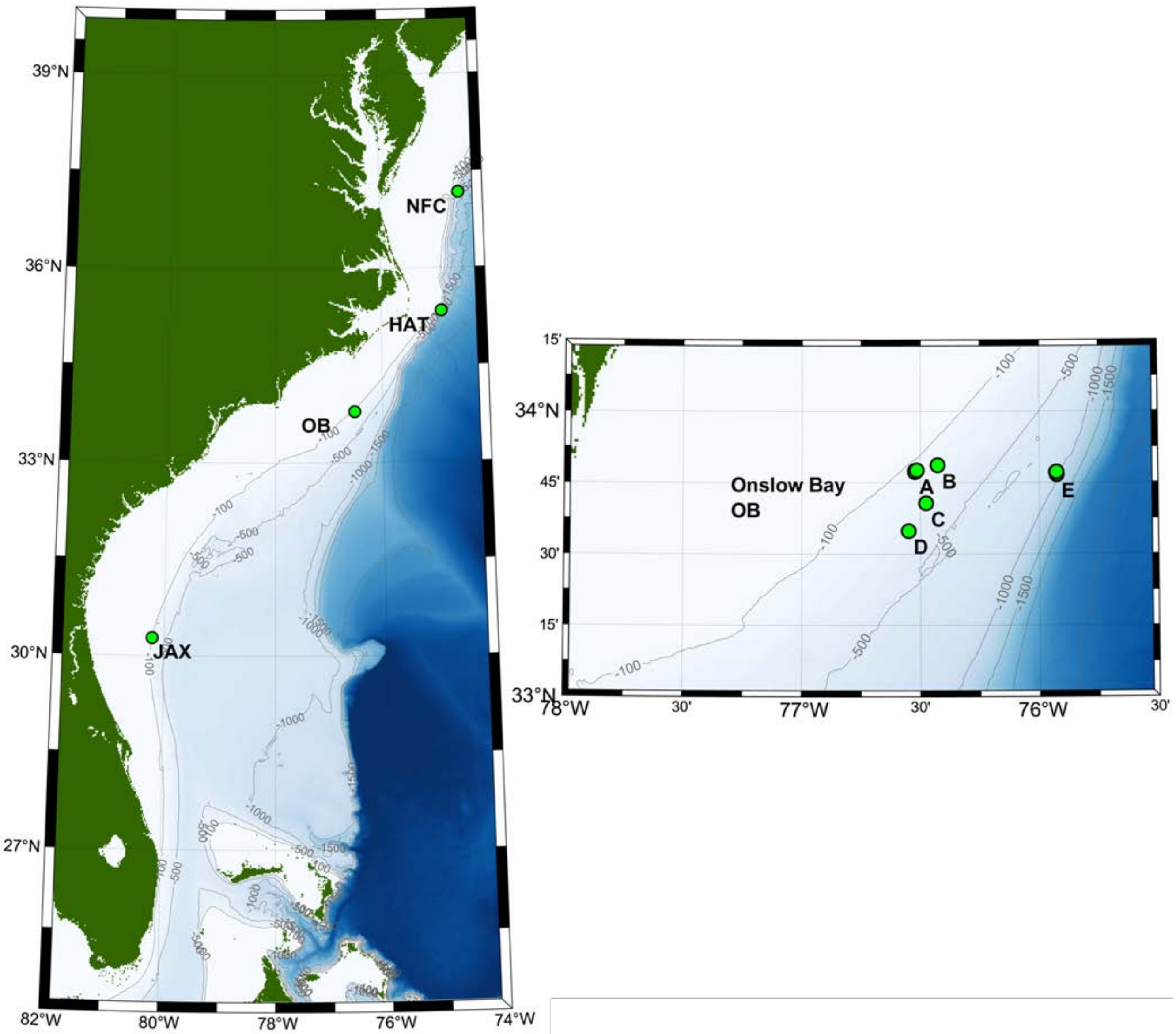

Figure 1: Location of the High-frequency Acoustic Recording Packages (HARPs) at the Onslow Bay (OB) site. Left: Large-scale view of the OB project location along the U.S. East Coast. Right: Zoomed-in view showing the positions of individual deployments at the A-E sites.

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 10 deployments were conducted in the Onslow Bay study area between 2007 and 2013 across five sites spanning a depth gradient: one shallow shelf site (A, 170 m), three mid-depth shelf sites (B–D, 230–340 m), and one slope site (E, 850–950 m). All recordings were duty cycled to extend deployment duration. As a result, acoustic coverage represents a subsample of real-time conditions, and short-duration or infrequent acoustic events may be underrepresented relative to continuous recordings.

The vast majority of the data collected were found to be error free. Some deployments experienced issues with instrument strumming and flow noise, particularly at the mid-depth shelf and slope sites, which intermittently elevated low-frequency noise levels (<30 Hz) and reduced the signal-to-noise ratio for baleen whale calls. These effects were most pronounced at the slope site during deployments 6E-8E, where strong Gulf Stream currents interacted with the mooring lines. Intermittent strumming was also noted at the mid-depth shelf sites during deployments 4C and 5D.

Intermittent data gaps appeared in deployments 1A and 5A due to datalogger malfunctions and disk write errors. Recording coverage began at 100% and was 82% and 91%, respectively, at the end of the recording periods. All other deployments maintained greater than 95% coverage, including deployment 08E, which produced the longest deep-water dataset with 250 days of high-quality recordings despite intermittent flow noise.

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 Onslow Bay 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 Onslow Bay sites, not spatial gradients across the western North Atlantic. Comparisons to other studies that include the Onslow Bay 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 (E), while analyses for the shallow and mid-depth shelf sites (A–D) 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. Onslow Bay 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.

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 of 10 clicks per cluster bin was set to include ephemeral beaked whale encounters (Solsona-Berga et al. 2024). 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).

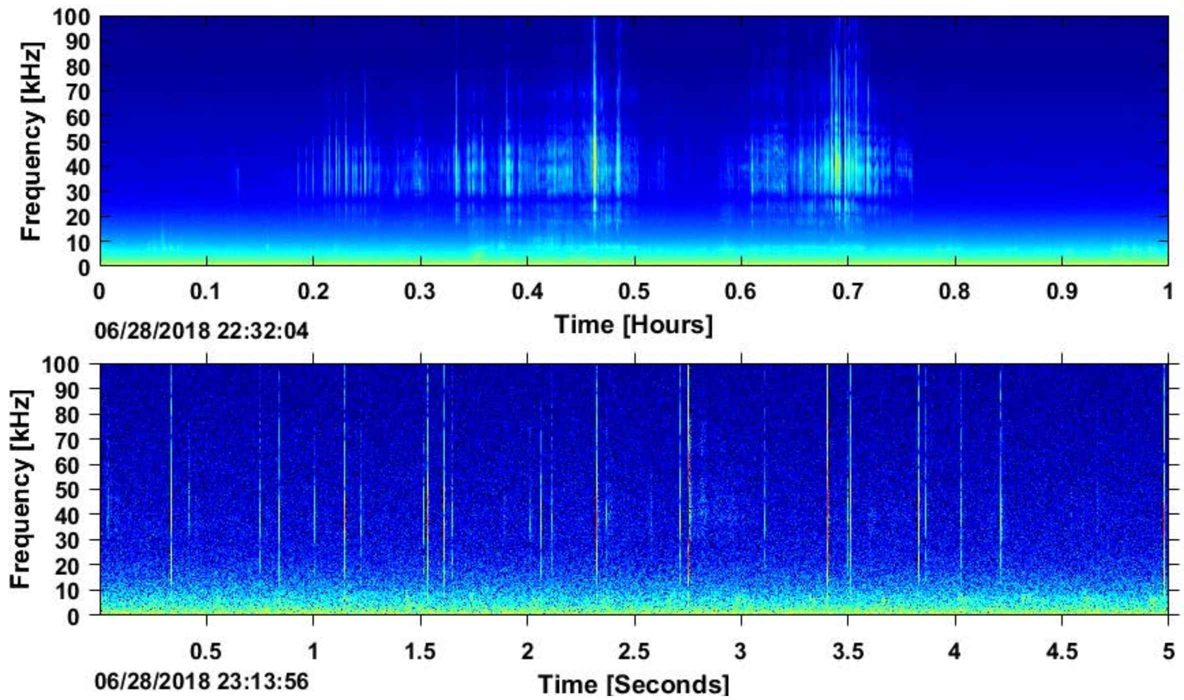

Figure 2: Goose-beaked whale signal in LTSA (top) and spectrogram (bottom).

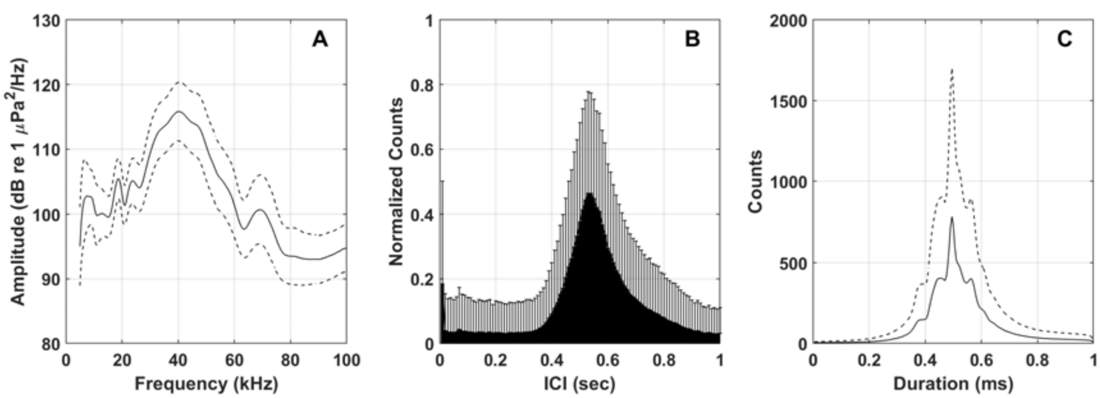

Figure 3: Left: Mean frequency spectrum of goose-beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.5 s; Right: Mean waveform envelope (solid line) and standard deviation (dashed line) of representative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

4.2.2 Gervais' Beaked Whale

Gervais' beaked whale echolocation signals have energy concentrated in the 30-50 kHz band (Gillespie et al. 2009), 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. 2009).

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).

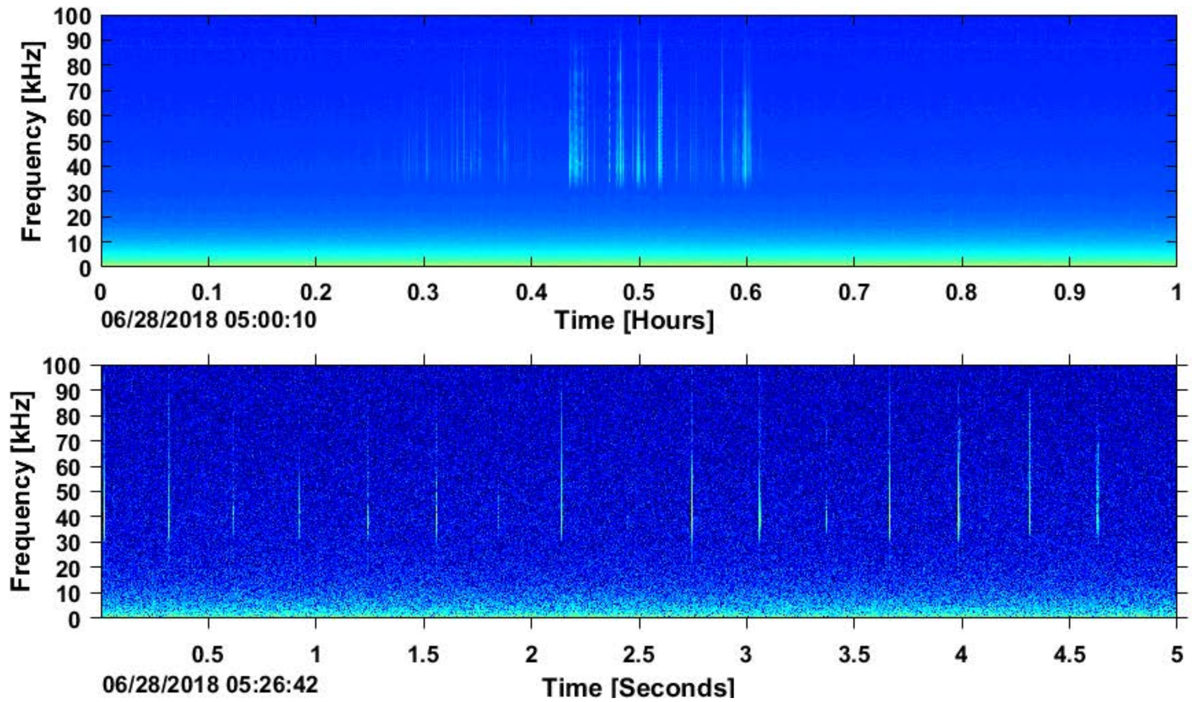

Figure 4: Gervais' beaked whale signal in LTSA (top) and spectrogram (bottom).

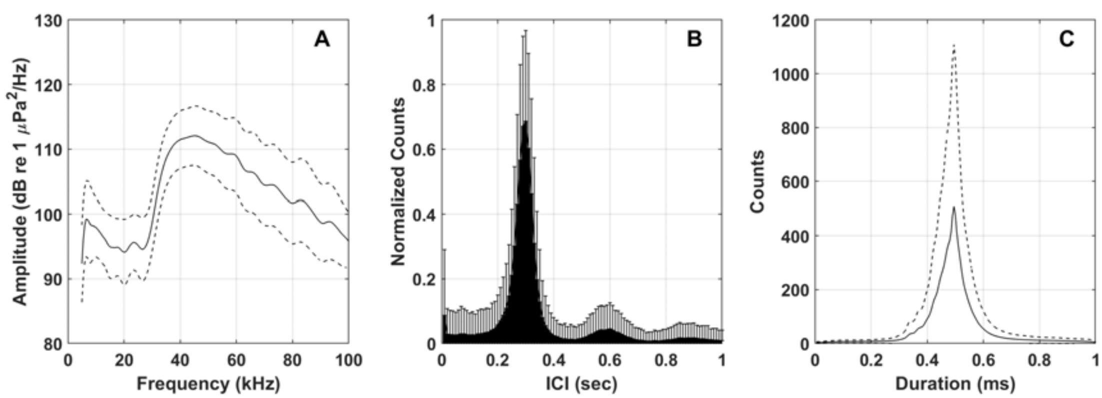

Figure 5: Left: Mean frequency spectrum of Gervais' beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.3 s. Smaller peaks can occur at multiples of the main peak, and represent cases where a subset of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

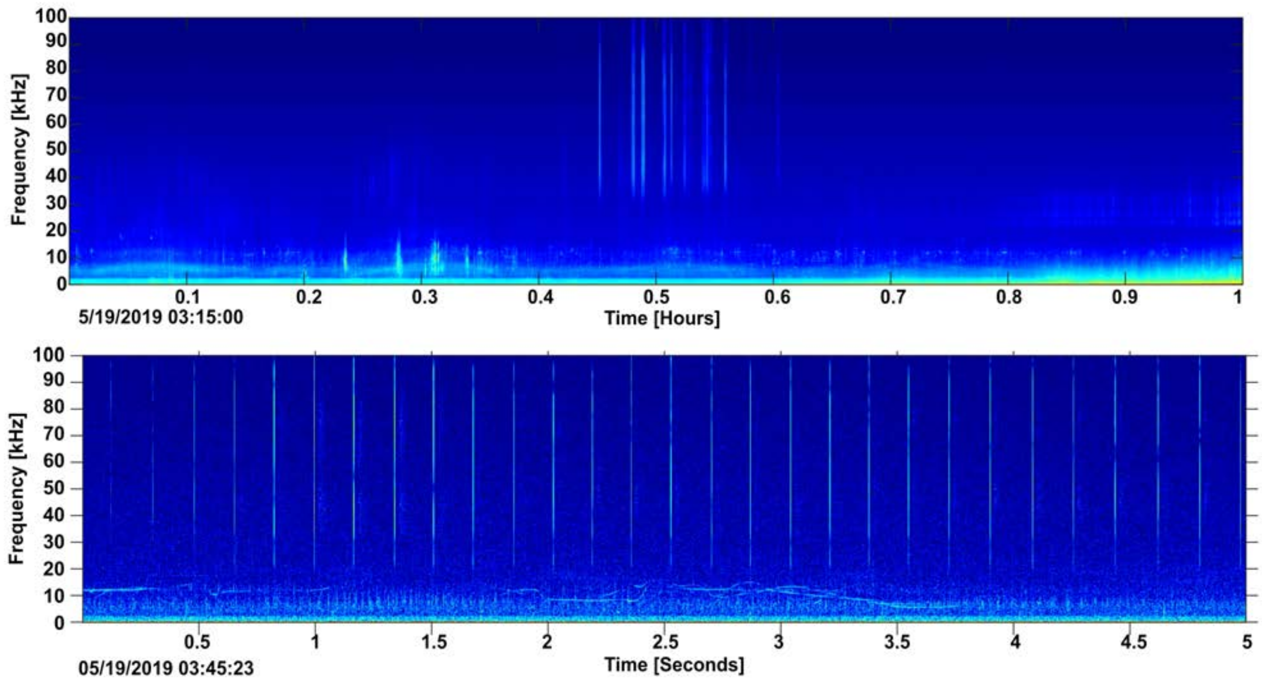

Figure 6: True's beaked whale signal in LTSA (top) and spectrogram (bottom).

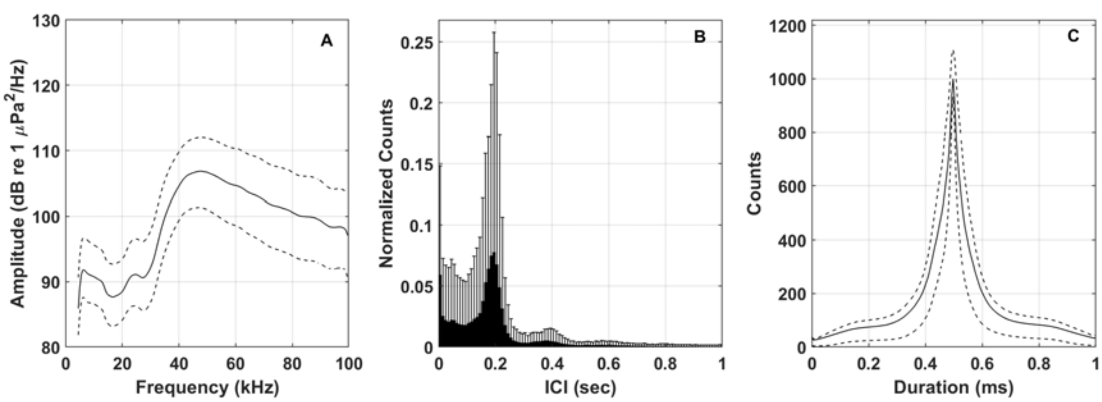

Figure 7: Left: Mean frequency spectrum of True's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.18 s; Right: Mean waveform envelope of representative clicks.

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).

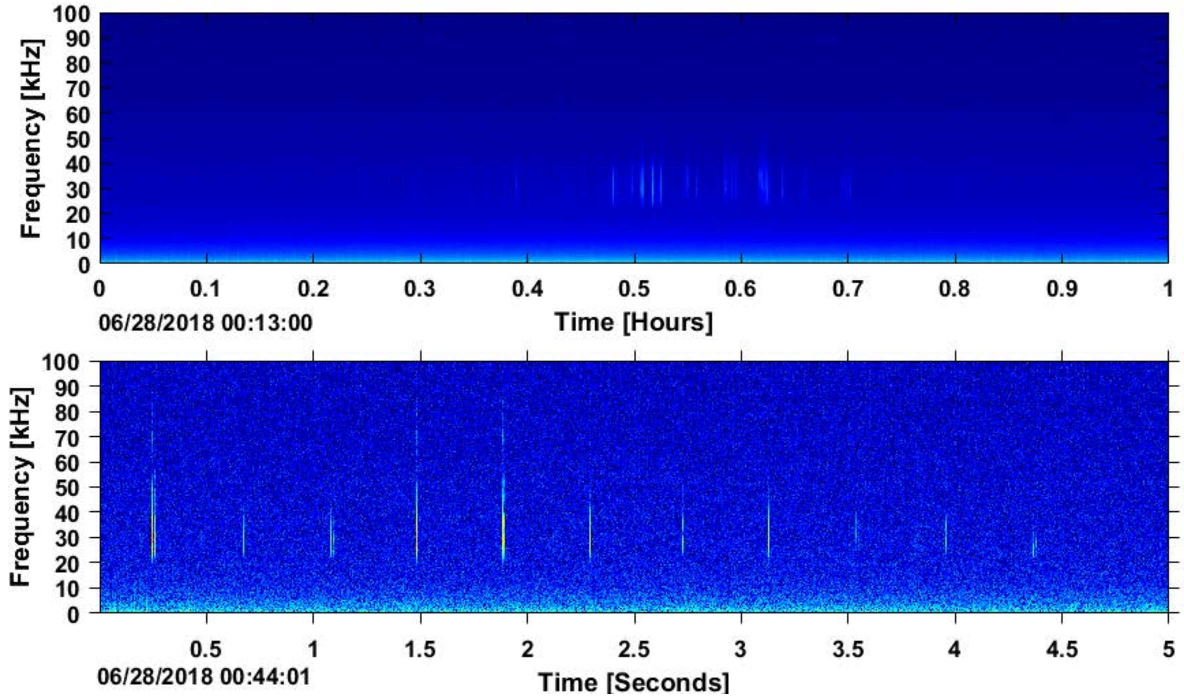

Figure 8: Blainville's beaked whale signal in LTSA (top) and spectrogram (bottom).

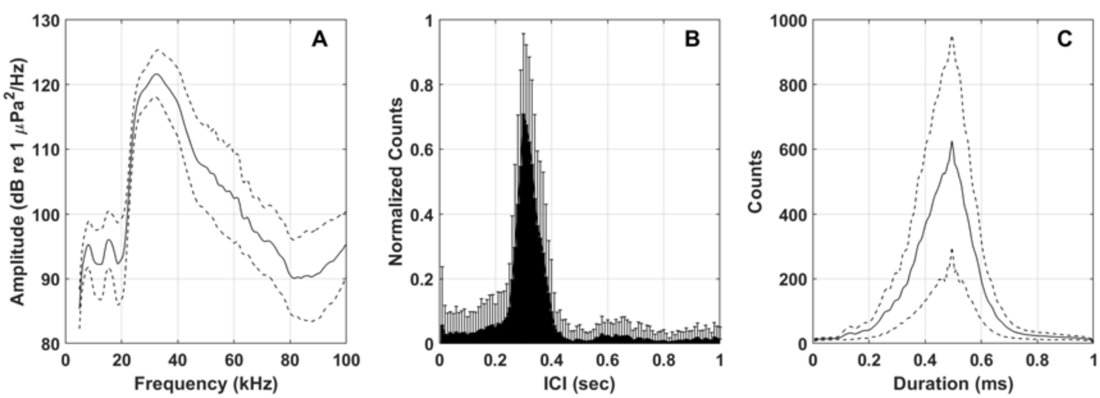

Figure 9: Left: Mean frequency spectrum of Blainville's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.3 s; Right: Mean waveform envelope of representative clicks.

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 (Clarke et al. 2019) (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).

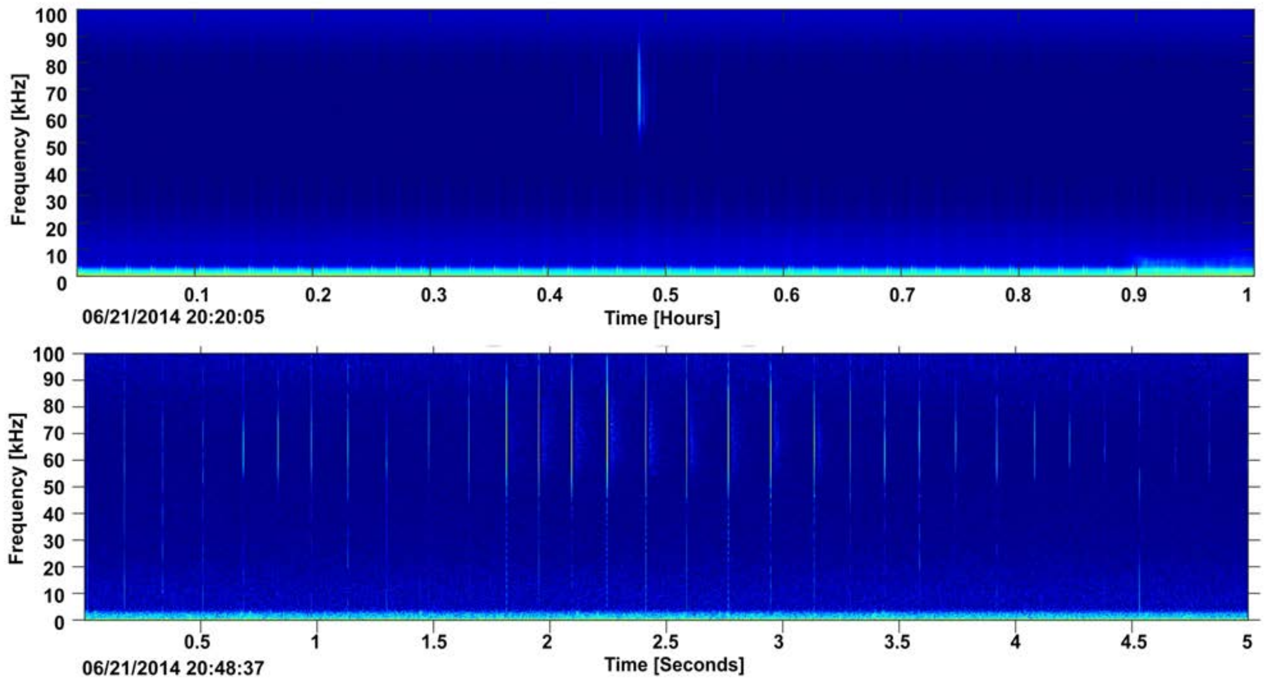

Figure 10: Sowerby's beaked whale signal in LTSA (top) and spectrogram (bottom).

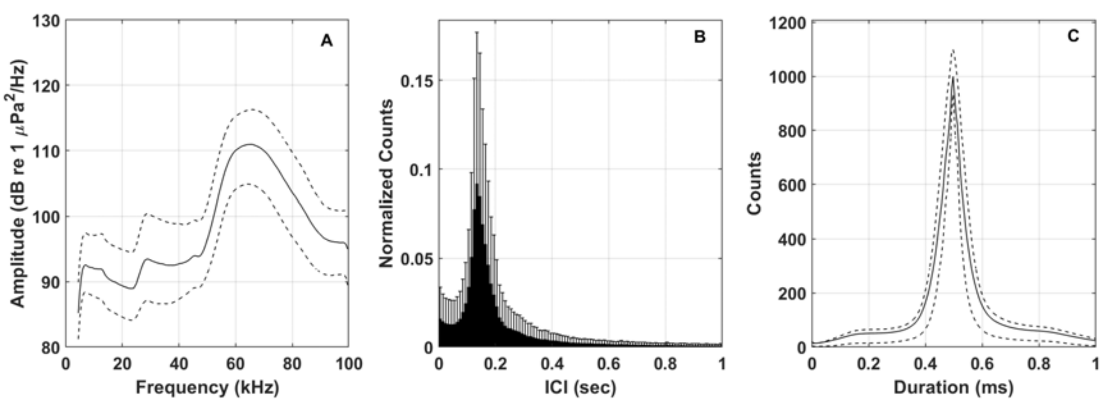

Figure 11: Left: Mean frequency spectrum of Sowerby's beaked whale echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.15 s; Right: Mean waveform envelope of representative clicks.

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.

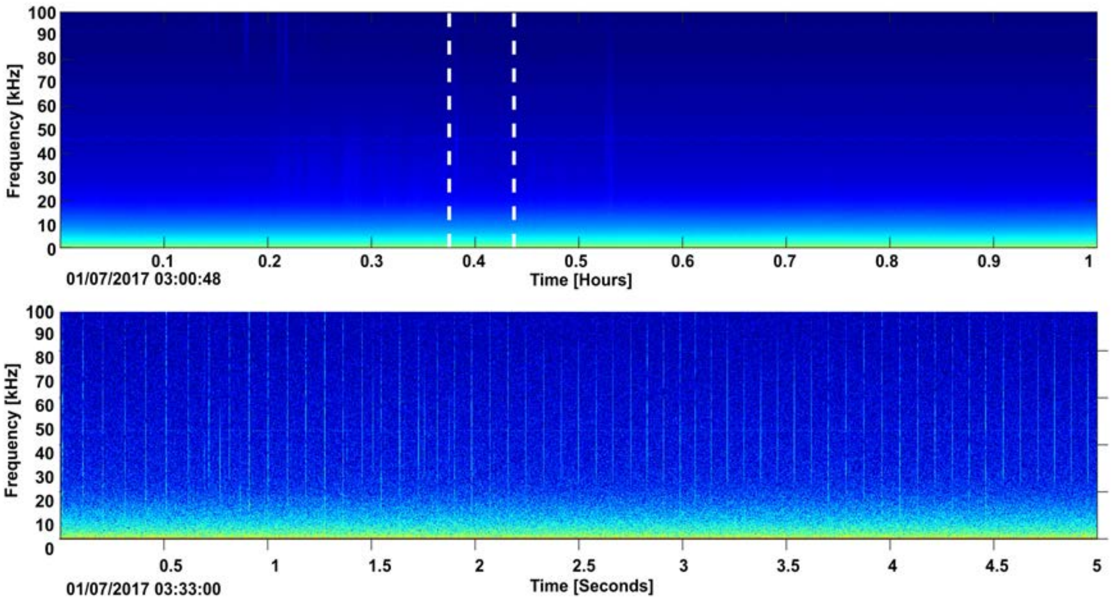

Figure 12: Beaked Whale Gulf (BWG) signal in LTSA (top) and spectrogram (bottom).

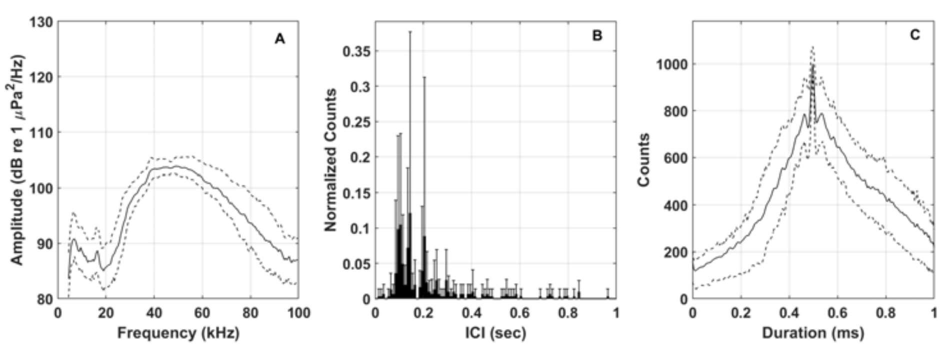

Figure 13: Left: Mean frequency spectrum of Beaked Whale Gulf (BWG) signals (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.18 s; Right: Mean waveform envelope of representative clicks.

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).

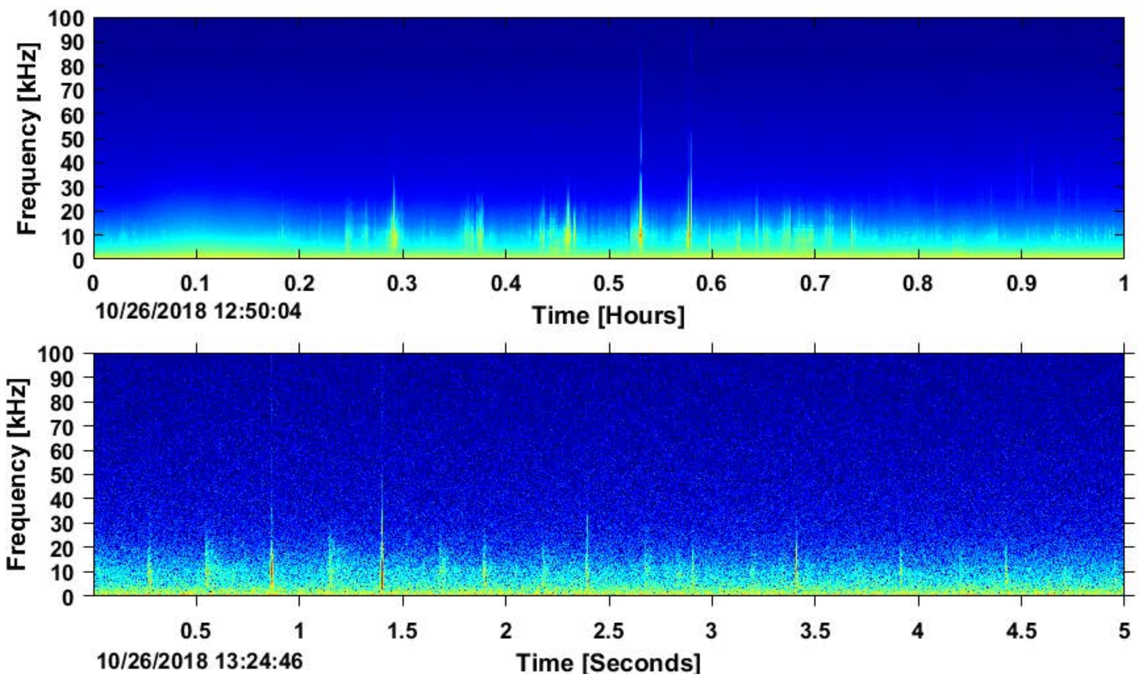

Figure 14: Sperm whale signals in LTSA (top) and spectrogram (bottom).

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).

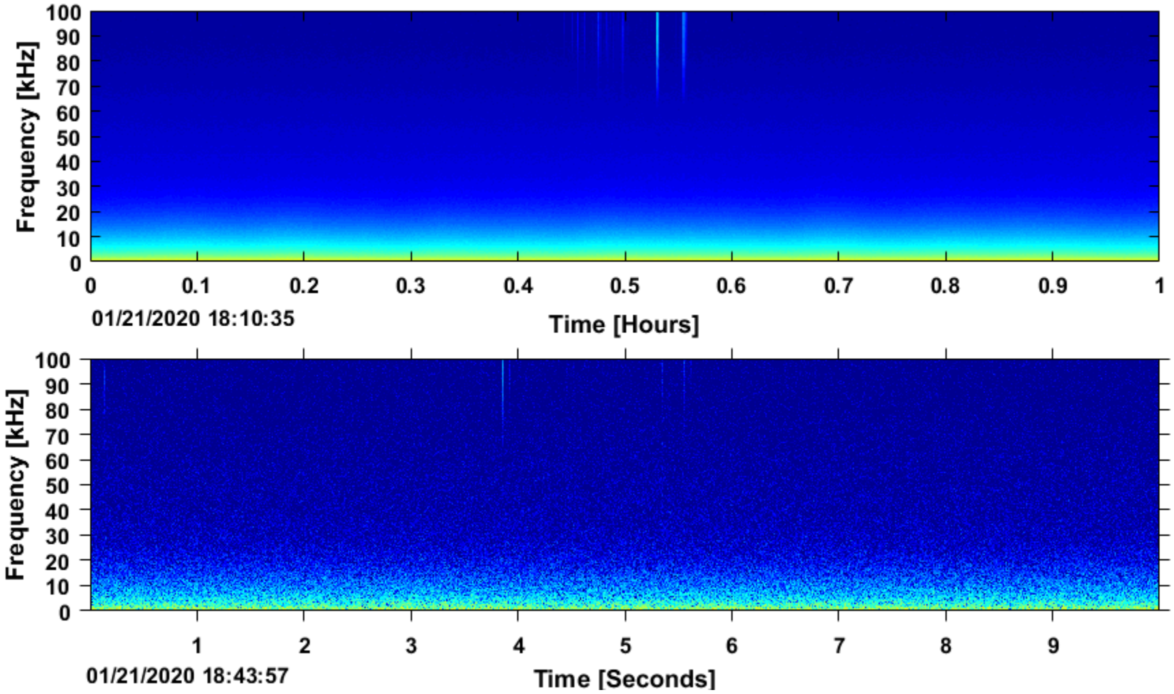

Figure 15: ***Kogia*** **spp. signals in LTSA (top) and spectrogram (bottom).**

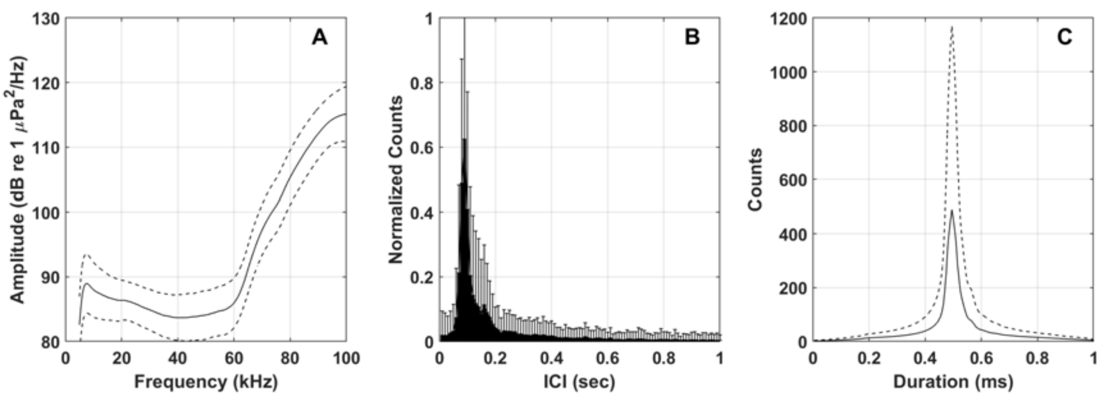

Figure 16: Left: Mean frequency spectrum of ***Kogia*** **spp. echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.1 s; Right: Mean waveform envelope of representative clicks.**

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).

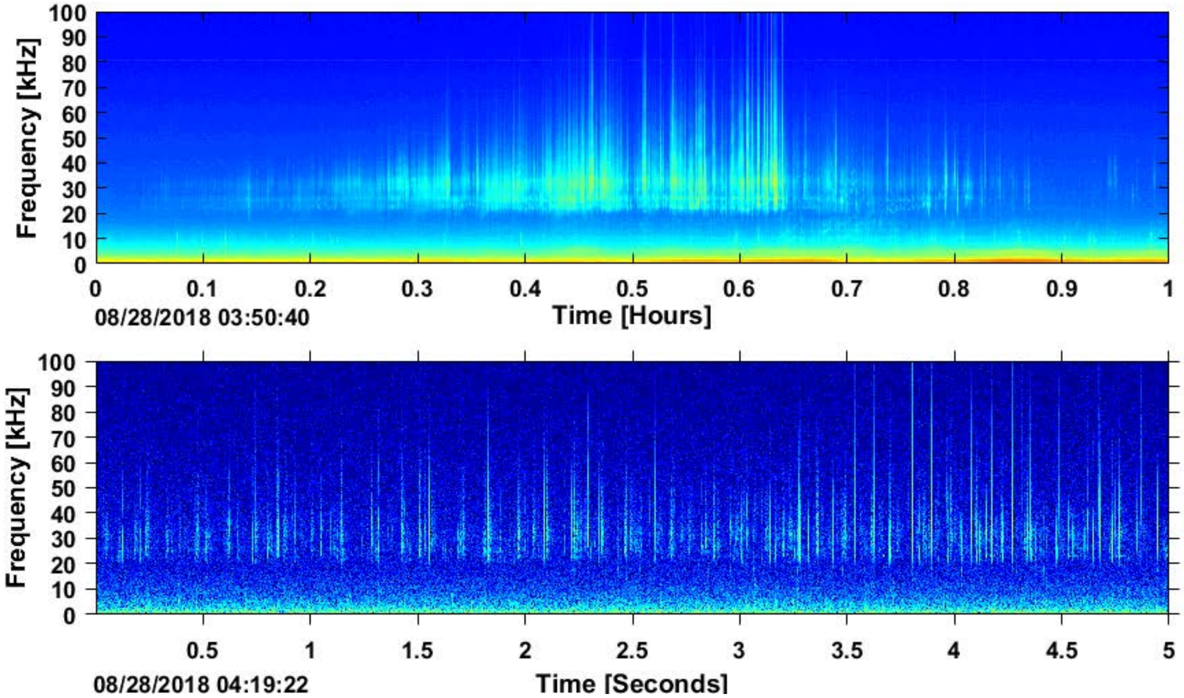

Figure 17: Risso's dolphins signals in LTSA (top) and spectrogram (bottom).

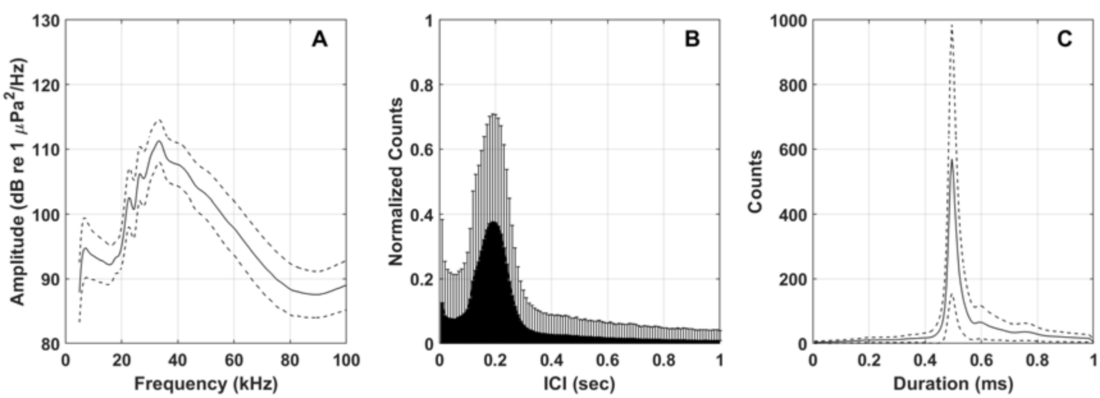

Figure 18: Left: Mean frequency spectrum of Risso's dolphins echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.2 s; Right: Mean waveform envelope of representative clicks.

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).

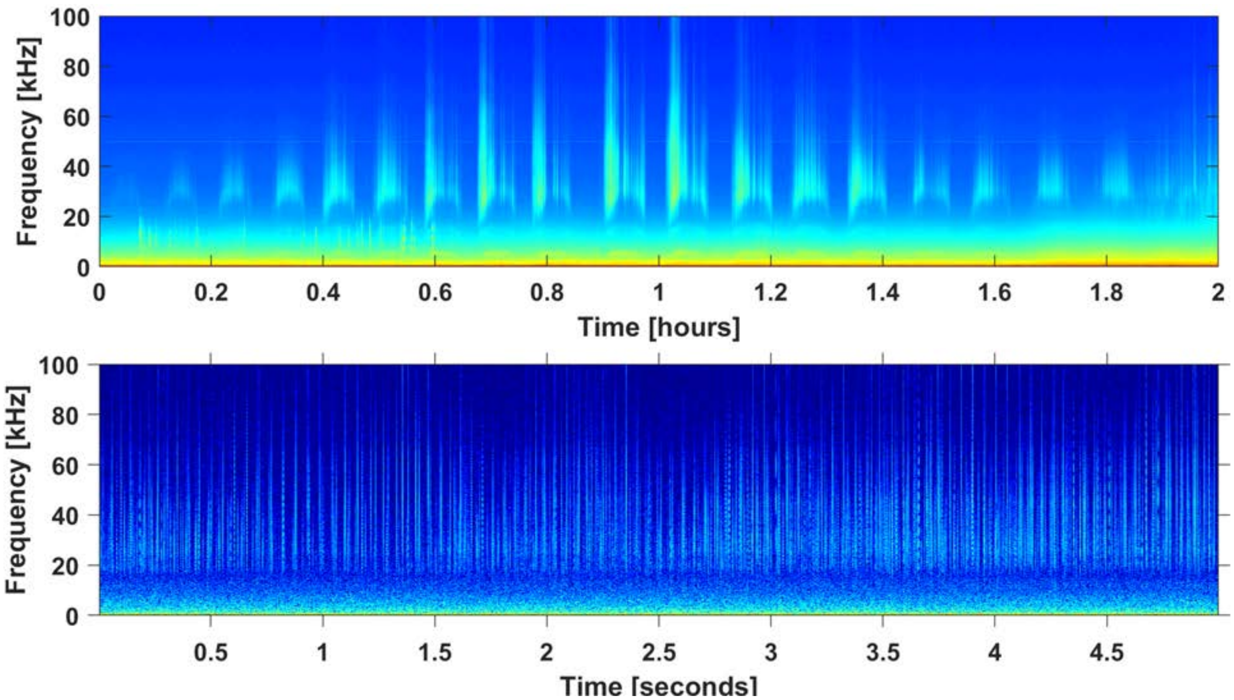

Figure 19: Unidentified dolphin high-frequency (UD HF) echolocation signals in LTSA (top) and spectrogram (bottom).

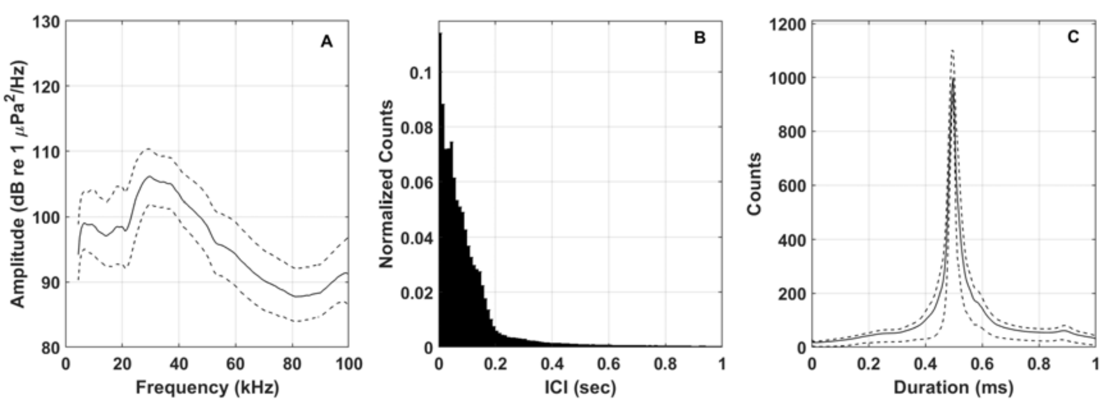

Figure 20: Left: Mean frequency spectrum of unidentified dolphin mid-frequency (UD HF) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.065 s and 0.1 s; Right: Mean waveform envelope of representative clicks.

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).

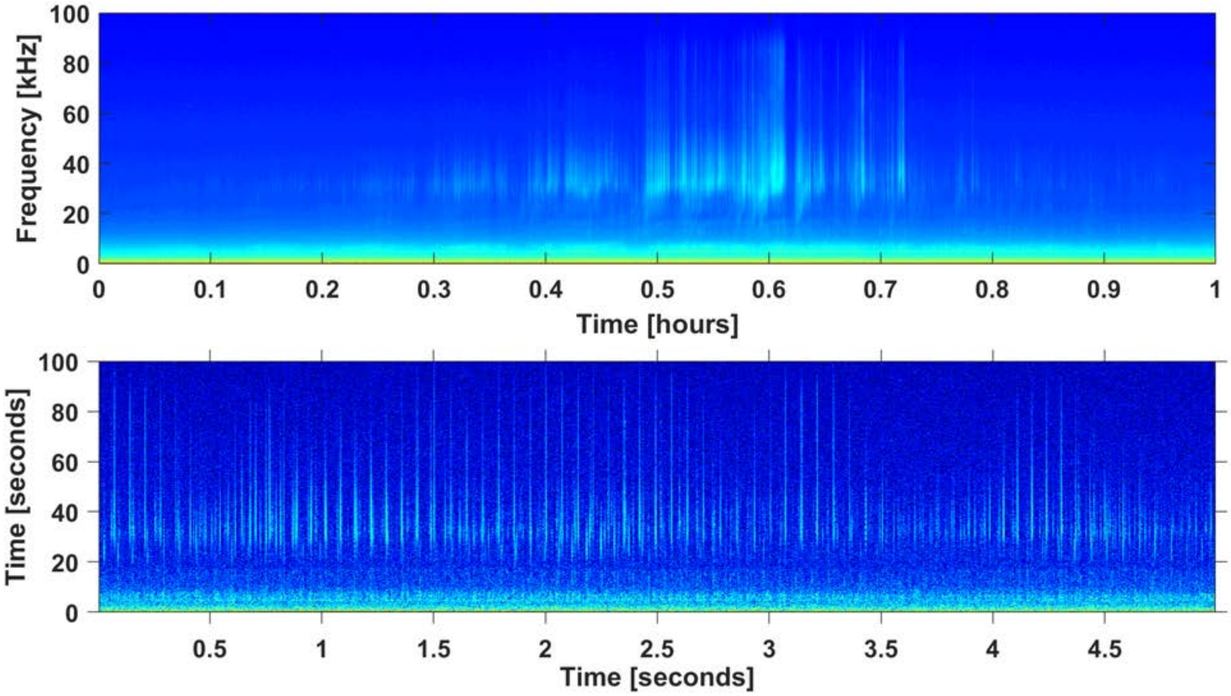

Figure 21: Unidentified dolphin 47 (UD47) echolocation signals in LTSA (top) and spectrogram (bottom).

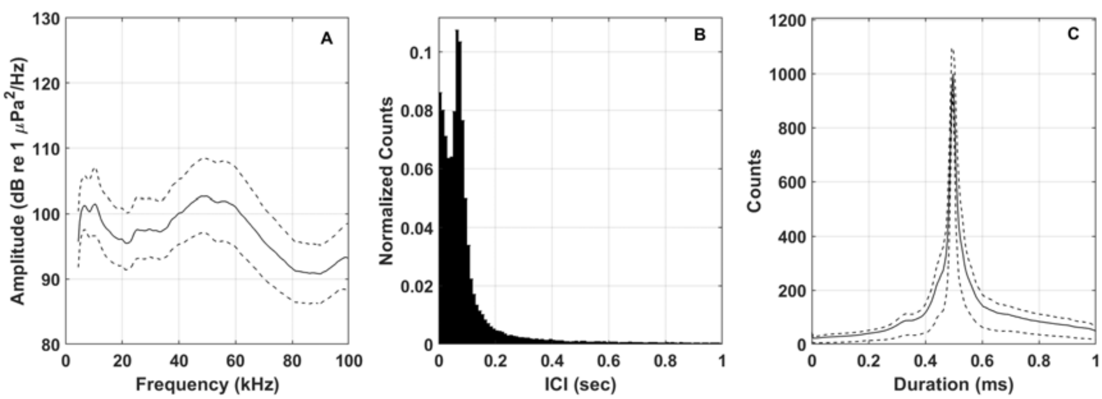

Figure 22: Left: Mean frequency spectrum of unidentified dolphin 47 (UD47) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.1 s; Right: Mean waveform envelope of representative clicks.

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).

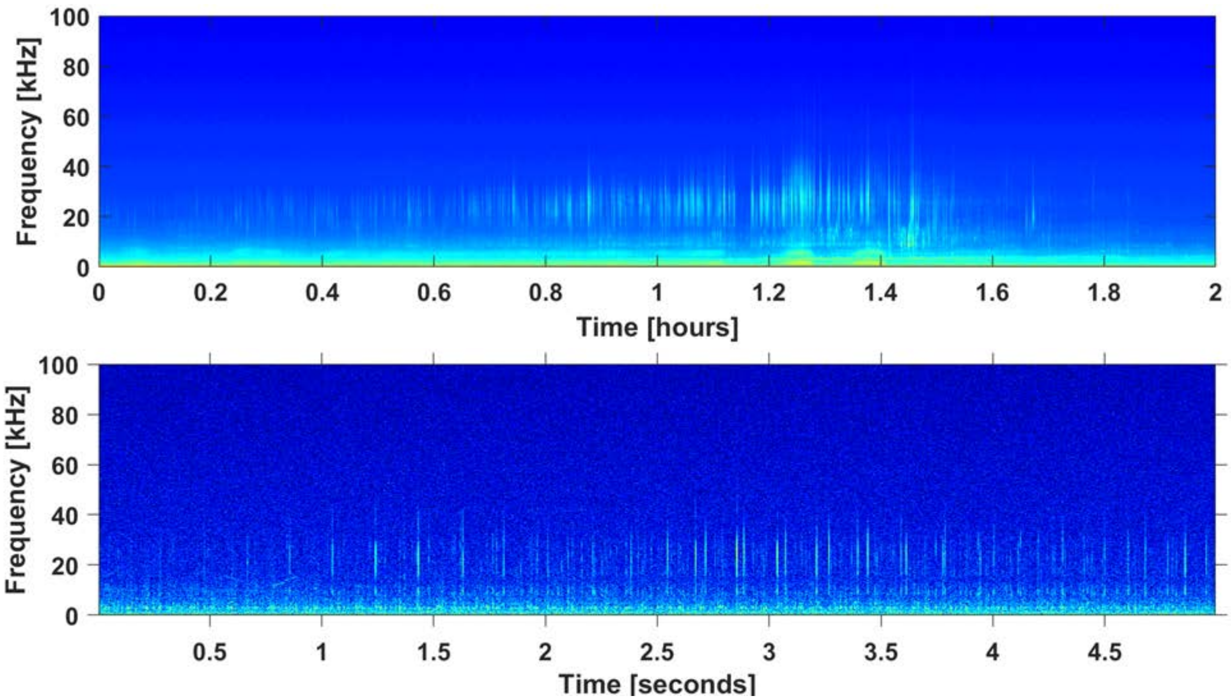

Figure 23: Unidentified dolphin low-frequency (UD LF) echolocation signals in LTSA (top) and spectrogram (bottom).

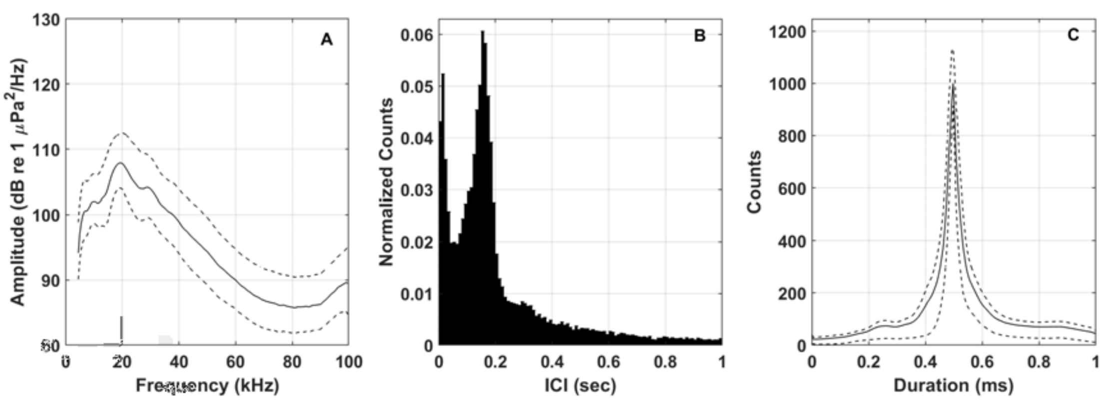

Figure 24: Left: Mean frequency spectrum unidentified dolphin low-frequency (UD LF) echolocation clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Inter-click interval distribution with peak near 0.2 s; Right: Mean waveform envelope of representative clicks.

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).

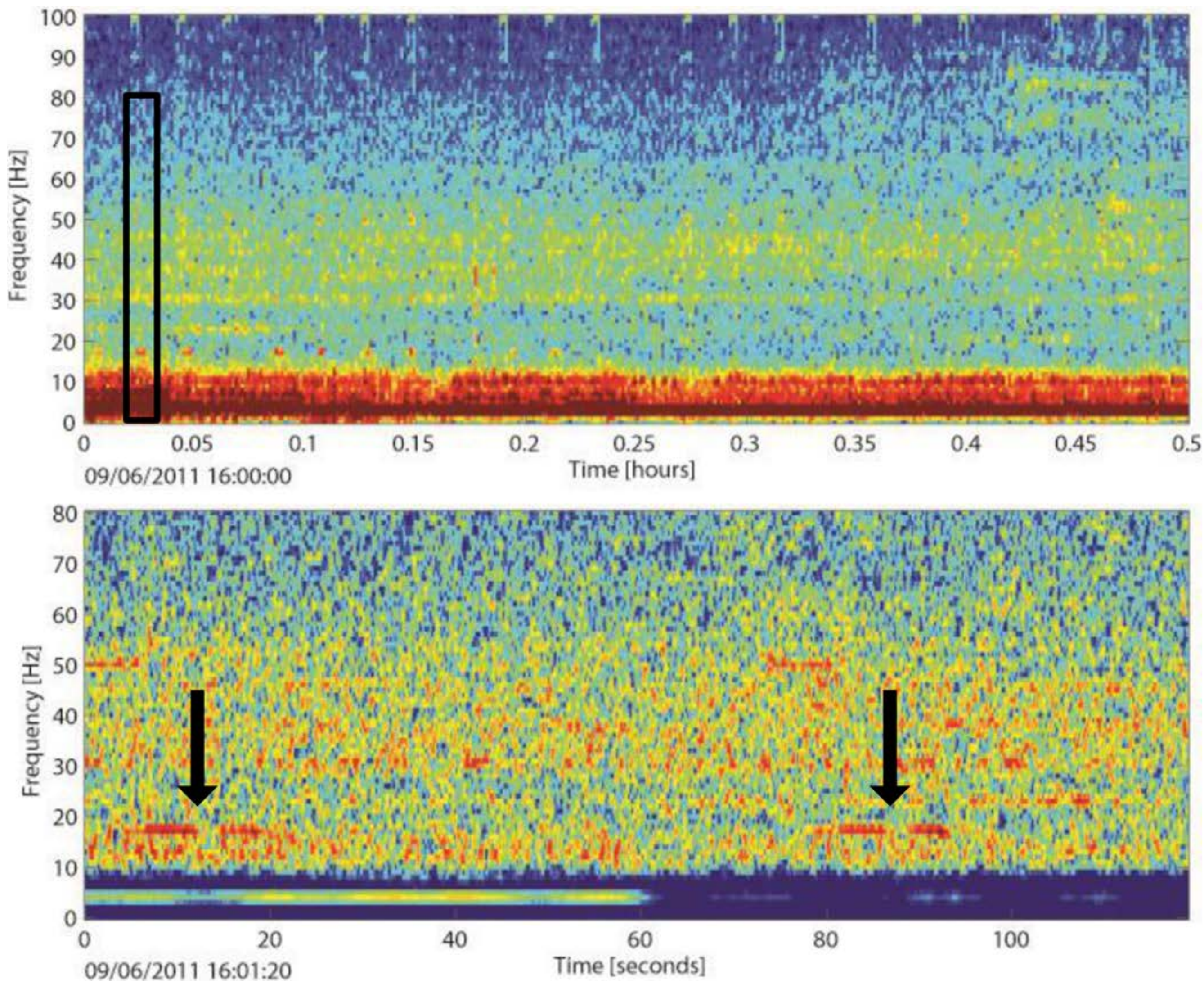

Figure 25: North Atlantic blue whale calls in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by black arrows.

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.

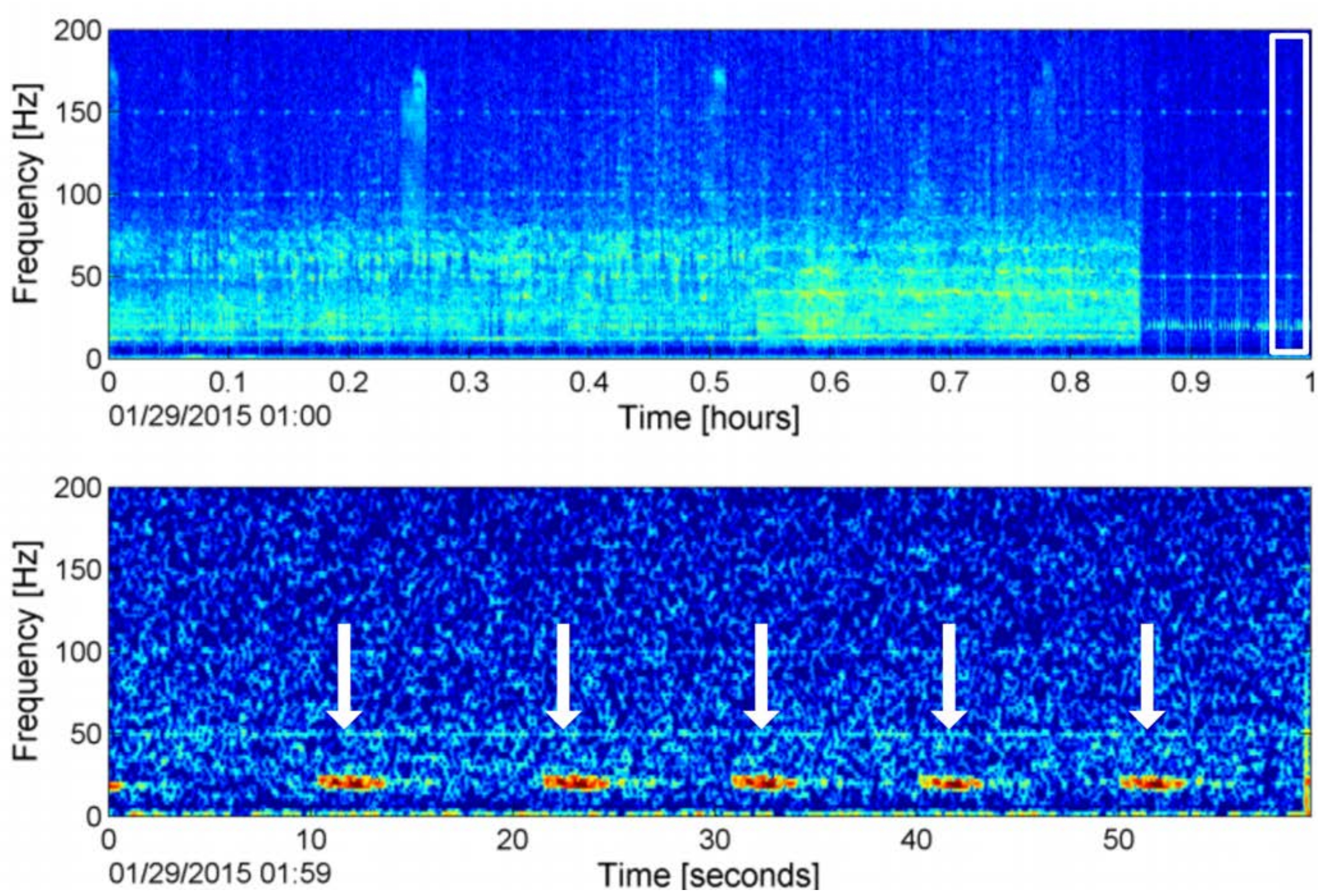

Figure 26: Fin whale 20 Hz calls in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

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).

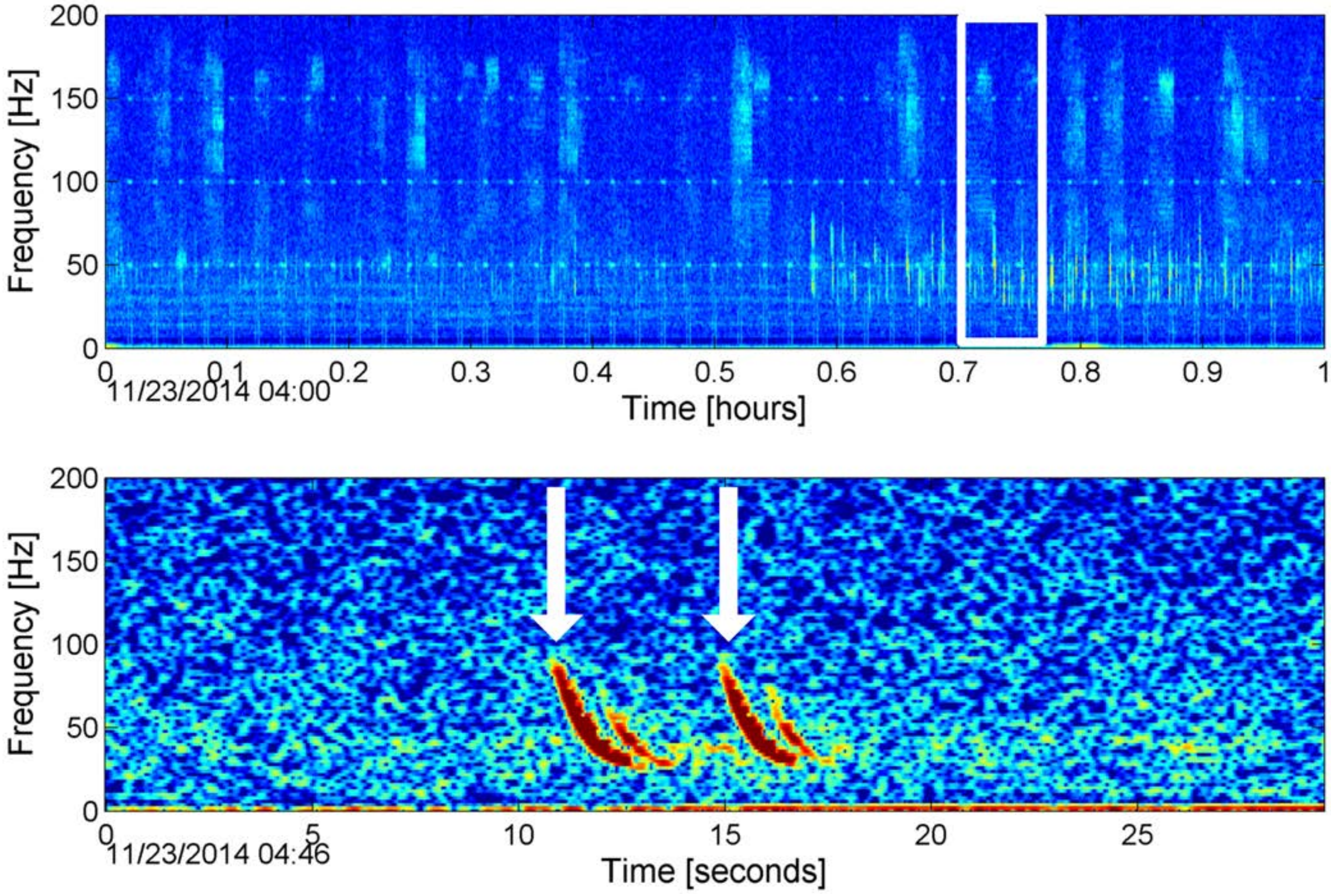

Figure 27: Sei whale downseep call in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

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).

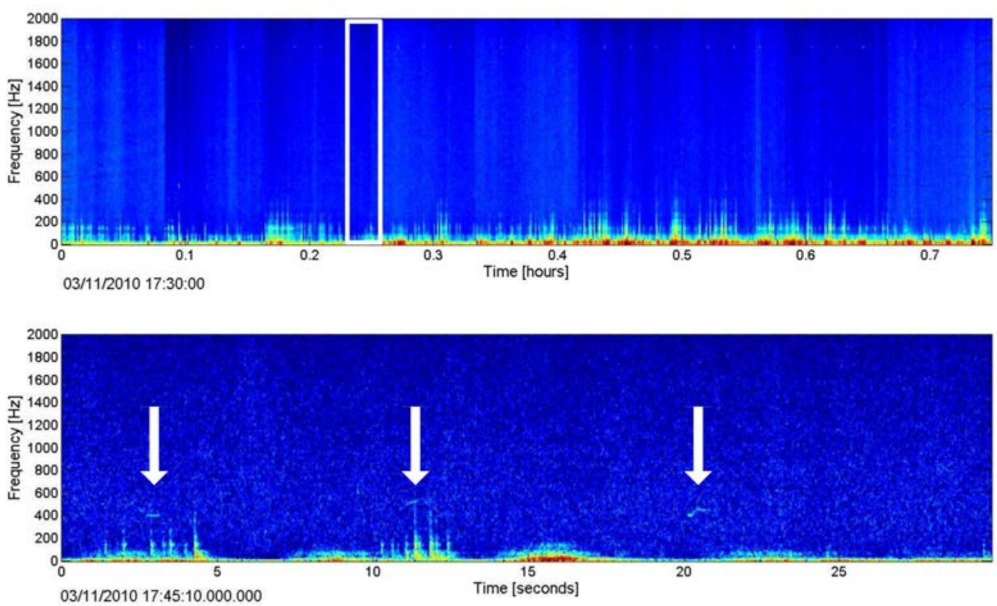

Figure 28: Humpback whale call in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the black arrows.

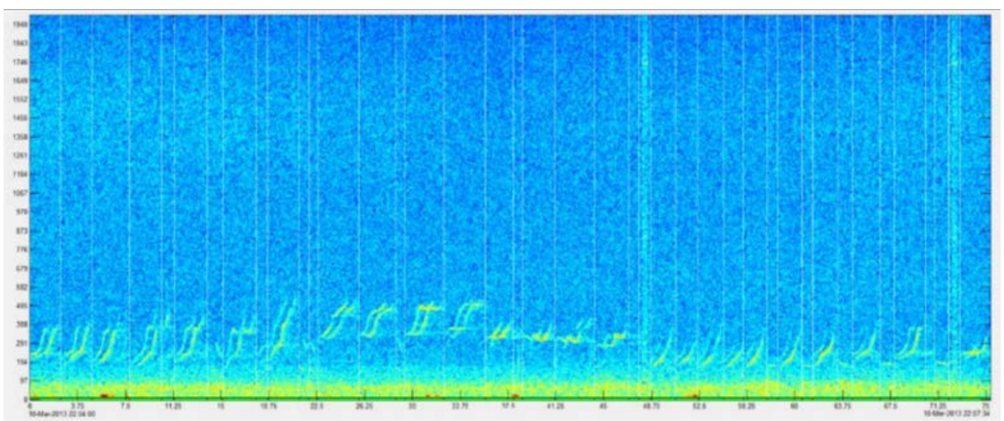

Figure 29: Concatenated humpback whale songs viewed in the software GPL review (Helble et al. 2012).

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).

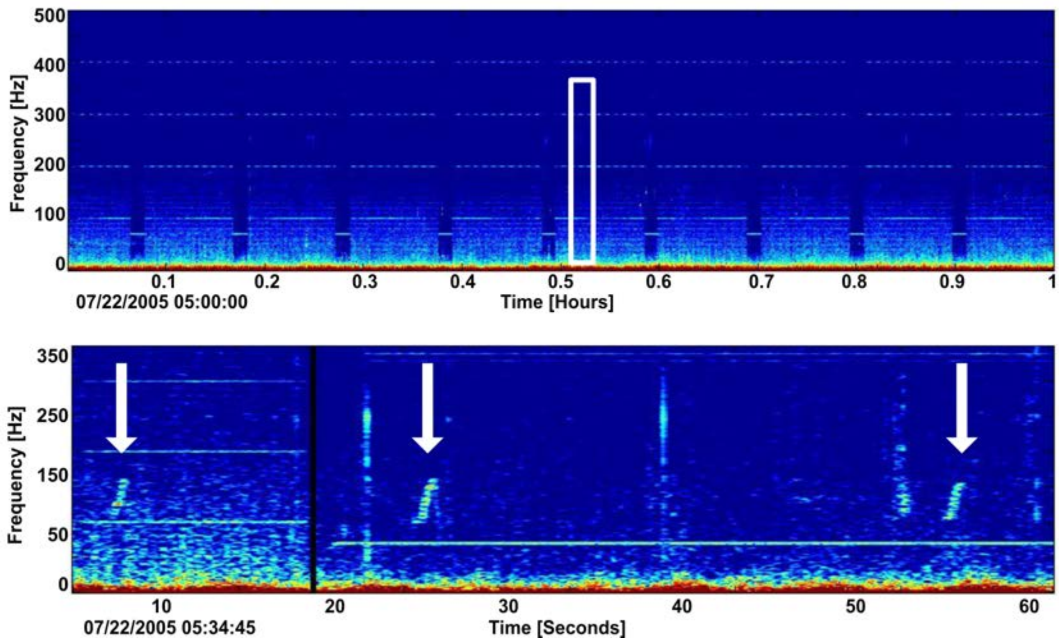

Figure 30: North Atlantic right whale upcall in LTSA (top), with white box indicating the region shown in the corresponding spectrogram (bottom); individual calls noted by the white arrows.

4.3.6 Minke Whales

For sites A, C, D, and deployment 6E, 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 site B and deployments 7E-8E, 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).

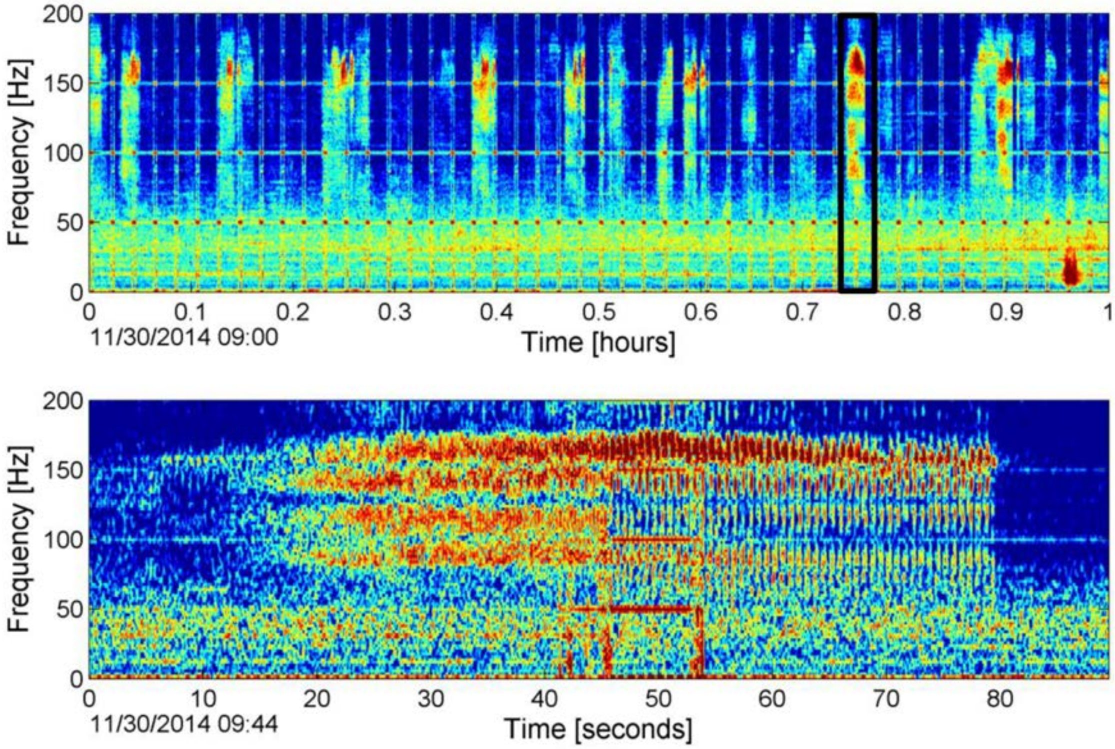

Figure 31: Minke whale pulse train in LTSA (top), with black box indicating the region shown in the corresponding spectrogram (bottom).

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 were acoustically present in the Onslow Bay study area between 2007 and 2013 (Figure 32). The following results describe site-specific temporal patterns at Onslow Bay sites A–E; we do not infer spatial gradients across the western North Atlantic, and references to other studies are provided only for context.

Among the deep divers, sperm whales and Gervais' beaked whales were the most regularly occurring species at the slope site (E), while other beaked whales and Kogia spp. were only intermittently present. Delphinids were widespread across all sites, with smaller-bodied delphinids occurring throughout the depth range but most pronounced at the shallow shelf (A) and slope (E) sites. In contrast, larger-bodied delphinids and Risso's dolphins were present at relatively low levels across the study area but showed higher presence at the slope site, particularly in 2013.

Mysticete detections were intermittent across the Onslow Bay sites, with most species occurring seasonally between fall and early spring. Minke and fin whales were the most regularly detected, with presence spanning multiple seasons and occasional detections during summer months. Blue and sei whales showed more defined peaks in fall and early winter, while humpback whales were detected only briefly in early spring. North Atlantic right whales were detected only once during the monitoring period. These results indicate that baleen whales use Onslow Bay primarily as a migratory corridor rather than a foraging habitat, with temporal variability reflecting both species-specific migration timing and variable monitoring effort among sites.

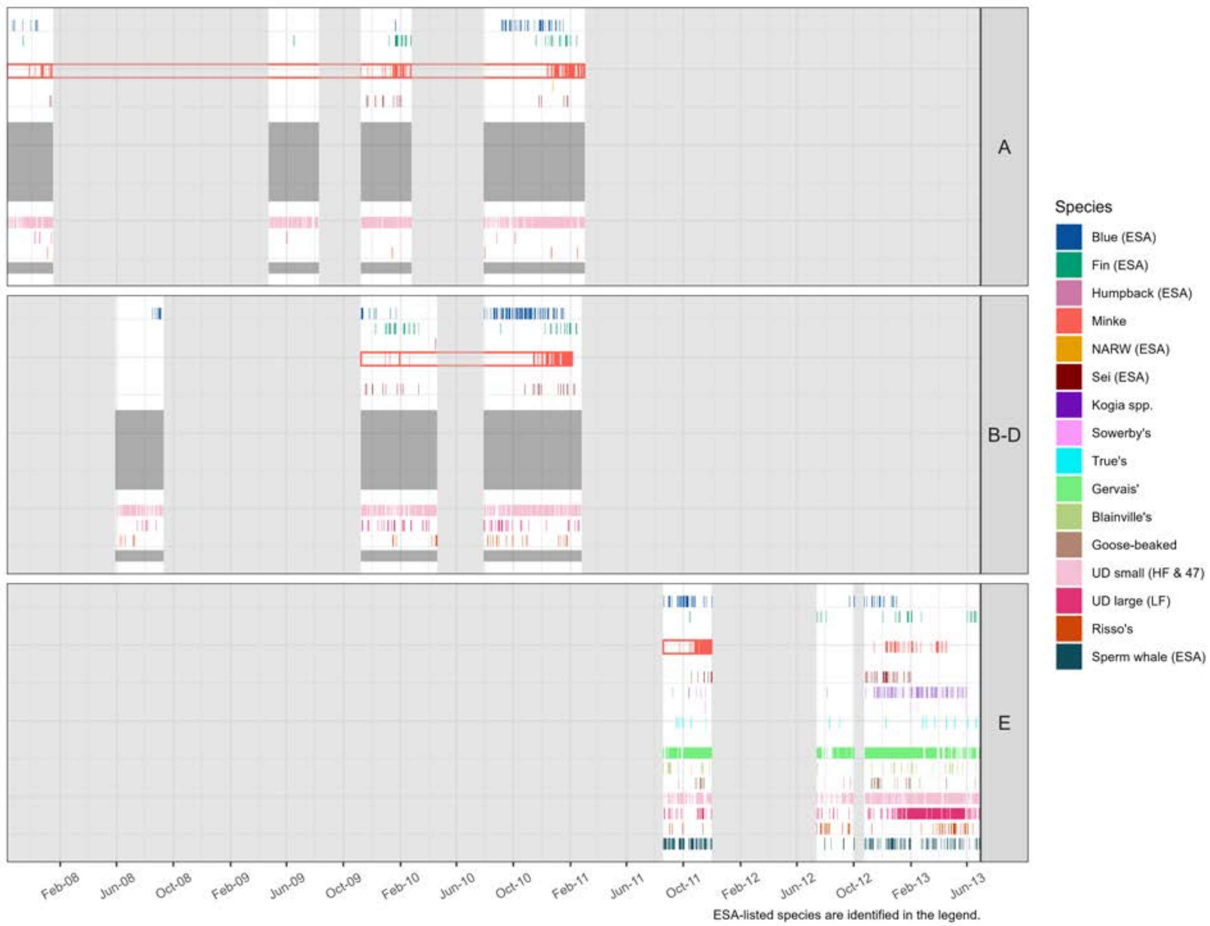

Figure 32: Daily presence of odontocetes and mysticetes at Onslow Bay sites A-E from 2008 to 2013. Colored bars indicate days with confirmed acoustic presence for each species or species group. For Gervais' beaked whales, a 25% daily-occurrence threshold was used to reduce visual saturation from high detection rates. 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 (A) and mid-depth shelf sites (B-D). 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/groups of odontocetes were acoustically present at the Onslow Bay study area between 2007 and 2013, with patterns of occurrence varying by species, season, and depth (Fig 32). Deep-diving species, including beaked whale species, sperm whales, and *Kogia* spp., occurred only at the slope site (E), while Risso's dolphins and unidentified delphinids occurred across all sites. The Beaked Whale Gulf (BWG) signal was included in the neural network classifier, but no encounters were identified during the analysis period.

Sperm whales occurred regularly at site E, particularly during fall and early winter, with presence often exceeding 10 hours per week between 2011 and 2013. Gervais' beaked whales were also consistently present, with highest occurrence in winter and spring. Other beaked whale species (goose-beaked, True's, Blainville's, and Sowerby's) and *Kogia* spp., were only intermittently present and generally at very low levels, with too few detections to describe clear temporal patterns.

Dolphin presence was widespread across all sites, but patterns differed between unidentified smaller-bodied and larger-bodied delphinids. Unidentified smaller-bodied delphinids (UD HF & 47) were more common at the shallow shelf site (A), where occurrence increased during fall and winter and diel patterns were predominantly crepuscular. The small-bodied delphinids also occurred at the mid-depth shelf sites (B-D), but with slightly lower overall presence. Presence occurred to increase at the slope site (E) during the last year of recording (2013). In contrast, unidentified larger-bodied delphinids (UD LF), had low presence across the shallow (A) and mid-depth (B-D) shelf sites but did show a peak in presence at site E in 2013. Risso's dolphins were also present across the time series at relatively lower levels, with brief increases in spring and summer, most notably at site E.

Together, these results emphasize the depth-stratified nature of odontocete presence in Onslow Bay. While Gervais' beaked whales and sperm whales were the most regularly occurring deep divers at the slope, delphinids were consistently present across the shelf-to-slope gradient, with distinctions between presumed small-bodied and large-bodied types. Seasonal and diel variability further underscore the influence of bathymetry and Gulf Stream dynamics in shaping odontocete use of this region.

5.1.1 Goose-Beaked Whale

Goose-beaked whales occurred intermittently at site E from 2011 to 2013 and were not detected at sites A-D. Weekly presence was low, typically under 2 hours per week, though occasional weeks in late 2011 and late 2012 exceeded this level (Figure 33). Presence was higher in fall and winter months (Figure 34). However, seasonal patterns are difficult to assess given that most months were represented by only a single year of data, with the exception of August–November. No consistent diel pattern was evident in goose-beaked whale acoustic presence, suggesting relatively uniform acoustic activity throughout the day (Figure 35).

These results are consistent with previous studies that found goose-beaked whales occur year-round at high levels from Cape Hatteras northward, with increased prevalence in winter and spring, and limited presence south of Hatteras (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 whale

- Goose-beaked whale acoustic presence occurred at low levels, with occasional peaks > 1–2 hours.
- Fall showed the highest presence, but seasonal patterns are difficult to interpret given limited years of data.
- No clear diel pattern was observed.

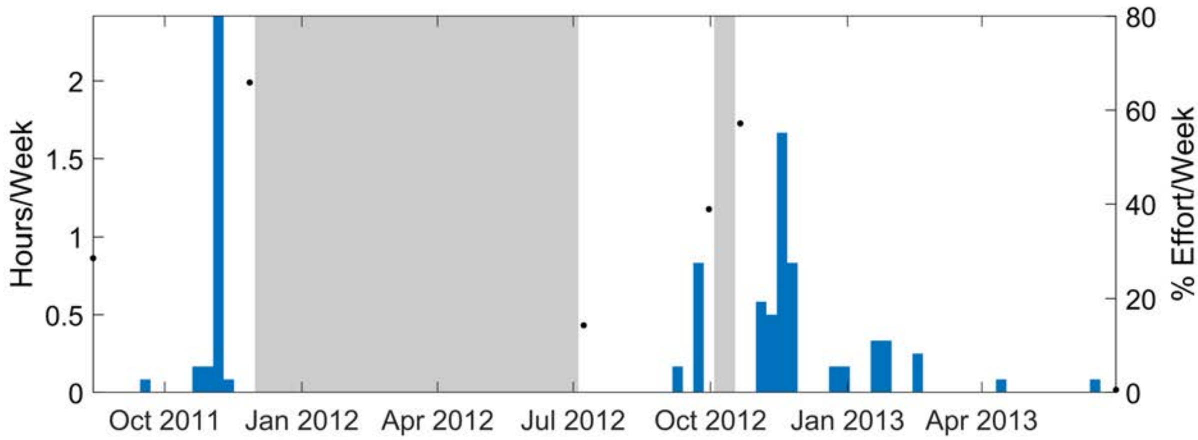

Figure 33: Cumulative hours/week of goose-beaked whale presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

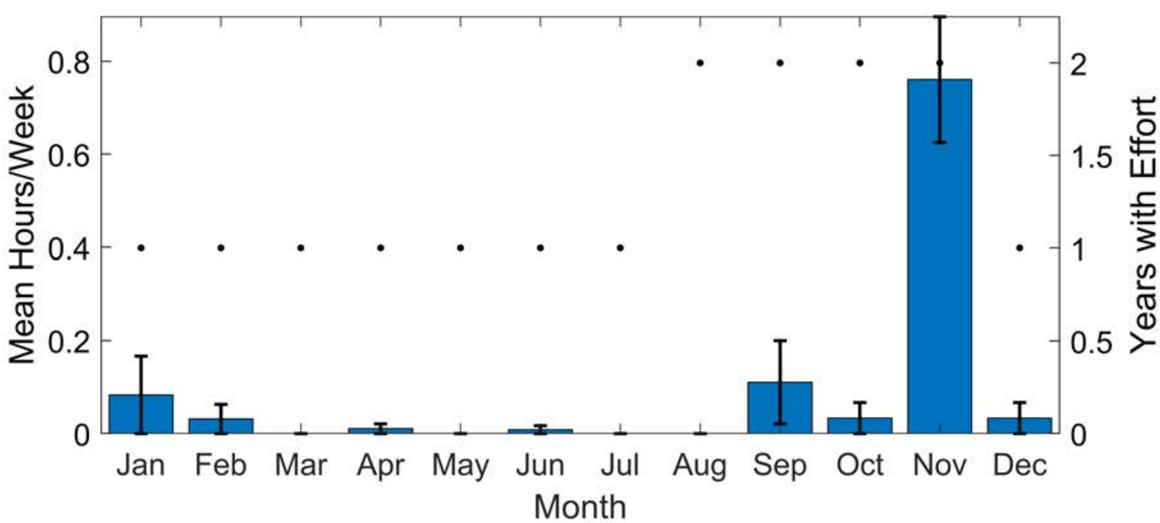

Figure 34: Monthly mean hours per week of goose-beaked whale acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

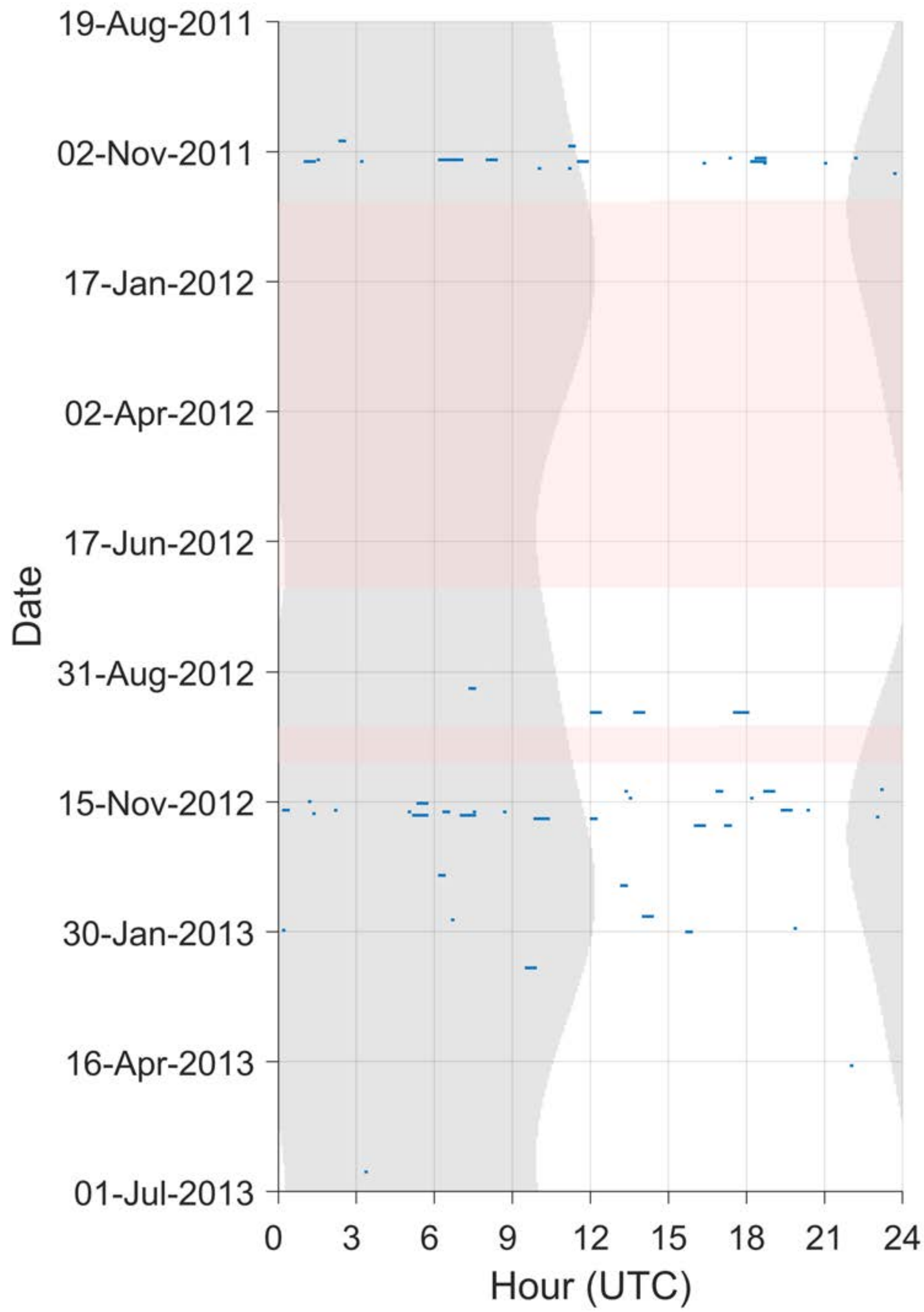

Figure 35: Goose-beaked whale acoustic presence in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.2 Gervais' and True's Beaked Whales

Gervais' and True's beaked whales both occurred at site E from 2011 to 2013 and was not detected at sites A-D. Gervais' beaked whales exhibited higher levels of acoustic presence compared to True's and other beaked whale species. Gervais' beaked whales often exceeded 10 hours of presence per week, with extended periods of higher presence reaching 30 hours/week (Figure 36).

True's beaked whale were considered rare at this site and the few detections could have been misclassified Gervais' clicks given how acoustically similar they are. Presence was observed year-round with lowest levels in late spring and early summer (May-June) and higher occurrence in fall and winter months. However, seasonal patterns are difficult to assess given that most months were represented by only a single year of data, with the exception of August–November (Figure 37).

No consistent diel pattern was evident, with activity broadly distributed across day and night hours (Figure 38).

These results are consistent with previous studies that found Gervais' beaked whales are much more common than True's at Cape Hatteras and southward, with Gervais' detections peaking from late summer through winter, while True's occur less frequently and primarily present from winter through summer (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

- Gervais' beaked whales occurred frequently at site E, with weekly presence often >10 hrs.
- Presence was lowest in late spring/early summer and highest in fall and winter, though seasonal patterns are difficult to interpret given limited years of data.
- No clear diel pattern was observed.

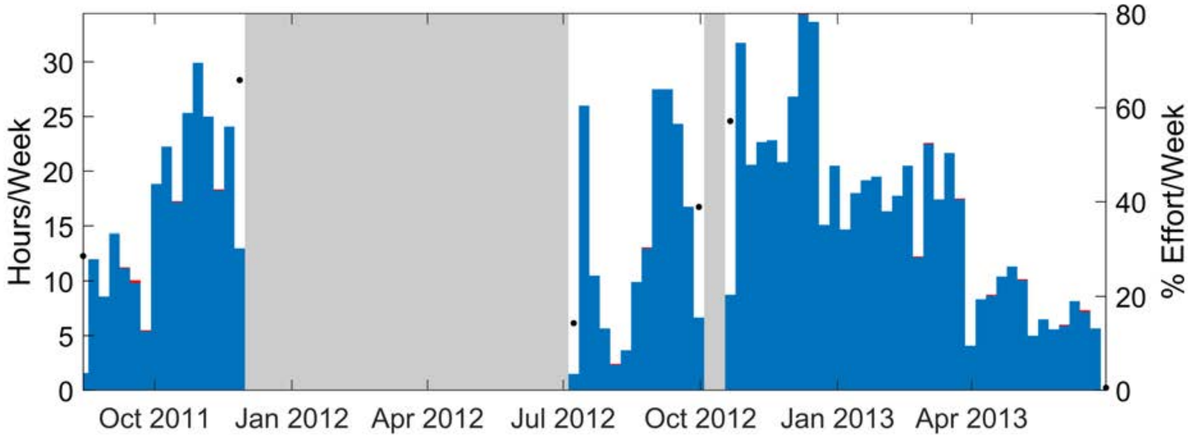

Figure 36: Cumulative hours/week of Gervais' (blue) and True's (red) beaked whale presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

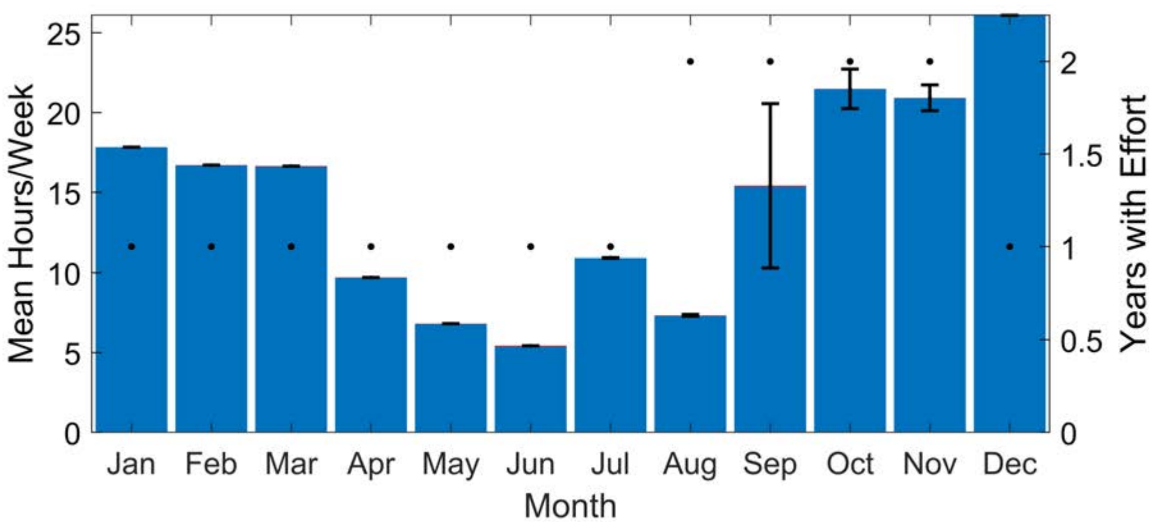

Figure 37: Monthly mean hours per week of Gervais' (blue) and True's (red) beaked whale acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black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

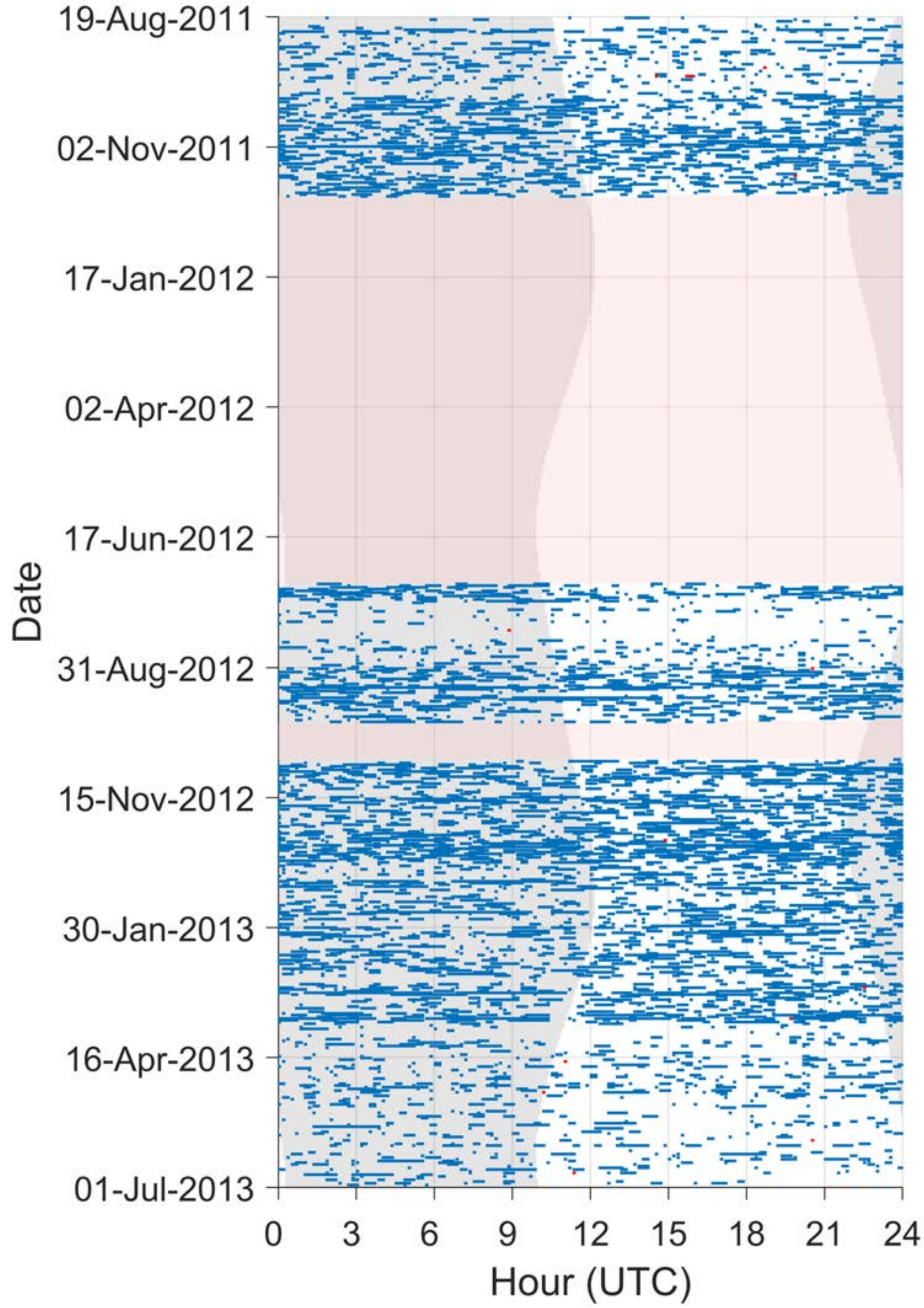

Figure 38: Gervais' (blue) and True's (red) beaked whale acoustic presence at site E in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.3 Blainville's Beaked Whale

Blainville's beaked whales were infrequent at site E from 2011 to 2013 and were not detected at sites A-D. Acoustic presence was generally under 2 hours per week (Figure 39). Presence was observed in every month but without a consistent trend, aside from a slight increase in August (Figure 40). Interpretation of seasonal patterns is limited, as most months were represented by only a single year of data, with the exception of August–November. No consistent diel pattern was evident, with the limited encounters distributed across day and night hours (Figure 41).

These results are consistent with previous studies that found Blainville's beaked whales are infrequently detected in the region and not associated with a major foraging hotspot (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 whale

- Blainville's beaked whales occurred less frequently at site E, generally <2 hrs/week.
- Presence was scattered across months, with a slight increase in August, though seasonal patterns are difficult to interpret with limited years of data.
- No clear diel pattern was observed.

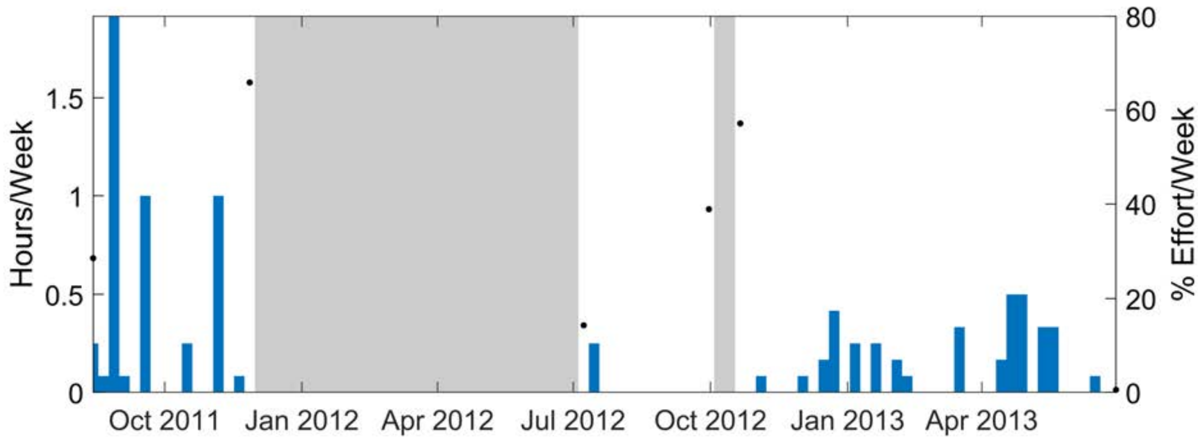

Figure 39: Cumulative hours/week of Blainville's beaked whale presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

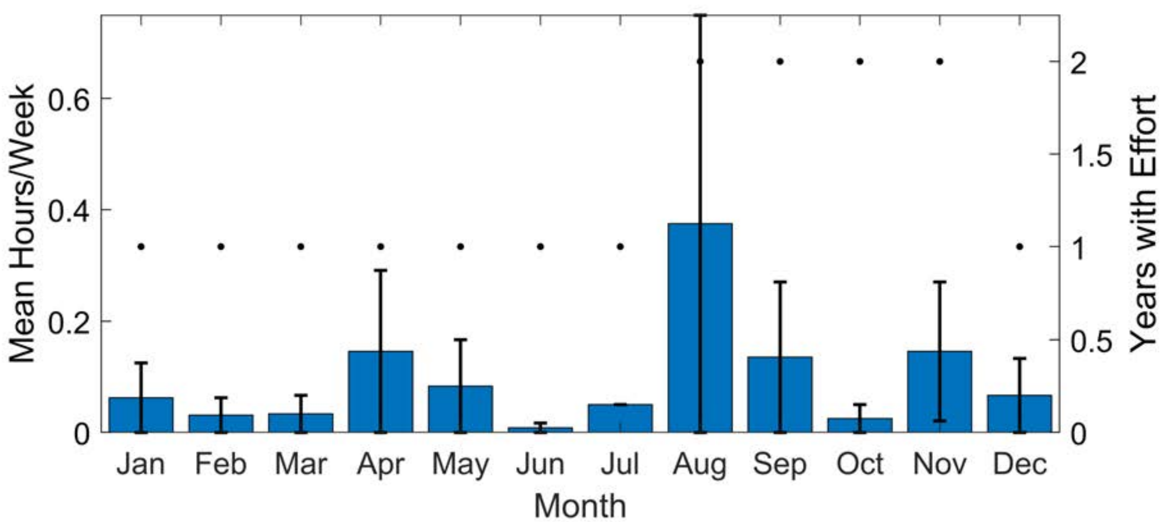

Figure 40: Monthly mean hours per week of Blainville's beaked whale acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

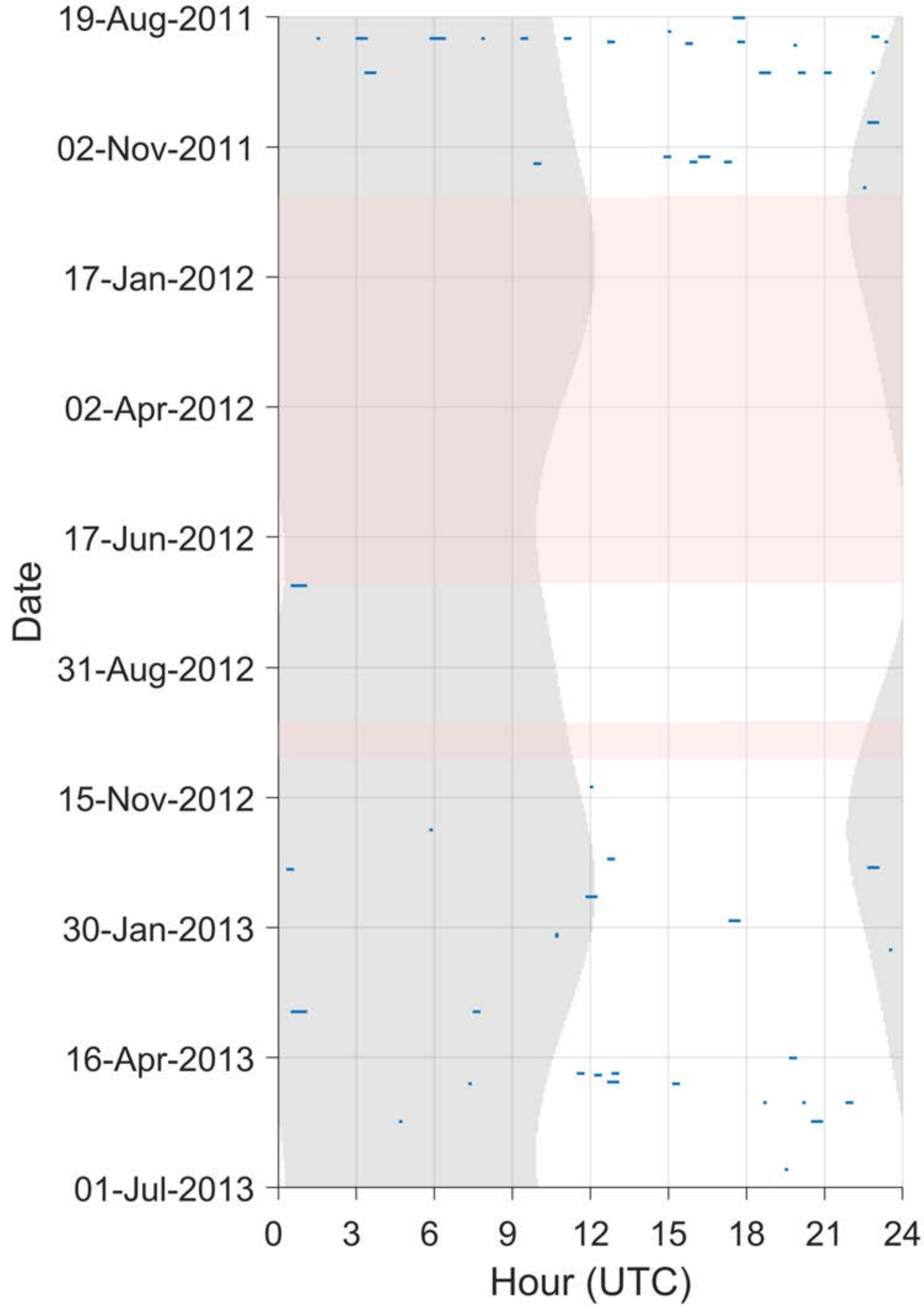

Figure 41: Blainville's beaked whale acoustic presence at site E in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.4 Sowerby's Beaked Whale

Sowerby's beaked whales were very rare at site E from 2011 to 2013 and was not detected at sites A-D. Acoustic presence was generally limited to brief, isolated events of less than five minutes per week (Figure 42). Individual detections occurred in January, February, May, and November (Figure 43). Interpretation of seasonal patterns is limited by the low number of encounters and the fact that most months were represented by only a single year of data, with the exception of August–November. No diel pattern was observed due to the limited number of encounters (Figure 44).

These results are consistent with previous studies that found Sowerby's beaked whales are uncommon at Cape Hatteras and southward, with their main foraging hotspots occurring farther north, particularly north of Norfolk Canyon (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

- Occurred very rarely at site E, with only a few encounters.
- Presence was scattered across the year with no clear seasonal pattern, though occasional detections occurred in winter, spring, and fall.
- No consistent diel pattern was observed due to the low number of encounters.

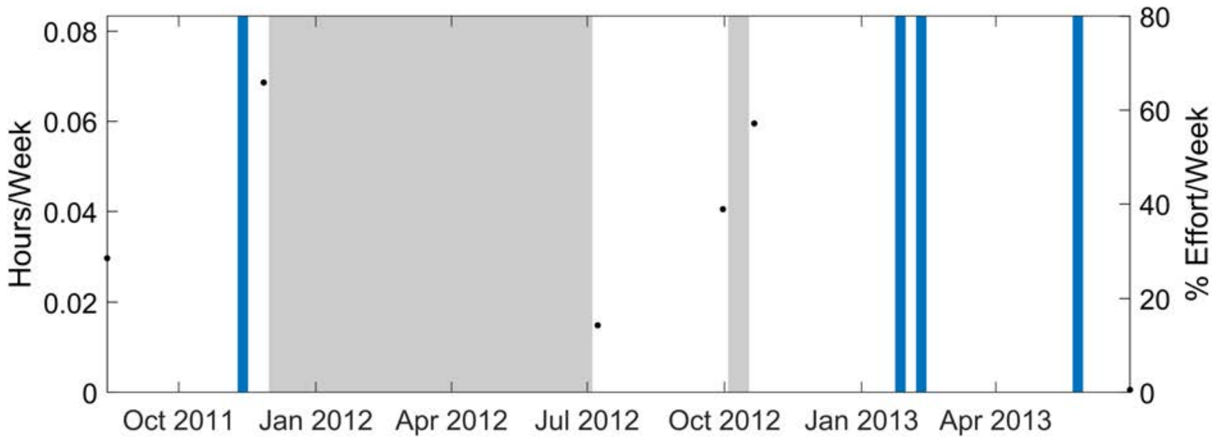

Figure 42: Cumulative hours/week of Sowerby's beaked whale presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

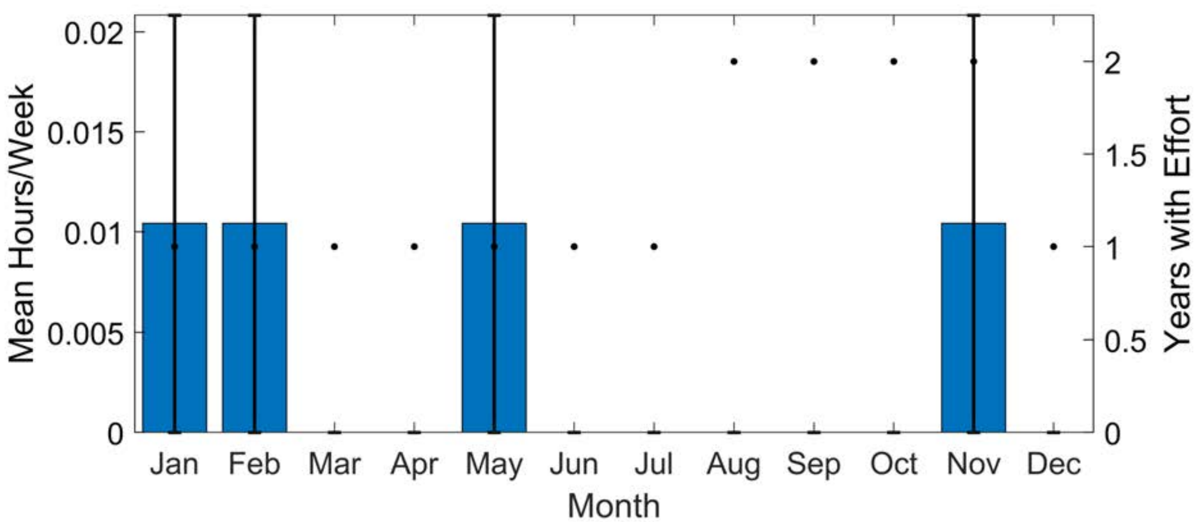

Figure 43: Monthly mean hours per week of Sowerby's beaked whale acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

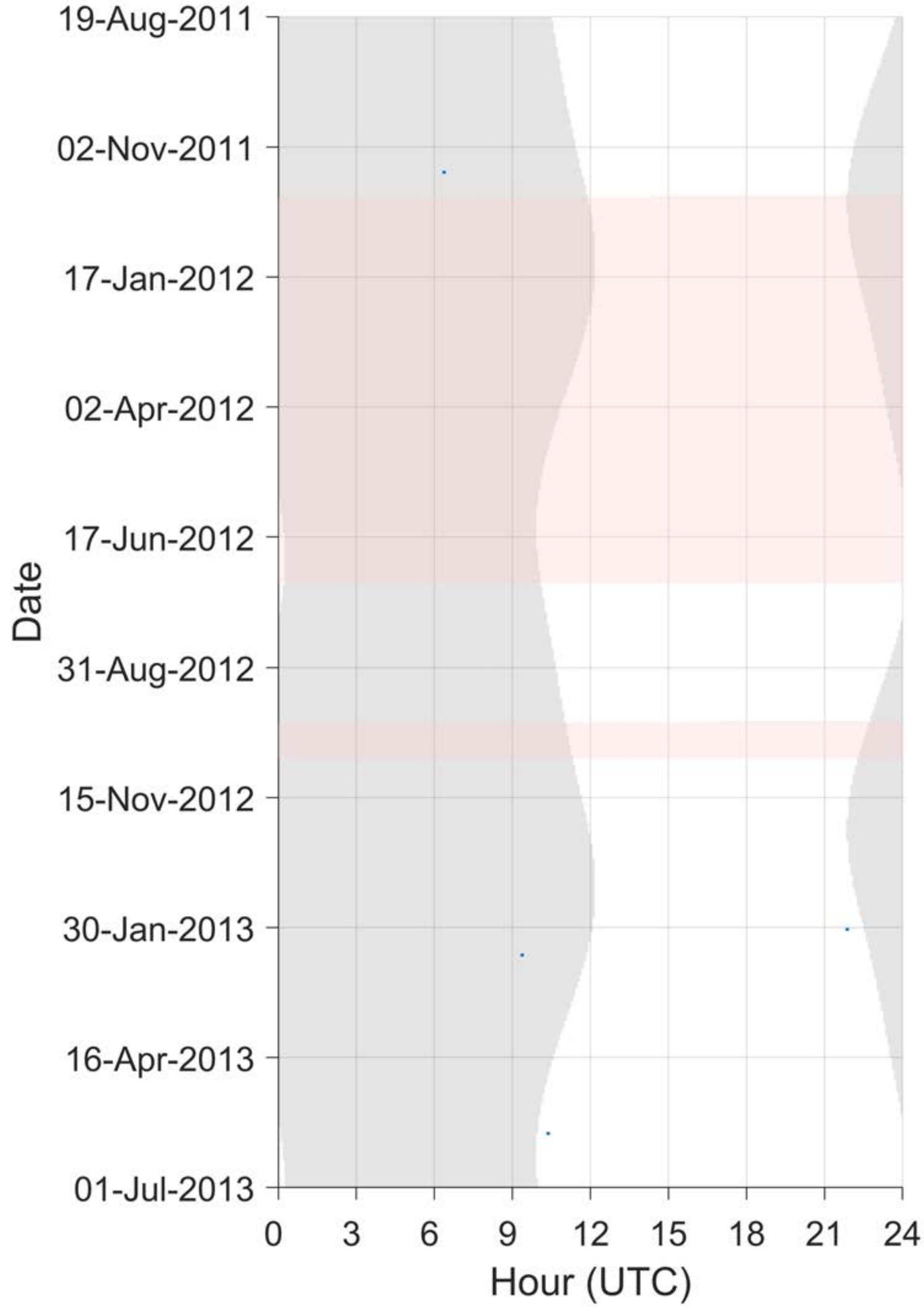

Figure 44: Sowerby's beaked whale acoustic presence at site E in 5-min bins. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.5 Sperm Whale

Sperm whales consistently occurred at site E from 2011 to 2013 and were not detected at sites A-D. Sperm whales had higher levels of acoustic presence compared to beaked whales (Figure 45). Weekly presence often exceeded 10 hours/week, though extended periods of lower presence also occurred. Acoustic presence was observed throughout the year, with the lowest levels in February and July and higher occurrence in fall and winter months, especially August–November and January (Figure 46). August showed the highest monthly mean, though variability was high. Seasonal patterns should be interpreted cautiously, as most months were represented by only a single year of data, with the exception of August–November. No consistent diel pattern was evident, with detections occurring across both day and night hours (Figure 47).

These results are consistent with previous studies documenting frequent sperm whale occurrence along the western North Atlantic slope, with higher prevalence from Cape Hatteras northward and seasonal use extending south into Onslow Bay (Stanistreet et al. 2018).

Summary of Results – Sperm whale

- Sperm whale acoustic presence was consistent throughout the study period, with weekly presence often exceeding 10 hours/week.
- Presence occurred year-round, lowest in February and July, and highest in fall and winter months.
- No clear diel pattern was observed.

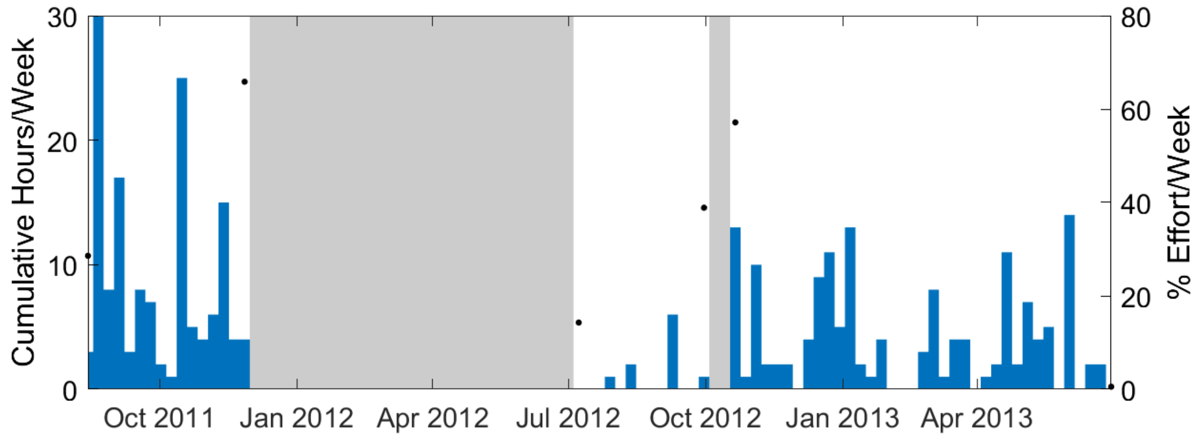

Figure 45: Cumulative hours/week of sperm whale presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

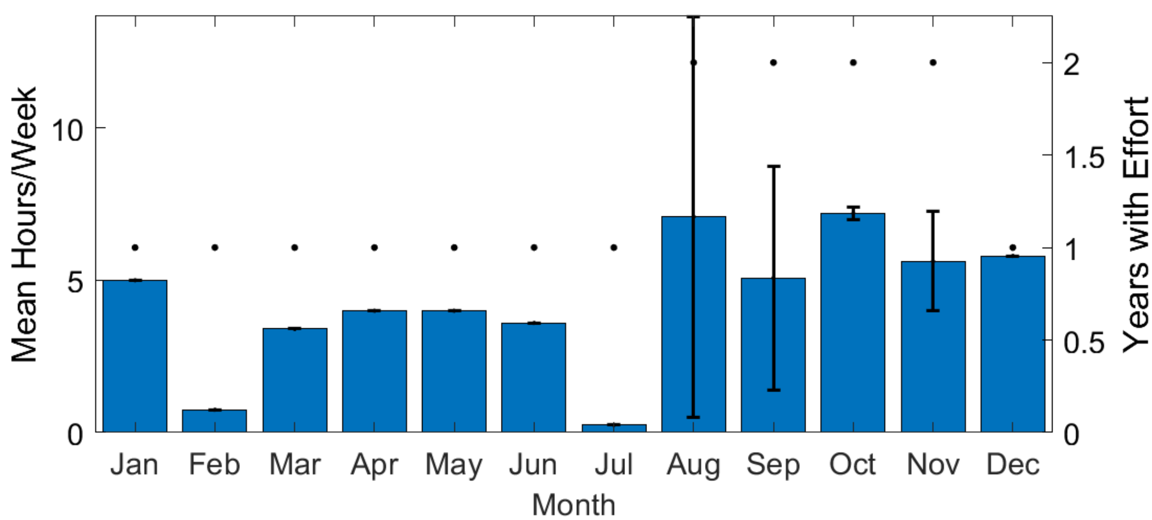

Figure 46: Monthly mean hours per week of sperm whale acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

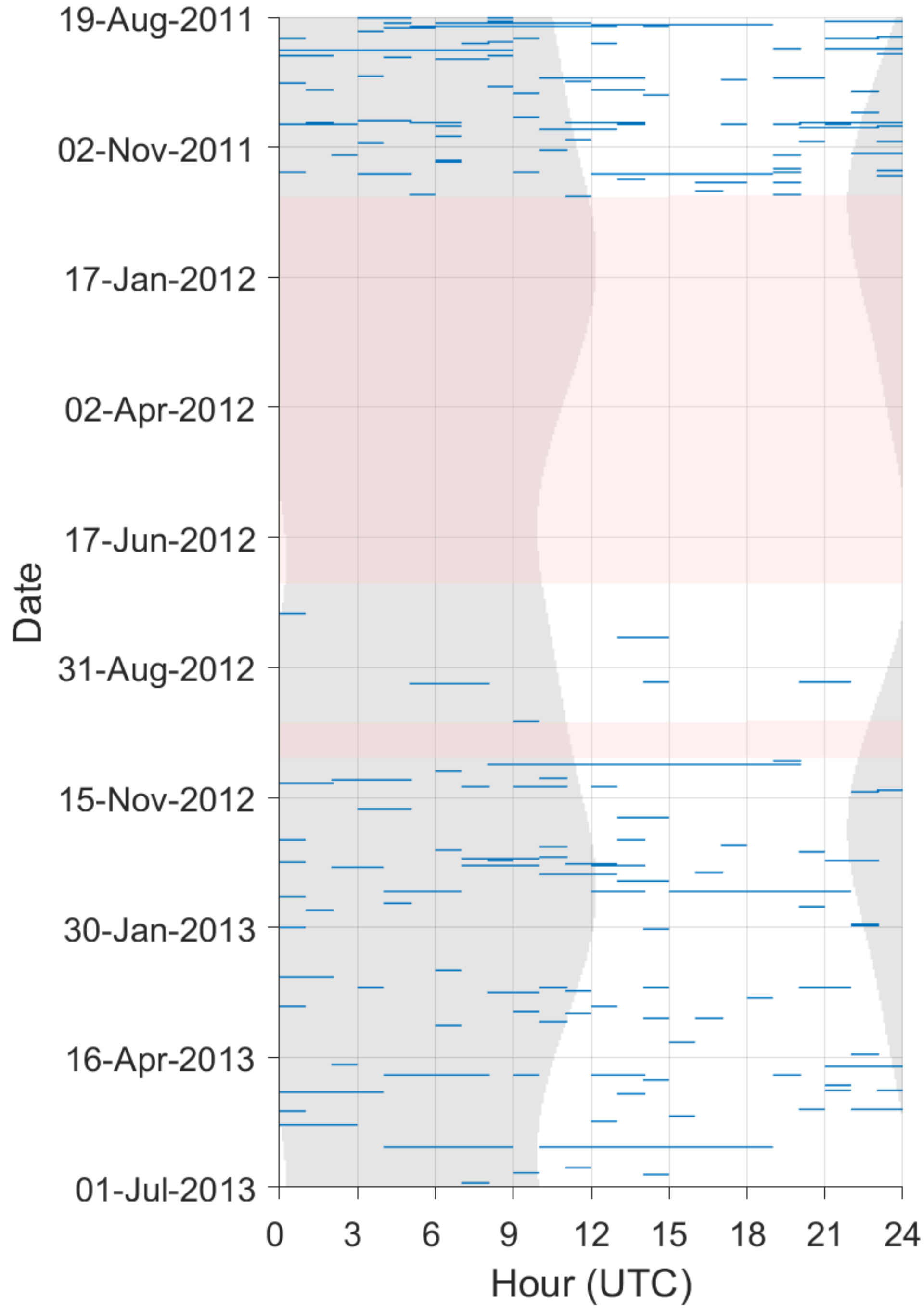

Figure 47: Sperm whale acoustic presence in 5-min bins at site E. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.6 *Kogia* spp.

Kogia spp. occurred intermittently at site E from 2011 to 2013 and was not detected at sites A-D. Acoustic presence was generally below 1 hour/week. Presence was sparse early in the monitoring period but more frequent in late 2012 through mid-2013 (Figure 48). Acoustic presence occurred in most months at low levels, with slightly higher occurrence in winter and spring (February–April) and again in late fall (November–December; Figure 49). Summer months showed little to no presence. However, seasonal patterns are difficult to assess given that most months were represented by only a single year of data, with the exception of August–November. No consistent diel pattern was observed, with detections distributed across both day and night hours (Figure 50).

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 Onslow Bay is closer to 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. had intermittent presence at site E, less than 1 hour/week.
- Presence increased notably from 2011 to 2013.
- More frequent detections occurred from late 2012 through mid-2013.
- Slight increases in winter–spring and late fall, though seasonal interpretation is limited by sparse data.
- No clear diel pattern was evident.

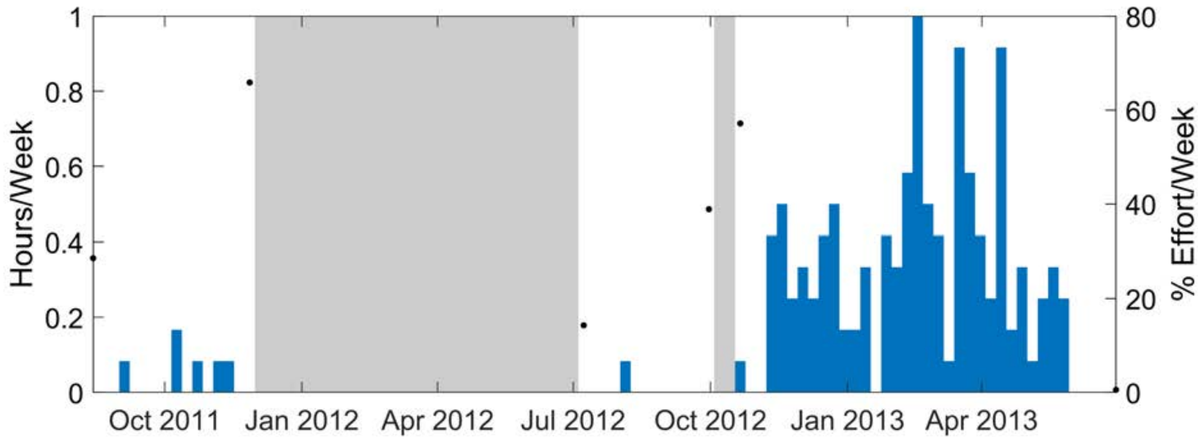

Figure 48: Cumulative hours/week of *Kogia* spp. presence at site E. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

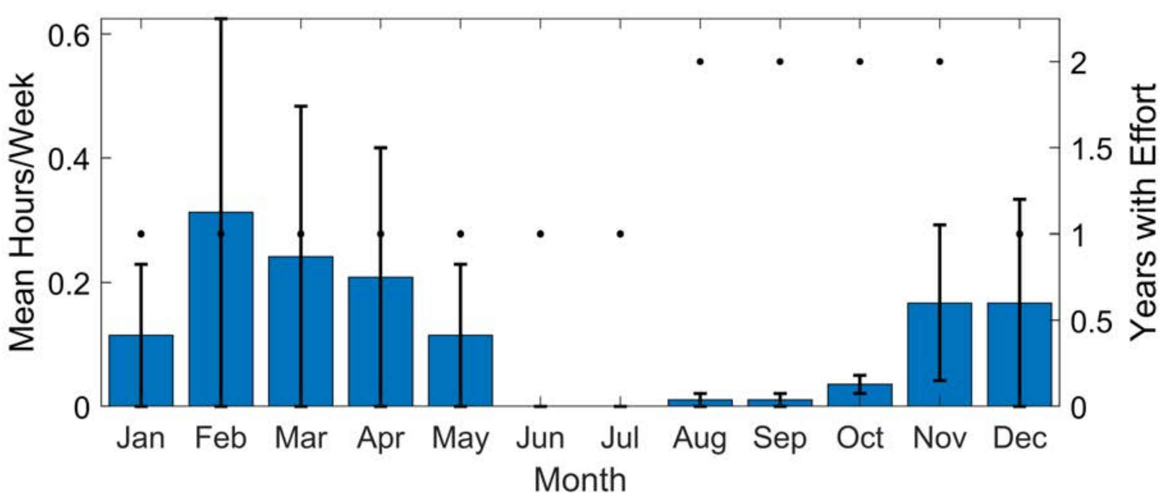

Figure 49: Monthly mean hours per week of *Kogia* spp. acoustic presence at site E. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

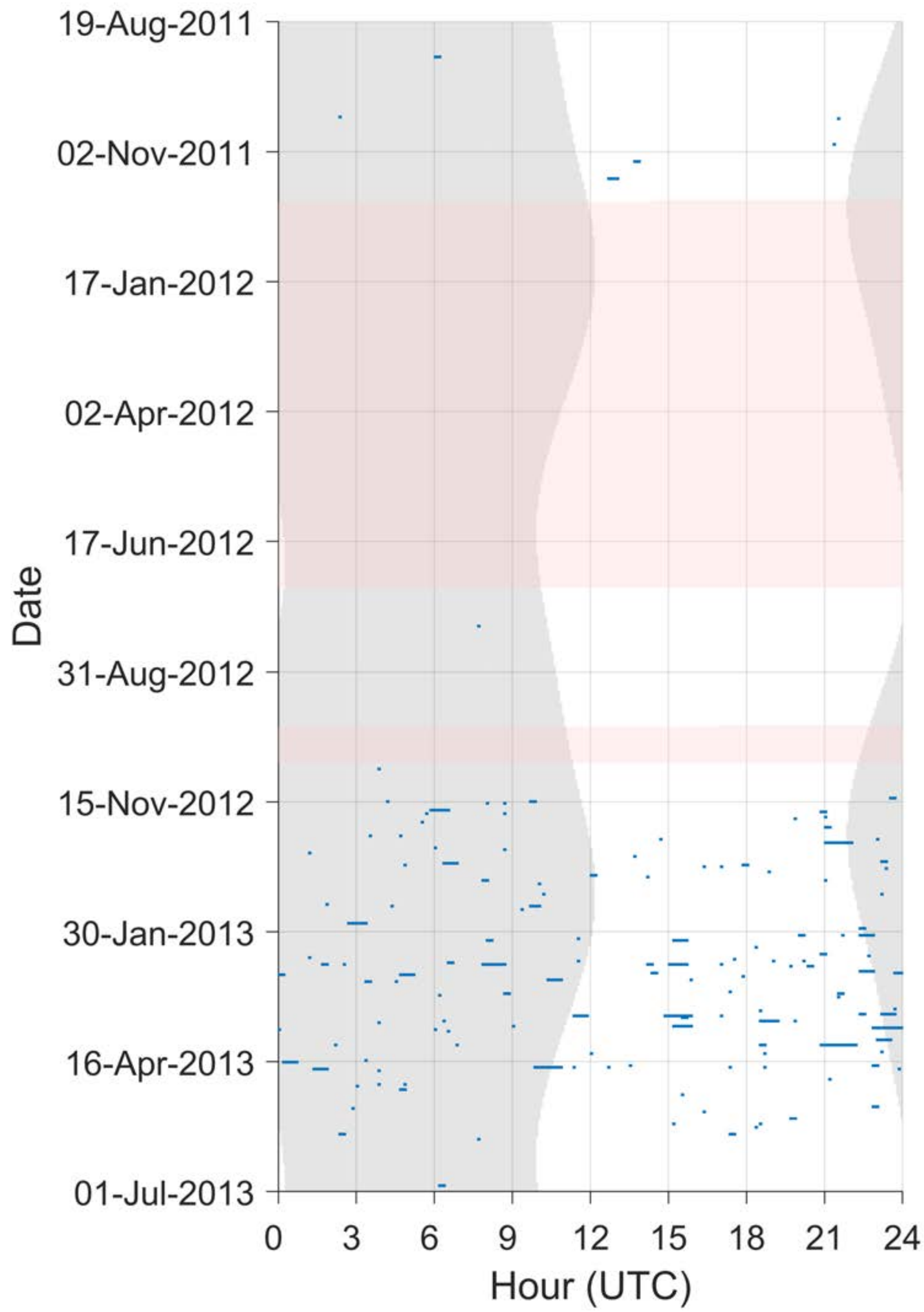

Figure 50: *Kogia* spp. acoustic presence in 5-min bins at site E. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.1.7 Risso's Dolphin

Risso's dolphins were recorded at all Onslow Bay sites between 2008 and 2013, though acoustic presence was generally low across the region (Figure 51). Presence was minimal at the shallow shelf site (A), remained low at the mid-depth shelf sites (B–D), and was somewhat higher at the slope site (E). Weekly presence typically remained under 1 hour, with only brief periods of elevated activity at site E in 2012 and 2013.

At site E, modest increases in presence occurred during April–May and again in July (Figure 52). Seasonal interpretation is limited, however, due to low overall presence and the fact that most sites were not represented by a full year of data. Similar constraints also limit diel interpretation. At site E, detections occurred throughout day and night hours, with no indication of a consistent daily pattern (Figure 53).

These results are broadly consistent with previous studies that found Risso's dolphins are usually found in areas north of Cape Hatteras or in deep slope waters, suggesting that the shallow and mid-depth shelf sites are generally outside of their preferred habitat (Baumgartner & Mussoline 2011; Haver et al. 2025; Cohen et al. 2023).

Summary of Results – Risso's Dolphin

- Occurred at all Onslow Bay sites from 2008 to 2013, but generally at low levels.
- Presence was greatest at site E, with brief increases in April–May and July.
- Presence at sites A–D was minimal, limiting seasonal interpretation.
- No consistent diel trend was observed; detections at site E occurred across all hours.

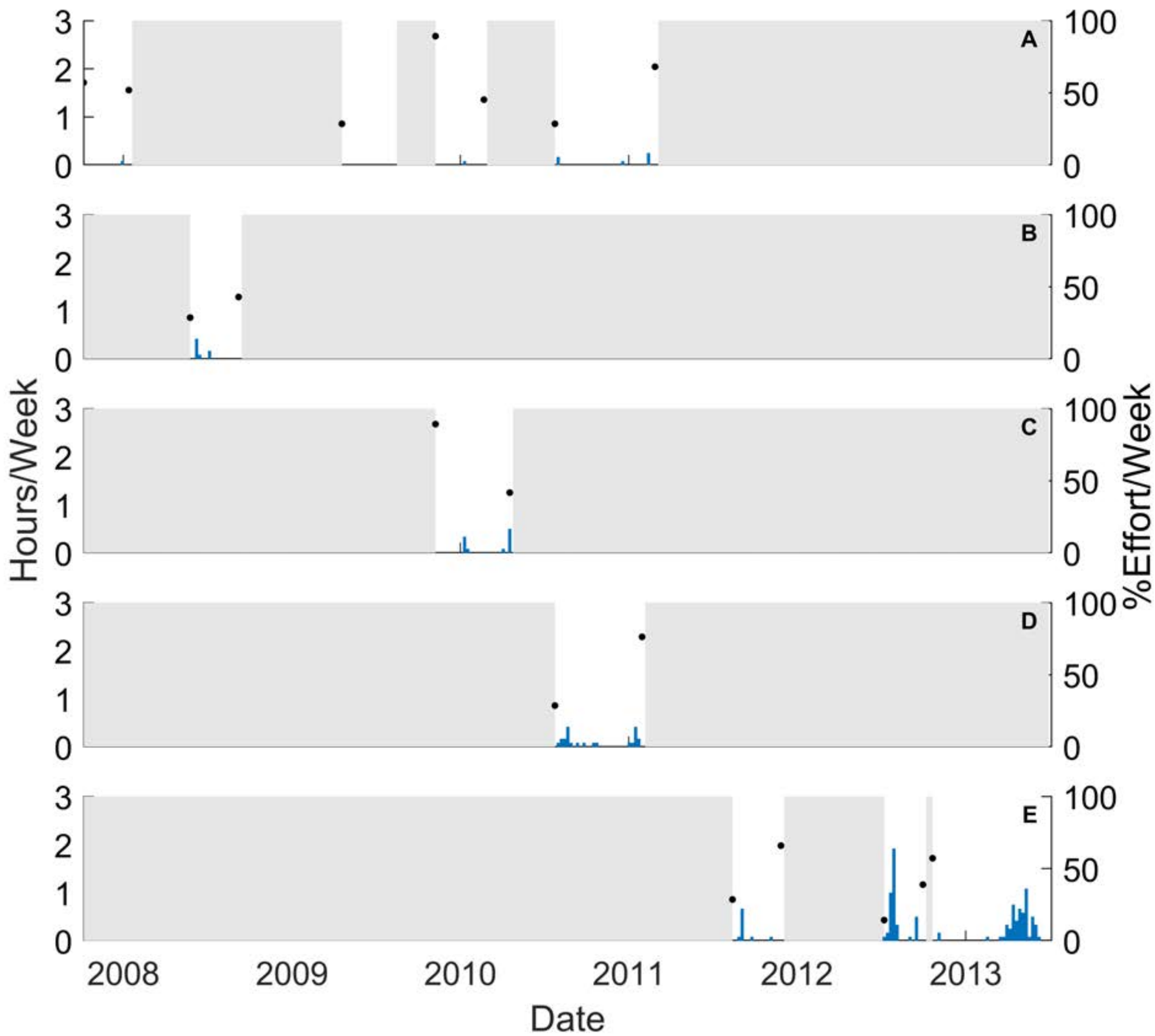

Figure 51: Cumulative hours/week of Risso's dolphin presence at all Onslow Bay sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

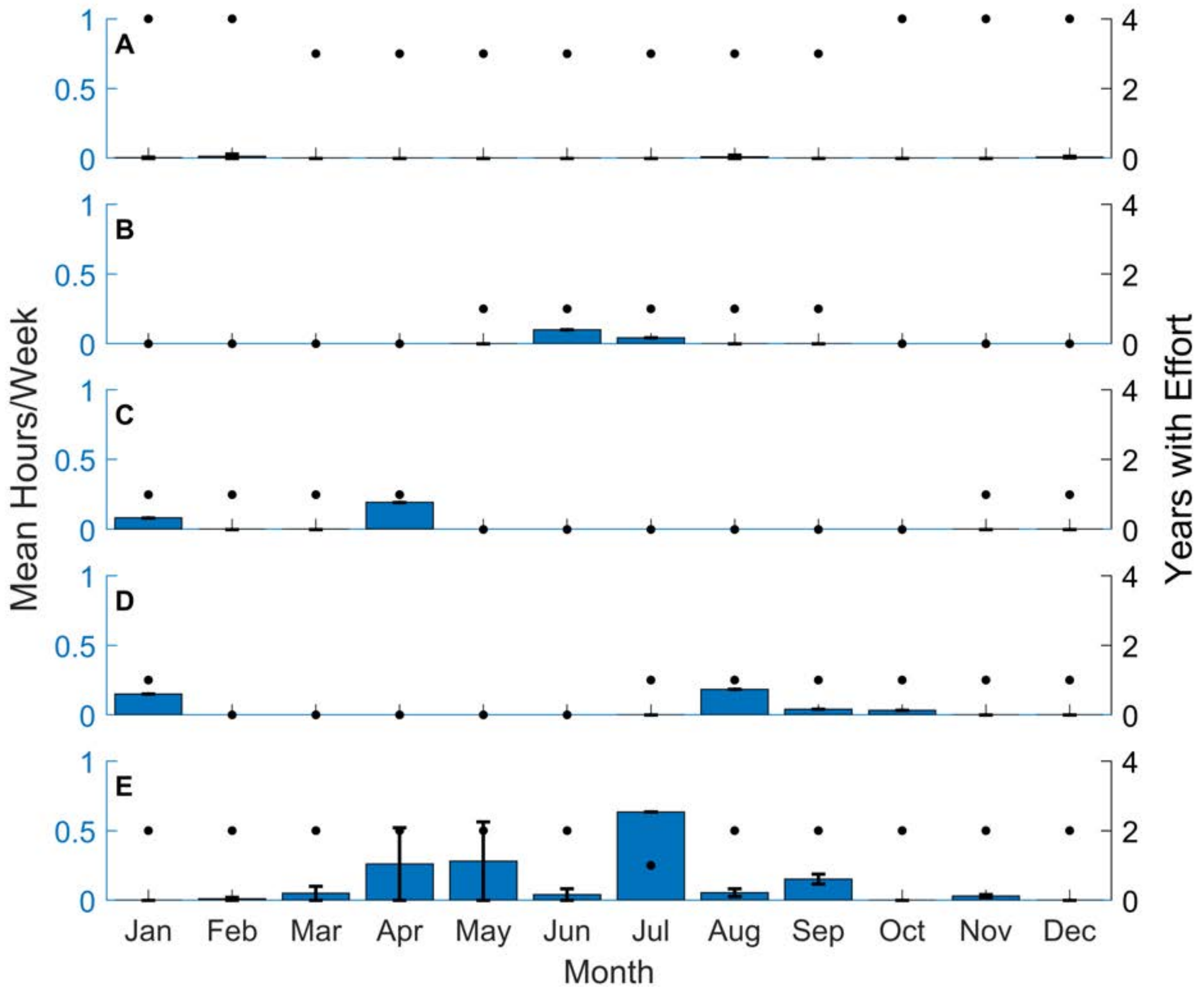

Figure 52: Monthly mean hours per week of Risso's dolphin acoustic presence at all Onslow Bay sites. Bars indicate the monthly mean (left y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (right y-axis) are represented by the black dots.

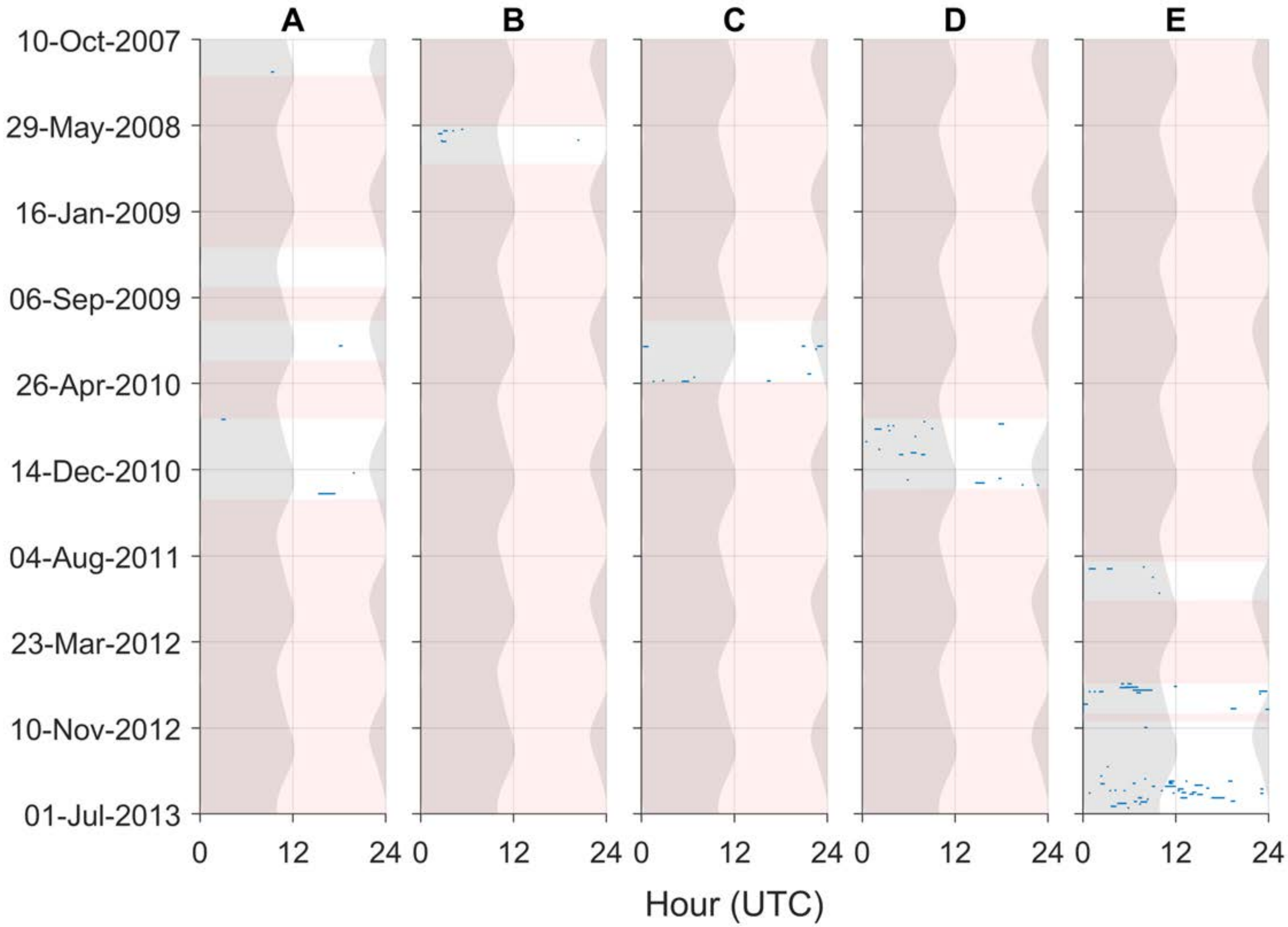

Figure 53: Risso's dolphin acoustic presence in 5-min bins at all Onslow Bay sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

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

Smaller-bodied delphinids, represented by the high-frequency (UD HF) and 47 kHz (UD47) click types, were present at all Onslow Bay sites between 2008 and 2013 (Figure 54). Acoustic presence was moderate overall, most consistently exceeding 5 hours per week at the shallow shelf site (A). Presence was lower at the mid-depth shelf sites (B–D) and at the slope site (E), with the exception of 2013 at site E, when levels were similar to those at site A.

Seasonal variation differed across sites (Figure 55). At site A, presence increased in late fall through winter and declined in spring and summer. At site E, presence was higher in fall and again in late winter to spring, with a summer decrease. Seasonal interpretation is limited at sites B–D due to reduced overall presence and incomplete annual coverage.

Diel patterns also varied by site (Figure 56). At the shallow shelf site (A), crepuscular activity was evident in December of several years, with peaks in the early morning hours. At the mid-depth shelf (B-D) and slope (E) sites, activity was most common at night, indicating some degree of consistent nocturnal behavior.

These results are consistent with previous studies that delphinids occurred through much of the year in Onslow Bay, with activity elevated at night/crepuscular periods. Smaller-bodied delphinids proudcing high-frequency clicks were commonly detected year-round along the slope, with higher prevalence in summer and fall. They also showed strong diel patterns, with detections occurring more frequently at night, 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)

- Occurred at all Onslow Bay sites from 2008 to 2013, with moderate levels of acoustic presence.
- Presence was highest at the shallow shelf site (A), with occasional increases at the slope site (E).
- Seasonal presence at site A increased in late fall and winter, while site E showed higher levels in fall and late winter–spring.
- Diel patterns varied: crepuscular activity at site A and more consistent nocturnal activity at sites B–E.

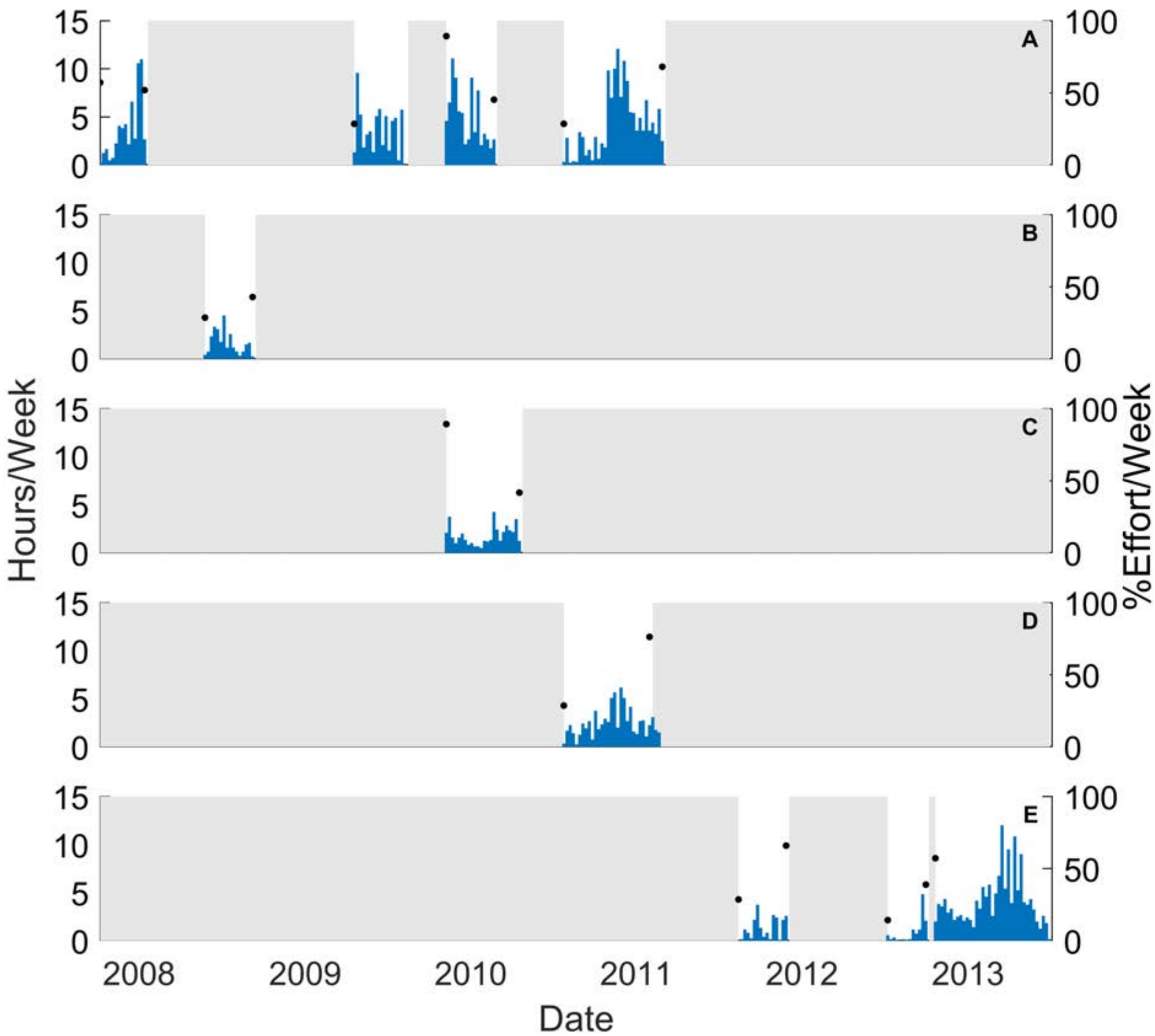

Figure 54: Cumulative hours/week of smaller-bodied delphinid (UD HF & 47) presence at all Onslow Bay sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

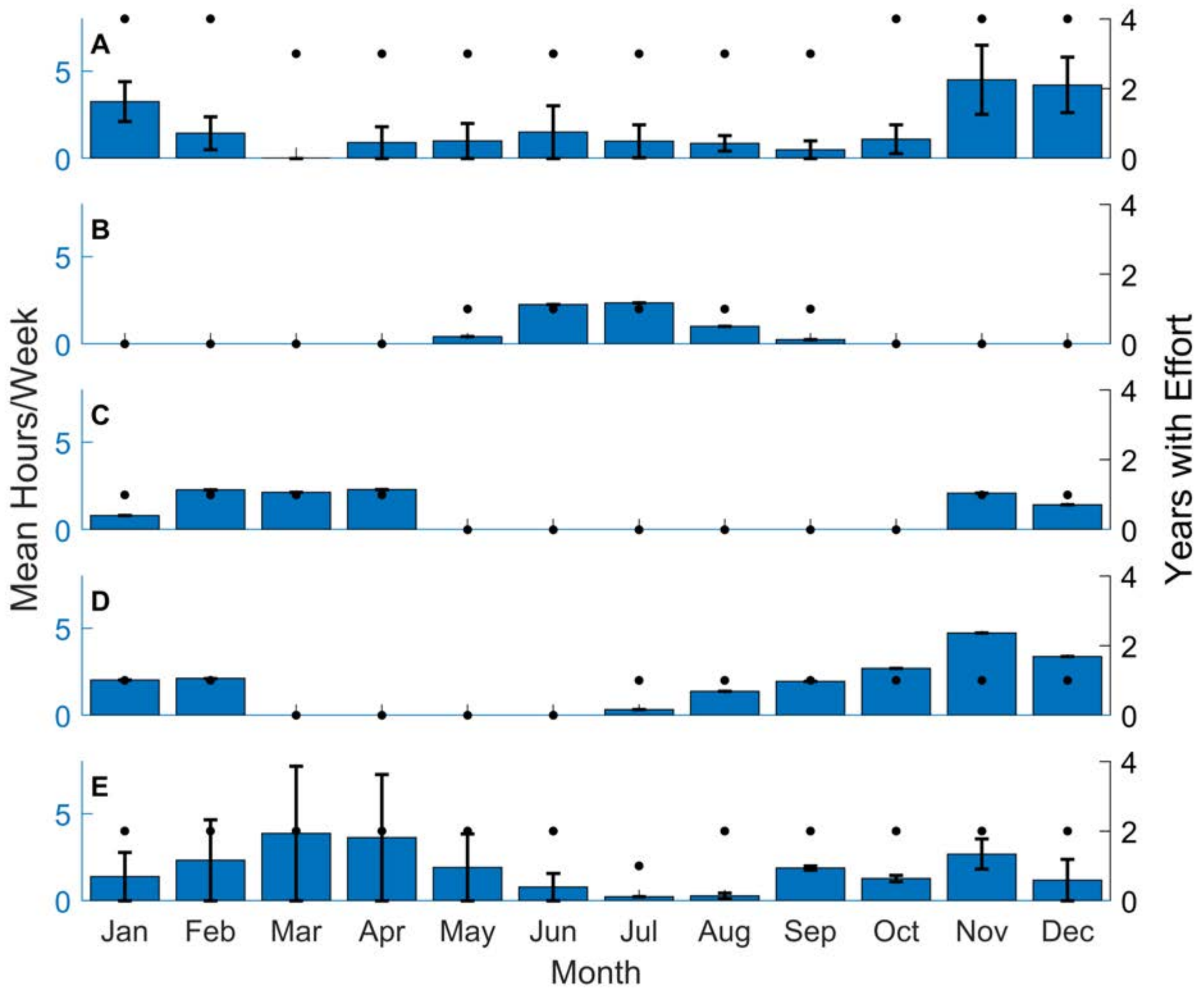

Figure 55: Monthly mean hours per week of smaller-bodied delphinid (UD HF & 47) acoustic presence at all Onslow Bay sites. Bars indicate the monthly mean (right y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (left y-axis) are represented by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

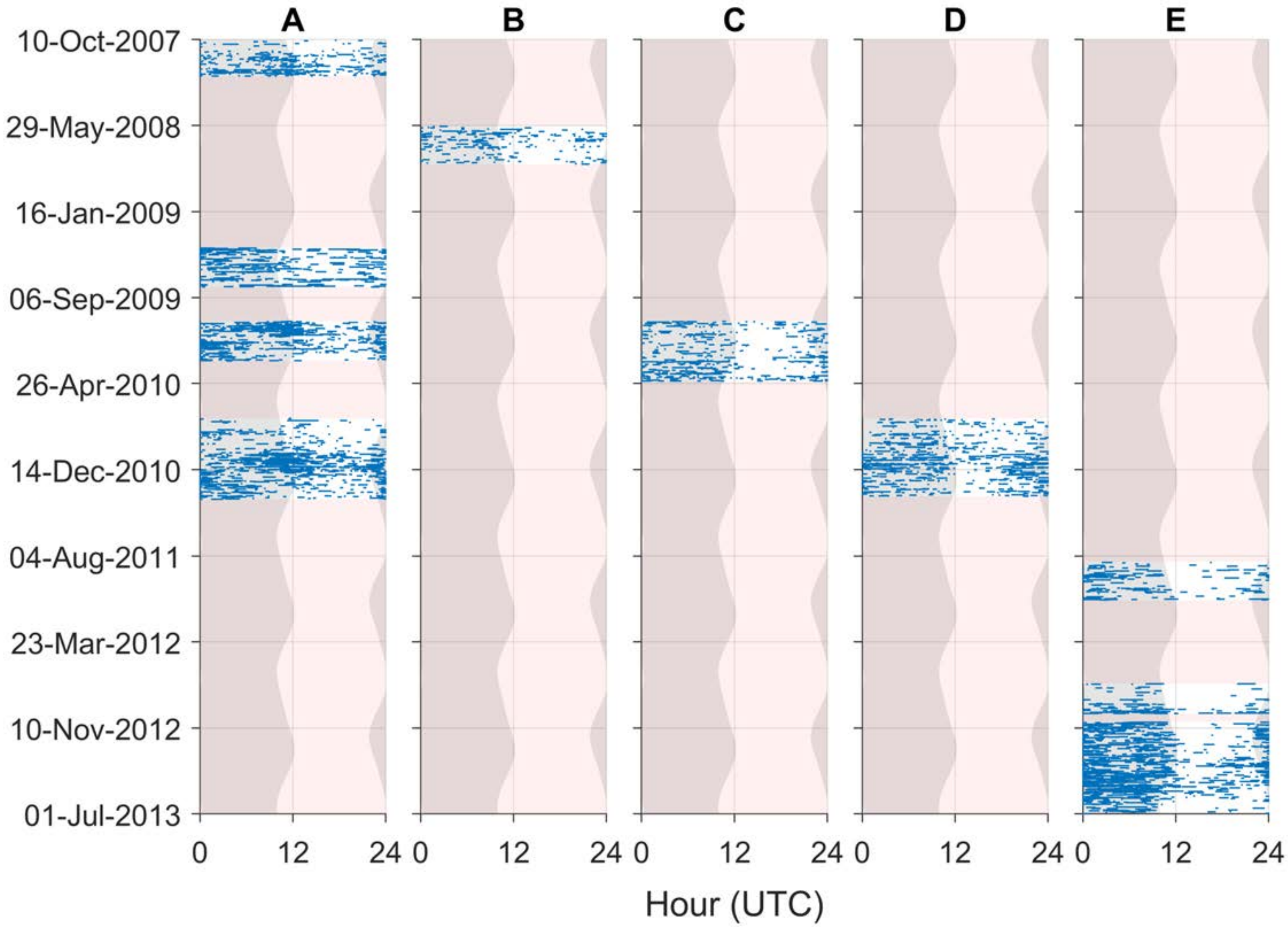

Figure 56: Smaller-bodied delphinid (UD HF & 47) acoustic presence in 5-min bins at all Onslow Bay sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

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 present at all Onslow Bay sites from 2008 to 2013, occurring at low levels at all sites except site E (Figure 57). The shallow shelf site (A) had the lowest levels of acoustic presence, with slightly higher levels at the mid-depth shelf sites (B-D) but still remaining under 1 hour/week. The slope site (E) had the highest presence, reaching over 10 hours/week during the winter and spring months (Figure 58). Seasonal interpretation is limited for the other sites that had very little acoustic presence and were not represented by a full year of data. Similar constraints also limit diel interpretation. At site E, detections occurred throughout day and night hours, with no indication of a consistent daily pattern (Figure 59).

These results are consistent with previous studies that found larger-bodied delphinids were rarely detected or observed south of Cape Hatteras along the slope, but when they were, they had higher prevalence in winter and spring (Cohen et al. 2022; Cohen et al. 2023).

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

- Occurred at all Onslow Bay sites from 2008 to 2013, but generally at low levels.
- Presence was greatest at site E, with increases in January-May.
- Presence at sites A–D was minimal, limiting seasonal interpretation.
- No consistent diel trend was observed; detections at site E occurred across all hours.

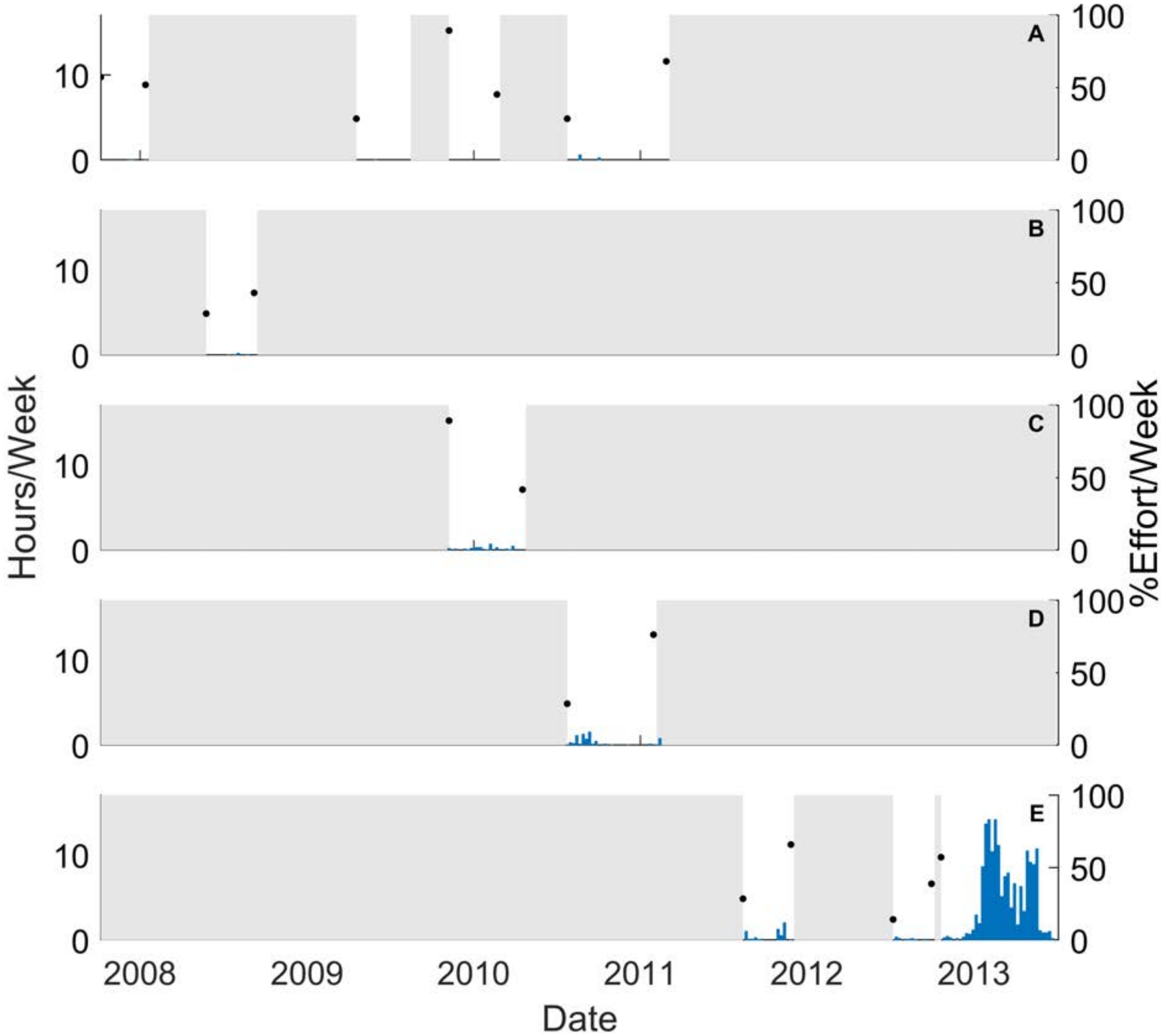

Figure 57: Cumulative hours/week of larger-bodied delphinid (UD LF) presence at all Onslow Bay sites. Gray bars indicate times of no effort and black dots represent weeks with partial effort.

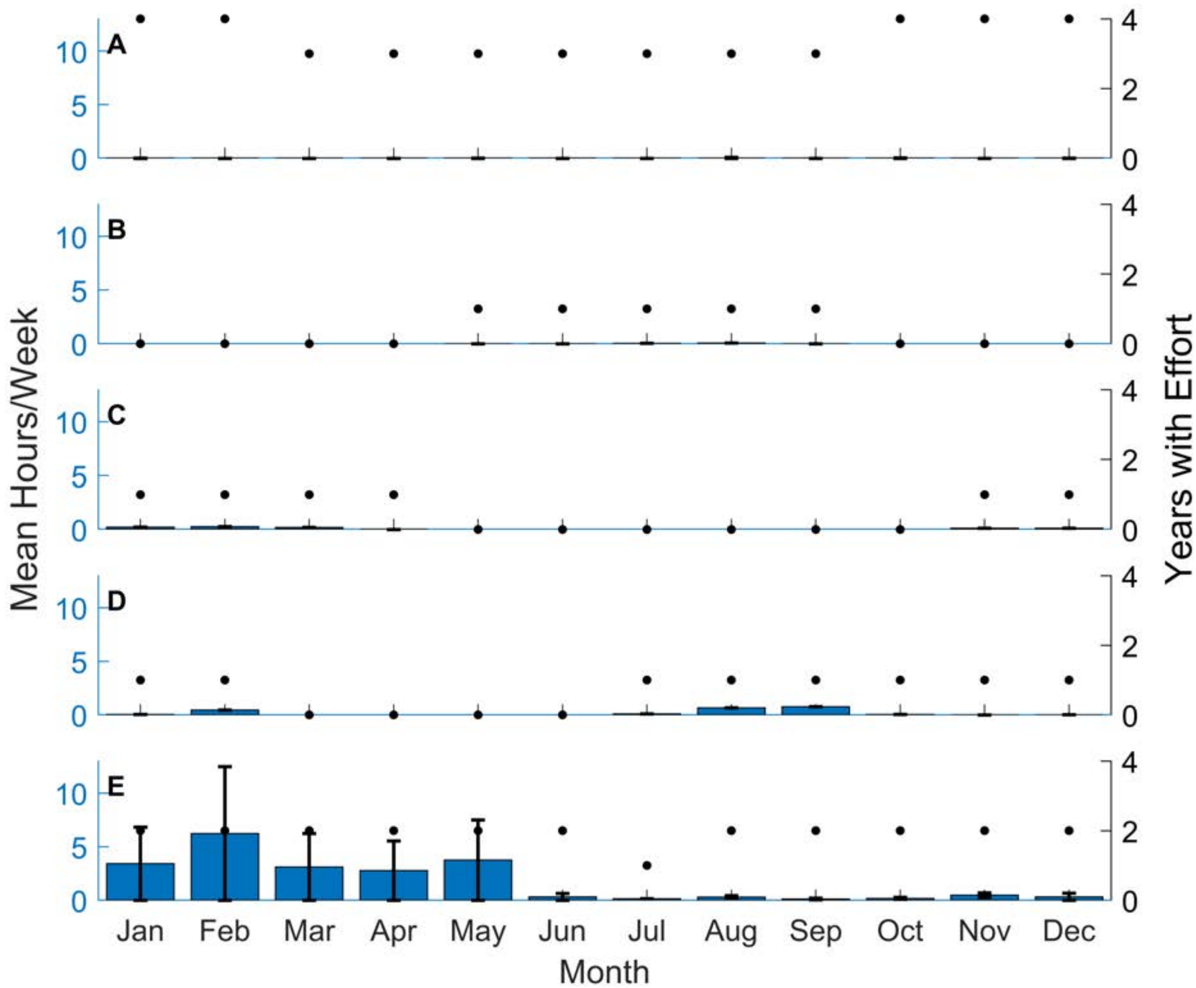

Figure 58: Monthly mean hours per week of larger-bodied delphinid (UD LF) acoustic presence at all Onslow Bay sites. Bars indicate the monthly mean (right y-axis), and error bars represent standard error of the mean across years. Years with effort for each month (left y-axis) are represented by the black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

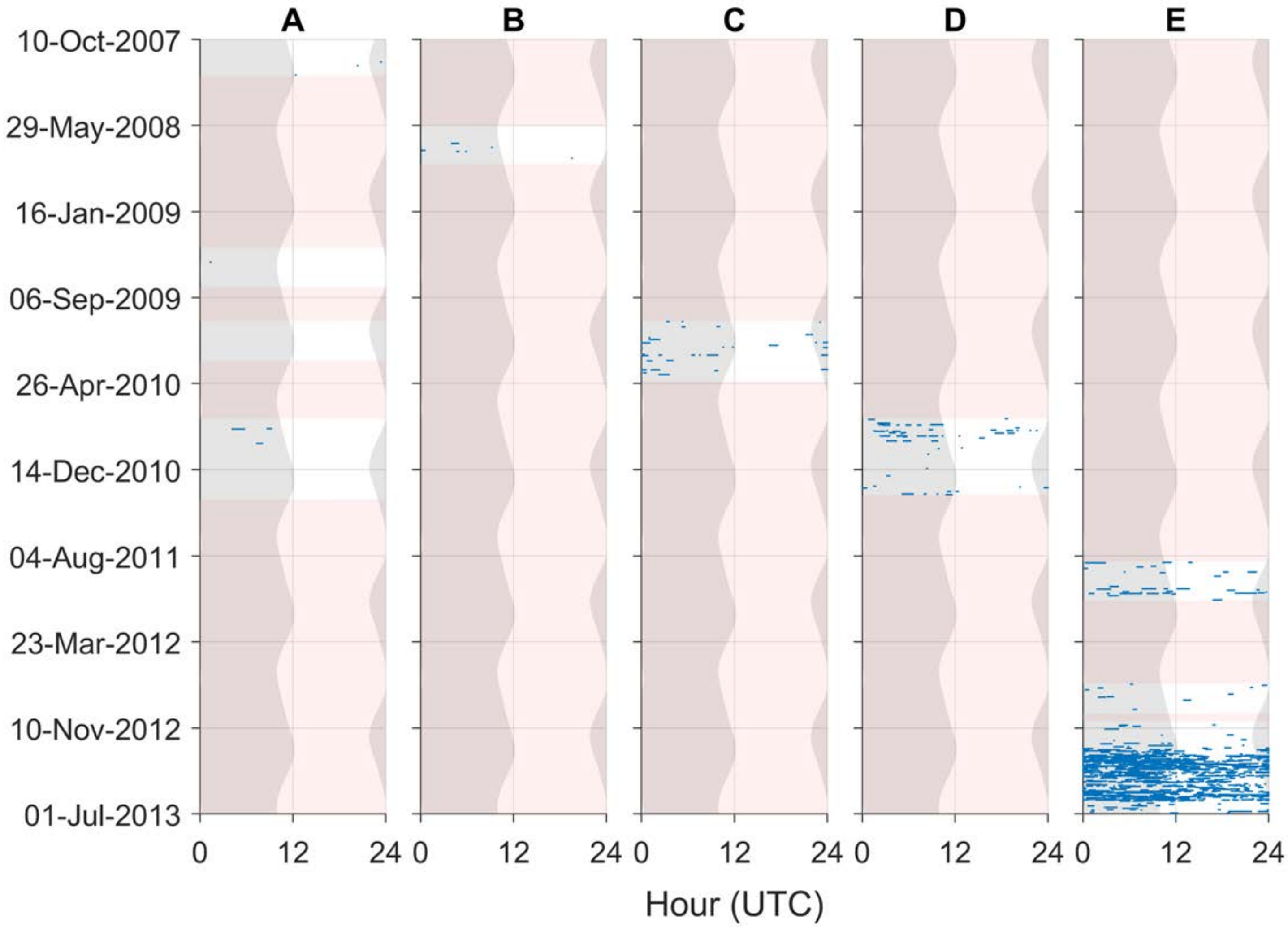

Figure 59: Larger-bodied delphinid (UD LF) acoustic presence in 5-min bins at all Onslow Bay sites. Gray vertical shading denotes nighttime and light red horizontal shading indicates times of no effort.

5.2 Mysticetes

Baleen whale acoustic presence in Onslow Bay was comparatively sparse and variable across sites and years (Figure 60 and 61). When present, most species occurred during fall through early spring, broadly consistent with seasonal migration along the U.S. East Coast. However, detections were intermittent and less frequent than those observed farther north at Cape Hatteras, reflecting more occasional or transitory use of the region.

Among the species detected, minke and fin whales showed the broadest temporal distribution, with detections spanning multiple seasons and evidence of both winter–spring and occasional summer presence. Blue and sei whales exhibited clearer seasonal peaks, with consistent detections during fall and early winter months, while humpback whales were rarely recorded and limited to a brief period in early spring. North Atlantic right whales were detected only once, indicating that Onslow Bay lies outside their core migratory corridor or foraging range.

These results suggest that, while several baleen whale species pass through Onslow Bay during migration, the region serves primarily as a transient pathway rather than a focal habitat for sustained seasonal use.

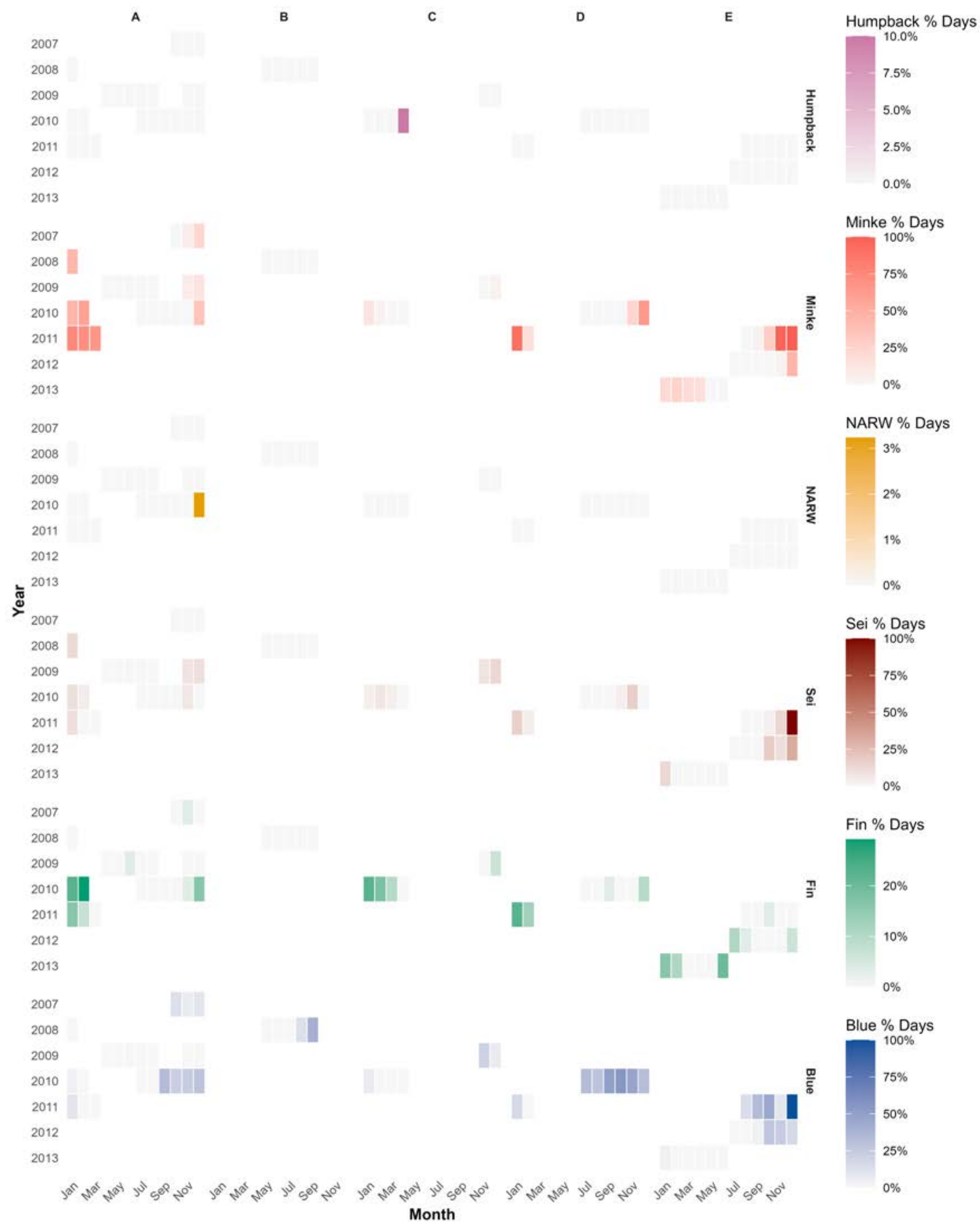

Figure 60: Annual monthly acoustic presence by species at all Onslow Bay sites, represented as the percentage of days each species was detected per month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when 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.

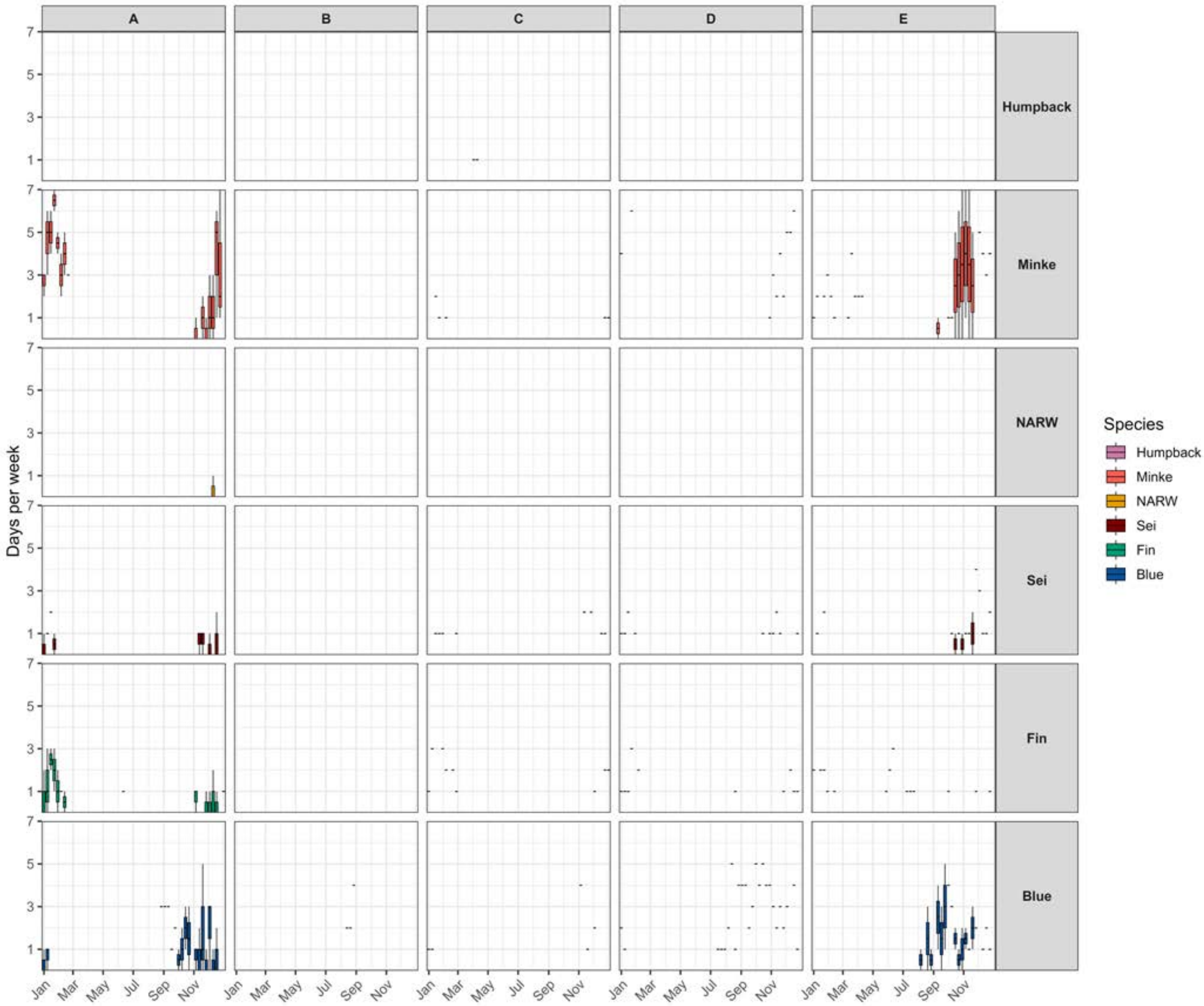

Figure 61: Average weekly acoustic presence (days per week) by species at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not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

5.2.1 Humpback Whales

Humpback whale occurrence was rare across the Onslow Bay sites (Figures 62 & 63). Limited acoustic presence was detected only at site C, confined to a brief period in early spring 2010. No detections were noted at sites A, B, D, or E, despite recording effort throughout the monitoring period.

Summary of Results – Humpback Whale

- Limited acoustic presence only at site C, confined to a brief period in early spring 2010.
- No detections at sites A, B, D, or E despite consistent recording effort.
- Overall occurrence was rare across the Onslow Bay sites.

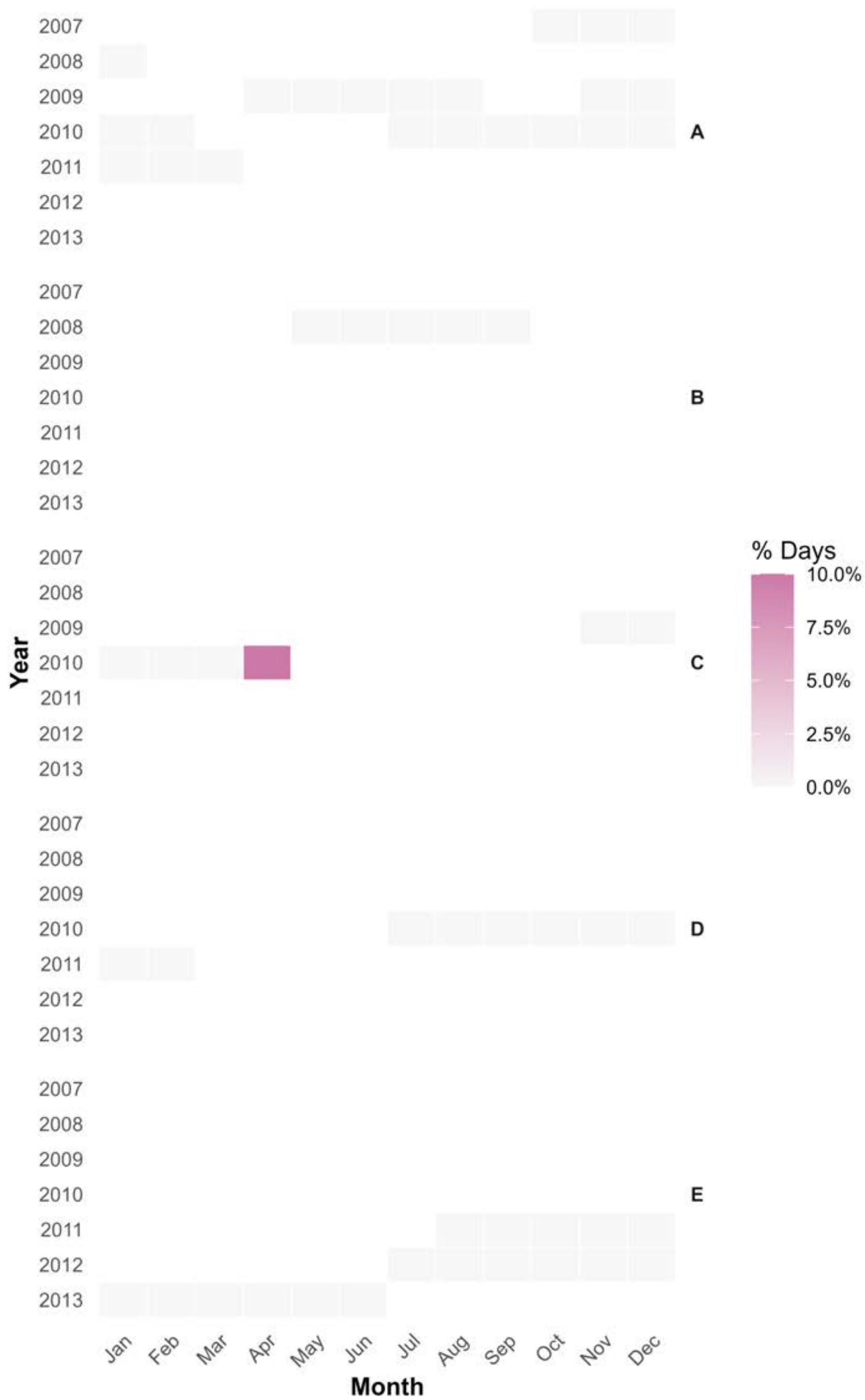

Figure 62: Annual monthly humpback whale acoustic presence at all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic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

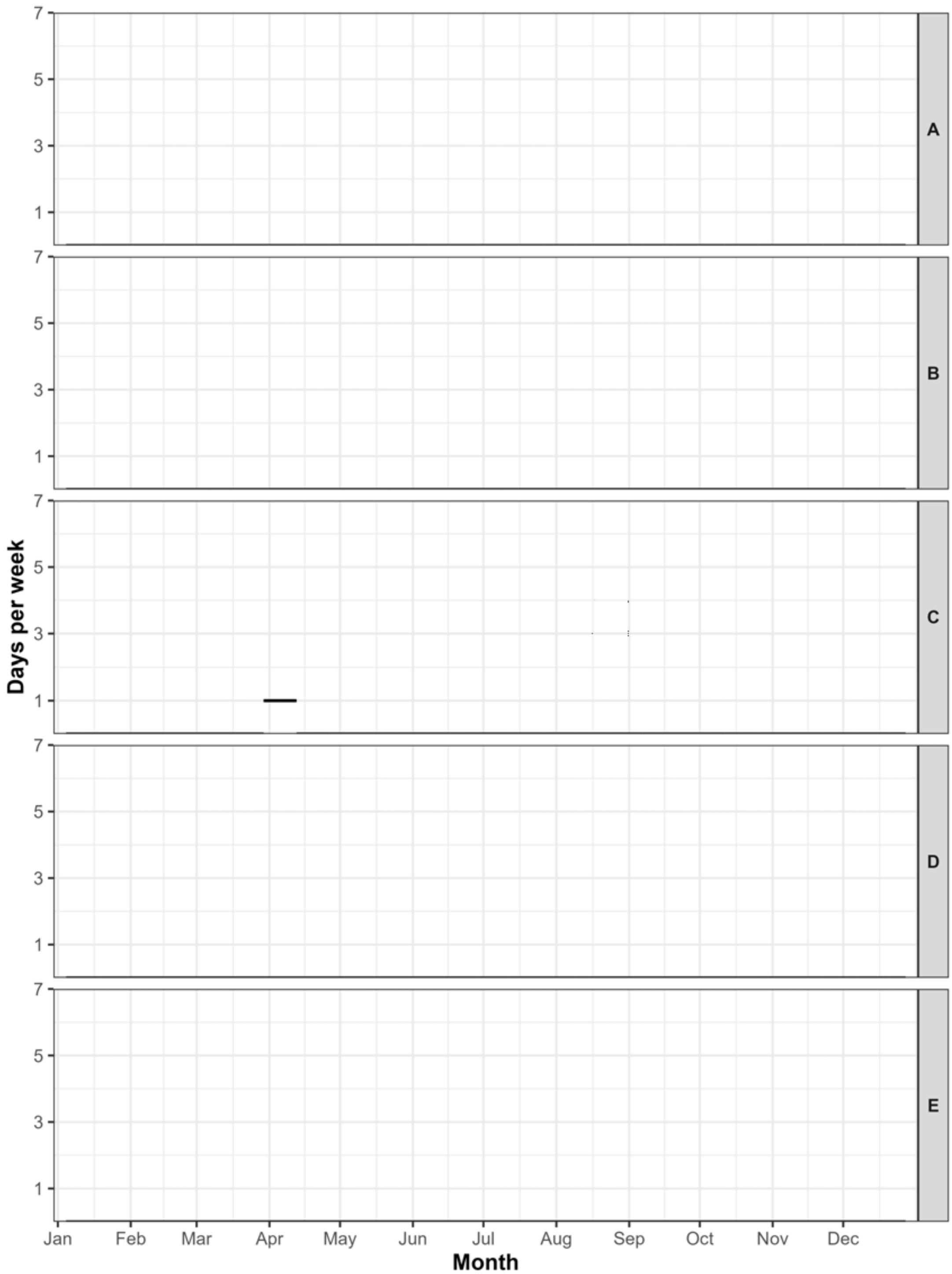

Figure 63: Average weekly acoustic presence of humpback whales (days per week) at all Onslow bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics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

5.2.2 Minke Whales

Minke whales were acoustically present at several Onslow Bay sites, with clear temporal variability across the sites (Figures 64 & 65). Presence was strongest at the shallow shelf site (A) and at the slope site (E), both showing clear seasonal peaks. At site A, detections occurred regularly during winter and early spring months (January–April) and again in late fall (November–December). At the slope site (E), detections were concentrated from September through December, indicating a strong fall–early winter presence farther offshore. Mid-depth shelf sites (C and D) had only occasional detections during winter and early spring. Interpretation of minke whale presence should consider that different detection approaches were used during the monitoring period, and manual and automated detections are not directly comparable.

It is important to note that apparent differences in presence among sites may largely reflect differences in monitoring effort. The shallow shelf (A) and slope (E) sites had the most consistent year-round coverage, while effort at the mid-depth shelf sites was limited to shorter deployments. In particular, site B had recording effort only from May through September 2008, months when Minke whales are typically acoustically absent from the region, likely explaining the lack of detections there.

Weekly acoustic presence during peak months frequently exceeded three to five days per week at the shallow shelf and slope sites, indicating regular seasonal occurrence. The timing and distribution of detections suggest Minke whales use both shelf and slope habitats in Onslow Bay during seasonal migrations, with greater use during winter and fall months.

Summary of Results – Minke Whale

- Clear seasonal presence at the shallow shelf (A) and slope (E) sites, peaking during fall and winter months.
- Occasional detections at mid-depth shelf sites (C and D); no detections at site B.
- Apparent differences in presence among sites likely reflect differences in monitoring effort, with the shallow shelf and slope sites having the most consistent year-round coverage.
- Weekly presence during peak months frequently exceeded three to five days per week at the shallow shelf and slope sites, indicating regular seasonal use of the region.

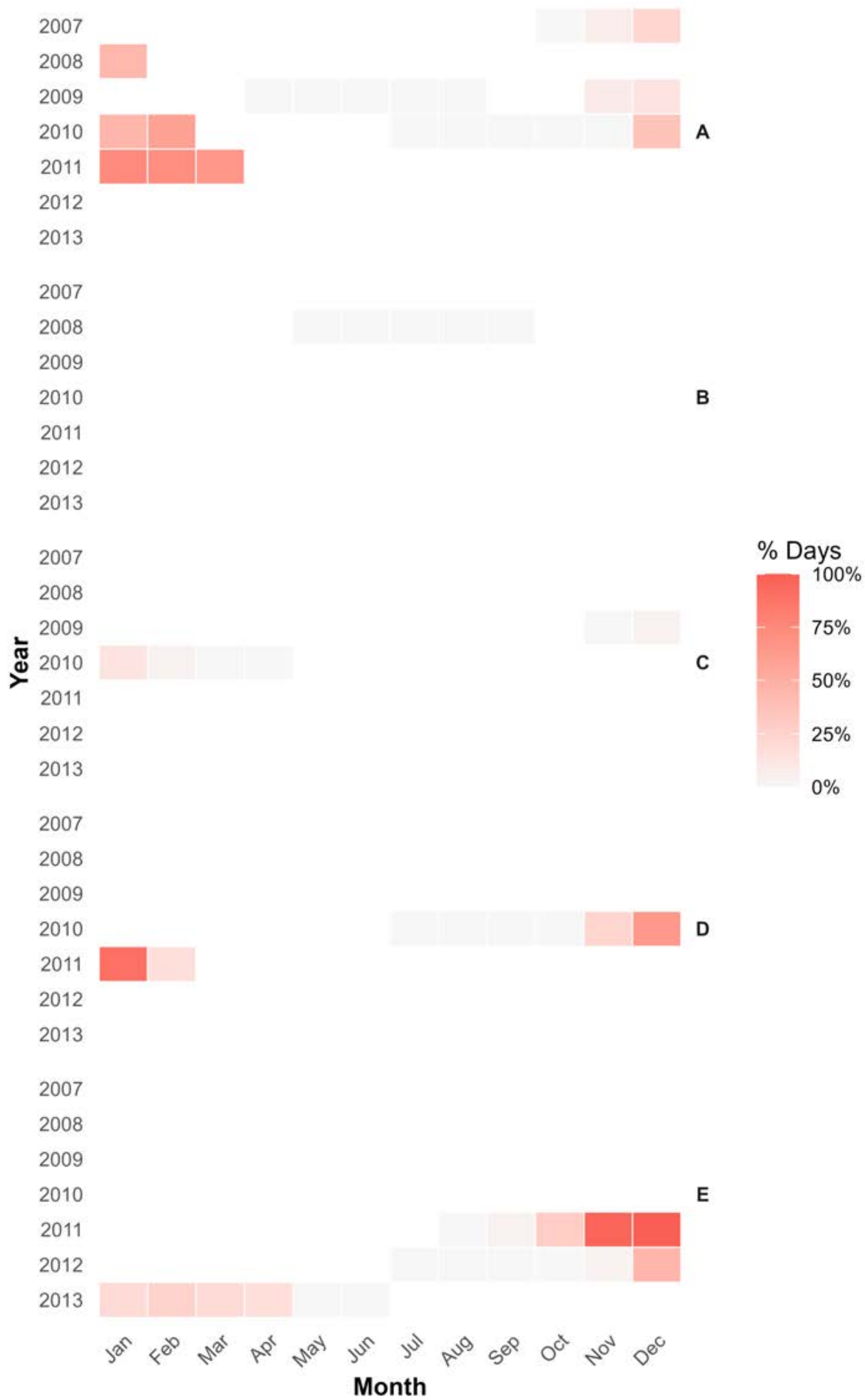

Figure 64: Annual monthly minke whale acoustic presence at all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic 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.

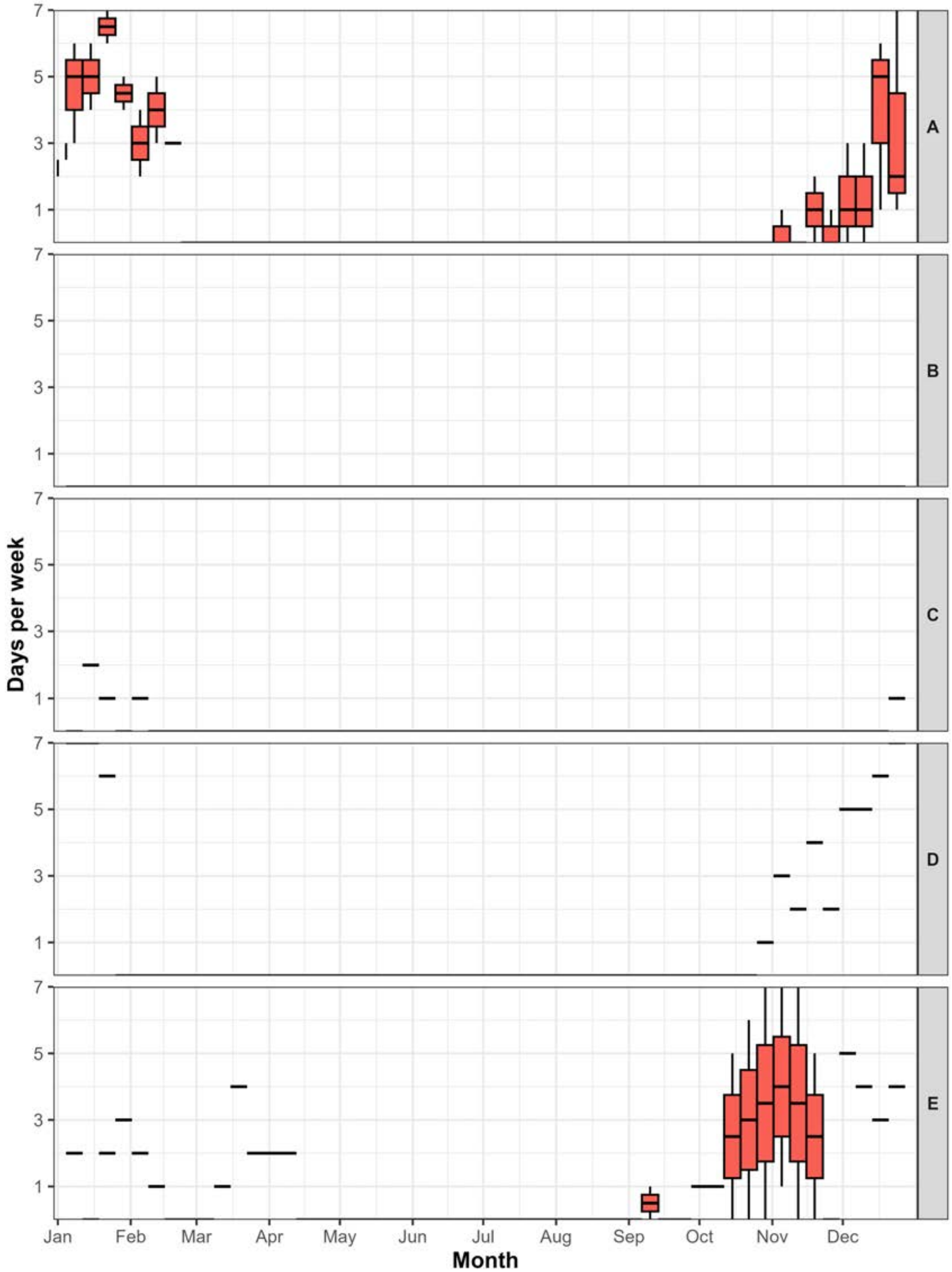

Figure 65: Average weekly acoustic presence of minke whales (days per week) at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could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

5.2.3 Blue Whales

Blue whale acoustic presence in Onslow Bay was strongly seasonal, with detections concentrated during fall and early winter months (Figures 66 & 67). Across sites, detections generally began in late summer (August) and continued through December, with peak occurrence during October and November. This pattern suggests regular use of the region during the southward portion of their annual migration.

Detections were recorded at both shelf and slope sites, indicating that blue whales use a range of habitats within Onslow Bay during their migratory passage. Although mid-depth shelf sites (B–D) showed consistent detections during fall and winter months, these sites were monitored for less than a full year, limiting interpretation of potential seasonal patterns there.

Weekly acoustic presence during peak months often exceeded three to four days per week, supporting a pattern of regular occurrence during the fall and early winter migration period along the U.S. East Coast (Davis et al. 2020).

Summary of Results – Blue Whale

- Strongly seasonal presence from August through December, with peak detections during October and November.
- Detections occurred across both shelf and slope sites, indicating use of a range of habitats within Onslow Bay.
- Mid-depth shelf sites (B–D) were monitored for less than a full year, limiting interpretation of seasonal patterns at those sites.
- Weekly presence during the fall often exceeded three to four days per week, suggesting regular seasonal occurrence.

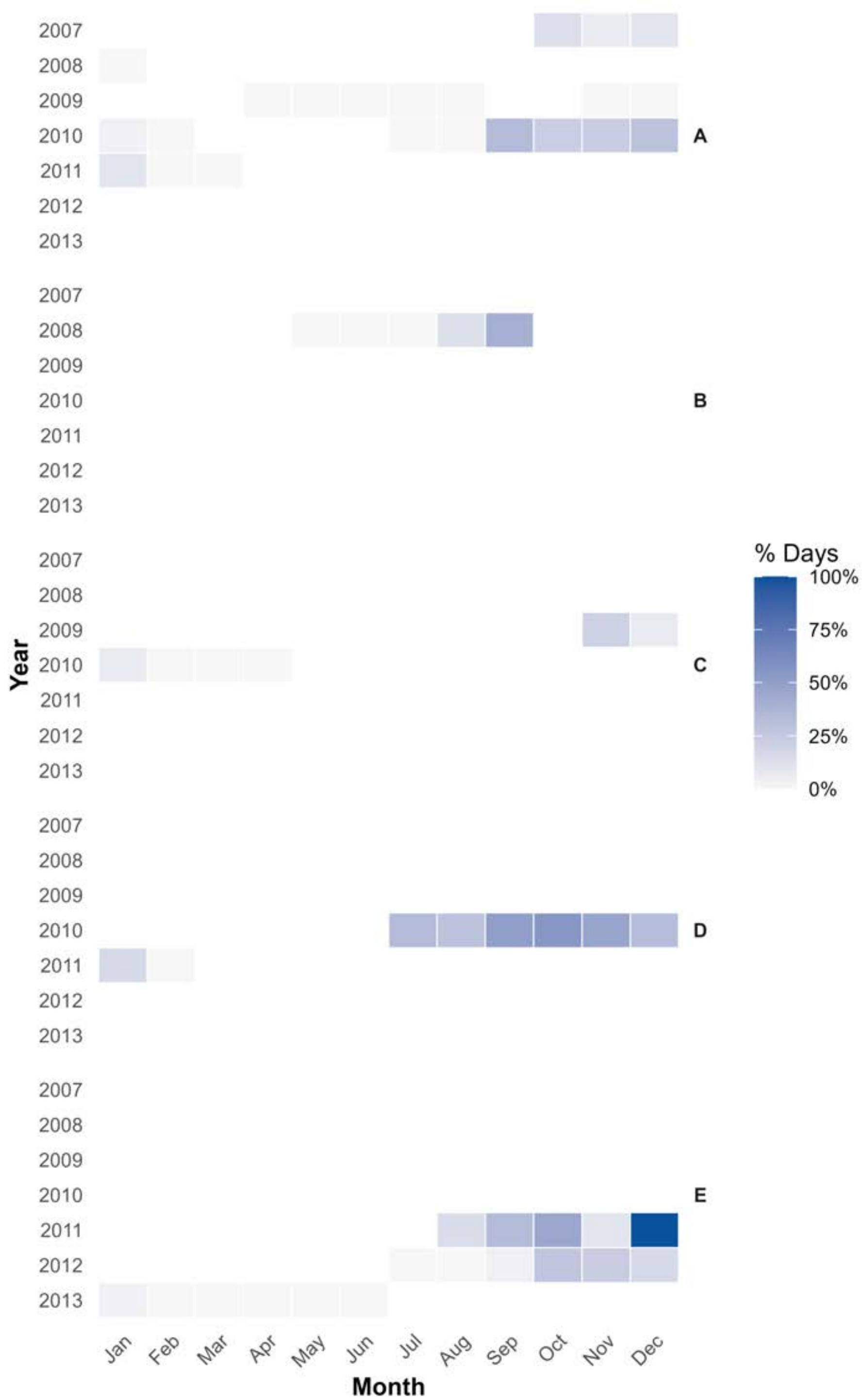

Figure 66: Annual monthly blue whale acoustic presence for all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic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

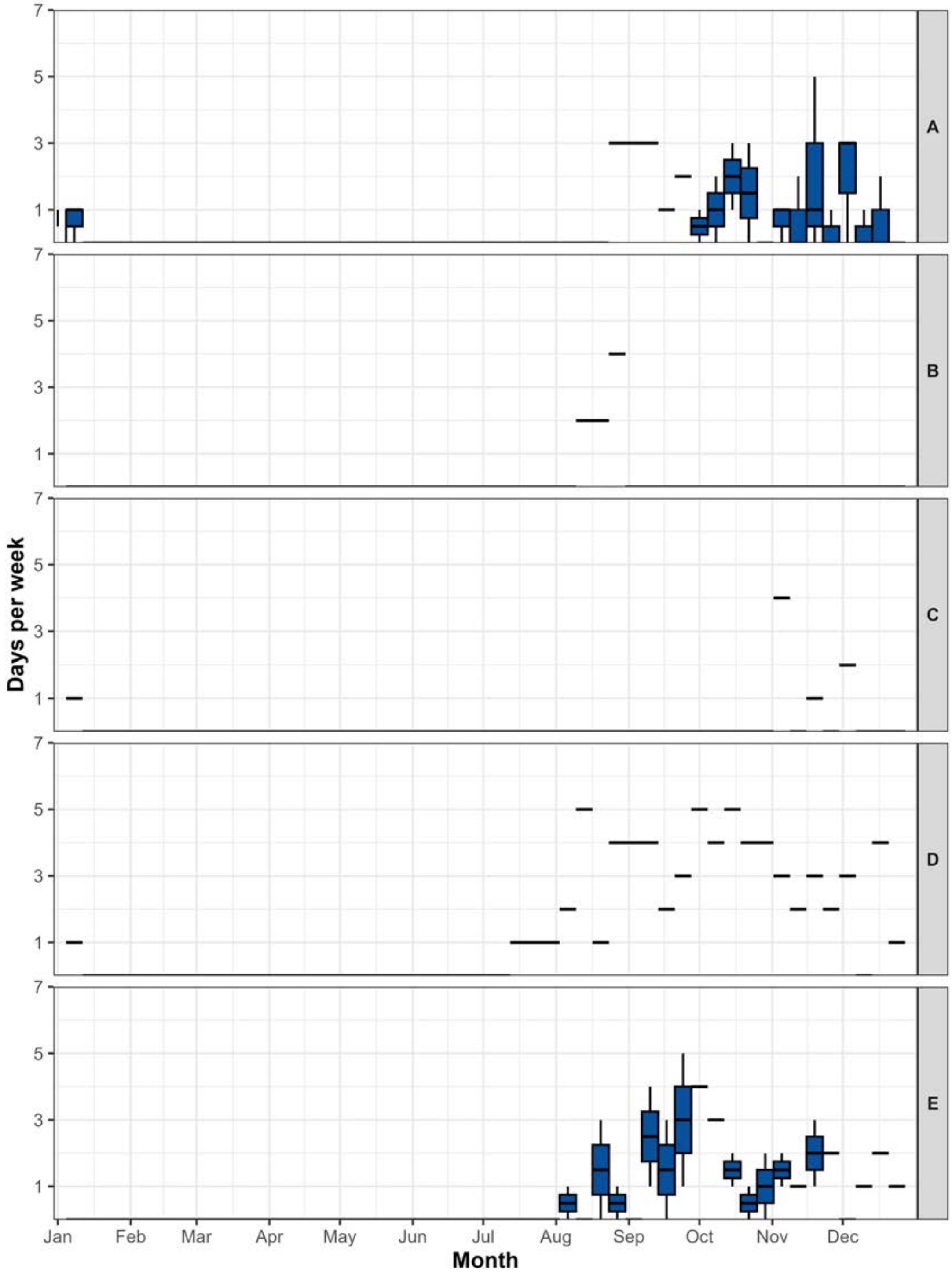

Figure 67: Average weekly acoustic presence of blue whales (days per week) at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could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

5.2.4 Fin Whales

Fin whale acoustic presence in Onslow Bay was variable across sites and years, with detections spanning multiple seasons (Figures 68 & 69). Calling activity occurred most frequently during winter and early spring months (January–March) and again in late fall, but detections were also observed sporadically in summer, indicating intermittent use of the region throughout the year. This pattern suggests that while fin whales may migrate through Onslow Bay seasonally, some individuals likely remain in or transit through the area outside of peak migration periods.

Detections were recorded at both shelf and slope sites, with the highest calling activity at the shallow shelf site (A) and consistent but lower-level detections at the slope site (E). The mid-depth shelf sites (C and D) showed limited detections during winter and summer months, while no detections were recorded at site B. Effort at the mid-depth shelf sites was limited to shorter deployments, restricting interpretation of seasonal patterns.

Weekly acoustic presence during peak periods typically ranged from one to three days per week, with the strongest calling activity in winter and early spring. The combination of winter–spring and occasional summer detections suggests that Onslow Bay may serve as both a migratory pathway and an intermittently used foraging or transiting area for fin whales (Davis et al. 2020).

Summary of Results – Fin Whale

- Acoustic presence observed during multiple seasons, most commonly in winter, early spring, and late fall.
- Occasional detections in summer indicate intermittent use of the region outside typical migratory periods.
- Detections occurred across both shelf and slope sites; limited detections at mid-depth shelf sites (C and D) and none at site B.
- Effort at mid-depth shelf sites (B–D) was limited to shorter deployments, restricting seasonal interpretation.
- Weekly presence during peak months typically ranged from one to three days per week, suggesting Onslow Bay functions as a migratory corridor and intermittent habitat for fin whales.

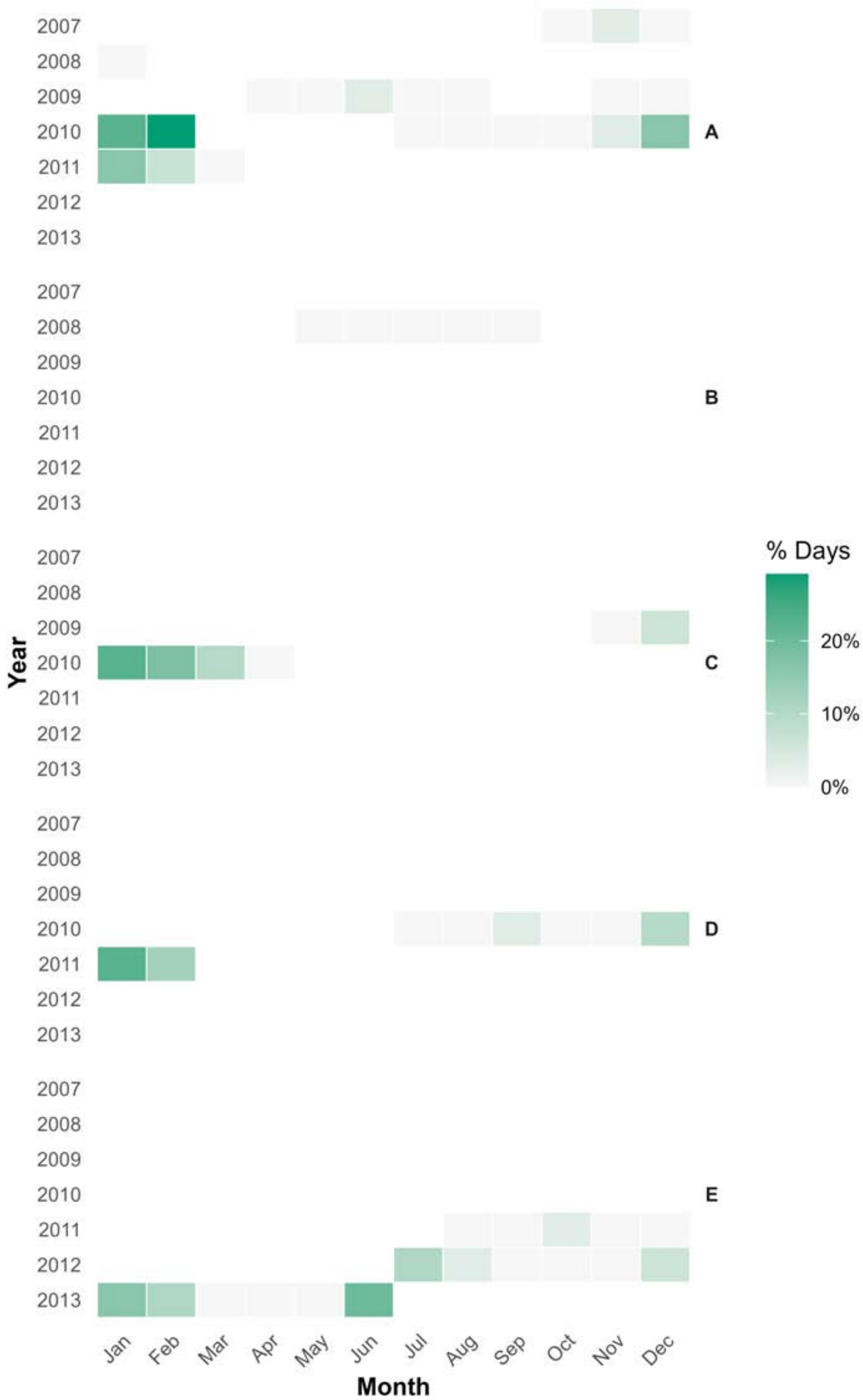

Figure 68: Annual monthly fin whale acoustic presence at all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic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

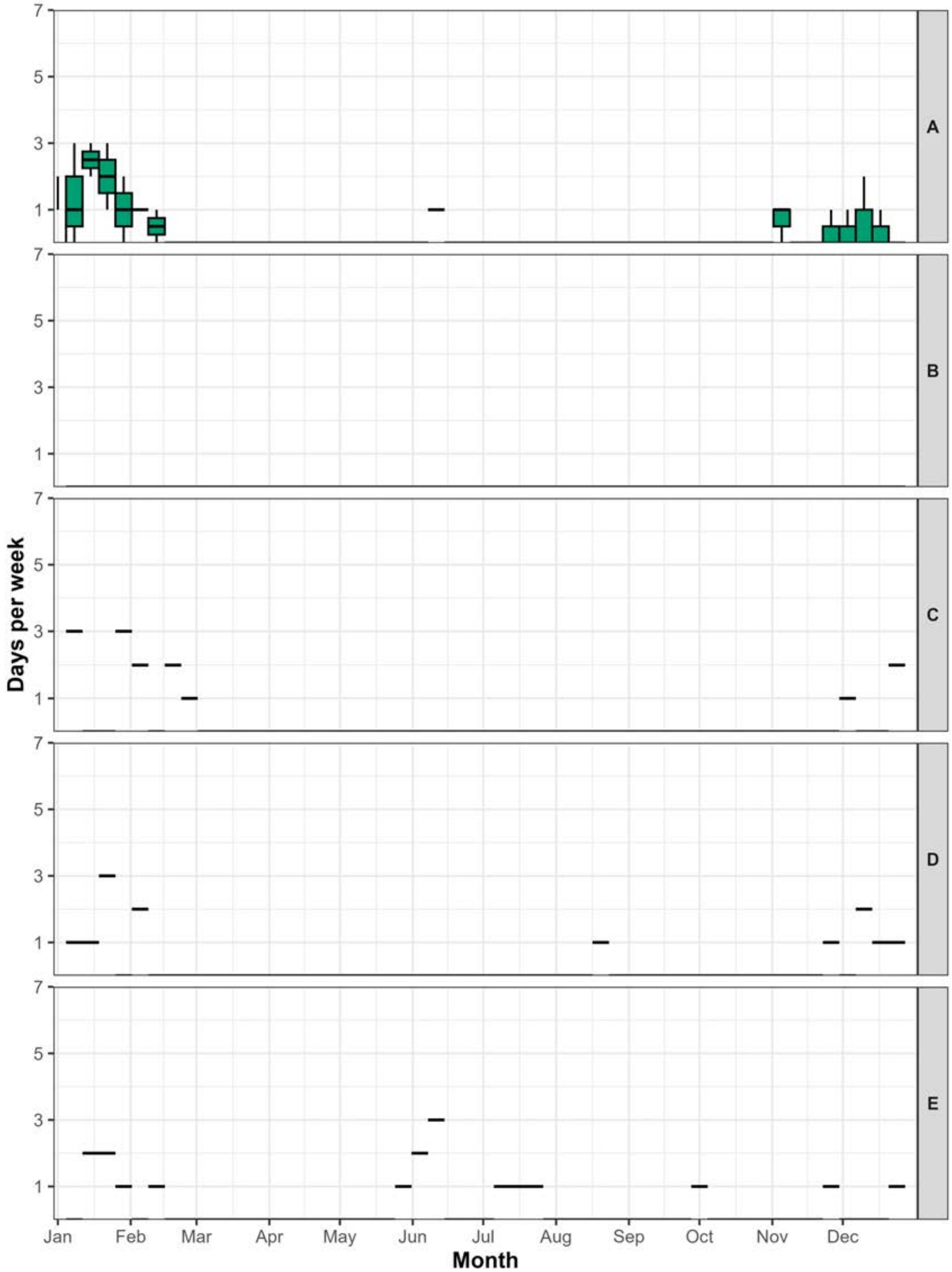

Figure 69: Average weekly acoustic presence of fin whales (days per week) at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could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

5.2.5 Sei Whales

Sei whale acoustic presence in Onslow Bay was intermittent across sites and years, with two main seasonal periods of occurrence (Figures 70 & 71). Detections occurred primarily during late winter (January–February) and again in late fall (October–December). While presence was not consistent across years, these two periods of activity suggest repeated use of the region during seasonal migrations.

Detections were recorded at both shelf and slope sites, with the highest presence at the slope site (E) during late fall. The shallow shelf site (A) also showed detections in both early and late seasons, while mid-depth shelf sites (C and D) had only occasional detections. No detections were recorded at site B. Because the mid-depth shelf sites were monitored for less than a full year, seasonal comparisons among sites are limited.

Weekly acoustic presence during peak months rarely exceeded two days per week, consistent with transient use of the area. The timing of detections supports the interpretation of Onslow Bay as a migratory corridor for sei whales moving along the U.S. East Coast (Davis et al. 2020).

Summary of Results – Sei Whale

- Intermittent presence with two seasonal peaks: late winter (January–February) and late fall (October–December).
- Detections across both shelf and slope sites, with strongest presence at the slope site (E); no detections at site B.
- Mid-depth shelf sites (C and D) were monitored for less than a full year, limiting seasonal interpretation.
- Weekly presence during peak periods rarely exceeded two days per week, consistent with transient migratory use of the region.

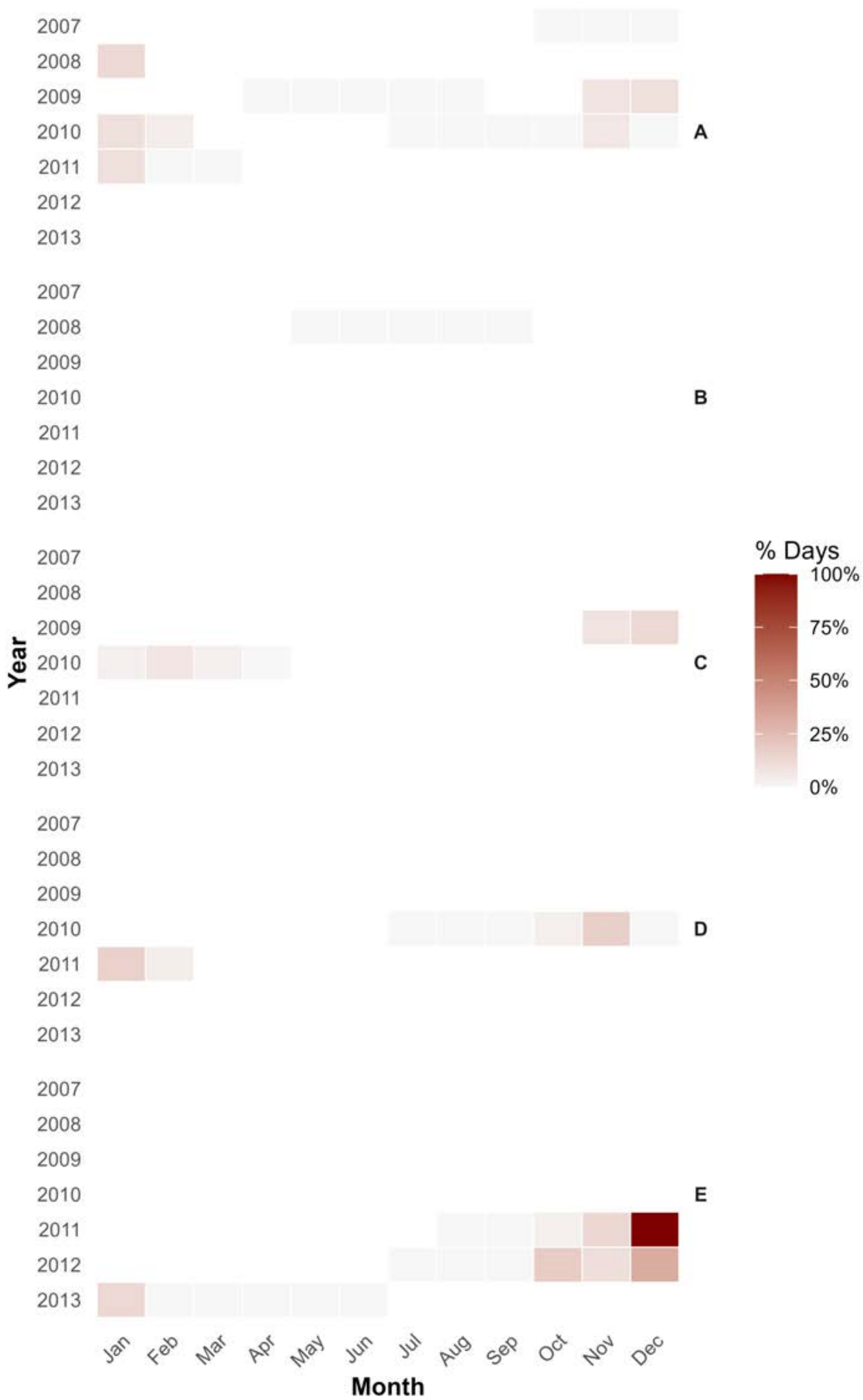

Figure 70: Annual monthly sei whale acoustic presence at all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic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

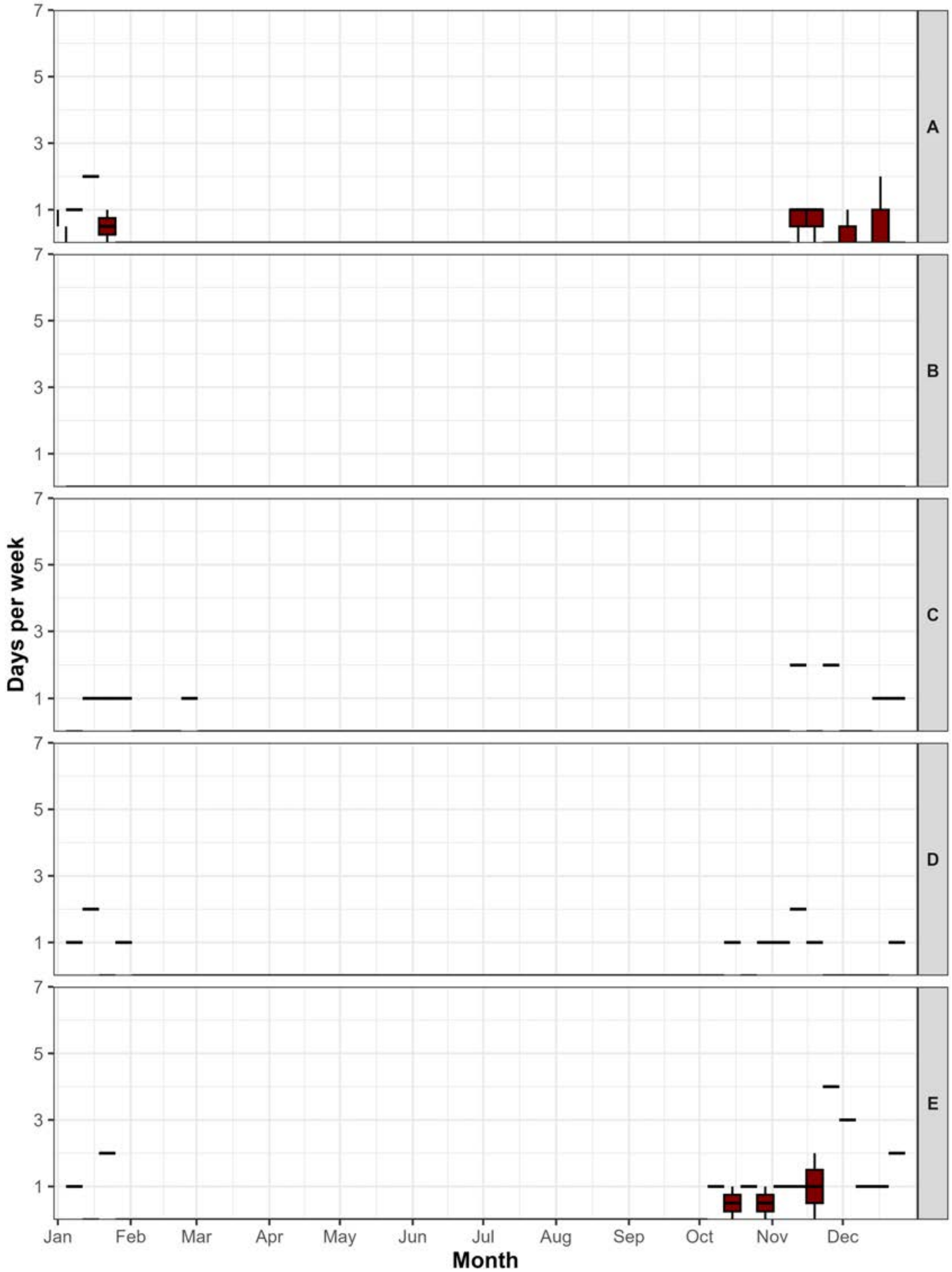

Figure 71: Average weekly acoustic presence of sei whales (days per week) at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could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

5.2.6 North Atlantic Right Whales

North Atlantic right whales were rarely detected in Onslow Bay, with only a single acoustic occurrence recorded during the monitoring period (Figures 72 & 73). A brief detection was observed at the shallow shelf site (A) in December 2011, while no detections were recorded at the mid-depth shelf or slope sites (B–E).

Given this extremely limited acoustic presence, no seasonal or interannual patterns can be inferred from this dataset. However, North Atlantic right whales are known to migrate through the broader Onslow Bay region. The limited detections at these monitoring locations likely reflect a combination of spatial factors—such as whales traveling inshore of the shallow shelf site—and behavioral factors, including reduced vocal activity during migration. As such, these results should not be interpreted as evidence of ecological absence, but rather as limited acoustic detections at the specific recording locations.

Summary of Results – North Atlantic Right Whale

- Only a single detection during the monitoring period, recorded at the shallow shelf site (A) in December 2011.
- No detections at mid-depth shelf or slope sites (B–E).
- Limited detections likely reflect spatial positioning of the recorders and reduced vocal behavior during migration rather than true absence.
- No seasonal or interannual patterns were observable in the acoustic dataset.

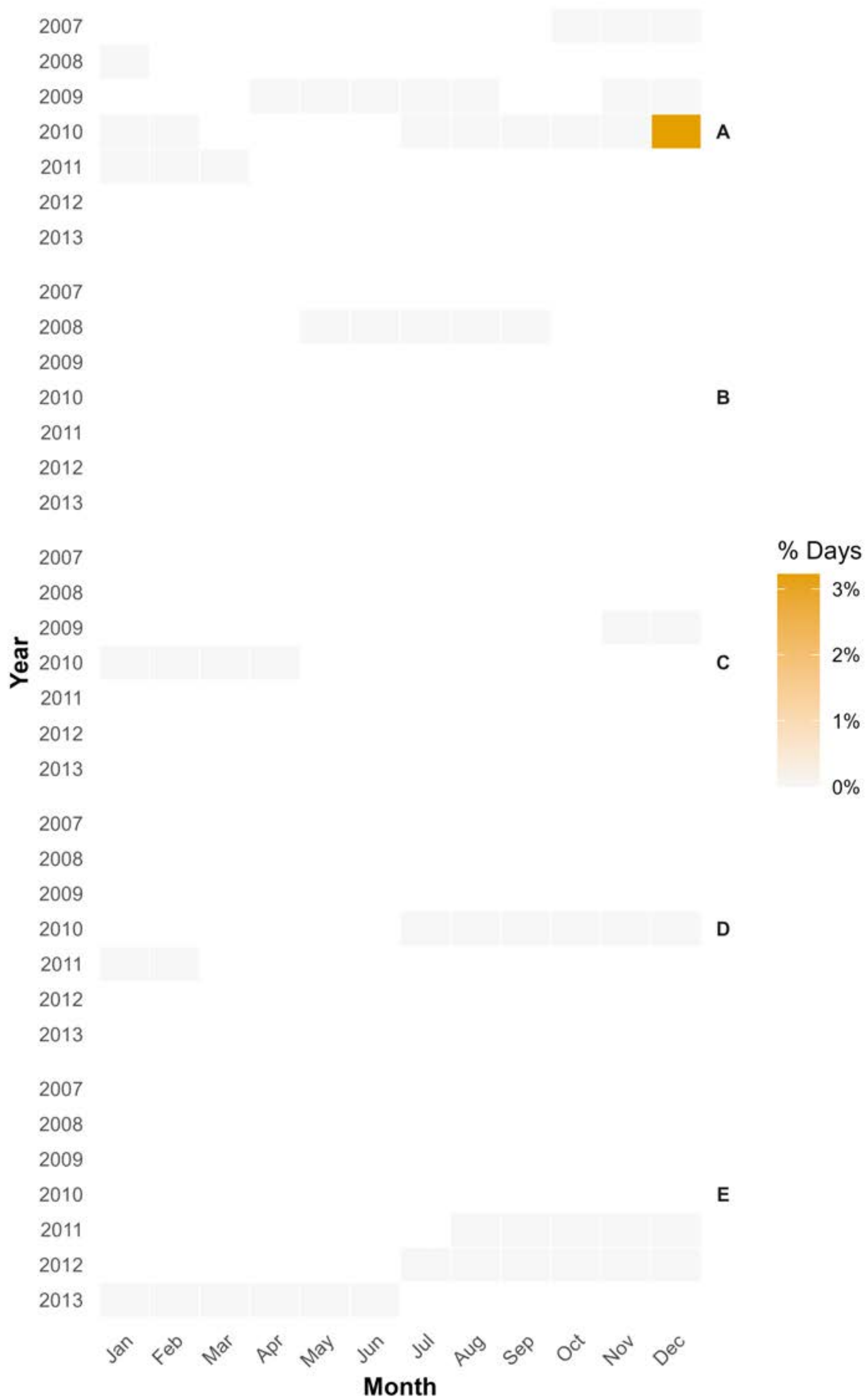

Figure 72: Annual monthly North Atlantic right whale acoustic presence at all Onslow Bay sites, represented as percentage of days with detections by month and year, corrected for effort by dividing the number of days with detections by the number of days with recordings. Gray boxes indicate periods when the acoustic recorders were active but no detections occurred, and white boxes represent months with no effort.

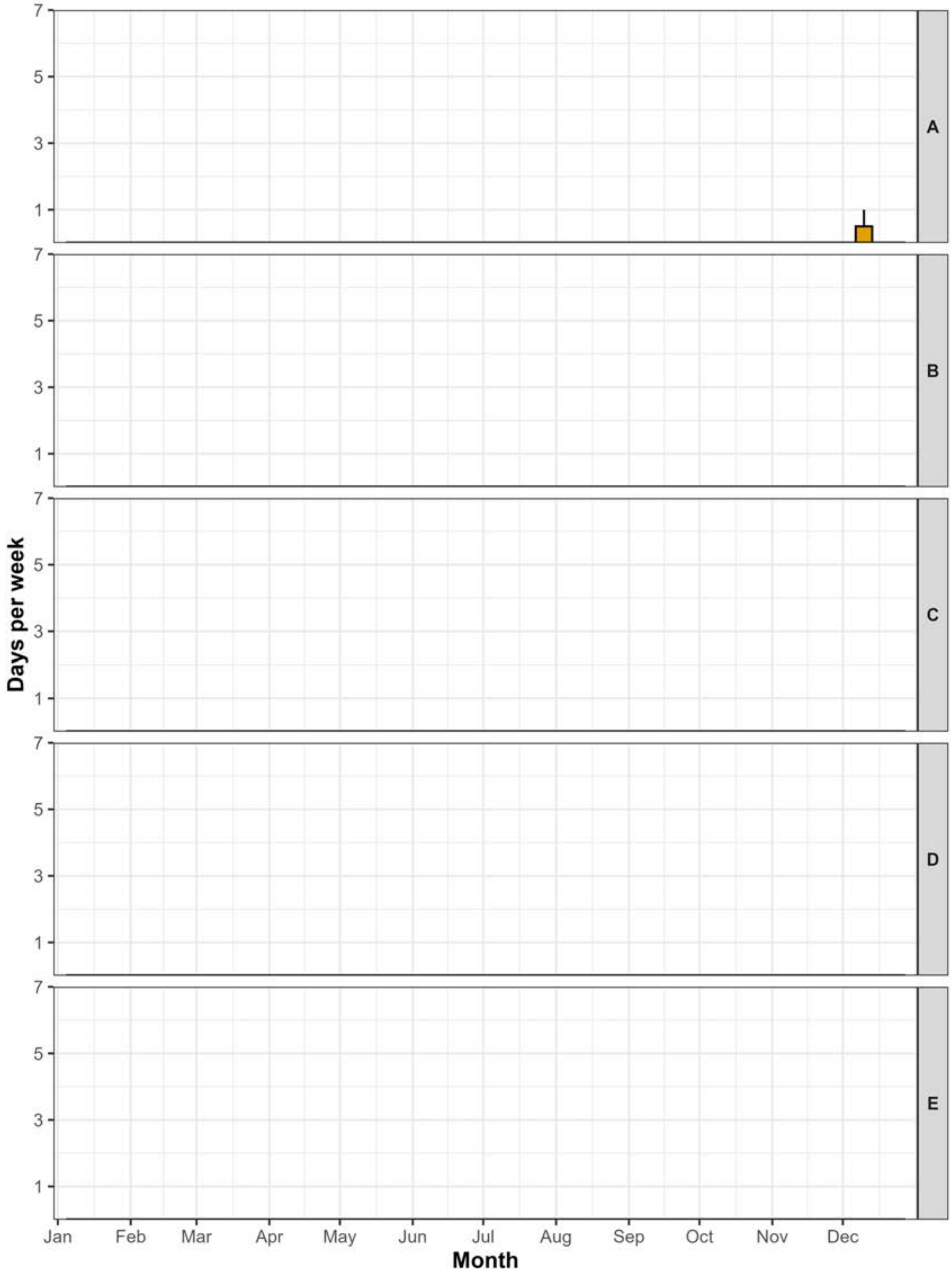

Figure 73: Average weekly acoustic presence of North Atlantic right whales (days per week) at all Onslow Bay sites. The boxplots show the interquartile range (box), median (line), data spread up to 1.5×IQR (whiskers), and outliers (dots). Points shown without boxes indicate limited data, where boxplot statistics could not be calculated.

5.3 Ambient Noise

Ambient sound levels at Onslow Bay between 2008 and 2013 reflected a combination of shipping, biological, and environmental sources, with depth playing a key role in shaping background levels. The five subsites, spanning shallow shelf (A), mid-depth shelf (B–D), and slope (E) waters, showed consistent gradients in spectral energy, with higher levels at the shelf sites and clearer biological contributions at the slope site (Figure 74; Figure 75).

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 (E), 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 and mid-depth shelf sites (A–C), 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 (E). Seasonal peaks at 20 Hz aligned with increased presence of fin whale vocalizations during winter and fall. 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 fall and winter months at all 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.

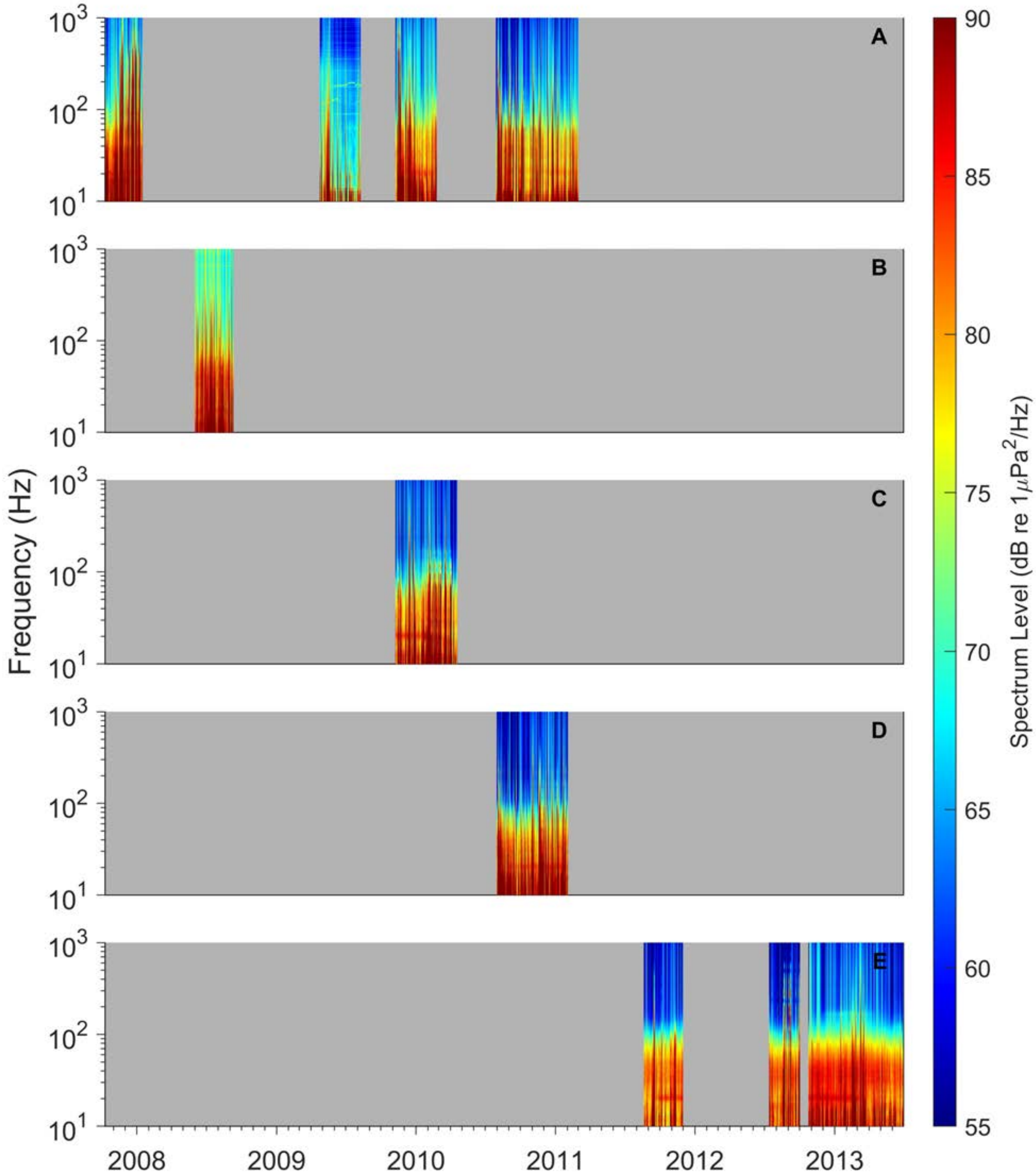

Figure 74: Long spectrograms using daily-averaged spectra for all Onslow Bay sites from 2008 to 2013. Gray blocks represent periods with no effort.

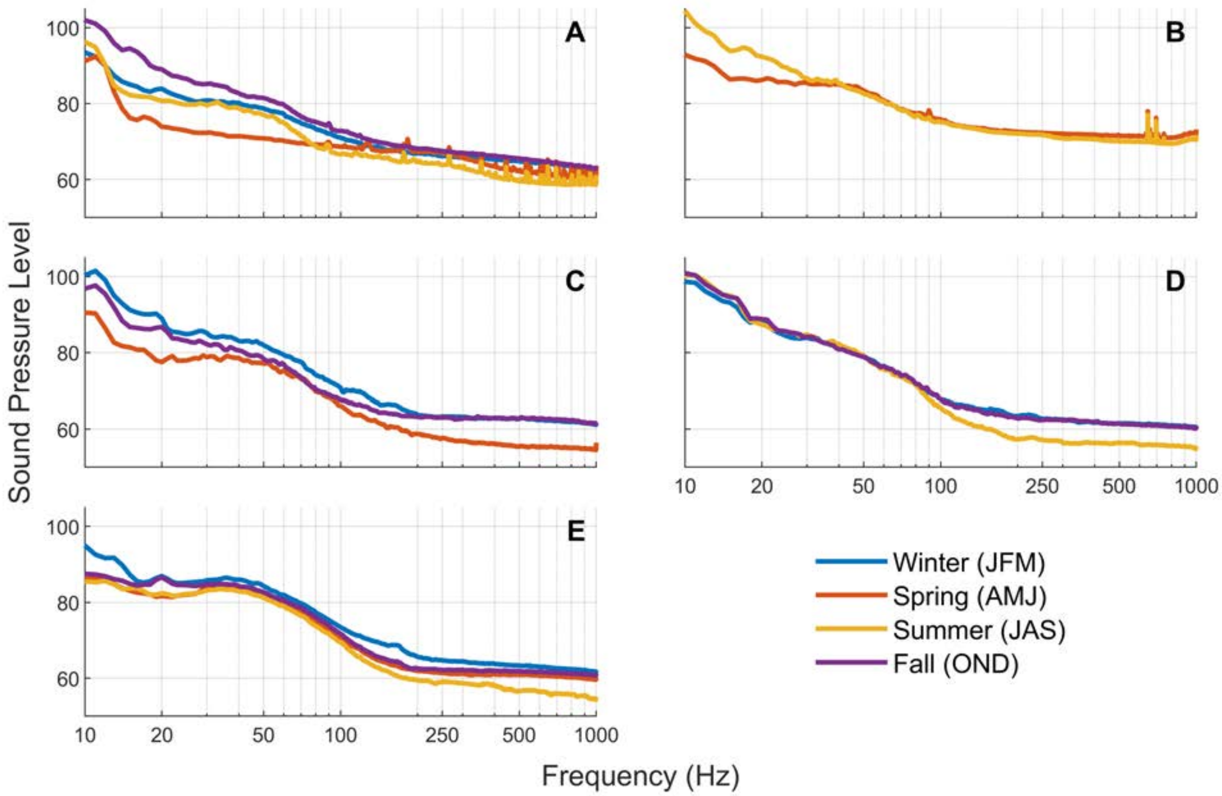

Figure 75: Full spectra averaged over each season for all Onslow Bay sites from 2008 to 2013. Winter is represented by January, February, March; spring as April, May, June; summer as July, August, September; and fall as October, November, and December.

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.
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