Steps toward Classification of Unidentified Odontocete Clicks within Passive Acoustic Recordings

Final Report

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Additional information on previous HARP deployments and availability of all associated reports is available on the project profile page of the U.S. Navy's Marine Species Monitoring Program web portal.

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Executive Summary

The U.S. Navy has been using High-frequency Acoustic Recording Packages (HARPs) to conduct passive acoustic monitoring in waters offshore of Virginia, North Carolina, and Florida to determine patterns of occurrence and distribution of cetacean species and anthropogenic sounds since 2007. Many baleen whale species and six known odontocete taxa (*Kogia* spp., Risso's dolphins (*Grampus griseus*), sperm whales (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavisrostris*), Gervais' beaked whale (*Mesoplodon europaeus*), and Blainville's beaked whale (*M. densirostris*)) had previously been identified within these recordings; however, a much larger number of detections of unidentified odontocete clicks remained. This work looked at steps toward classification of these unidentified odontocete clicks.

The objectives of this work were to assign click types to all available datasets from Norfolk Canyon, Cape Hatteras, Onslow Bay, and Jacksonville, using consistent methods for more comparable results; investigate possible spectral banding patterns in pilot whale clicks, using positional data from satellite tagged pilot whales to identify their clicks within the HARP records; and compare click types found at shallow versus deep Jacksonville sites to identify candidate Atlantic spotted dolphin click type(s).

Seven main click type groups and 13 minor click type groups were identified when combining templates from all HARP deployments. One of the main click type groups (composed of several different click type templates) may be associated with pilot whales (*Globicephala macrorhynchus*) as they have low peak frequencies, are associated with pilot whale-like calls, and were detected during times when satellite tagged pilot whales were within 5 nm of the HARPs. It is likely that bottlenose dolphins (*Tursiops truncatus*) and Atlantic spotted dolphins (*Stenella frontalis*), the two species most commonly observed in the shallower waters of Onslow Bay and Jacksonville, produce at least some of the remaining major click type groups based on their abundance in the acoustic recordings at those shallower locations.

In classifying the unidentified odontocete clicks to click type groups, a few interesting diel patterns emerged. Seasonal crepuscular patterns were seen for some click types. When these occurred, they did not appear at all sites within a main geographical area. This may be an indication of horizontal movement within a geographical area and/or a change in behavioral state only at specific sites.

The different click types that are thought to represent pilot whales also showed different diel patterns, perhaps related to differences in behavioral state, depth, or prey. Future work should include exploring the possibility of multiple pilot whale click types by examining the acoustic record for click types produced by satellite tagged pilot whales that approach within 2 nm of the HARP array system located in Cape Hatteras. Using this tracking array to look at specific depths of different click types would provide further information on the context in which various types are produced. In addition, combining the HARP array data with visual sighting information could assist in associating specific click types to a particular species. This would not only provide a closer look at how much variability is coming from individual animals and species, but also would assist in determining if multiple species (such as bottlenose dolphins and Atlantic spotted dolphins) share similar click types.

Overall, this work shows that there are categories of unidentified odontocete clicks that show promising structure for future classification as algorithms are developed further.

I. Introduction

A. Project Background

In October 2005, the U.S. Department of the Navy proposed the installation of an Undersea Warfare Training Range (USWTR) in one of four sites along the Atlantic coast, for the purpose of anti-submarine warfare training using mid-frequency tactical sonar (1-10 kHz) in outer continental shelf waters. The initial preferred site for the USWTR was Onslow Bay, North Carolina. As part of a multi-institutional monitoring plan for Onslow Bay, an acoustic monitoring effort, funded by the U.S. Atlantic Fleet, was initiated in 2007 by Duke University with assistance from Scripps Institution of Oceanography (SIO). In 2008, the preferred site was changed to Jacksonville, Florida. While acoustic monitoring continued in Onslow Bay, it also began in Jacksonville in 2009, once again led by Duke University with assistance from SIO. In broad support of Atlantic Fleet Training and Testing, acoustic monitoring later expanded to an area off Cape Hatteras, North Carolina (2012), and near Norfolk Canyon, off the coast of Virginia (2014). The primary objectives of the passive acoustic monitoring program are as follows:

1) Determine the patterns of occurrence of marine mammal species at each monitoring site;
2) Compare patterns of occurrence to better understand distributional patterns; and
3) Document species-specific characteristics of the vocalizations of marine mammals in each area.

B. Odontocetes in Study Areas

Odontocetes thought to be in the four main study areas include short-beaked common dolphins (*Delphinus delphis*), short-finned pilot whales (*Globicephala macrorhynchus*), long-finned pilot whales (*Globicephala melas*), Risso's dolphins (*Grampus griseus*), pygmy sperm whales (*Kogia breviceps*), dwarf sperm whales (*Kogia sima*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), Fraser's dolphin (*Lagenodelphis hosei*), Sowerby's beaked whales (*Mesoplodon bidens*), Blainville's beaked whales (*Mesoplodon densirostris*), Gervais' beaked whales (*Mesoplodon europaeus*), True's beaked whales (*Mesoplodon mirus*), killer whales (*Orcinus orca*), melon-headed whale (*Peponocephala electra*), false killer whales (*Pseudorca crassidens*), harbor porpoises (*Phocoena phocoena*), sperm whales (*Physeter macrocephalus*), Pantropical spotted dolphins (*Stenella attenuata*), Clymene dolphins (*Stenella clymene*), striped dolphins (*Stenella coeruleoalba*), Atlantic spotted dolphins (*Stenella frontalis*), spinner dolphins (*Stenella longirostris*), rough-toothed dolphins (*Steno bredanensis*), bottlenose dolphins (*Tursiops truncatus*), and Cuvier's beaked whales (*Ziphius cavirostris*). Based on visual surveys, two main species are present at the shallow water sites (<350 m) of Onslow Bay and Jacksonville: Atlantic spotted dolphins and bottlenose dolphins. For these two locations, spotted dolphins have only very rarely been observed in waters past the 200-m shelf break.

C. Odontocete Sounds

Odontocetes produce sounds that are separated into three categories: narrow-band tonal whistles, broad-band clicks, and broad-band burst-pulsed sounds (Richardson et al. 1995), although Murray et al. (1998) describes the graded nature of odontocete calls, categorizing them into two groups (whistles and clicks) with burst-pulses as intermediate sounds. The focus of this work was clicks, which can function in echolocation (to navigate through the environment and also to find prey; Au 1993) or possibly in communication (Watkins and Schevill 1977, Dawson 1991, Benoit-Bird and Au 2008), extend into the ultrasonic range, with frequencies ranging from less than 20 kHz to beyond 140 kHz for different species (Richardson et al. 1995). Although several species of odontocetes can now be identified based on their clicks (*e.g.*, sperm whales: Backus and Schevill 1966, Watkins and Schevill 1977, Weilgart and Whitehead 1988; Risso's dolphins and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*): Soldvilla *et al.* 2008; several beaked whale species: Baumann-Pickering *et al.* 2013), species specificity in clicks has not been identified for many delphinids.

D. Objectives of this Work

The objectives of the work reported here were as follows:

1) Assign click types to all available datasets from Norfolk Canyon, Cape Hatteras, Onslow Bay, and Jacksonville, keeping methods consistent and focusing on the overall goal of determining species identifications for the unidentified delphinid category;
2) Investigate possible spectral banding patterns in pilot whale clicks, using positional data from satellite tagged pilot whales to identify the occurrence of pilot whales near the Cape Hatteras and Norfolk Canyon HARPs and then identify pilot whale clicks within the HARP records; and
3) Compare click types found at shallow versus deep Jacksonville HARP sites, to facilitate the identification of candidate Atlantic spotted dolphin click type(s).

II. Methods

A. Instruments

Autonomous High-frequency Acoustic Recording packages (HARPs; Wiggins and Hildebrand 2007) were used to collect passive acoustic data in four main areas: Norfolk Canyon, VA; Cape Hatteras, NC; Onslow Bay, NC; and Jacksonville, FL. The HARP data-logging system includes a 16-bit analog-to-digital converter, a hydrophone suspended approximately 10-22 m above the seafloor depending on the mooring style, an acoustic release system, ballast weights, and flotation. The data-loggers are capable of sampling up to 320 kHz and can be set to record continuously or on a duty cycle to accommodate variable deployment durations. These instruments combine high- and low-frequency hydrophone elements to detect the vocalizations of both odontocete and mysticete cetaceans. The units sample at rates high enough to capture the clicks of many odontocetes.

B. Analysis

For this project, data were analyzed from a total of 32 HARP deployments: two deployments in Norfolk Canyon (one site), six in Cape Hatteras (two sites), ten in Onslow Bay (five sites), and 14 in Jacksonville (four sites) (**Figure 1**). **Table 1** includes the location, depth, deployment and retrieval dates, recording dates, information on duty cycle, and mooring type of the fourteen HARP deployments analyzed for this project. All HARPs analyzed here sampled at 200 kHz.

For this project, automated detectors were used to detect odontocete echolocation signals. These echolocation signals were detected using a modified version of a Teager energy detector (Soldevilla *et* *al.* 2008, Roch *et al.* 2011). Then, following Frasier *et al.* (2017), detections were divided into successive five-minute windows from which dominant click types were identified automatically. An automated clustering algorithm was used to identify recurrent types based on spectral features (focusing on the frequency band between 10 – 60 kHz) and inter-click interval (ICI) distributions (Frasier *et al.* 2017). Recurrent types were used as templates. Initially, templates were created for each deployment separately. From these, major click templates were selected and then all selected templates were compared and the best examples were combined together to make a merged template database to use on all datasets, with the exception of one click type from Norfolk Canyon. This single Norfolk Canyon click type was only used when classifying clicks for that site, the reason for which will be discussed later. Templates were attributed to a specific species if known (*e.g.*, Risso's dolphins, Cuvier's beaked whales, Gervais' beaked whales) or assigned a number if the species was unknown. Finally, the algorithm matched click types within each five-minute window to template if there was a strong match, otherwise labeled them as unknown.

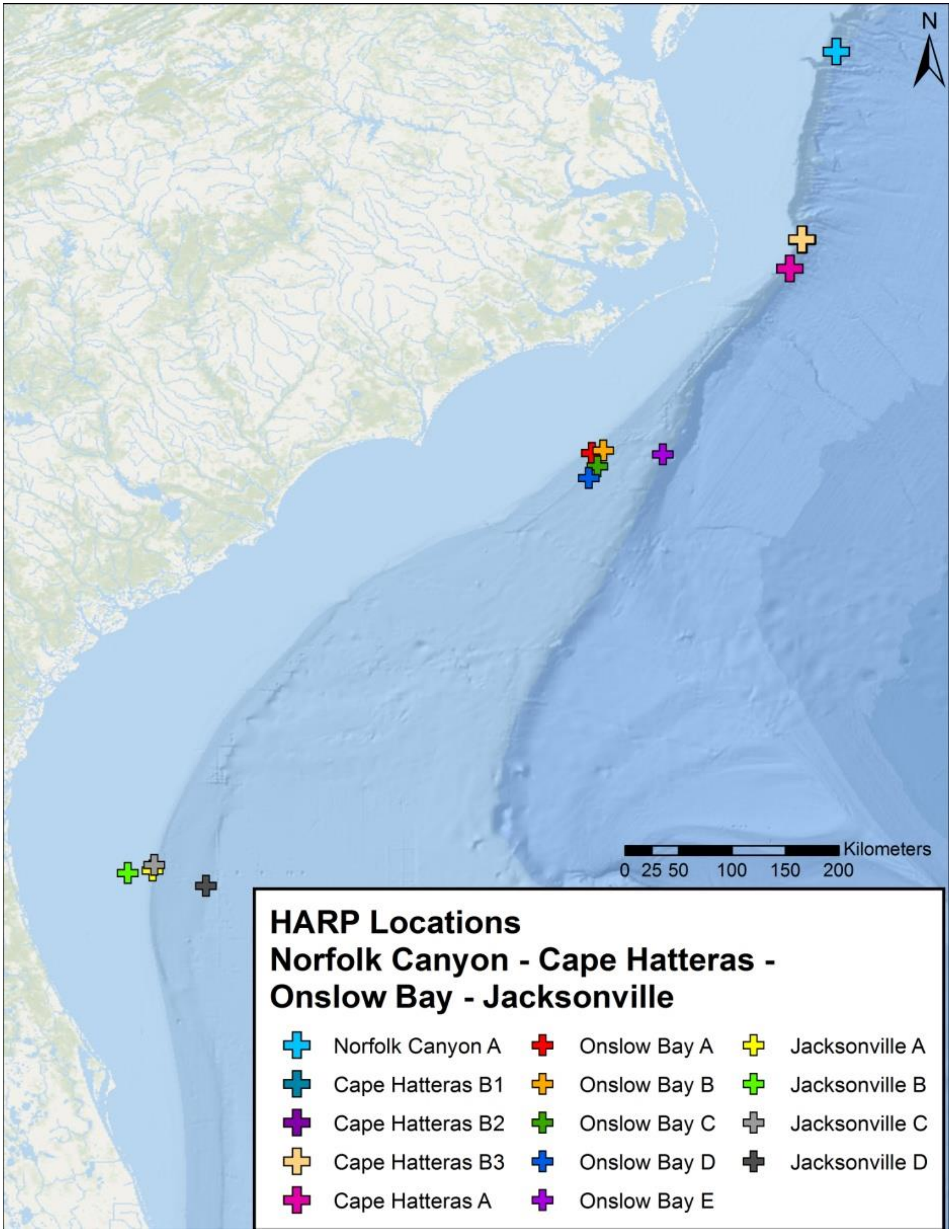


Figure 1. Locations of HARP deployments. Cape Hatteras Sites B1, B2, and B3 are located within approximately 1 km of each other in a triangular tracking array formation.

Table 1. Details of HARP deployments in Norfolk Canyon, Cape Hatteras, Onslow Bay, and Jacksonville used in this analysis.

NORFOLK CANYON												
Location	Deployment ID	Latitude	Longitude	Depth (m)	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Duty Cycle (min on/off)	Mooring Type	Status of Analysis	Reports
Norfolk Canyon A	NFC01A	37.16623	-74.46692	982	19JUN14	07APR15	19JUN14	05APR15	continuous	compact	HF, LF	S, D
Norfolk Canyon A	NFC02A	37.1652	-74.4666	968	30APR16	30JUN17	30APR16	28JUN17	continuous	compact	In progress	

CAPE HATTERAS												
Location	Deployment ID	Latitude	Longitude	Depth (m)	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Duty Cycle (min on/off)	Mooring Type	Status of Analysis	Reports
Cape Hatteras A	HAT01A	35.34054	-74.85761	950	15MAR12	09OCT12	15MAR12	11APR12	continuous	large	HF, LF	S
Cape Hatteras A	HAT02A	35.3406	-74.85590	970	09OCT12	29MAY13	09OCT12	09MAY13	continuous	large	HF, LF	S, D
Cape Hatteras A	HAT03A	35.34445	-74.8521	970	29MAY13	8MAY14	29MAY13	15MAR14	continuous	large	HF, LF	S, D
Cape Hatteras A	HAT04A	35.34677	-74.84805	850	08MAY14	06APR15	9MAY14	11DEC14**	continuous	large	HF, LF	S, D
Cape Hatteras A	HAT05A	35.34218	-74.85726	980	06APR15	29APR2016	07APR15	21JAN16	continuous	compact	HF, LF	S, D
Cape Hatteras A	HAT06A	35.3057	-74.8776	1020	29APR16	9MAY17	29APR16	6FEB17	continuous	compact	In progress	

ONSLOW												
Location	Deployment ID	Latitude	Longitude	Depth (m)	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Duty Cycle (min on/off)	Mooring Type	Status of Analysis	Reports
Onslow Bay A	USWTR01A	33.79138	-76.52382	162	09OCT07	27MAY08	10OCT07	16JAN08	5/5*	large	HF, LF	S
Onslow Bay B	USWTR02B	33.81107	-76.42829	232	30MAY08	24NOV08	30MAY08	10SEP08	5/5	large	HF, LF	S
Onslow Bay A	USWTR03A	33.78951	-76.51920	174	24APR09	16SEP09	24APR09	09AUG09	5/5	large	HF, LF	S
Onslow Bay A	USWTR04A	33.78733	-76.52409	171	08NOV09	19JUN10	08NOV09	24FEB10	5/10	large	HF, LF	S
Onslow Bay C	USWTR04C	33.67784	-76.47689	335	08NOV09	19JUN10	08NOV09	20APR10	5/10	large	HF, LF	S
Onslow Bay A	USWTR05A	33.79316	-76.51620	171	29JUL10	10JUN11	30JUL10	03MAR11	5/5	large	HF, LF	S
Onslow Bay D	USWTR05D	33.58065	-76.55015	338	29JUL10	10JUN11	30JUL10	24FEB11	5/5	large	HF, LF	S
Onslow Bay E	USWTR06E	33.77794	-75.92641	952	18AUG11	13JUL12	19AUG11	01DEC11	5/5	large	HF, LF	S, D
Onslow Bay E	USWTR07E	33.78666	-75.92915	914	13JUL12	24OCT12	14JUL12	02OCT12	5/5	large	HF, LF	S, D
Onslow Bay E	USWTR08E	33.78696	-75.92801	853	24OCT12	08AUG13	24OCT12	30JUN13	5/5	large	HF, LF	S

JACKSONVILLE												
Location	**Deployment ID**	**Latitude**	**Longitude**	**Depth (m)**	**Deployment Date**	**Retrieval Date**	**Recording Start Date**	**Recording End Date**	**Duty Cycle (min on/off)**	**Mooring Type**	**Status of Analysis**	**Reports**
JAX A	JAX01A	30.2771	-80.1258	82	30MAR09	16SEP09	02APR09	25MAY09	5/10	large	HF	S
JAX B	JAX01B	30.2582	-80.4282	37	30MAR09	16SEP09	02APR09	05SEP09	5/10	large	HF, M	S
JAX A	JAX02A	30.28052	-80.21603	83	16SEP09	21FEB10	16SEP09	15DEC09	5/10	large	HF, M	S
JAX A	JAX03A	30.28111	-80.21530	89	21FEB10	26AUG10	22FEB10	30JUL10	5/10	large	HF, M	S
JAX B	JAX04B	30.25919	-80.42566	38	09MAR10	26AUG10	09MAR10	19AUG10	5/10	large	HF, LF	S, D
JAX A	JAX05A	30.26819	-80.20894	91	26AUG10	01FEB11	26AUG10	25JAN11	5/10	large	HF, LF	S, D
JAX B	JAX05B	30.25708	-80.43269	37	26AUG10	01FEB11	27AUG10	01FEB11	5/10	large	HF, LF	S, D
JAX A	JAX06A	30.27818	-80.22085	91	01FEB11	14JUL11	01FEB11	14JUL11	5/10	large	HF, LF	S, D
JAX B	JAX06B	30.25768	-80.42781	37	02FEB11	14JUL11	02FEB11	14JUL11	5/10	large	HF, LF	S, D
JAX C	JAX09C	30.33287	-80.20071	94	12MAY13	17FEB14	13MAY13	20JUN13	continuous	large	HF, LF	S, D
JAX C	JAX10C	30.32643	-80.20493	88	17FEB14	23AUG14	17FEB14	23AUG14	continuous	small	HF, LF	S, D
JAX D	JAX11D	30.15060	-79.77005	806	23AUG14	2JUL15	23AUG14	29MAY15	continuous	small	HF, LF	S, D
JAX D	JAX12D	30.1489	-79.7711	800	02JUL15	26APR16	02JUL15	04NOV15	continuous	small	HF, LF	S, D
JAX D	JAX13D	30.1518	-79.7702	736	26APR16	25JUN17	26APR16	25JUN17	continuous	compact	HF, LF	Report

Notes: All HARPs sampled at 200 kHz. For Status of Analysis: HF = high-frequency (odontocete, > 1 kHz) analysis completed; LF = low-frequency (mysticete, < 1 kHz) analysis completed; M = low-frequency analysis completed only for minke whale pulse trains; For Reports: S = summary report; D = detailed technical report; Key: * = represents the initial duty cycle, but instrument recorded continuously starting 01 January 2008. ** = represents end of normal recording – there were four more files on four different days between 26DEC14 and 15JAN15 (skipping caused by disk error issues).

III. Results

One objective of this work was to assign click types to all available HARP datasets collected in Norfolk Canyon, Cape Hatteras, Onslow Bay, and Jacksonville, using consistent methods to make results more comparable. Previous reports have provided details on the occurrence of odontocetes that can be identified to clicks (Risso's dolphins, sperm whales, *Kogia* spp., beaked whales). Thus, these groups are not reported on here. This research focused on the goal of determining species identifications for the unidentified delphinid category.

Seven main click type groups and 13 minor click type groups were identified when combining the templates from all HARP deployments. Variations (possibly due to geographical differences) existed for some click types, so multiple templates were used in those cases but results were merged to show overall temporal and spatial patterns. Some of the minor click types perhaps could have been merged with others. One click type (***Group D***) was only detected at Norfolk Canyon. It was a major click type for that area. It was originally included in the combined template database run on all datasets, but later removed and only used for Norfolk Canyon as it seemed similar to two of the other main click types. One grouping of click types (***Group G***) included some spectra that were similar but also some that were quite different. It is thought that this grouping represents pilot whale click types as they have low peak frequencies, are associated with pilot whale-like calls, and show up consistently when comparing times that satellite tagged pilot whales were within 5 nm of the HARPs.

Snapping shrimp were often detected in the acoustic record from Jacksonville Site B. These likely caused misclassifications for some click types and since there was no manual review of the automated click type assignments, click classifications from this site may be less reliable.

A. Click Types

In each of the figures for each click type grouping that follow, the top panel shows the average spectra and ICIs for each template used and the bottom panel shows the temporal patterns of the click types found at each site (Norfolk Canyon; Hatteras Site B; Hatteras Site A; Onslow Bay Site A; Onslow Bay Sites B, C, and D combined; Onslow Bay Site E; Jacksonville Site A; Jacksonville Site B; Jacksonville Site C; and Jacksonville Site D). In the bottom panel, the horizontal bars (or dots) represent the detections (black unless indicated on spectra in top panel, different colors if there was uncertainty as to its inclusion in the group), and the dark gray vertical shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated either by red horizontal lines (Norfolk Canyon and Jacksonville Site D) or lighter horizontal shading (all others). For Onslow Bay, Sites B, C, and D are combined in one diel plot.

1. Major Click Types

The following figures show the templates used and the temporal patterns at each location for the major groupings of click types. The following tables provide information on the modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in the major groups. Only frequency peaks and notches greater than or equal to 10 kHz and less than or equal to 60 kHz were included. Frequencies less than 10 kHz were not included as they could include boat noise, portions of whistles, sonar, or other low-frequency sounds. Frequencies greater than 60 kHz were not included as those frequencies were not examined in this study. Frequencies outside of the 10-60 kHz range may also contain valuable species information and thus should be examined further in the future.

a. Group A

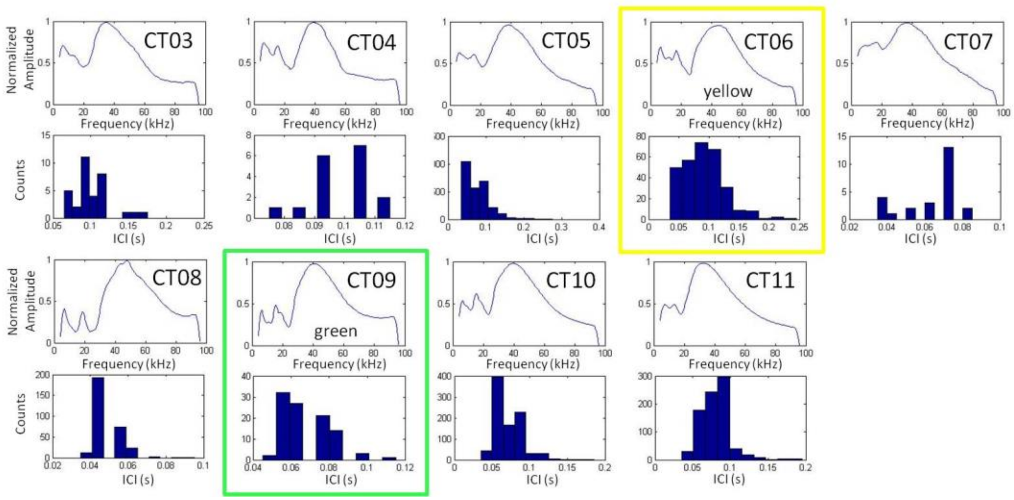


Figure 2. Group A click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

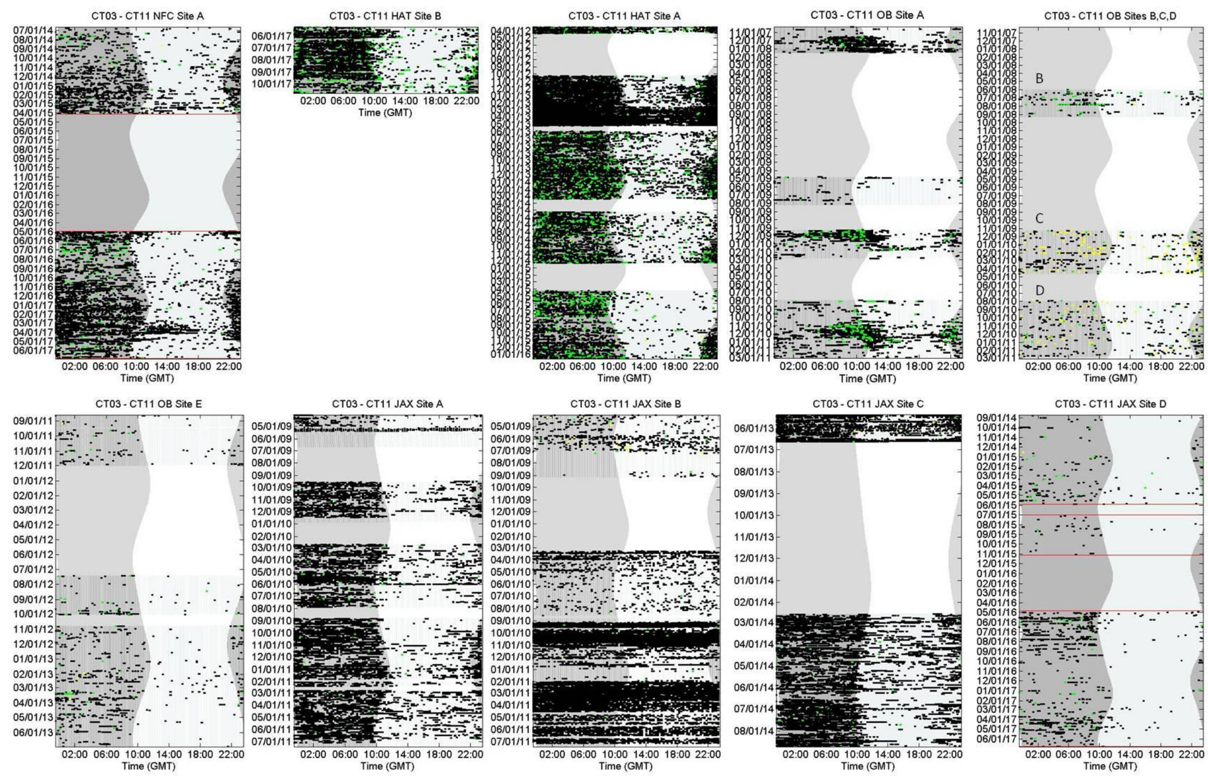


Figure 3. Group A click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 2. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group A. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT03	0.095	13.3, 34.9	12.2, 20.0
CT04	0.105	15.7, 39.2	12.2, 24.3
CT05	0.035	15.7, 38.8	12.2, 21.2
CT06	0.095	12.2, 16.9, 45.1	10.2, 14.1, 25.5
CT07	0.075	16.5, 36.5	11.4, 20.8
CT08	0.045	18.8, 47.8	13.7, 23.5
CT09	0.055	11.0, 15.7, 40.8	12.2, 23.9
CT10	0.055	15.3, 39.6	11.4, 23.1
CT11	0.075	13.3, 32.5	10.6, 17.6

This group of click types was detected at all sites. It had a strong nocturnal presence at all sites except for Jacksonville Site B and Onslow Bay Site A. At Jacksonville Site B, there was no obvious diel pattern but there were fewer detections during summer months. At Onslow Bay Site A, this group of click types had a strong crepuscular presence, with a strong pulse of longer-duration and clustered click events in the late night-dawn-early morning period. This diel pattern, which was seasonal (starting in November and lasting through January), was not seen at the other Onslow Bay sites for ***Group A*** click types. The only other potential seasonal pattern was at Jacksonville Site D, with possibly more detections between April and August. In general, this group of click types was detected in much greater numbers at sites that were closer to shore, regardless of depth.

b. Group B

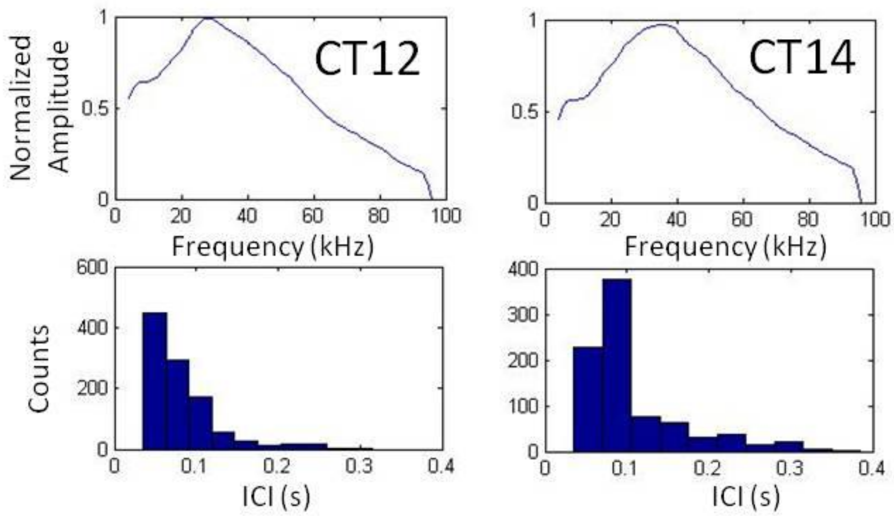


Figure 4. Group B click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of both spectra are represented by black dots/horizontal bars.

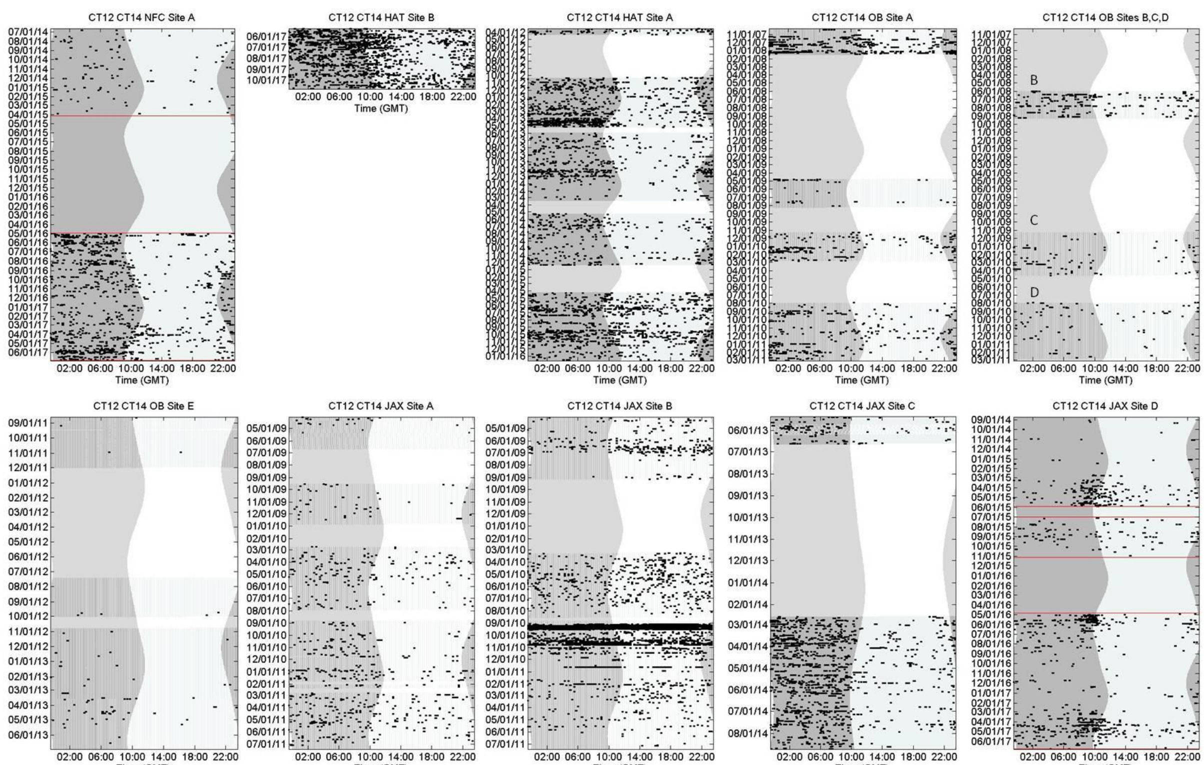


Figure 5. Group B click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 3. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group B. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT12	0.035	28.2	N/A
CT14	0.085	35.7	N/A

This group of click types also was detected at all sites. For most sites, its diel pattern was not as clear, although there was more of a nocturnal presence at Jacksonville Site C and a crepuscular presence at Jacksonville Site D. There were no obvious seasonal patterns for this group, except at Jacksonville Site D, where these click types occurred more often between March and June, and possibly at Jacksonville Site B, with more detections between September and October.

c. Group C

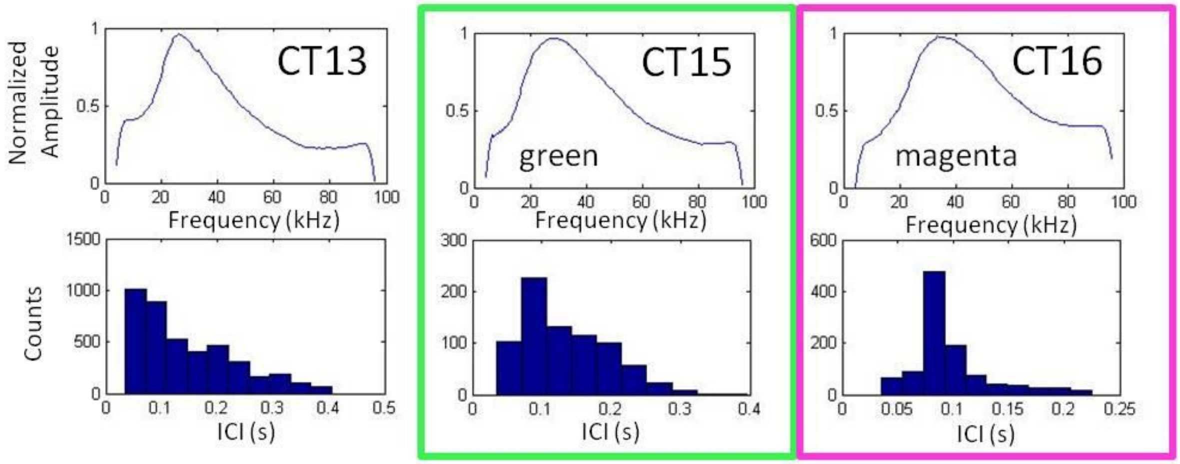


Figure 6. Group C click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

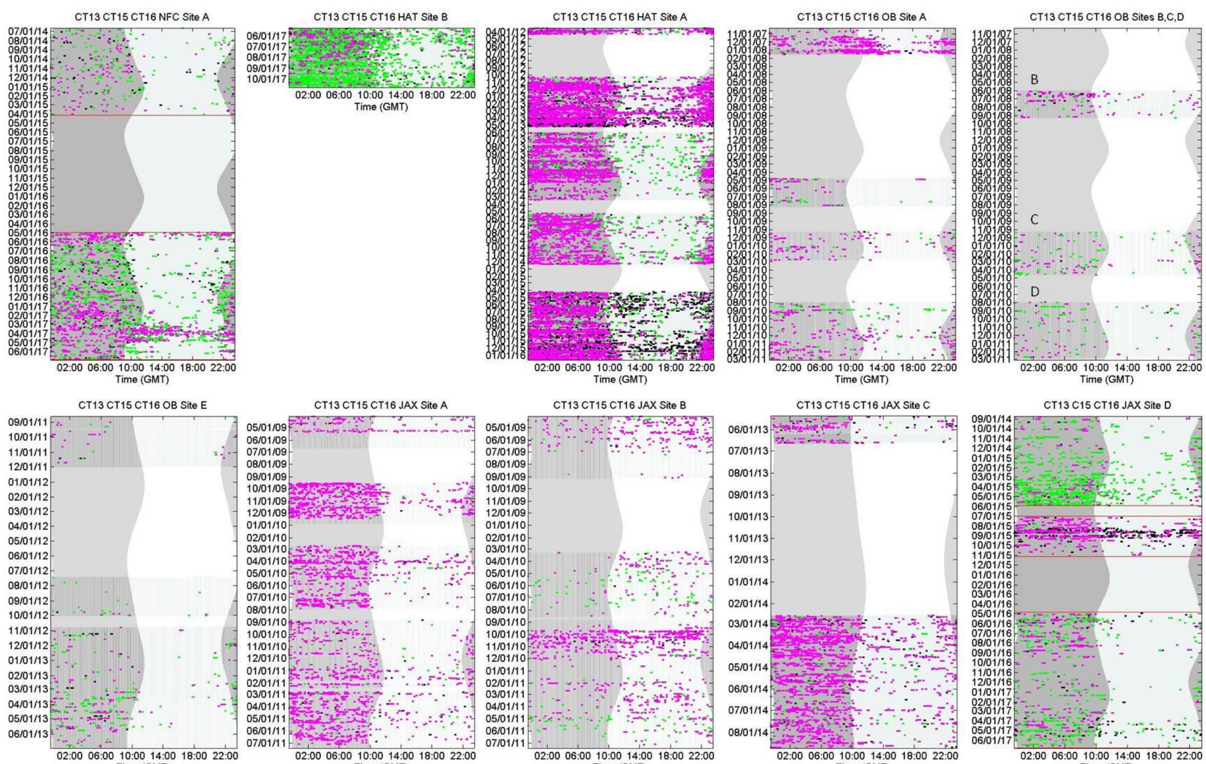


Figure 7. Group C click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 4. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group C. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT13	0.035	26.3	N/A
CT15	0.085	29.0	N/A
CT16	0.075	33.3	N/A

This group of click types was detected at all sites as well. It mainly had a nocturnal presence, although it had no diel pattern at Jacksonville Site B and the pattern at Onslow Bay Site A was unclear (with a crepuscular occurrence during the first deployment but not afterward). There were no obvious seasonal patterns for this group, except at Jacksonville Site D, where these click types occurred more often between March and September, and possibly at Jacksonville Site B, with more detections between September and November.

d. Group D

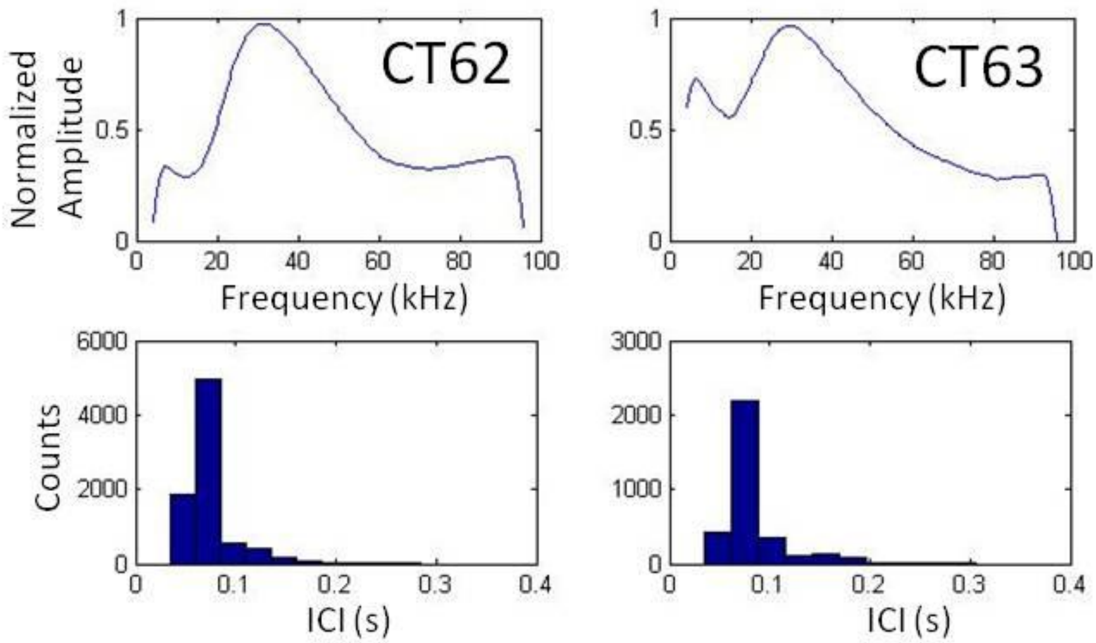


Figure 8. Group D click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of both spectra are represented by black dots/horizontal bars.

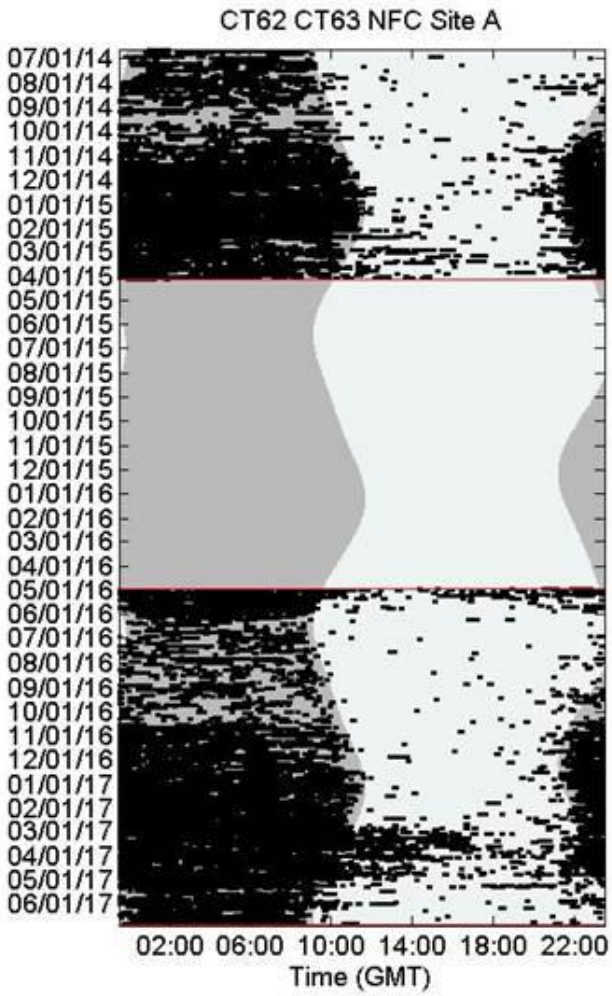


Figure 9. Group D click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 5. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group D. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT62	0.075	31.8	12.5
CT63	0.075	29.8	14.9

This group, which was only found in the Norfolk Canyon data, showed a very strong nocturnal pattern. Although there were very high numbers of detections year round, there seemed to be slightly fewer during late summer-early fall.

e. Group E

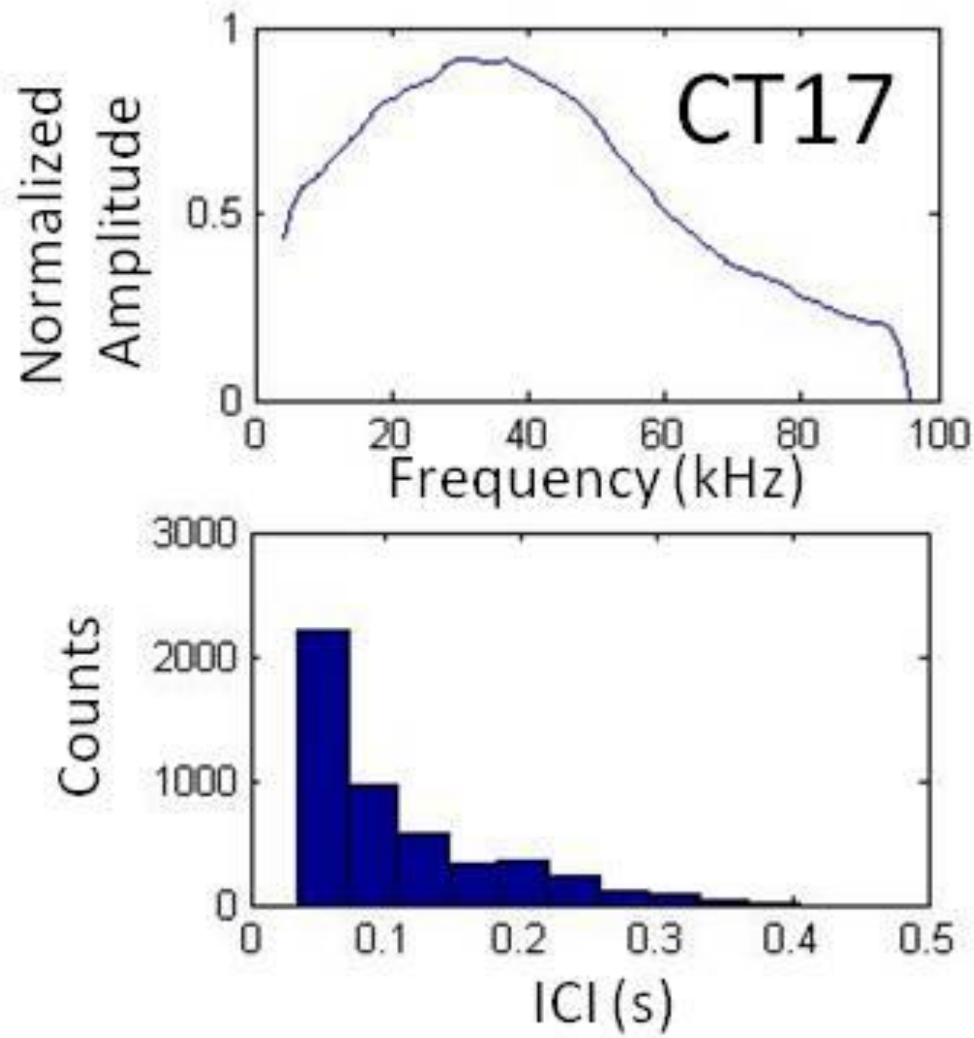


Figure 10. Group E click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

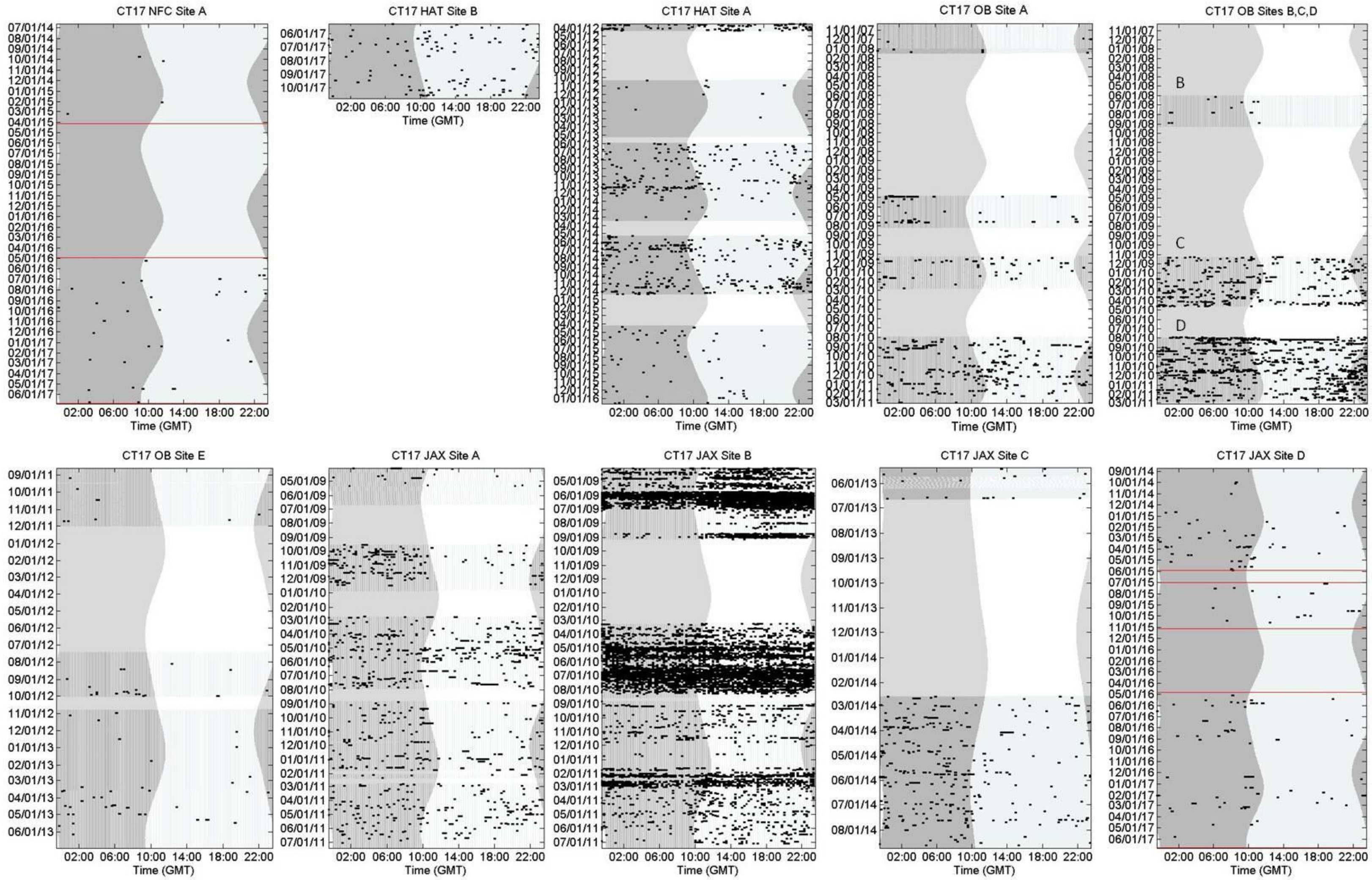


Figure 11. Group E click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 6. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group E. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT17	0.035	35.7	N/A

This group was present at all sites, with no obvious diel or seasonal pattern.

f. **Group F**

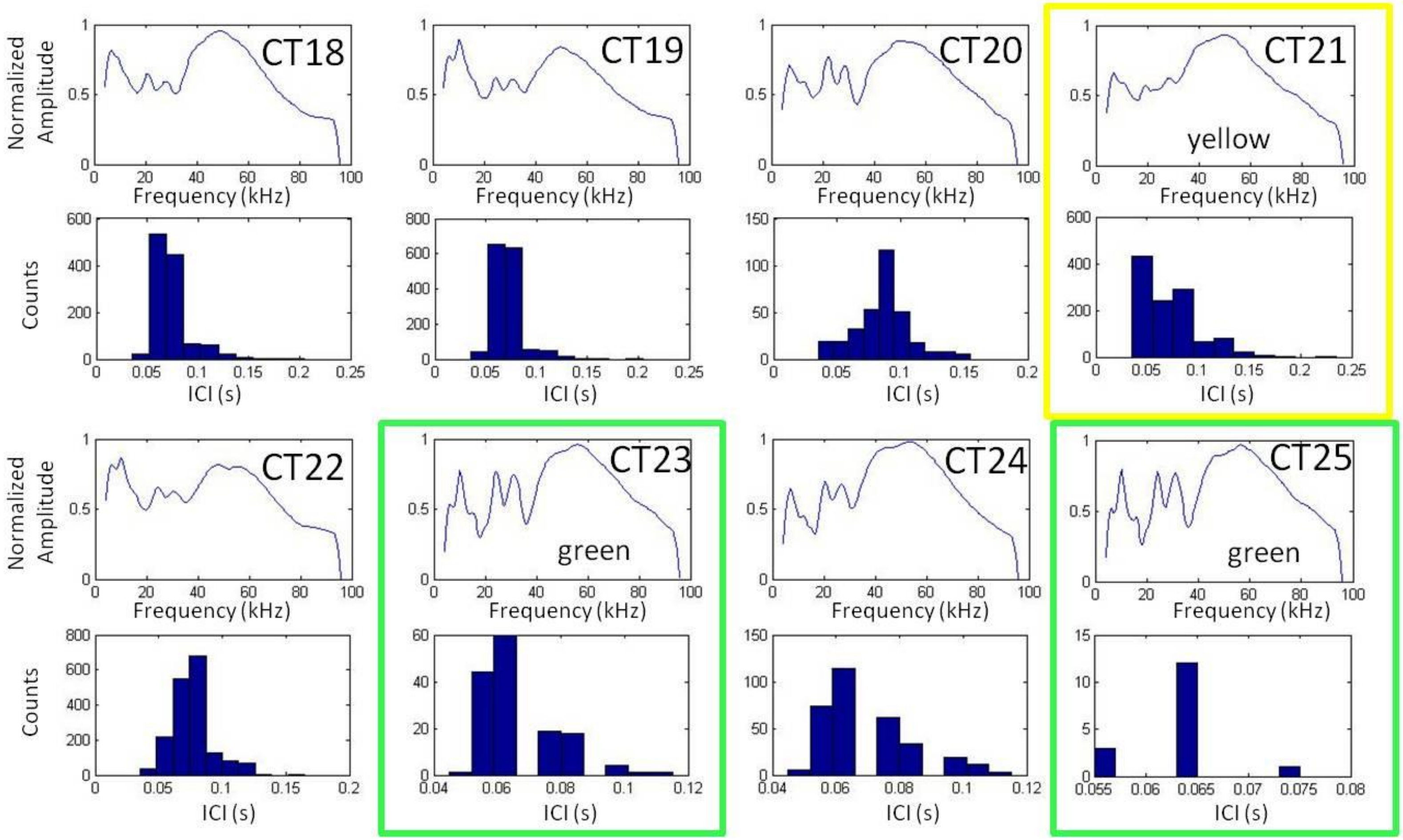


Figure 12. Group F click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

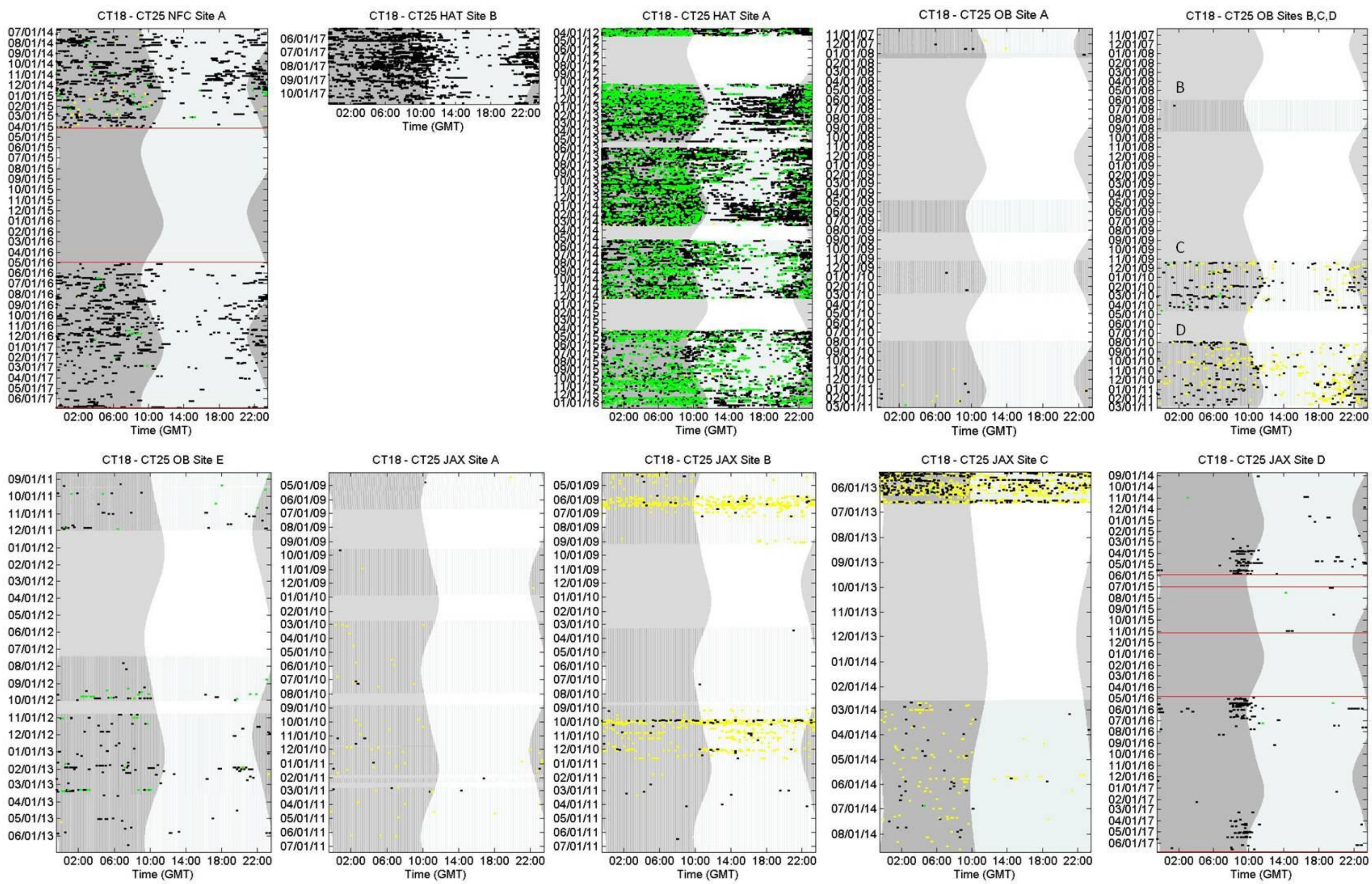


Figure 13. Group F click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 7. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group F. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT18	0.065	20.8, 27.8, 49.4	16.9, 24.3, 31.8
CT19	0.075	10.2, 24.7, 31.4, 49.8	20.4, 27.8, 35.7
CT20	0.095	12.5, 22.4, 28.6, 50.2	11.4, 16.1, 25.5, 33.3
CT21	0.035	11.0, 19.2, 28.2, 49.8	10.2, 16.1, 21.2, 31.0
CT22	0.065	10.2, 24.7, 30.6, 48.2, 56.1	19.6, 27.5, 35.3, 52.2
CT23	0.065	10.2, 14.9, 24.3, 31.4, 56.1	13.7, 18.0, 27.5, 36.1
CT24	0.065	12.2, 20.4, 27.1, 45.5, 53.3	11.0, 16.5, 23.1, 31.0, 45.9
CT25	0.065	10.2, 16.1, 24.3, 31.0, 47.1, 56.5	14.9, 18.0, 27.1, 36.1, 48.2

This group mainly showed nocturnal patterns of occurrence, although there was no clear pattern at Jacksonville Sites B and C and a crepuscular pattern was seen at Jacksonville Site D. This group only showed seasonal patterns at Jacksonville Site D, where it was most commonly detected between April and June.

g. Group G

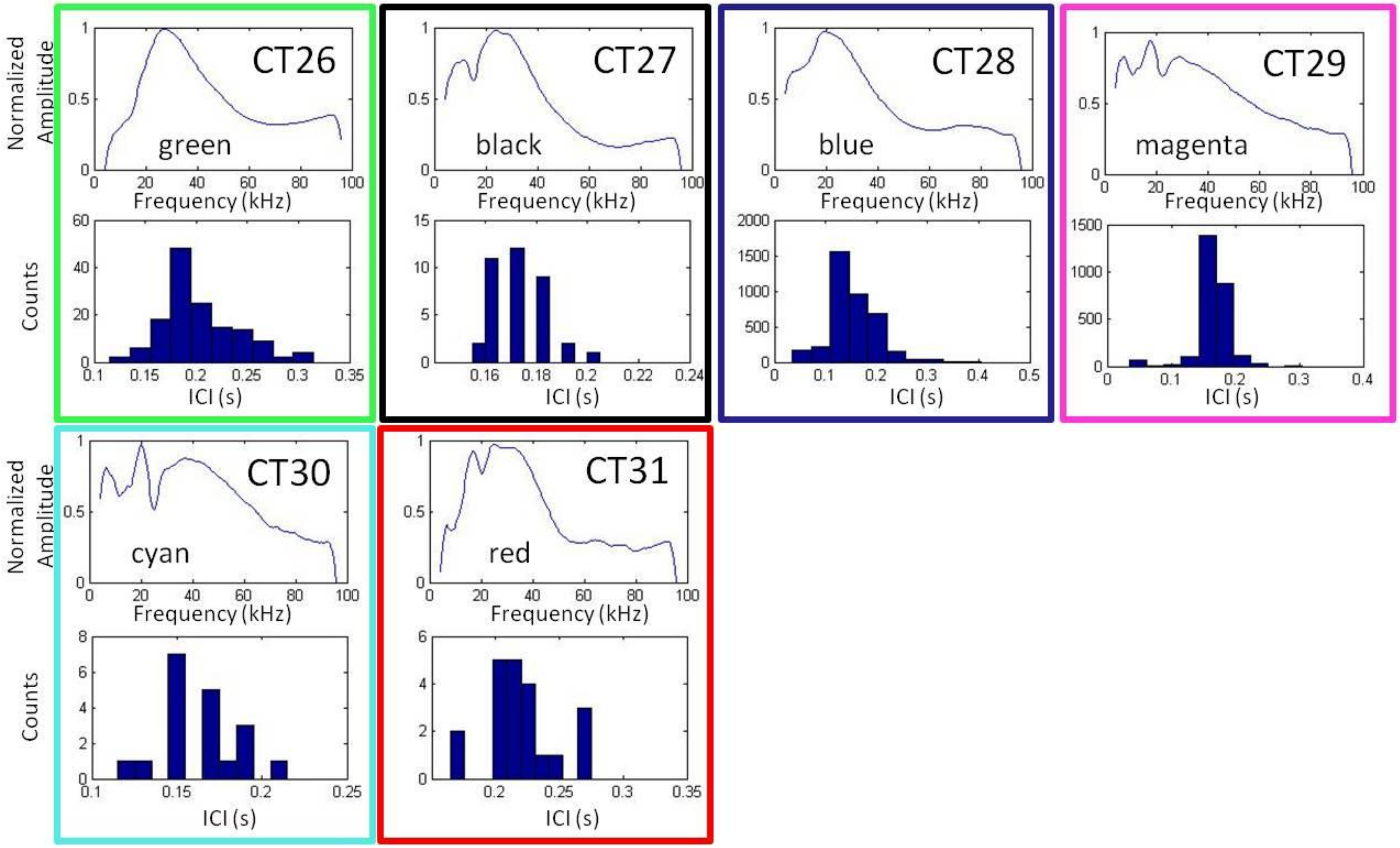


Figure 14. Group G click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of each spectrum are represented by the name of the color that appears within the mean frequency spectrum plot.

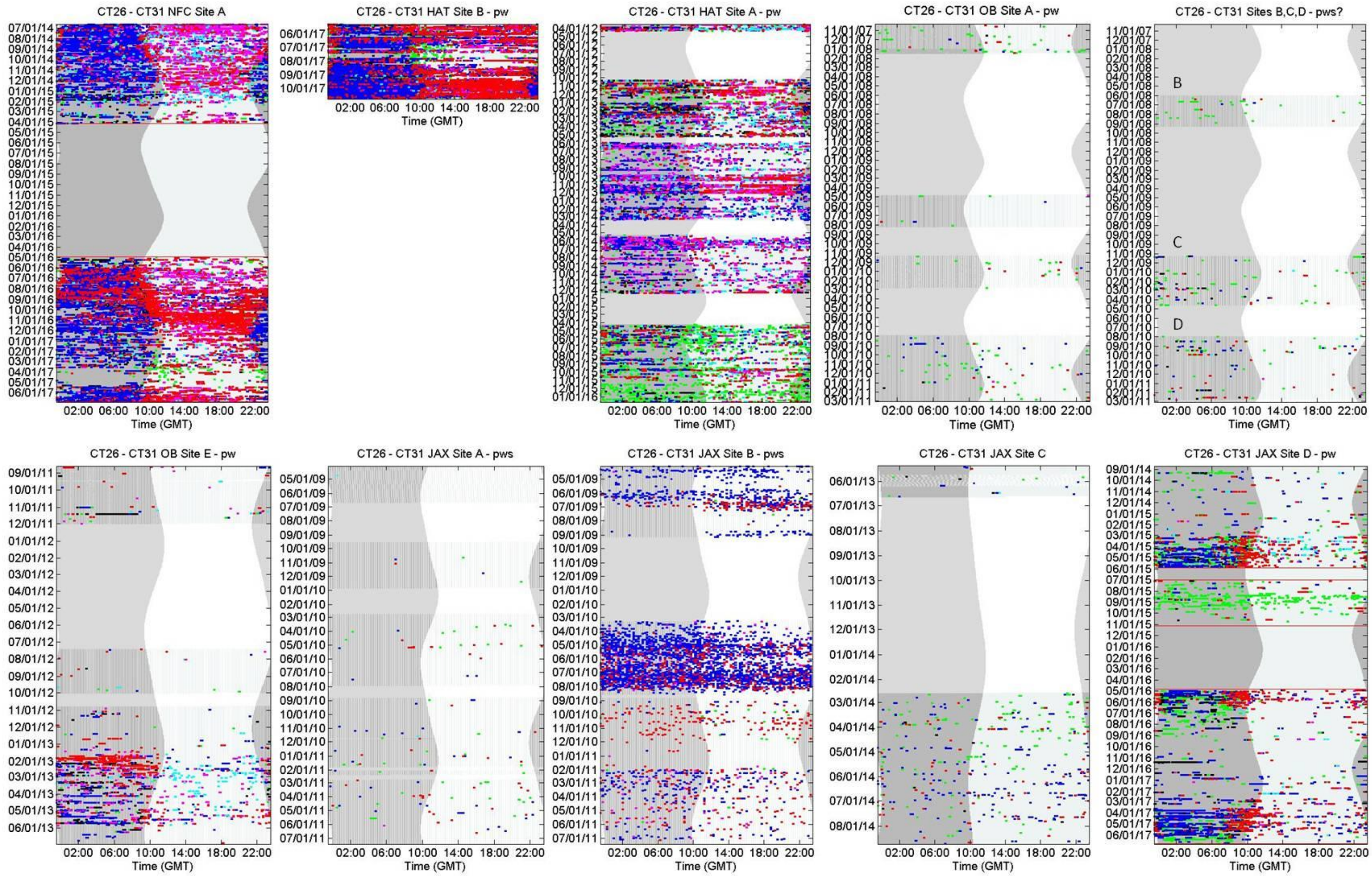


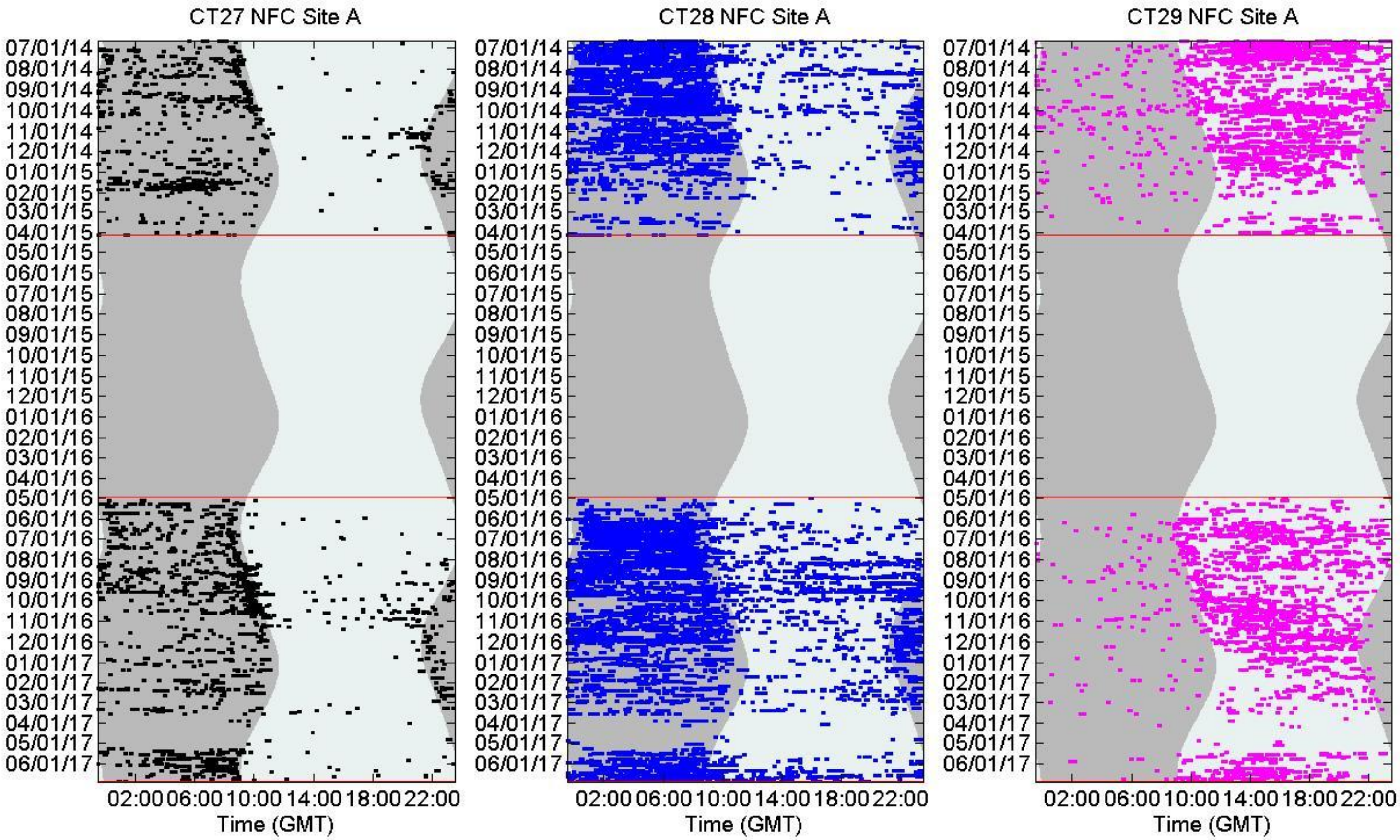
Figure 15. Group G click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by different colors including black.

Table 8. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group G. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT26	0.185	27.5	N/A
CT27	0.175	11.4, 23.9, 27.5	15.3, 27.1
CT28	0.135	20.0	N/A
CT29	0.155	12.5, 17.6, 29.0	11.0, 13.7, 22.4
CT30	0.165	14.9, 20.0, 36.9	11.8, 15.7, 25.1
CT31	0.205	16.9, 24.7, 29.4	20.4, 28.2

This group, composed of the possible pilot whale click types which will be discussed in more detail below (see Section 3 under Click Types in Results and Section B of Discussion), showed different diel patterns depending on click type template. The detections at Jacksonville Site B should be viewed with caution as they may include snapping shrimp. Aerial surveys in the Jacksonville study area have found short-finned pilot whales in waters greater than 200 m only so it is likely that the detections at Jacksonville Site B are misclassifications. Seasonal patterns for ***Group G*** were only seen at Jacksonville Site D (with detections occurring more between March and August) and potentially at Onslow Bay Site E (with detections occurring more between February and May).

The following figures highlight the diel patterns for the major clicks types found at each of the deep water sites.


CT27 NFC Site A
CT28 NFC Site A
CT29 NFC Site A
07/01/14
08/01/14
09/01/14
10/01/14
11/01/14
12/01/14
01/01/15
02/01/15
03/01/15
04/01/15
05/01/15
06/01/15
07/01/15
08/01/15
09/01/15
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11/01/15
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10/01/16
11/01/16
12/01/16
01/01/17
02/01/17
03/01/17
04/01/17
05/01/17
06/01/17
02:00 06:00 10:00 14:00 18:00 22:00
Time (GMT)

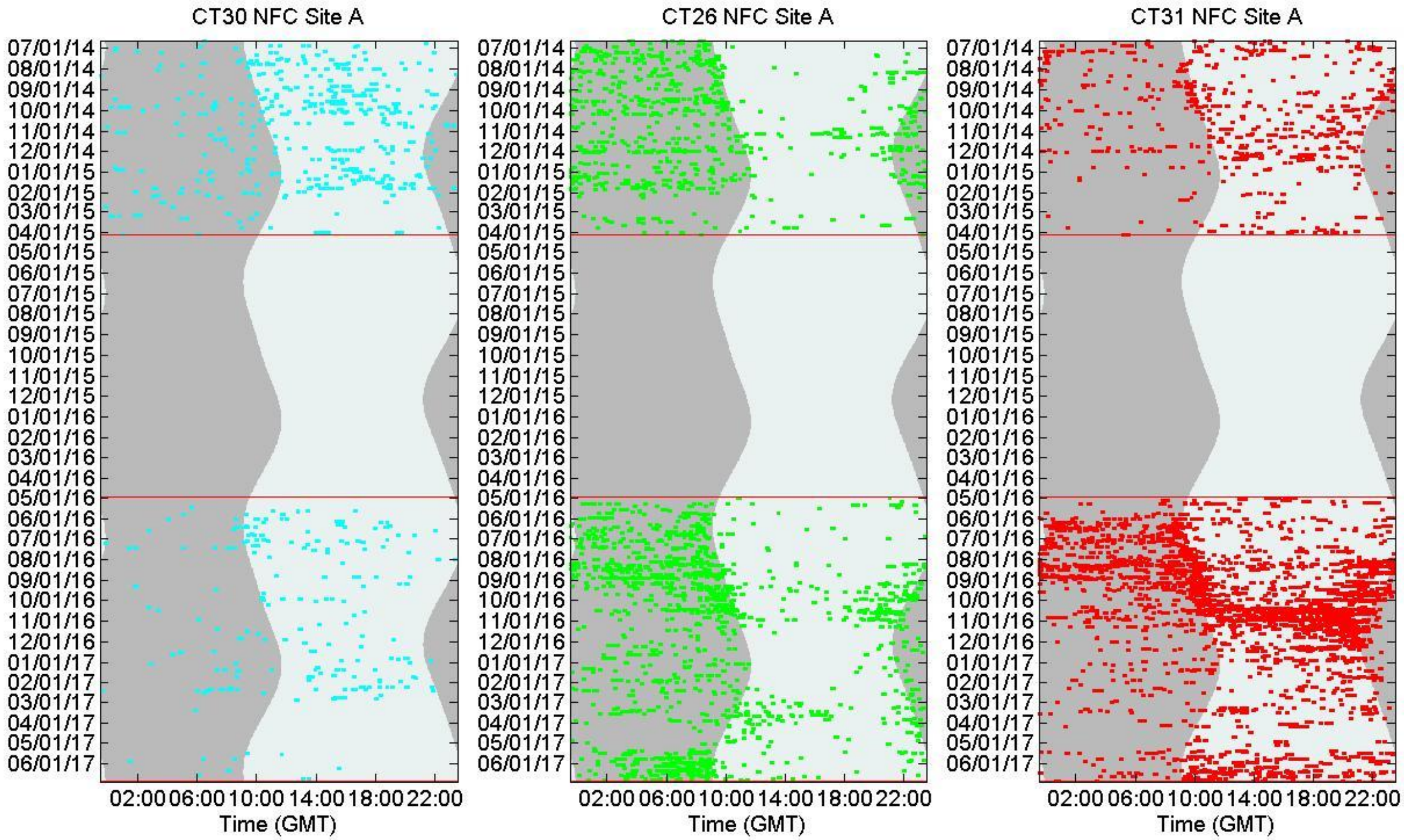


Figure 16. Group G click detections by click type in five-minute bins at Norfolk Canyon Site A. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See Figure 14 for which click types are represented by different colors including black.

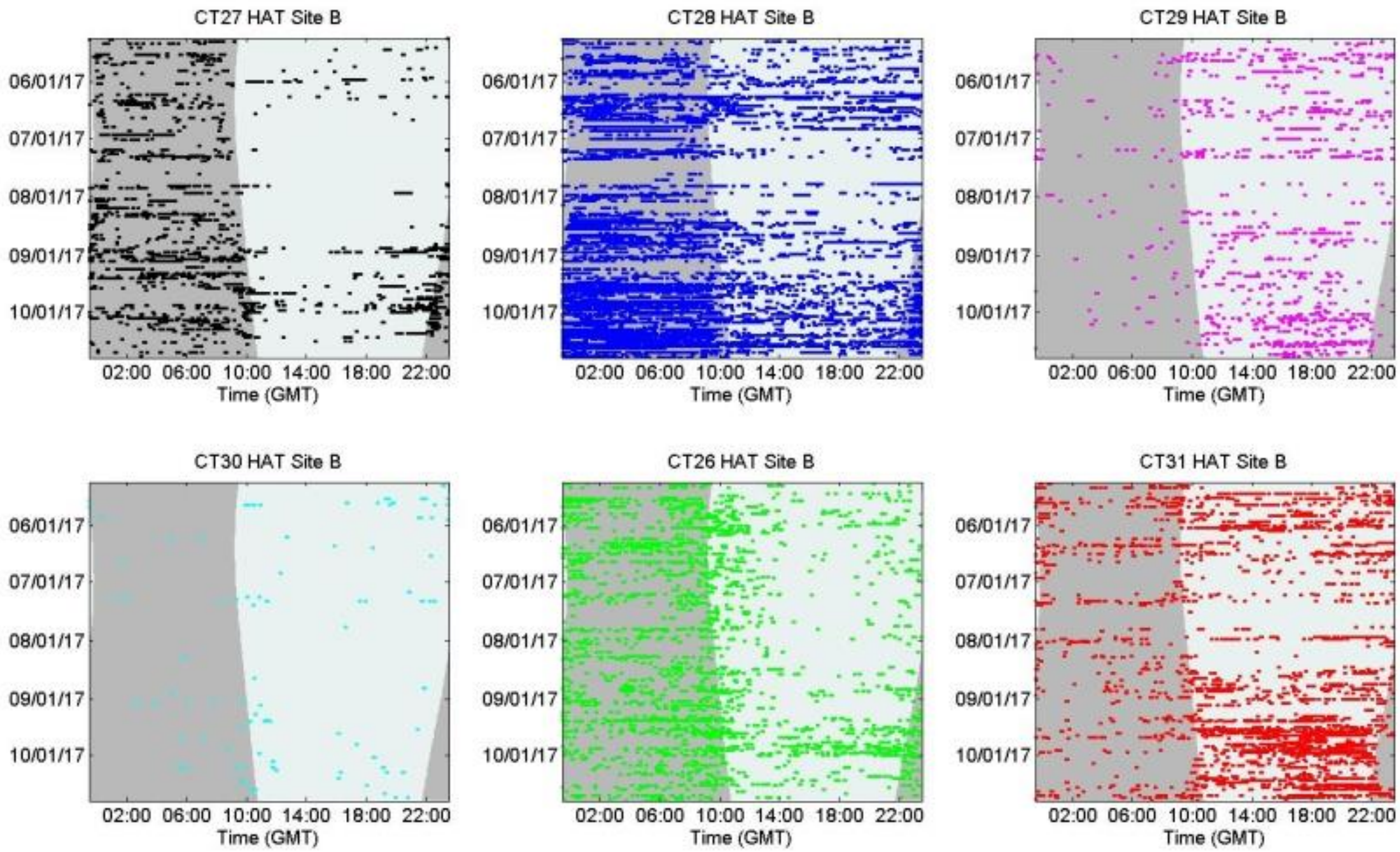
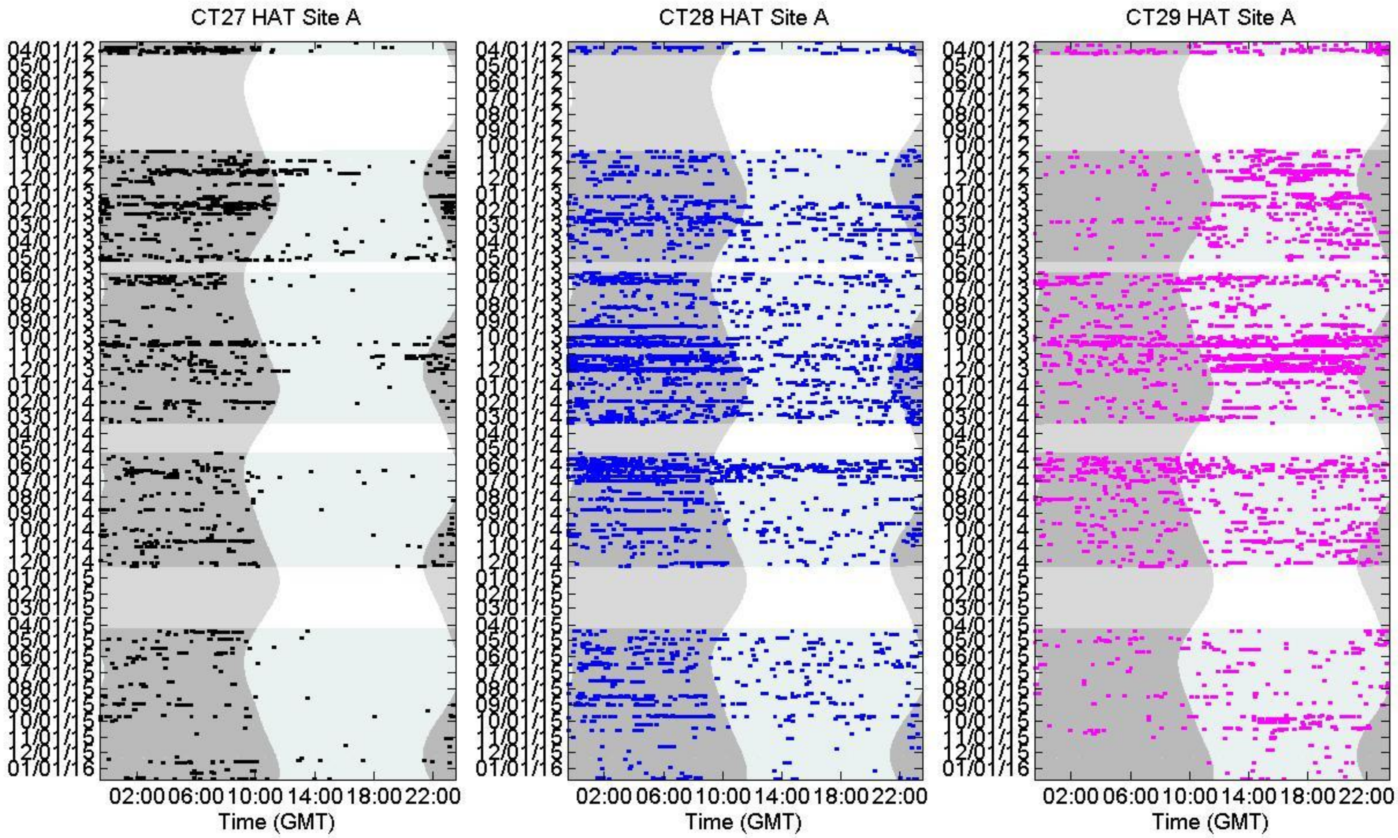


Figure 17. Group G click detections by click type in five-minute bins at Cape Hatteras Site B. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading. Detections are represented by the black and colored dots/horizontal bars. See Figure 14 for which click types are represented by different colors including black.



CT27 HAT Site A
CT28 HAT Site A
CT29 HAT Site A
04/01/12
05/01/12
06/01/12
07/01/12
08/01/12
09/01/12
10/01/12
11/01/12
12/01/12
01/01/13
02/01/13
03/01/13
04/01/13
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05/01/15
06/01/15
07/01/15
08/01/15
09/01/15
10/01/15
11/01/15
12/01/15
01/01/16
02:00 06:00 10:00 14:00 18:00 22:00
Time (GMT)

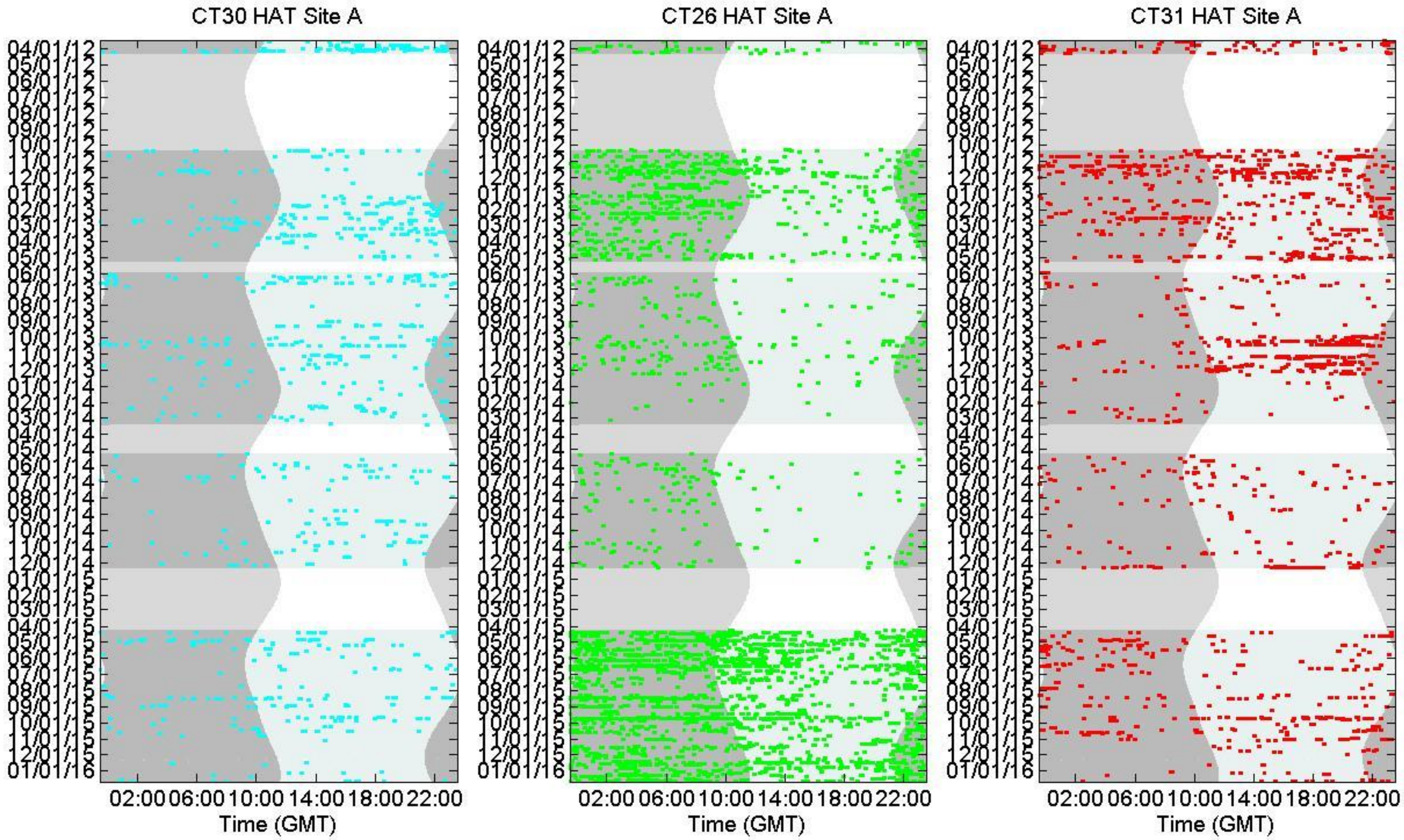
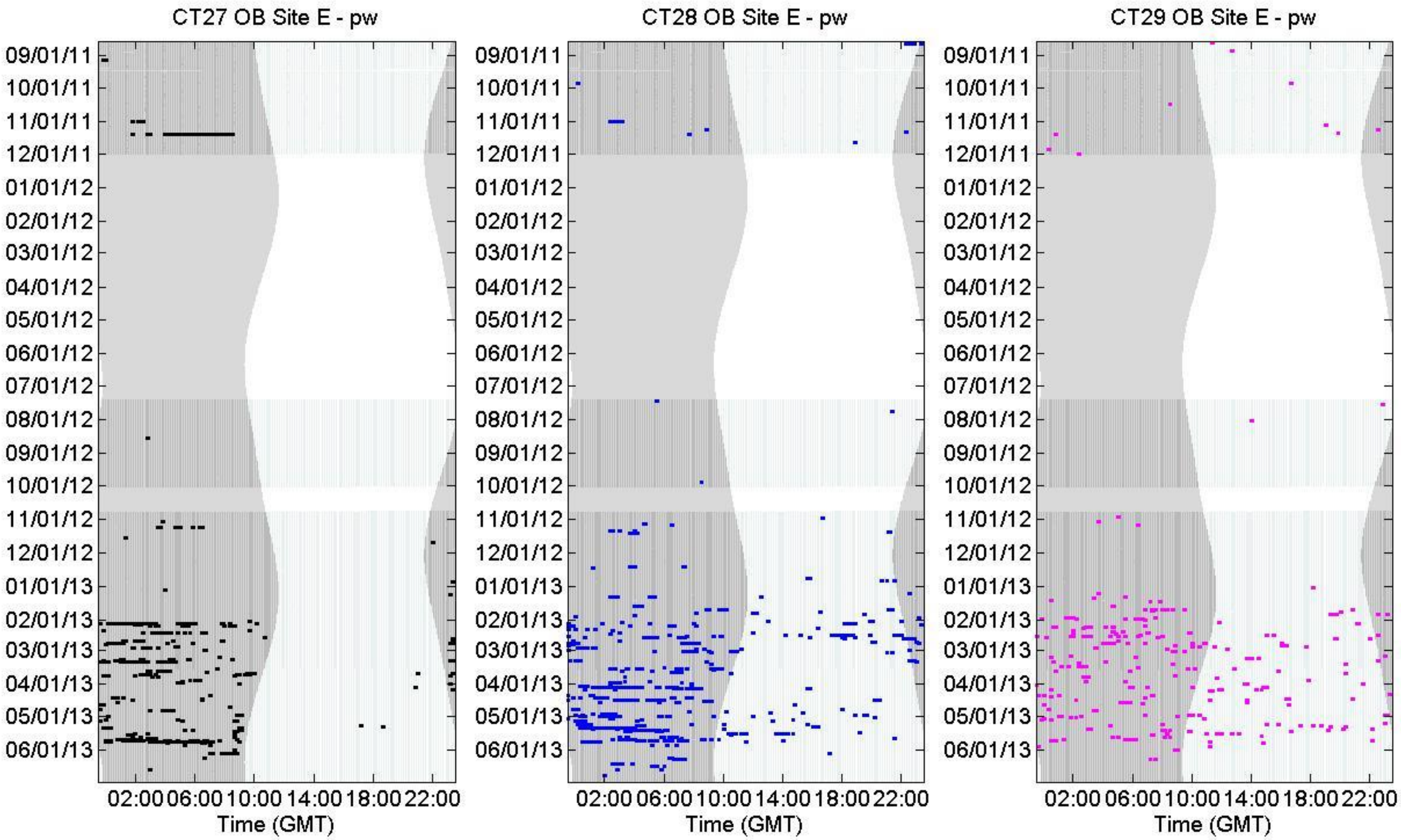


Figure 18. Group G click detections by click type in five-minute bins at Cape Hatteras Site A. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading. Detections are represented by the black and colored dots/horizontal bars. See Figure 14 for which click types are represented by different colors including black.



CT27 OB Site E - pw
CT28 OB Site E - pw
CT29 OB Site E - pw
09/01/11
10/01/11
11/01/11
12/01/11
01/01/12
02/01/12
03/01/12
04/01/12
05/01/12
06/01/12
07/01/12
08/01/12
09/01/12
10/01/12
11/01/12
12/01/12
01/01/13
02/01/13
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04/01/13
05/01/13
06/01/13
02:00 06:00 10:00 14:00 18:00 22:00
Time (GMT)

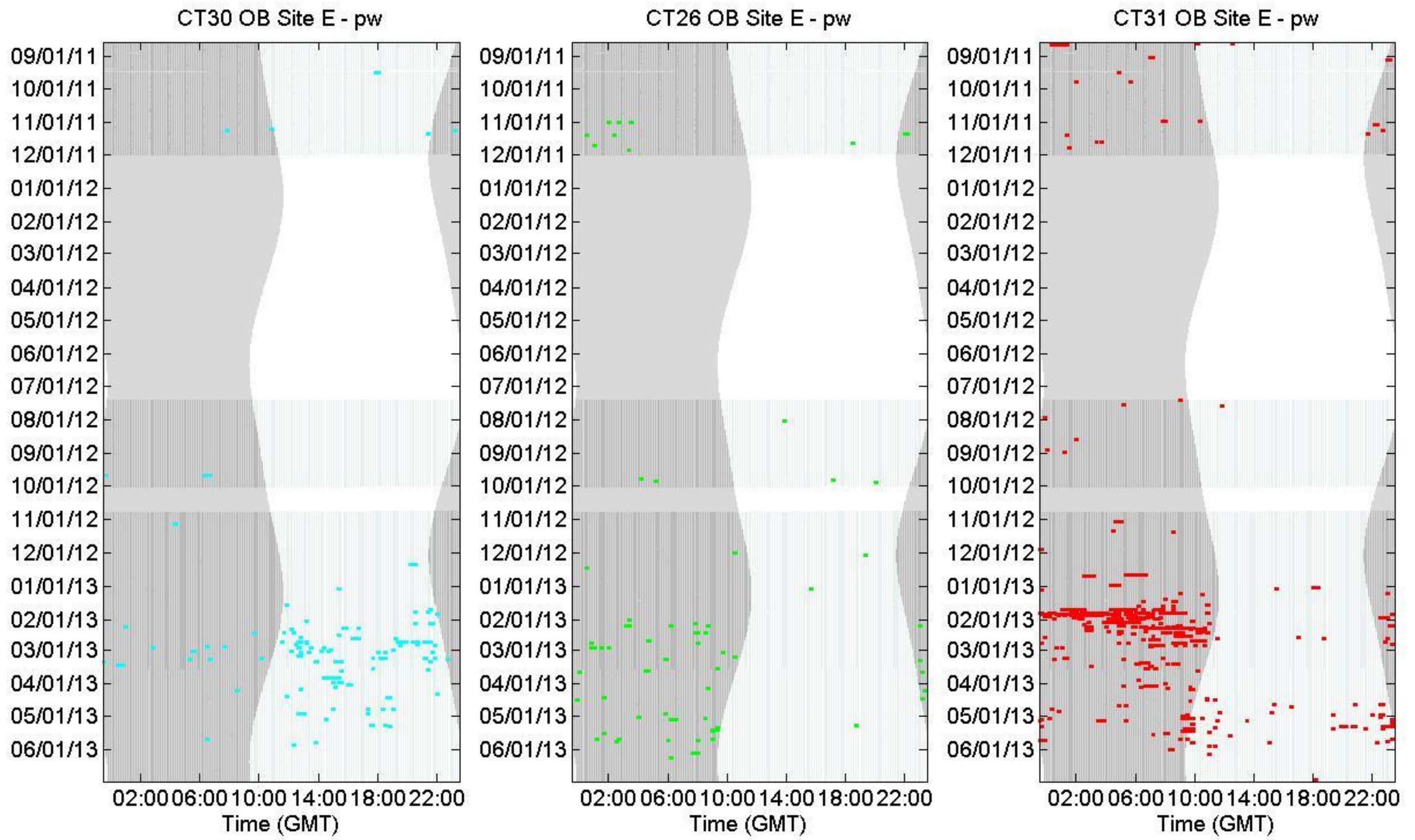
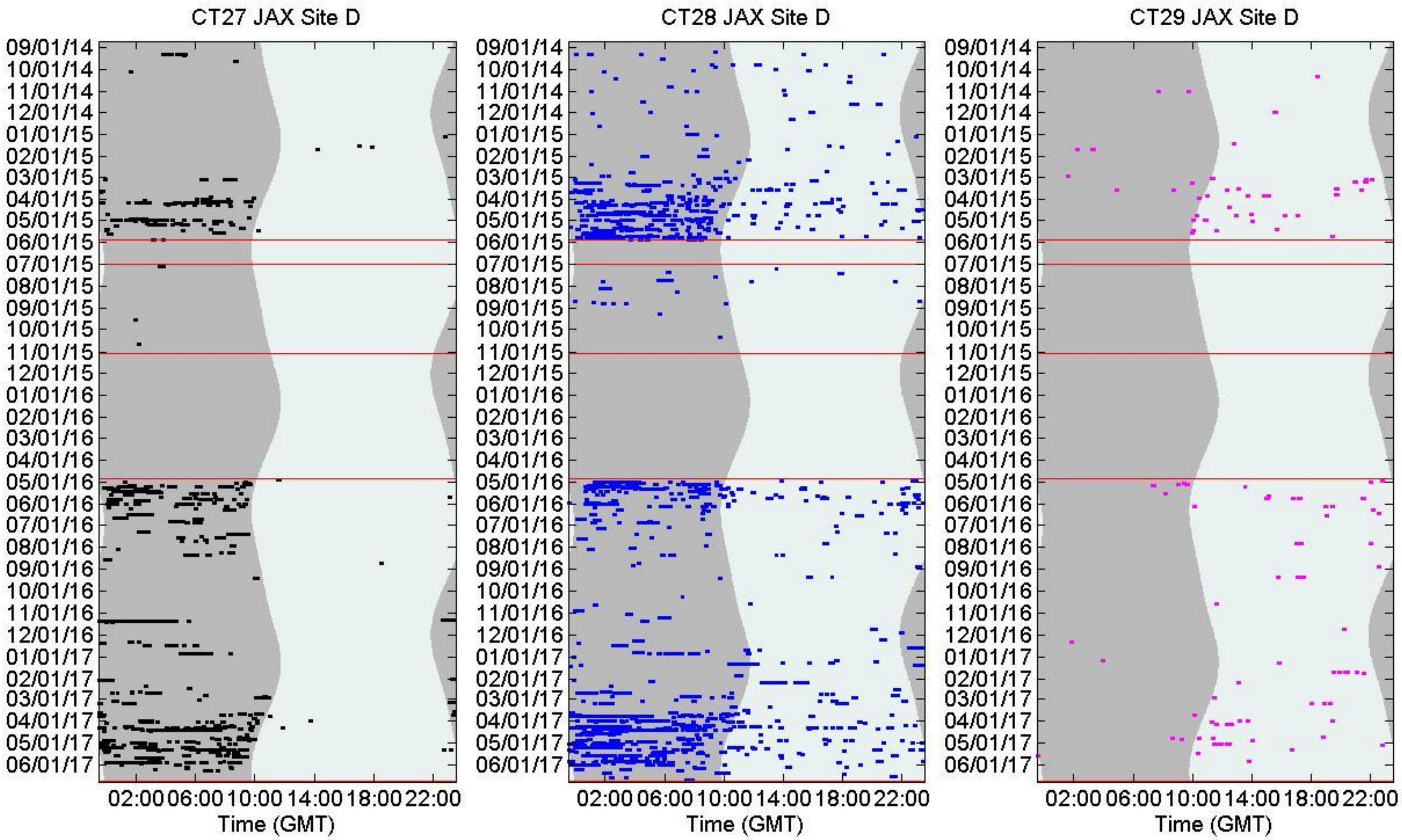


Figure 19. Group G click detections by click type in five-minute bins at Onslow Bay Site E. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading. Detections are represented by the black and colored dots/horizontal bars. See Figure 14 for which click types are represented by different colors including black.


CT27 JAX Site D
CT28 JAX Site D
CT29 JAX Site D
09/01/14
10/01/14
11/01/14
12/01/14
01/01/15
02/01/15
03/01/15
04/01/15
05/01/15
06/01/15
07/01/15
08/01/15
09/01/15
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11/01/15
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12/01/16
01/01/17
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04/01/17
05/01/17
06/01/17
02:00 06:00 10:00 14:00 18:00 22:00
Time (GMT)

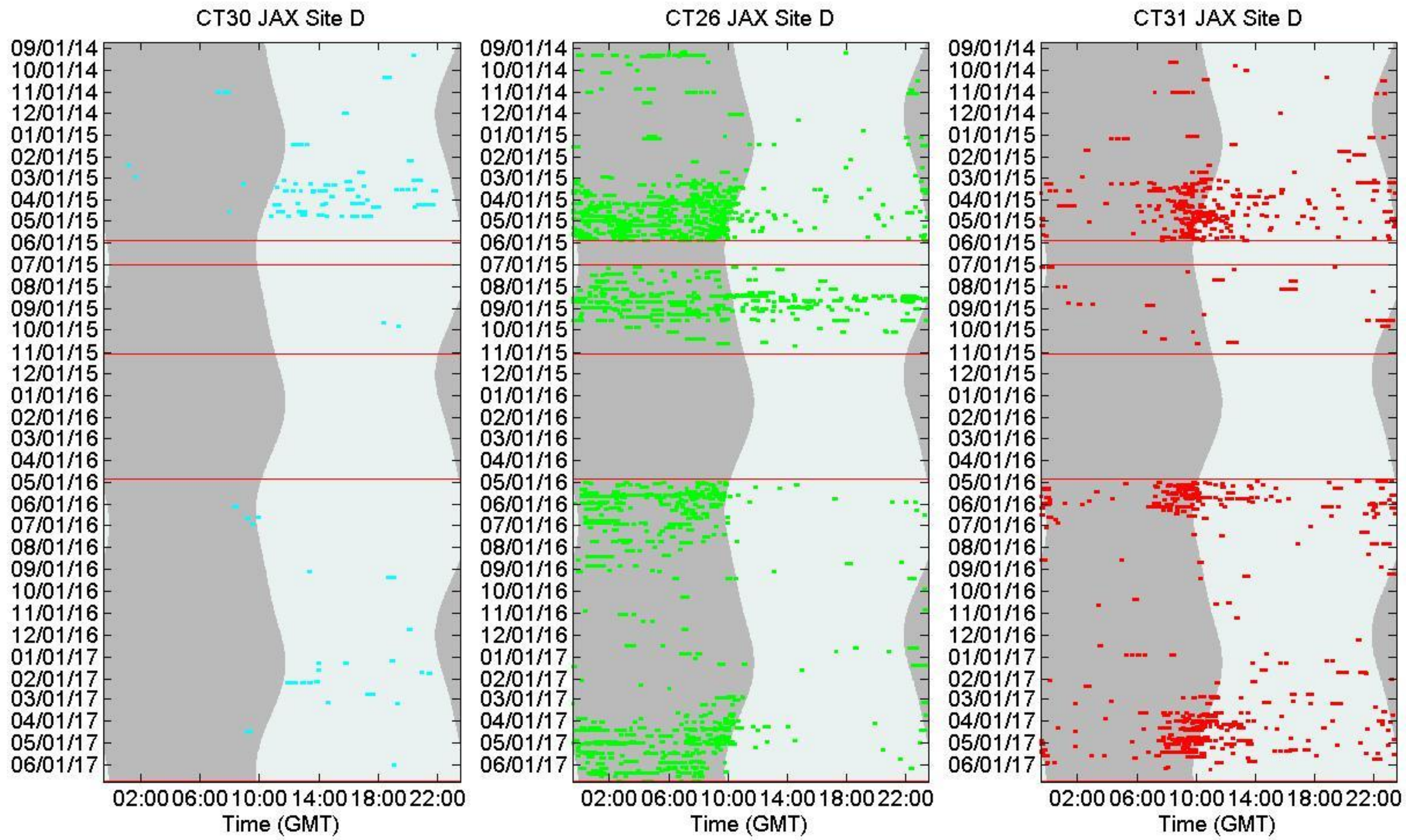

Figure 20. Group G click detections by click type in five-minute bins at Jacksonville Site D. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See Figure 14 for which click types are represented by different colors including black.

As seen above, CT26 (green detection events), CT27 (black), and CT28 (blue) have mostly nocturnal patterns at each site. These three templates do share similarities in their spectra, with peak frequency being very similar. CT29 (magenta) and CT30 (cyan) are detected mainly during the day (except for CT29 at Onslow Bay Site E which seems to have more of a nocturnal occurrence). CT29 and CT30 have very similar spectra. Finally, CT31 (red) show different diel patterns depending on the site, with a strong nocturnal presence at Onslow Bay Site E and a strong crepuscular pattern at Jacksonville Site D.

Minor Click Types

The following figures show the templates used and the temporal patterns at each location for the minor groupings of click types. The following tables provide information on the modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in the major groups. As previously mentioned, only frequency peaks and notches greater than or equal to 10 kHz and less than or equal to 60 kHz were included. Frequencies less than 10 kHz were not included as they could include boat noise, portions of whistles, sonar, or other low-frequency sounds. Frequencies greater than 60 kHz were not included as those frequencies were not examined in this study. Frequencies outside of the 10-60 kHz range may also contain valuable species information and thus should be examined further in the future.

a. Group H

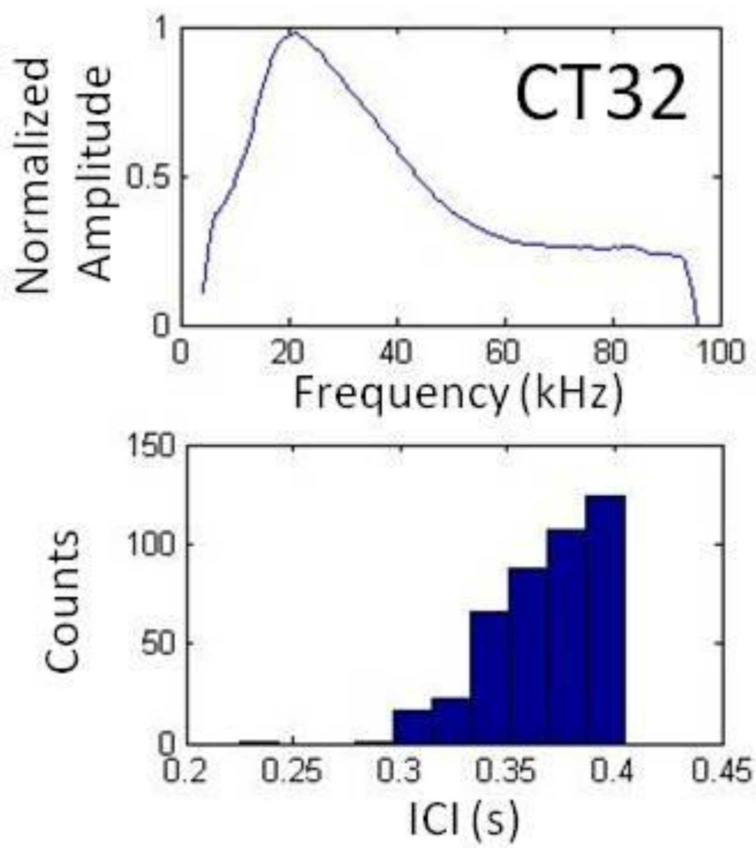

Figure 21. Group H click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

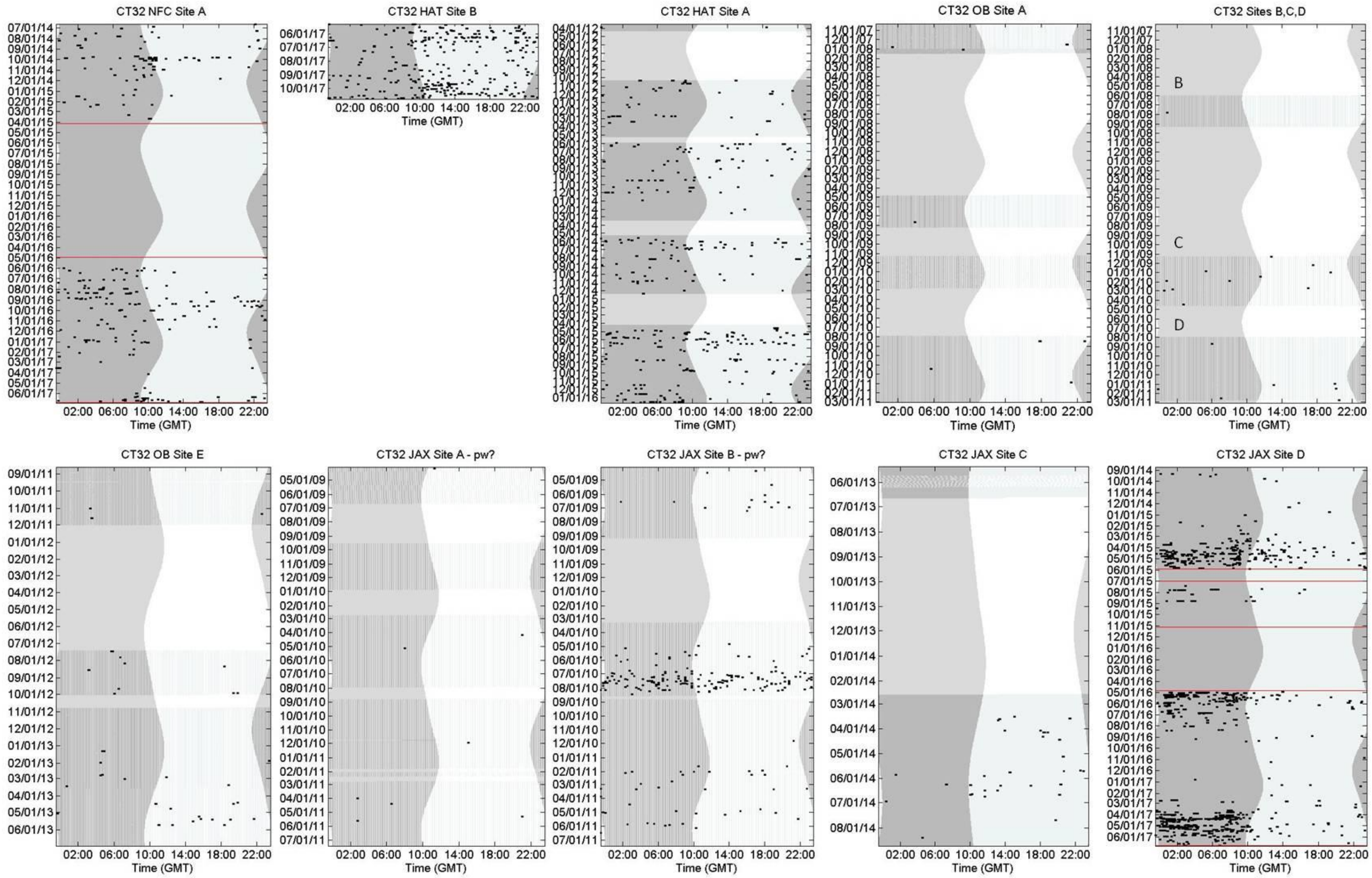

Figure 22. Group H click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 9. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group H. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT32	0.405	21.2	N/A

This group had a nocturnal and seasonal (occurring mainly between March and June) presence at Jacksonville Site D but no other temporal patterns were apparent at other sites.

b. Group I

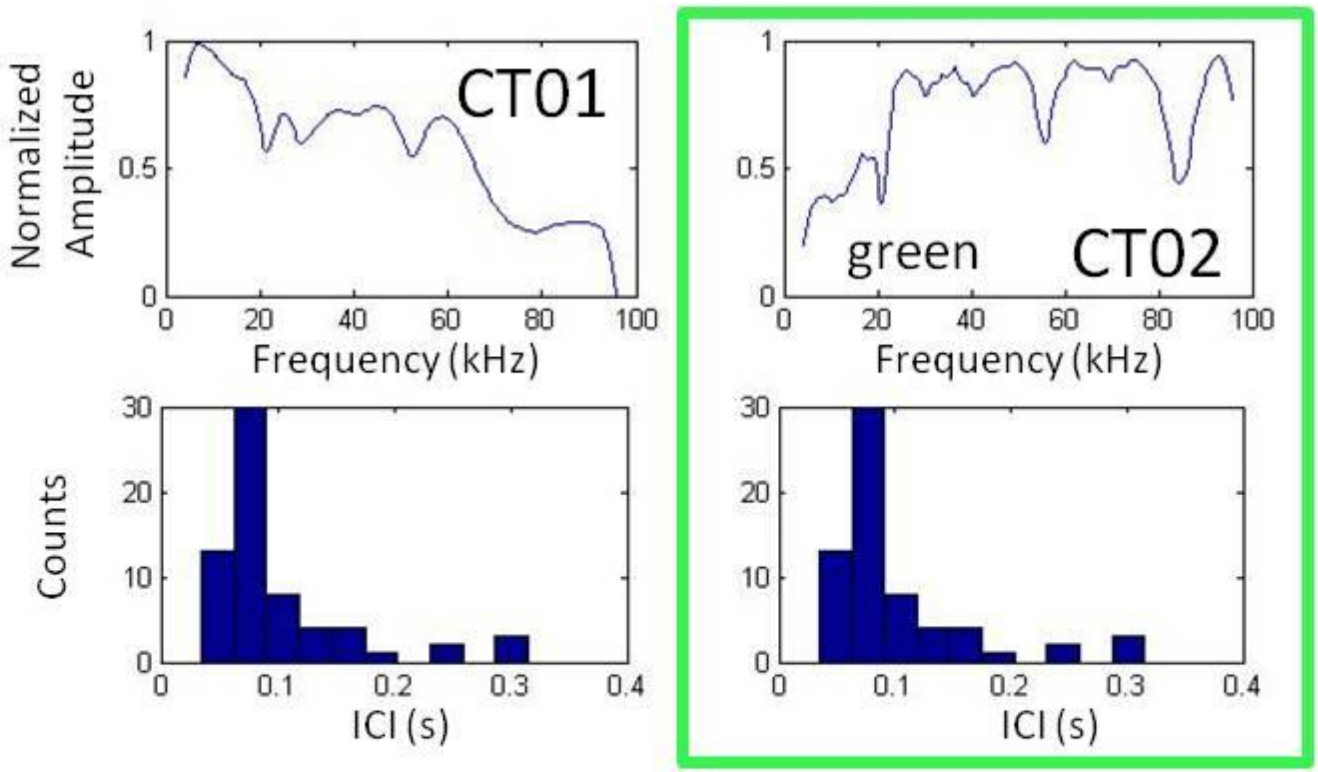

Figure 23. Group I click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

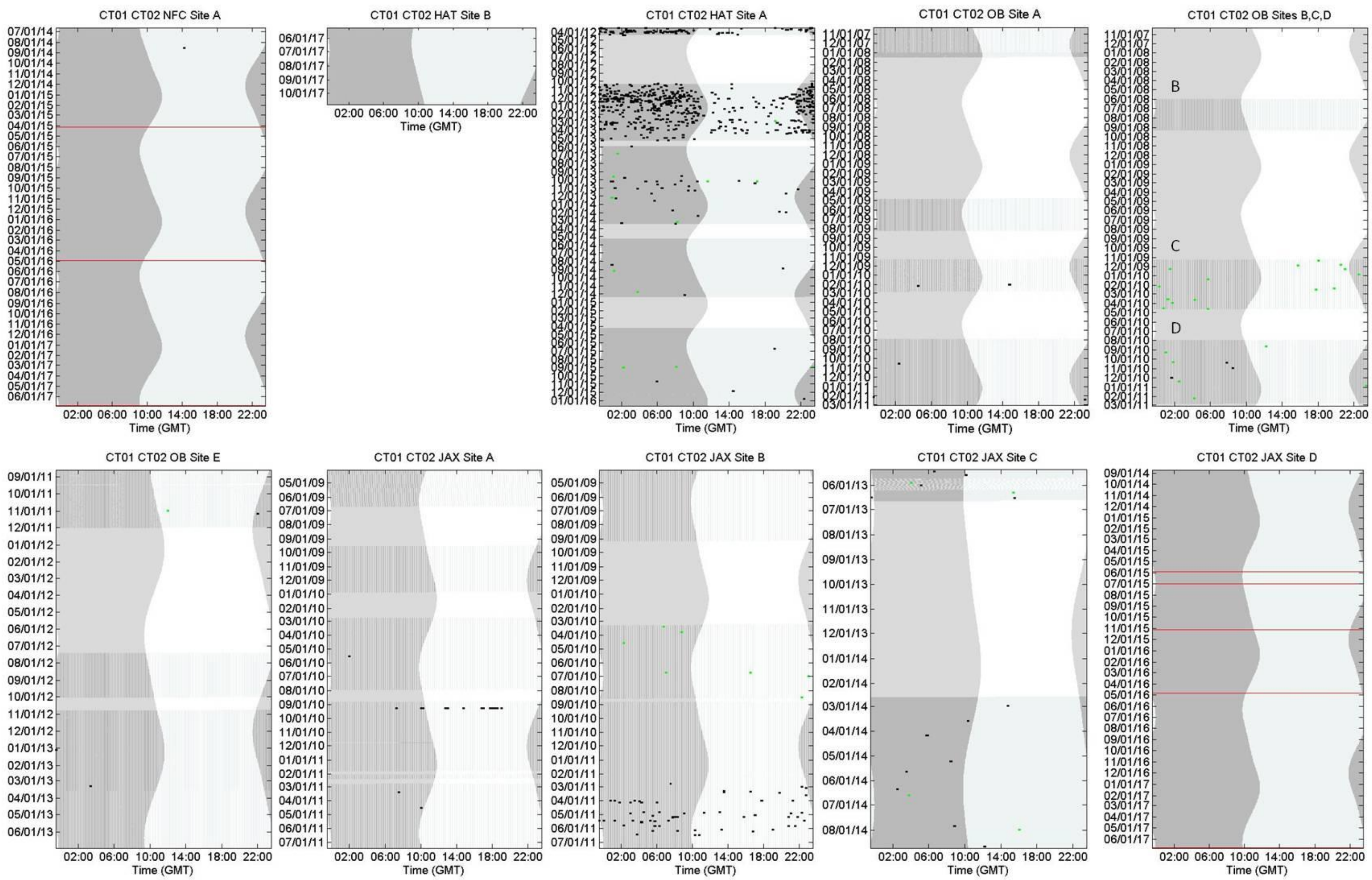

Figure 24. Group I click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 10. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group I. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT01	0.065	25.1, 36.5, 45.1, 58.8	21.6, 29.0, 41.2, 52.5
CT02	0.065	16.9, 18.8, 26.3, 36.5, 49.4	10.6, 18.0, 20.8, 30.2, 40.4, 55.7

This group had a nocturnal occurrence when present in Cape Hatteras Site A. Although it seemed like it would have a seasonal pattern of occurrence, it has almost disappeared starting in 2014. There were no other obvious temporal patterns.

c. Group J

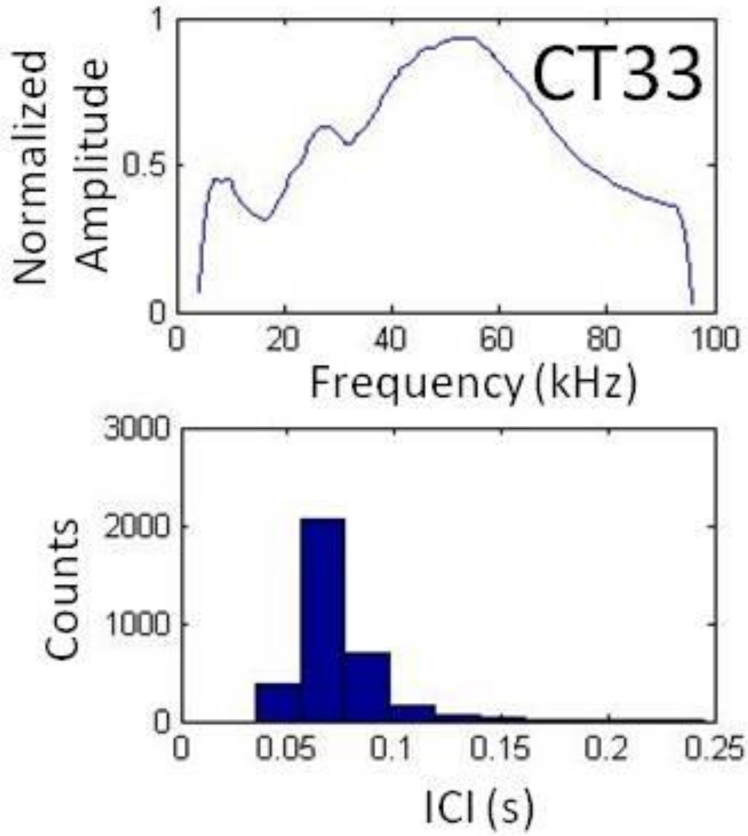

Figure 25. Group J click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

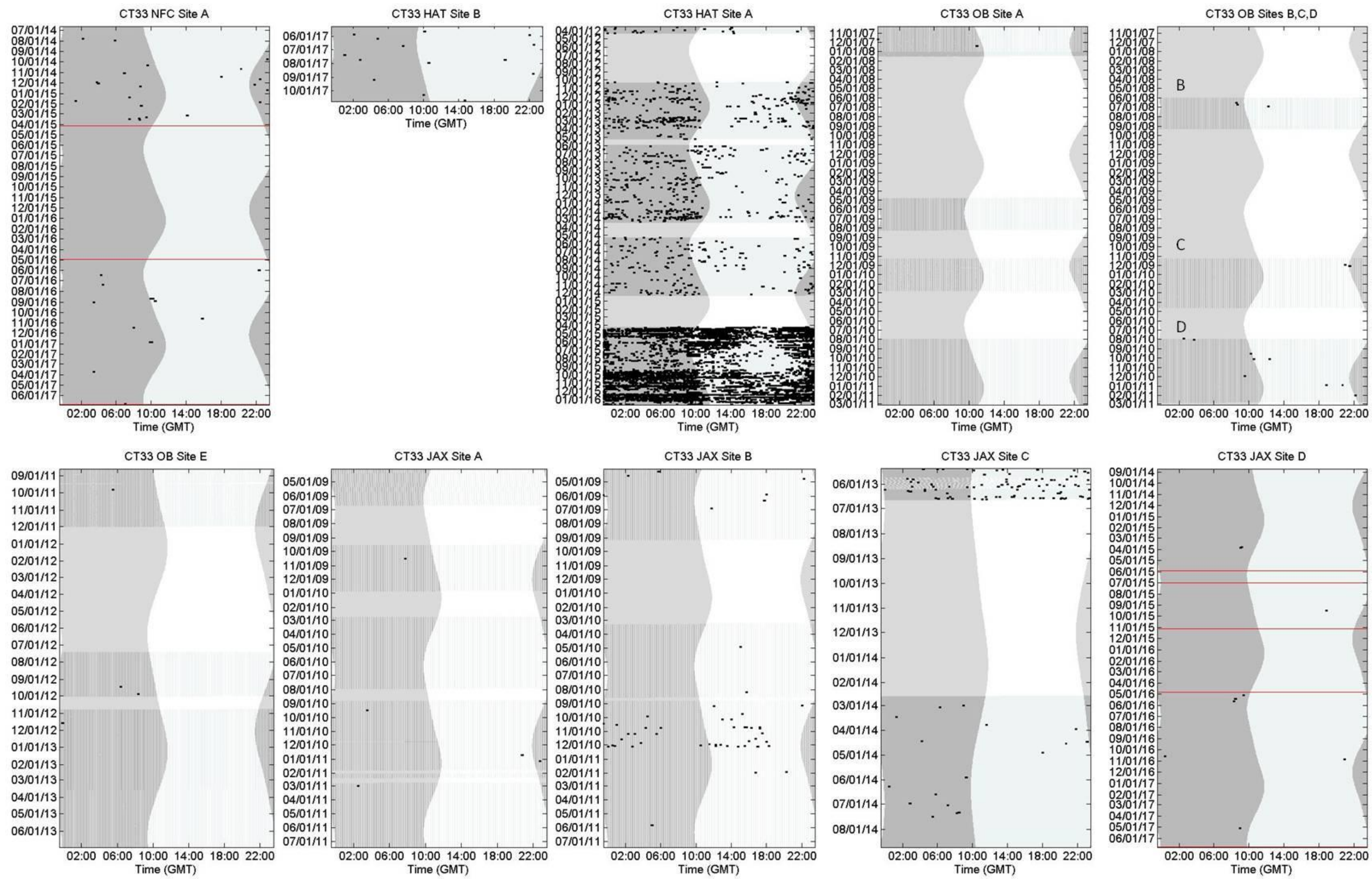

Figure 26. Group J click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 11. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group J. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT33	0.075	27.1, 54.9	16.9, 32.5

This group mainly occurred at Cape Hatteras Site A, with the number of detections greatly increased during the fifth deployment there. There are no obvious diel or seasonal patterns, although there is potentially some seasonality at Jacksonville Site B.

d. Group K

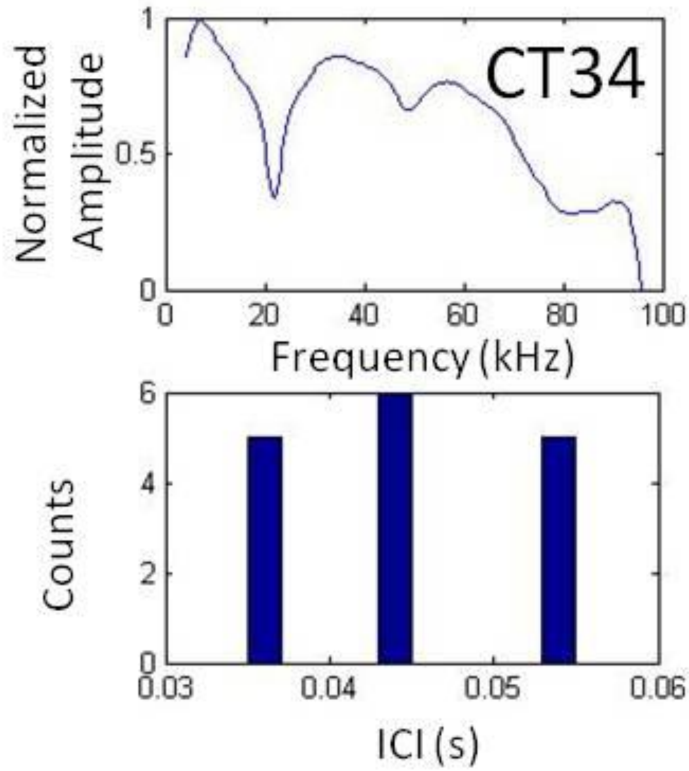

Figure 27. Group K click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

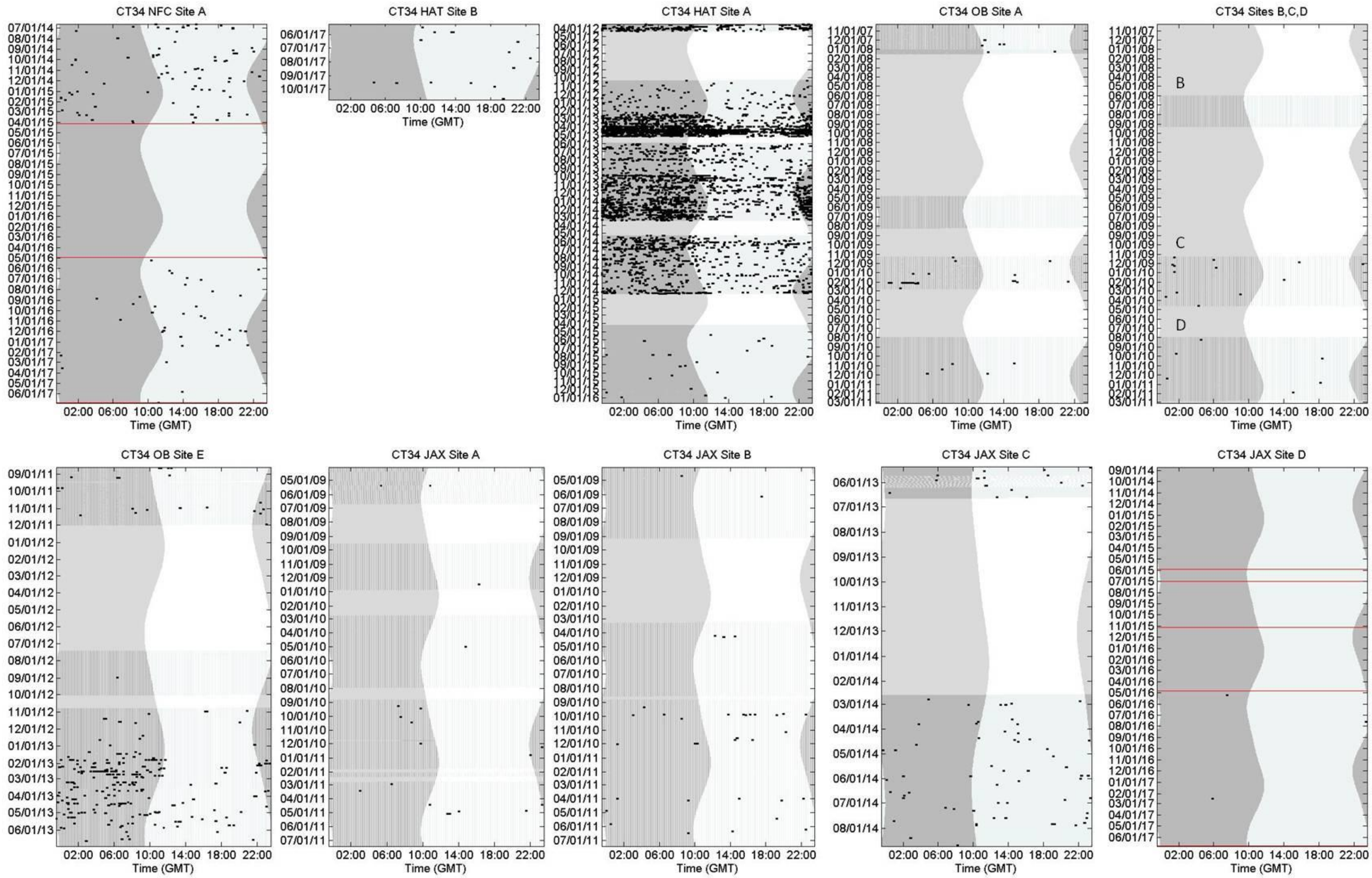

Figure 28. Group K click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 12. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group K. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT34	0.045	34.5, 56.5	22.0, 49.0

This group was detected mainly at Cape Hatteras Site A, although the fifth deployment had very few detections compared to the other deployments. There may be a slight nocturnal presence at Cape Hatteras Site A and Onslow Bay Site E but there were no other obvious diel pattern nor were there any obvious seasonal patterns.

e. Group L

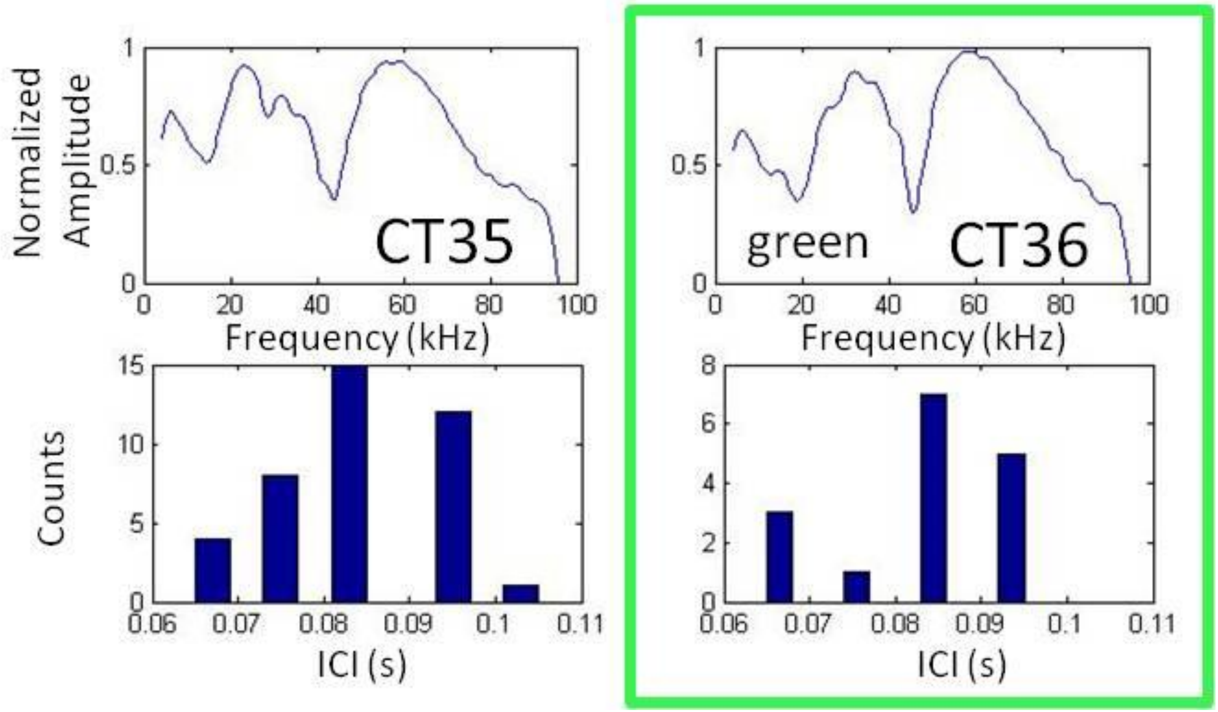

Figure 29. Group L click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

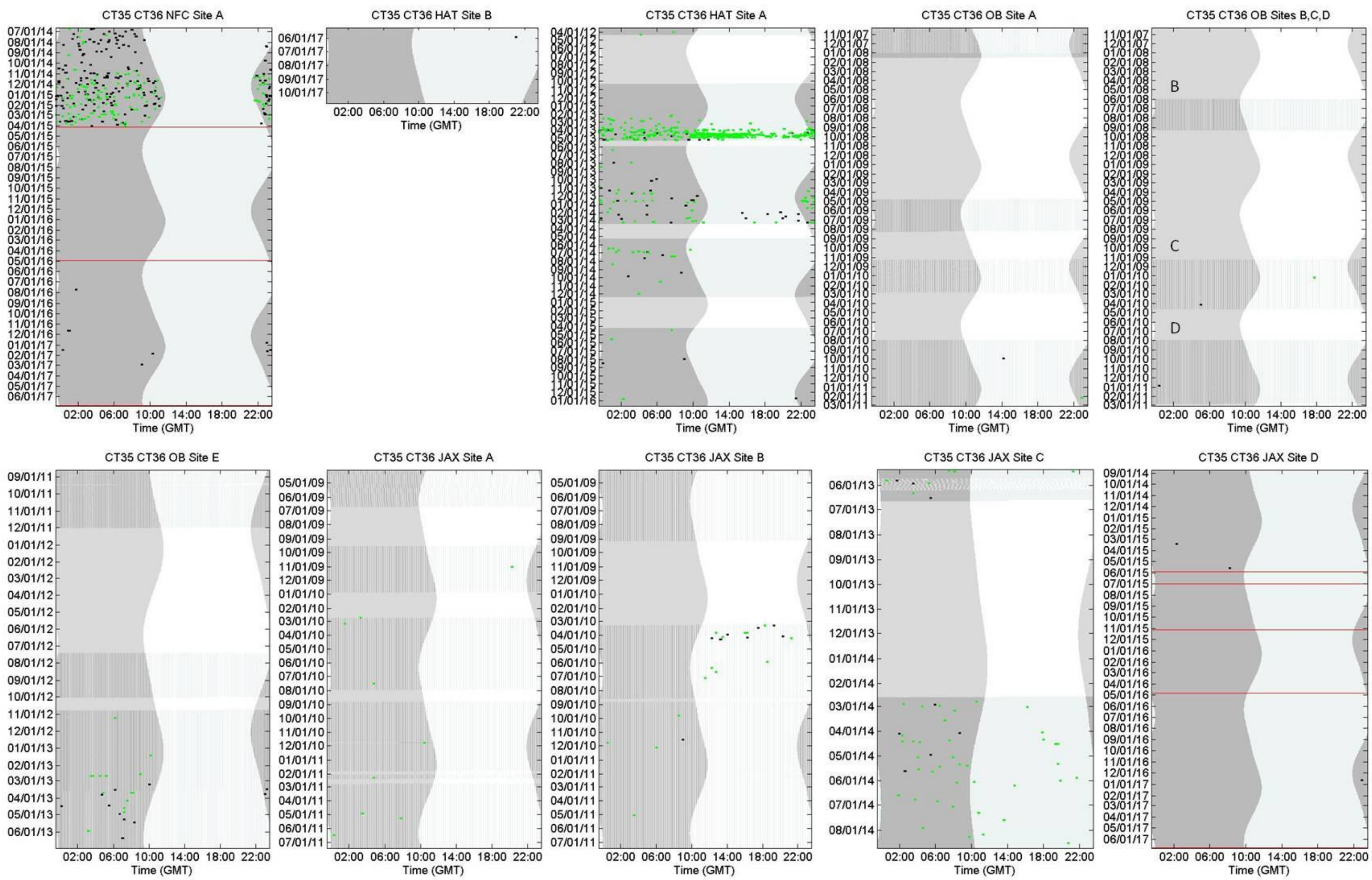

Figure 30. Group L click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 13. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group L. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT35	0.085	23.1, 31.8, 59.2	14.5, 28.6, 43.9
CT36	0.085	14.5, 27.1, 32.2, 36.5, 58.8	12.9, 18.8, 27.5, 35.3, 45.5

This group, which has some spectral and ICI similarities to ***Group F***, had a nocturnal pattern of occurrence at Norfolk Canyon Site A and Onslow Bay Site E, whereas at Jacksonville Site B, it occurred mainly during the day. No other diel patterns were apparent.

f. Group M

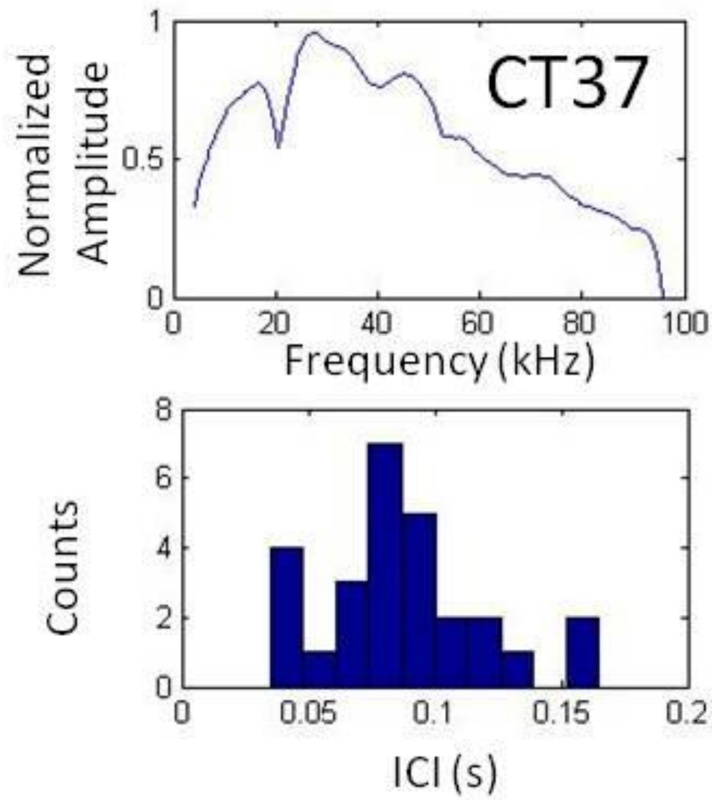

Figure 31. Group M click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

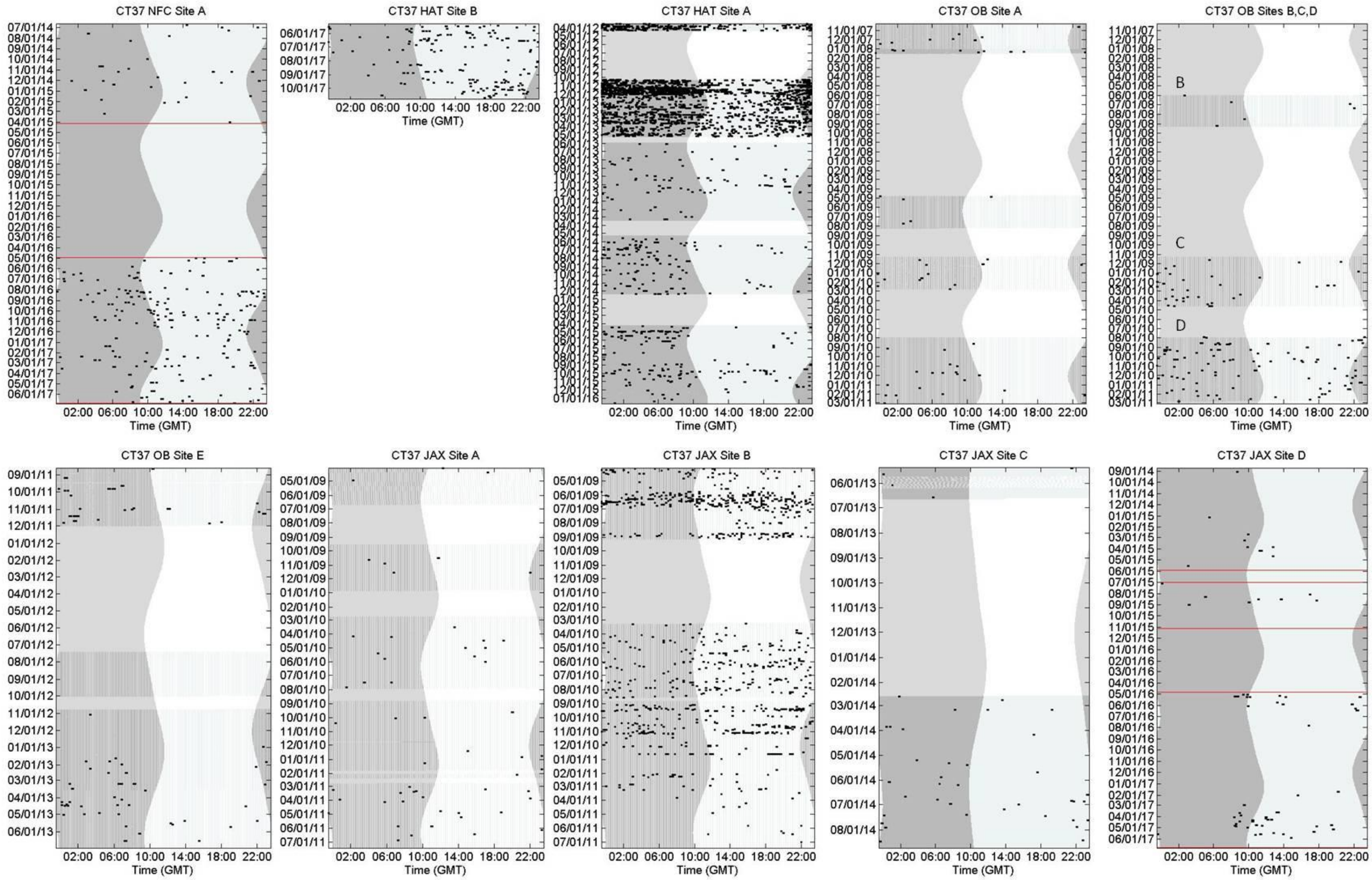

Figure 32. Group M click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 14. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group M. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Valleys (kHz)
CT37	0.095	16.9, 27.5, 45.1, 56.1	20.8, 40.0, 53.3

This group was detected at all sites, with no obvious diel pattern. The only site to show possible seasonality was Jacksonville Site D. It is interesting that the two earliest Cape Hatteras Site A datasets had so many more detections than the latter three datasets at that site.

g. **Group N**

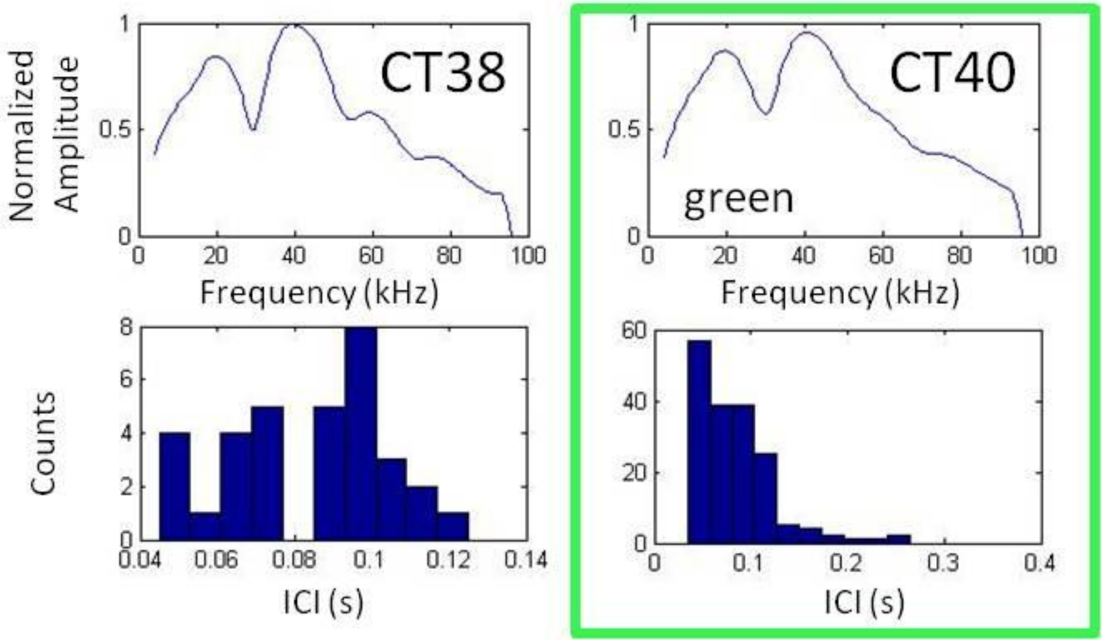

Figure 33. Group N click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

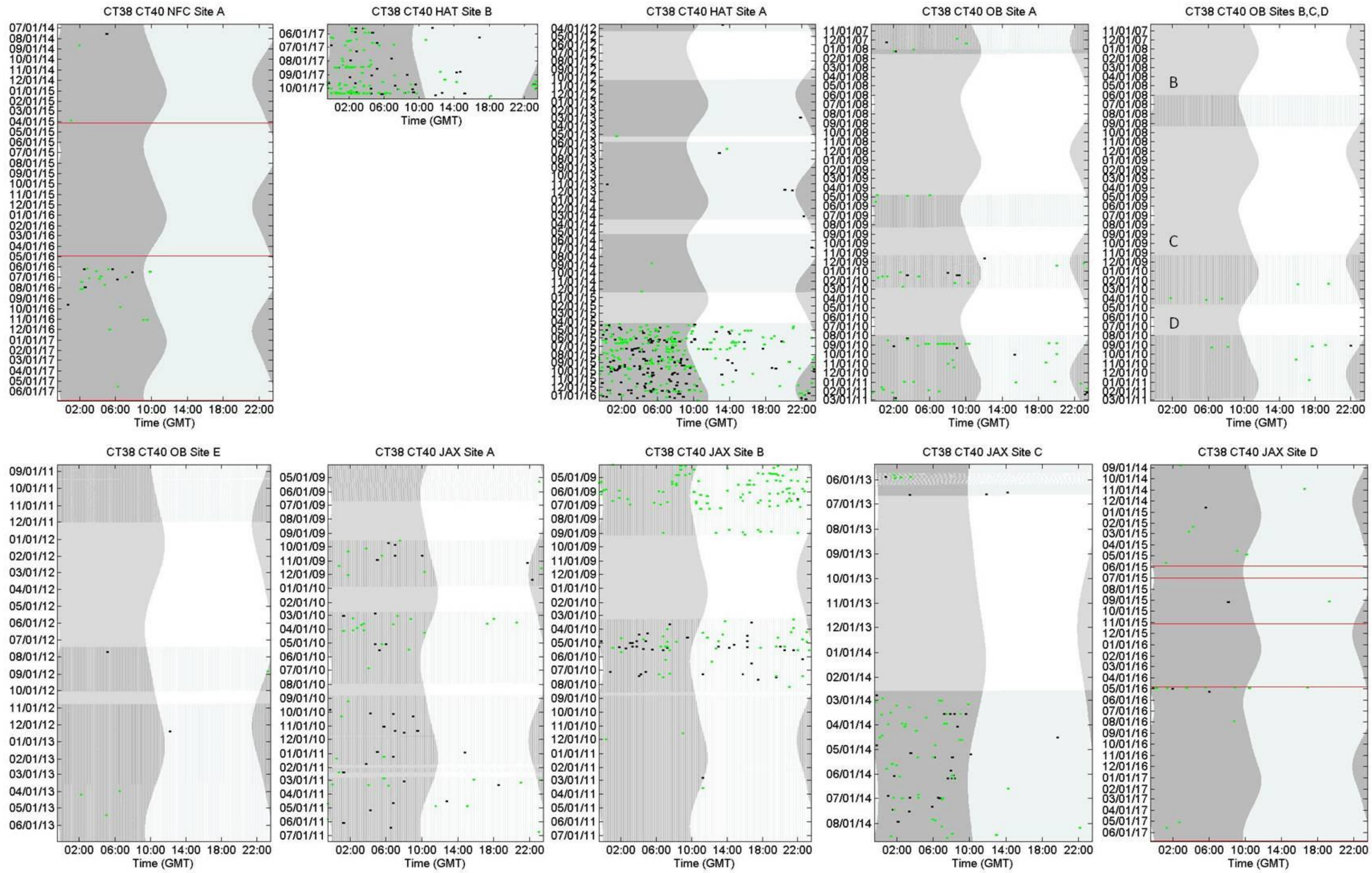

Figure 34. Group N click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 15. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group N. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT38	0.095	19.6, 39.2, 59.2	29.4, 54.5
CT40	0.085	19.6, 40.8	30.2

This group seemed to have a nocturnal presence at most sites. There were too few detections to determine seasonality. It is interesting that Cape Hatteras Site A did not have many detections before the fifth deployment, and then detections were numerous.

h. Group O

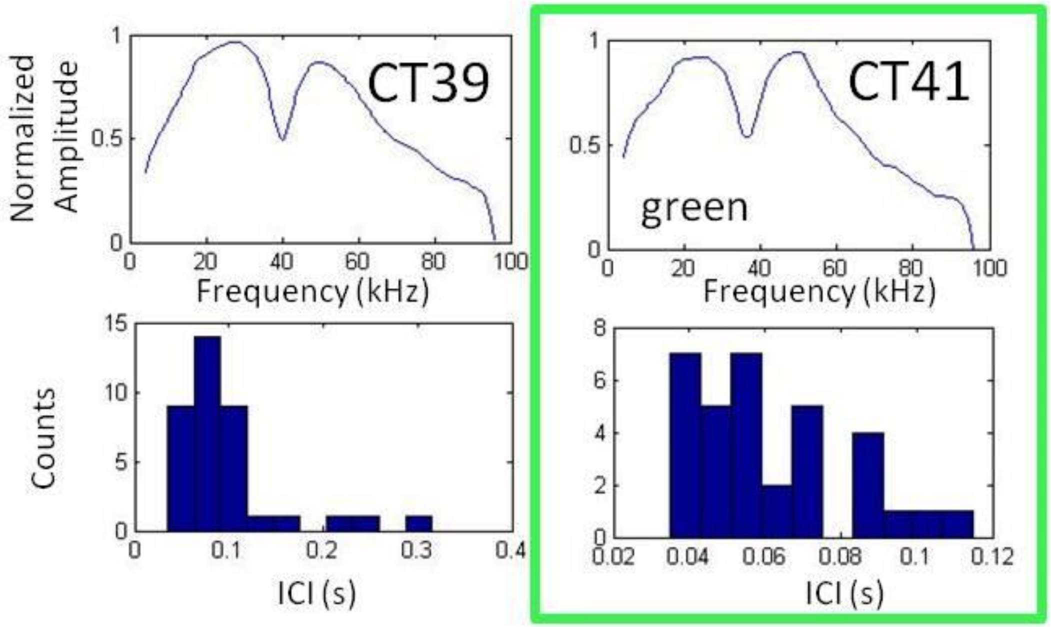

Figure 35. Group O click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars unless a name of a color appears within a mean frequency spectrum plot, in which case the inclusion of that particular spectrum in the group is uncertain and therefore its detections are represented by that color.

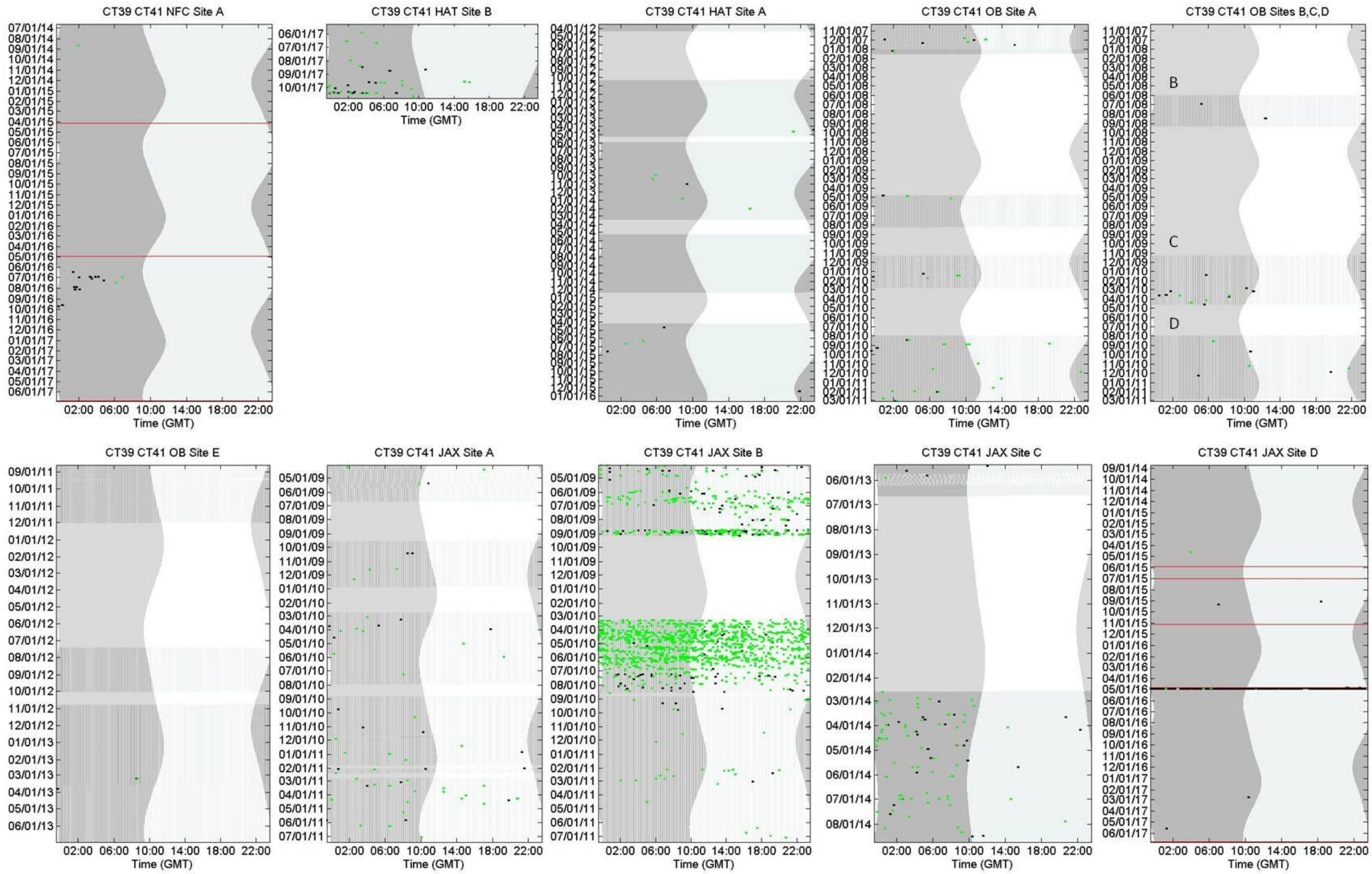

Figure 36. Group O click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black and colored dots/horizontal bars. See preceding figure for which click types are represented by colors other than black.

Table 16. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group O. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT39	0.065	27.8, 49.8	40.0
CT41	0.035	25.9, 49.0	36.5

This group also seemed to have a nocturnal presence at most sites. The detections at Jacksonville Site B should be viewed with caution as they may be due to misclassifications caused by snapping shrimp. Also for this group, the detections at the beginning of the last dataset for Jacksonville Site D are likely due to the poor quality data at the beginning of that deployment discussed previously. There were too few detections to determine seasonality.

i. Group P

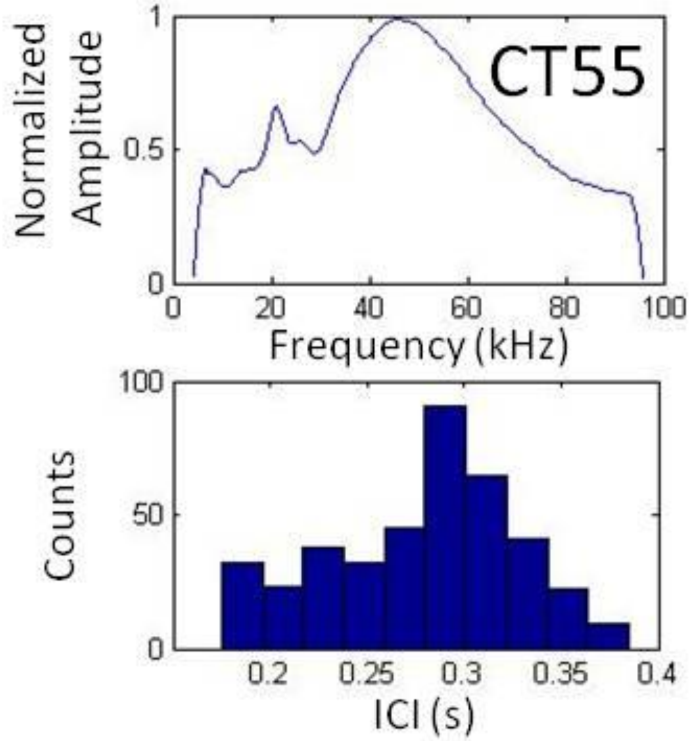

Figure 37. Group P click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

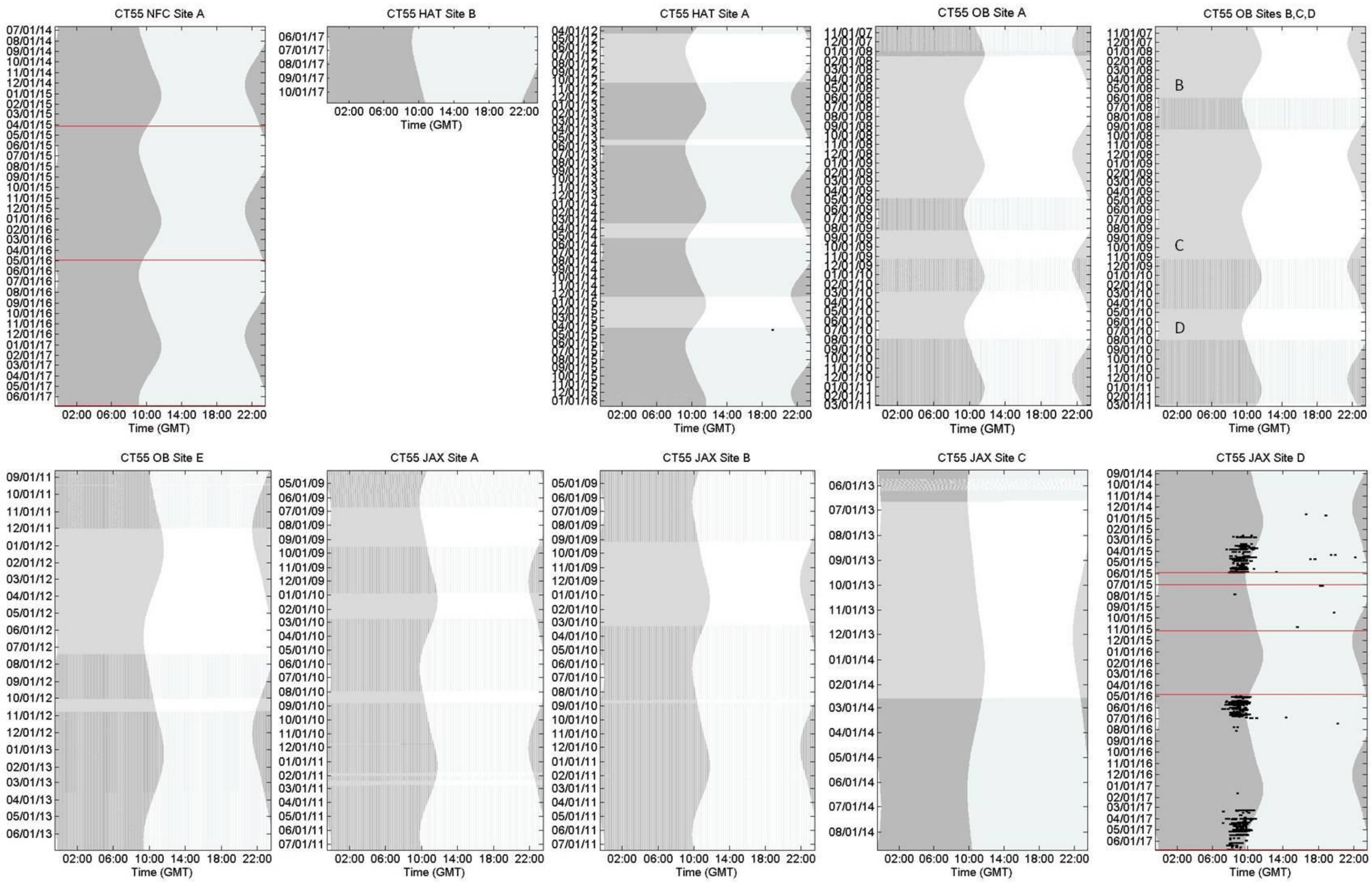

Figure 38. Group P click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 17. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group P. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT55	0.285	15.3, 21.2, 25.9, 45.9	11.4, 16.1, 24.3, 28.6

Except for one detection, this group only occurred at Jacksonville Site D. It had strong diel (crepuscular) and seasonal (occurring mainly between March and June) patterns at this one site.

j. Group Q

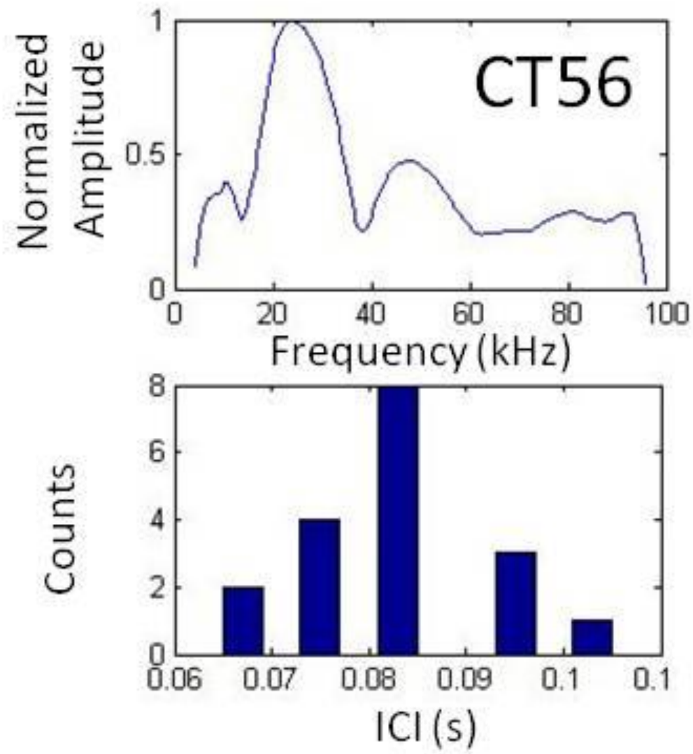

Figure 39. Group Q click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

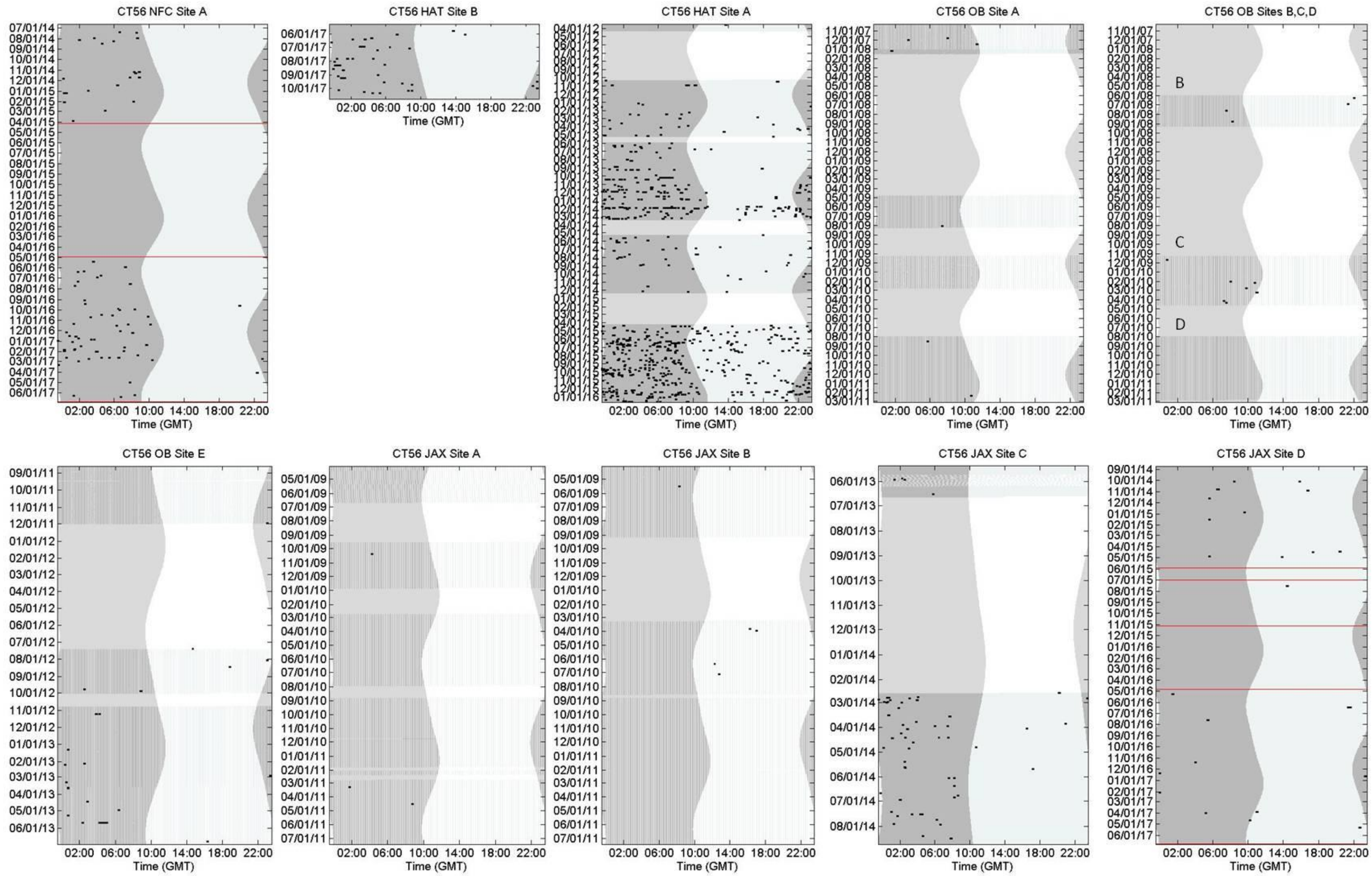

Figure 40. Group Q click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 18. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group Q. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT56	0.085	10.6, 23.9, 47.8	13.7, 38.4

This group mainly had a nocturnal presence, with no obvious seasonality at any of the sites.

k. Group R

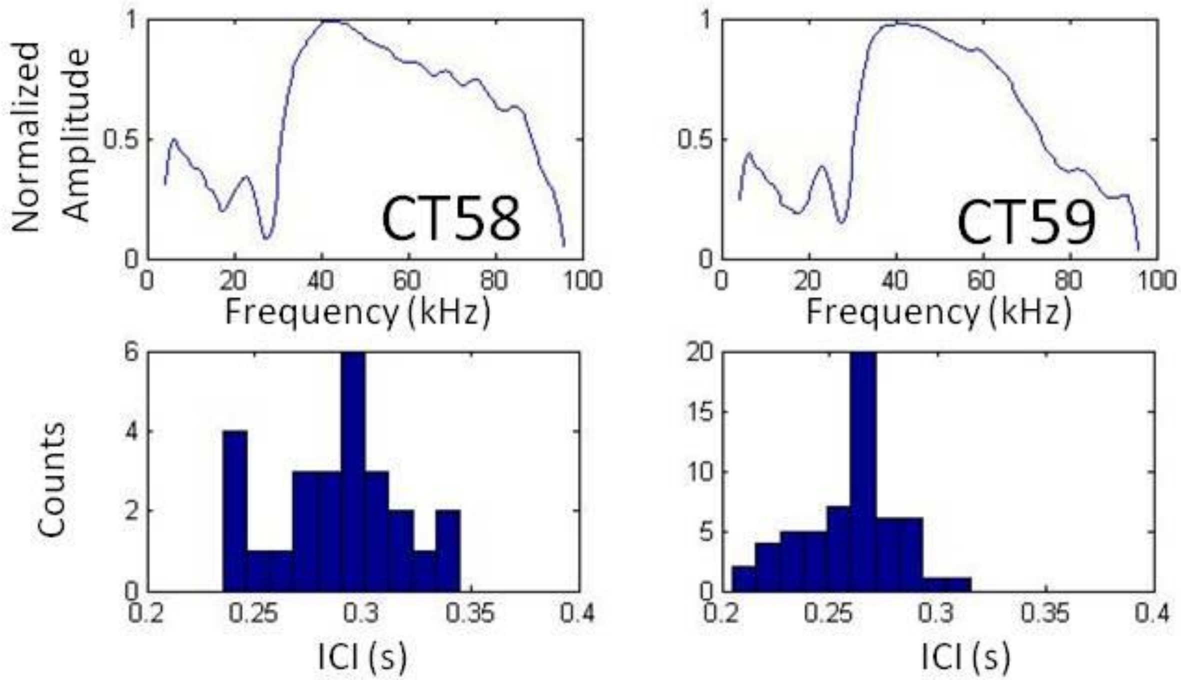

Figure 41. Group R click types showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figure, detections of all spectra are represented by black dots/horizontal bars.

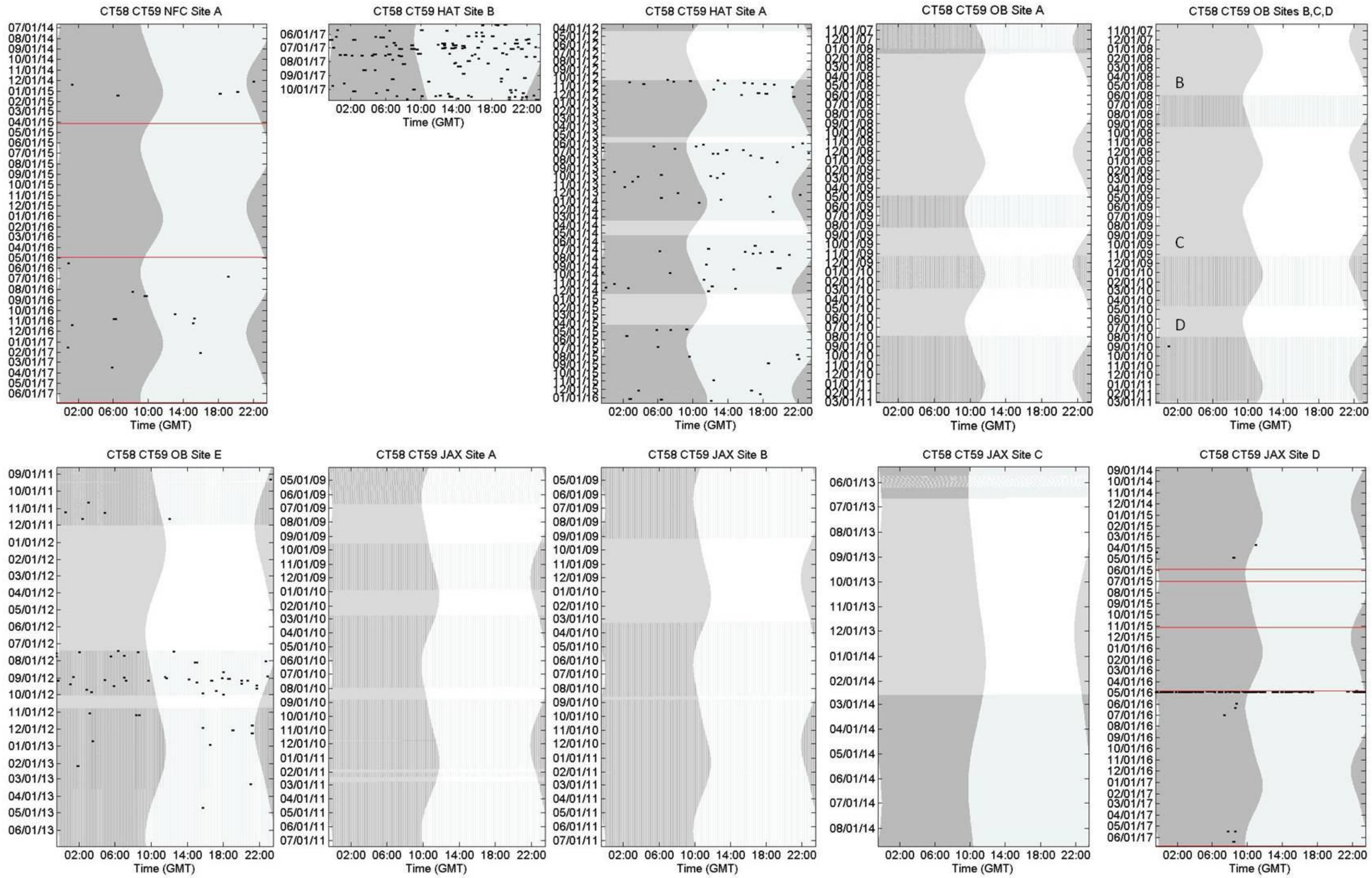

Figure 42. Group R click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 19. Modal inter-click intervals, average frequency peaks, and average frequency notches of each click type in Group R. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT58	0.295	22.7, 41.6	17.6, 27.1
CT59	0.265	23.1, 41.6	17.3, 27.5

This group, whose templates came from Cape Hatteras Site B, was almost exclusively detected at the deep water sites. There was no apparent diel or seasonal pattern. The detections at the beginning of the last dataset for Jacksonville Site D are likely due to the poor quality data at the beginning of that deployment discussed previously.

I. Group S

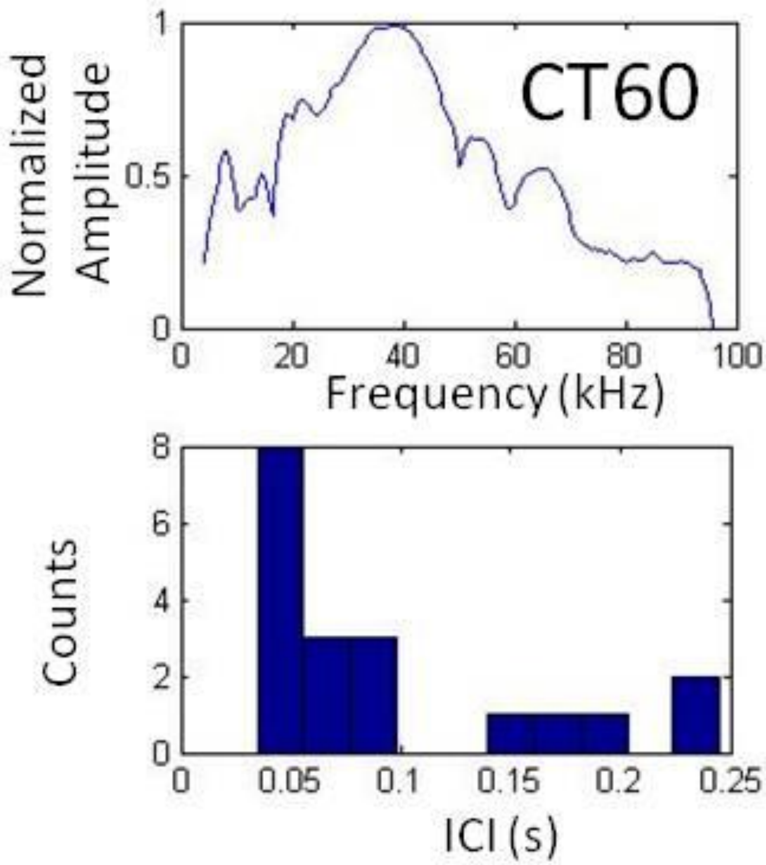

Figure 43. Group S click type showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

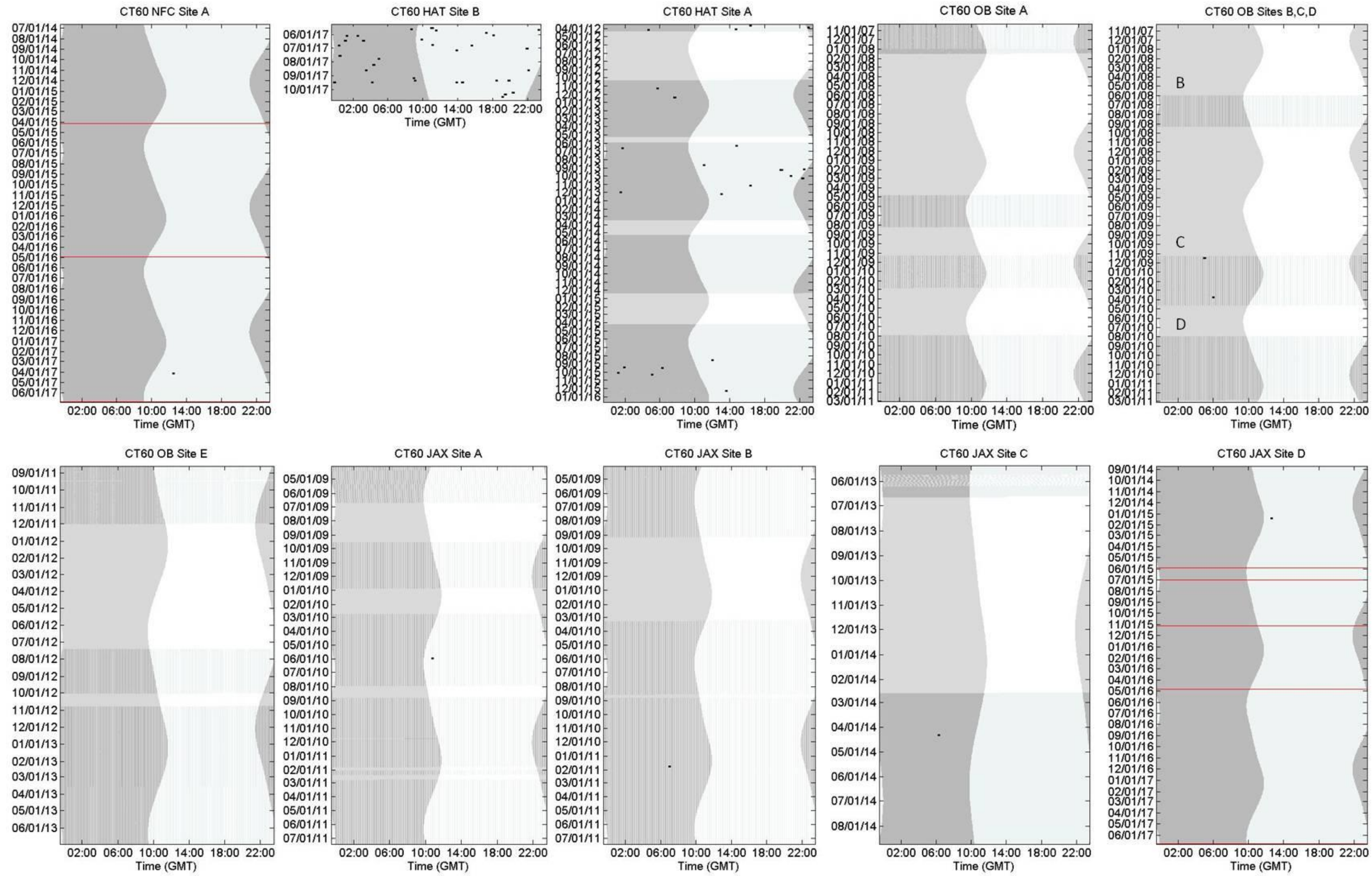

Figure 44. Group S click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 20. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group S. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT60	0.035	14.5, 19.2, 21.6, 38.4, 53.7	10.6, 16.5, 20.0, 24.7, 50.2, 58.8

There were not many detections from this group, whose lone template came from Cape Hatteras Site B. Most detections were from the more northern HARP sites. There was no obvious diel or seasonal pattern.

m. Group T

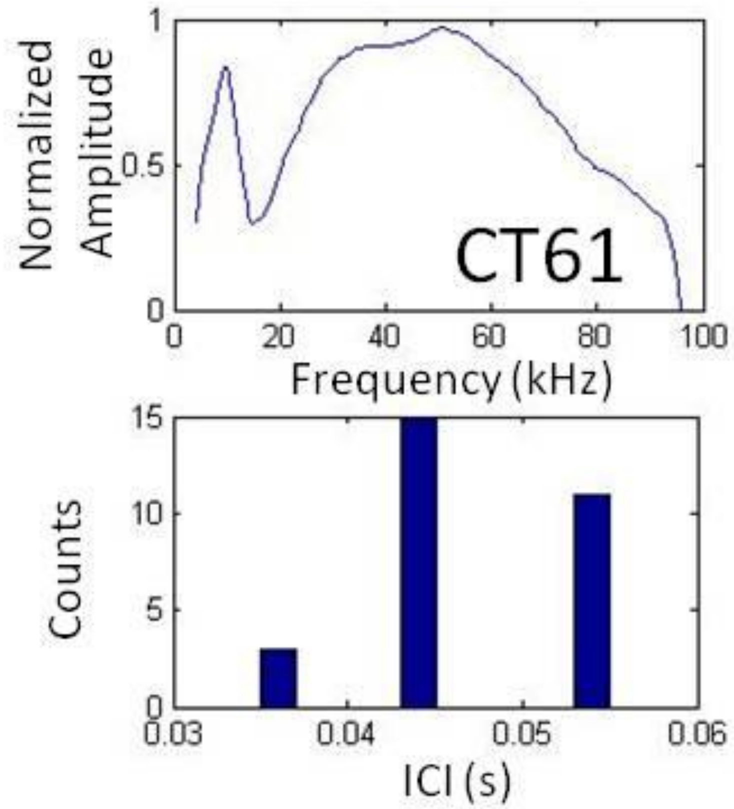

Figure 45. Group T click types showing the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters. In the following figure, detections of this spectrum are represented by black dots/horizontal bars.

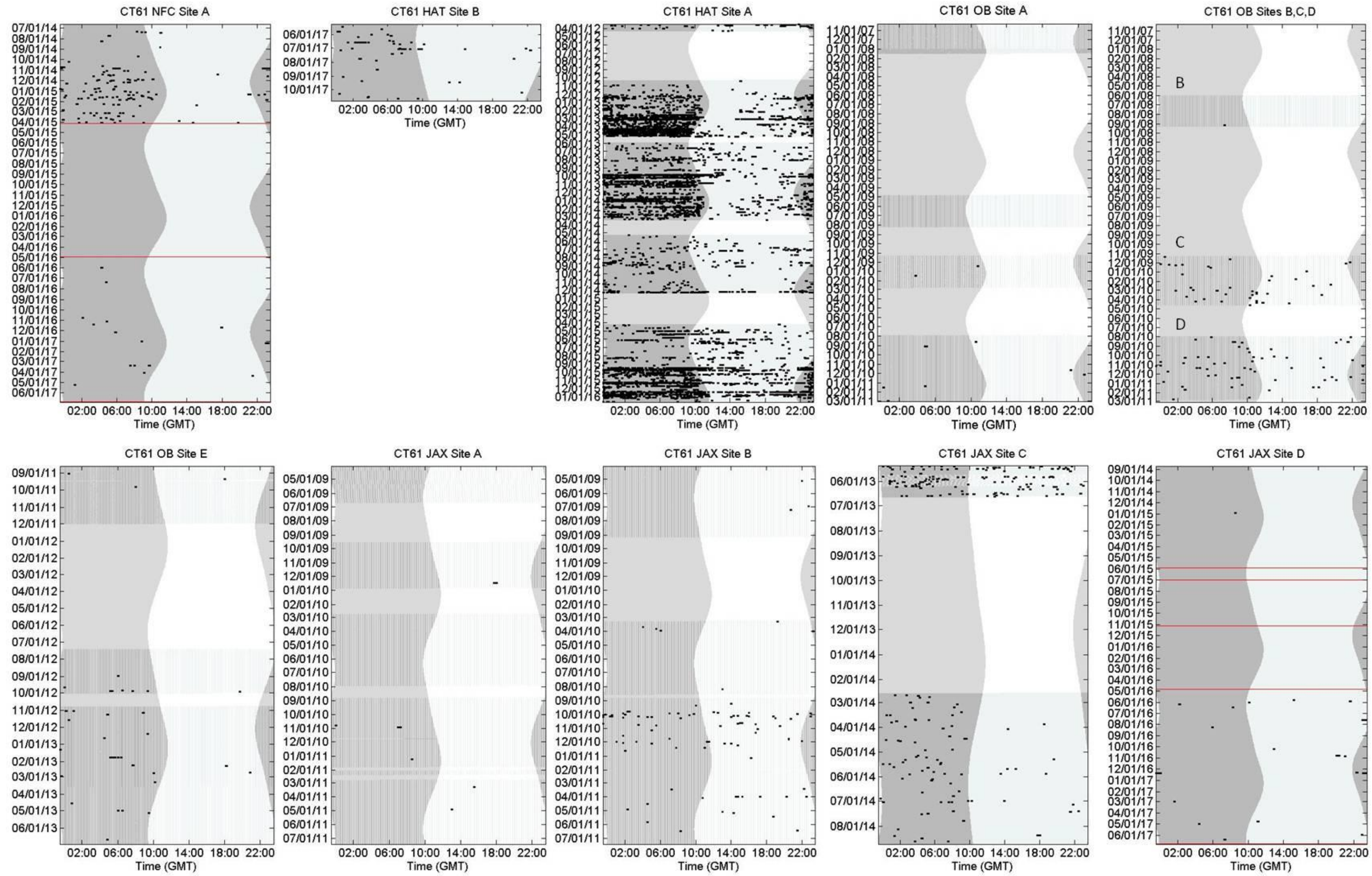

Figure 46. Group T click detections in five-minute bins at the various HARP deployment locations. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black dots/horizontal bars.

Table 21. Modal inter-click intervals, average frequency peaks, and average frequency notches of the click type in Group T. Only frequencies between 10-60 kHz are reported as this was the frequency band examined in detail for this study. CT = click type, ICI = inter-click interval.

CT#	Modal ICI (s)	Frequency Peaks (kHz)	Frequency Notches (kHz)
CT61	0.045	37.6, 50.6	14.9, 39.2

This group mainly occurred at Cape Hatteras Site A, where it mostly had a nocturnal presence, with a greater number of detections occurring between October and April. While the number of detections was not as great as at Cape Hatteras Site A, this click type also had a nocturnal occurrence at Norfolk Canyon Site A, Cape Hatteras Site B, and Onslow Bay Site E. No other temporal patterns were apparent.

2. **Satellite Tag Detections with Possible Pilot Whale Clicks**

The following figures show the templates for ***Group G*** click types and their co-occurrence with detections of satellite tagged short-finned pilot whales at Norfolk Canyon Site A and Cape Hatteras Sites A and B.

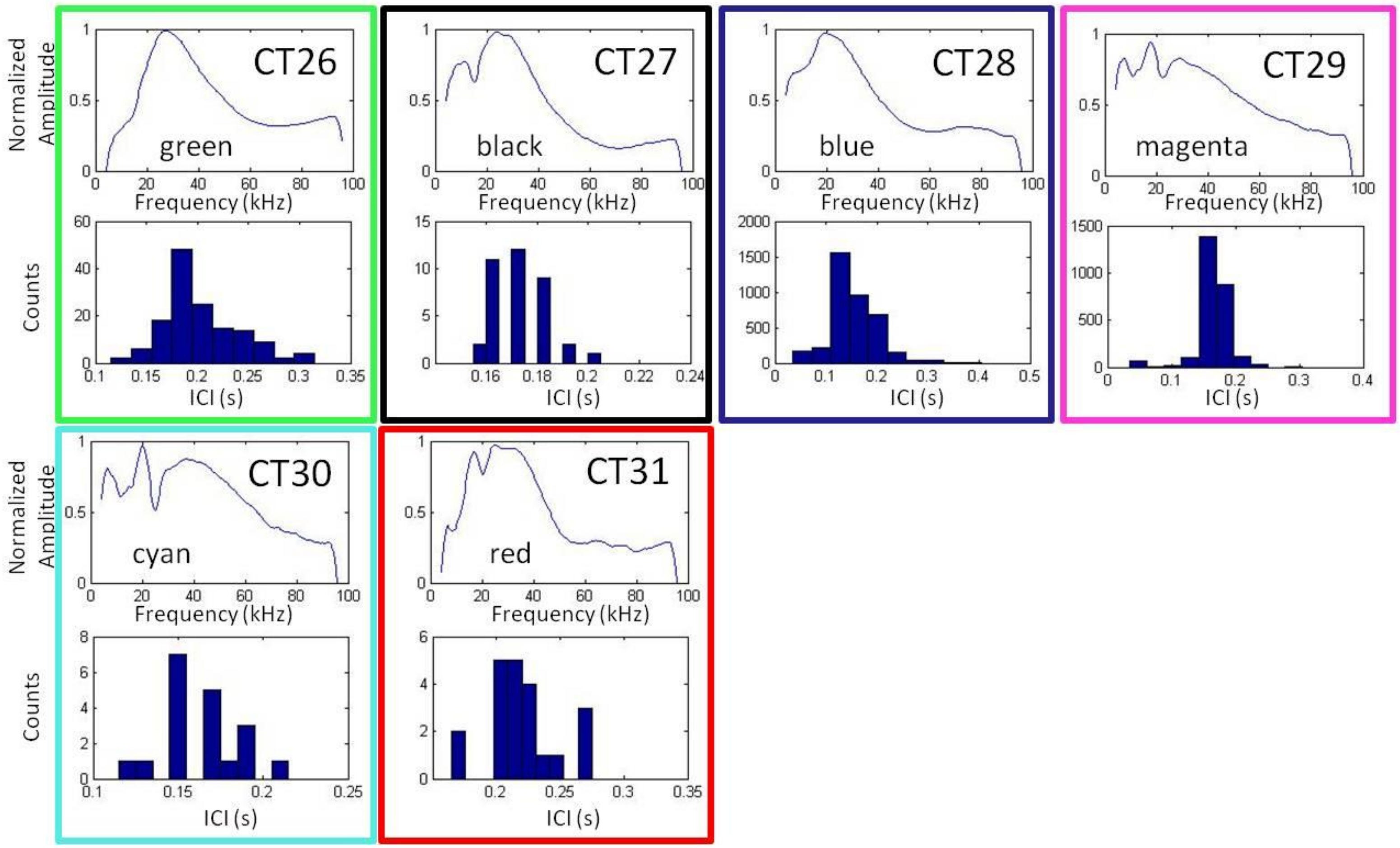

Figure 47. Group G click types (templates) showing mean frequency spectra of click clusters (top sets of panels) and distribution of inter-click intervals (ICIs) (bottom sets of panels) within click clusters. In the following figures (Figures 48-50), detections of each spectrum are represented by the name of the color that appears within the mean frequency spectrum plot.

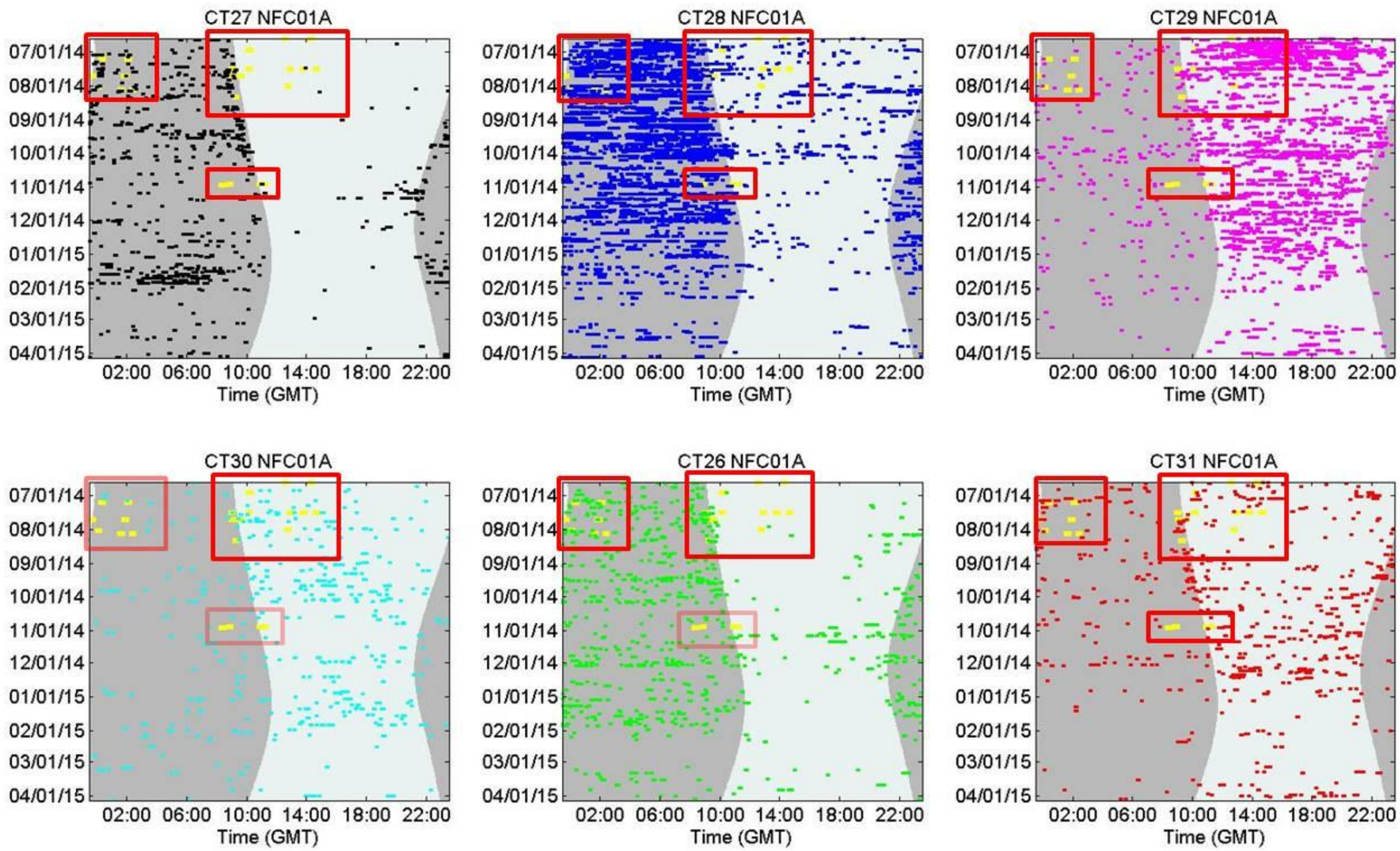

Figure 48. Group G click types and their co-occurrence with detections of satellite tagged short-finned pilot whales at Norfolk Canyon Site A. The different colored horizontal bars represent the different templates except for yellow, which represents the detections of satellite tagged pilot whales within 5 nm of the HARPs. The red boxes are highlighting the detections of satellite tagged animals, with darker shades of red indicating higher co-occurrence and lighter shades of red indicating lower co-occurrence.

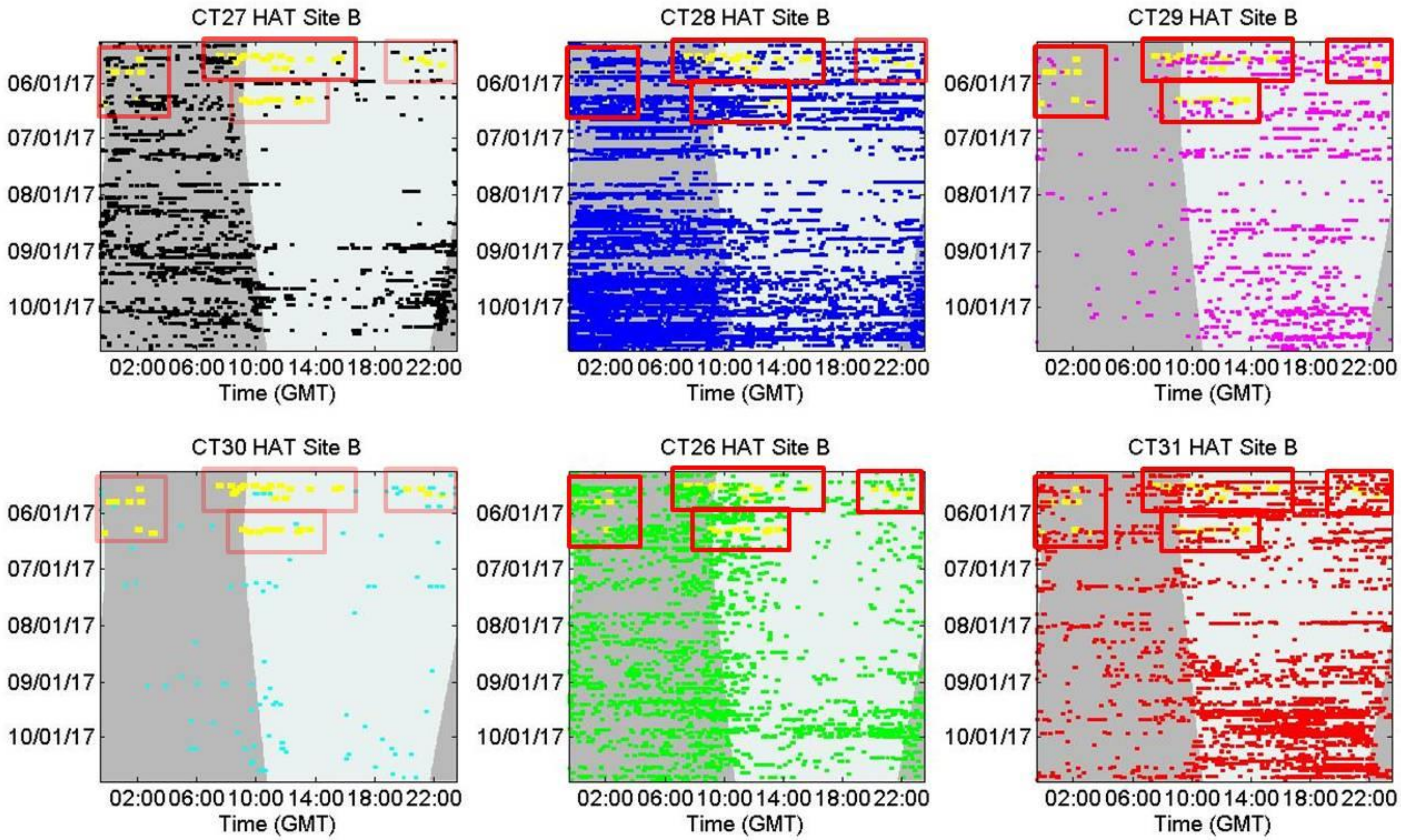

Figure 49. Group G click types and their co-occurrence with detections of satellite tagged short-finned pilot whales at Cape Hatteras Site B. The different colored horizontal bars represent the different templates except for yellow, which represents the detections of satellite tagged pilot whales within 5 nm of the HARPs. The red boxes are highlighting the detections of satellite tagged animals, with darker shades of red indicating higher co-occurrence and lighter shades of red indicating lower co-occurrence.

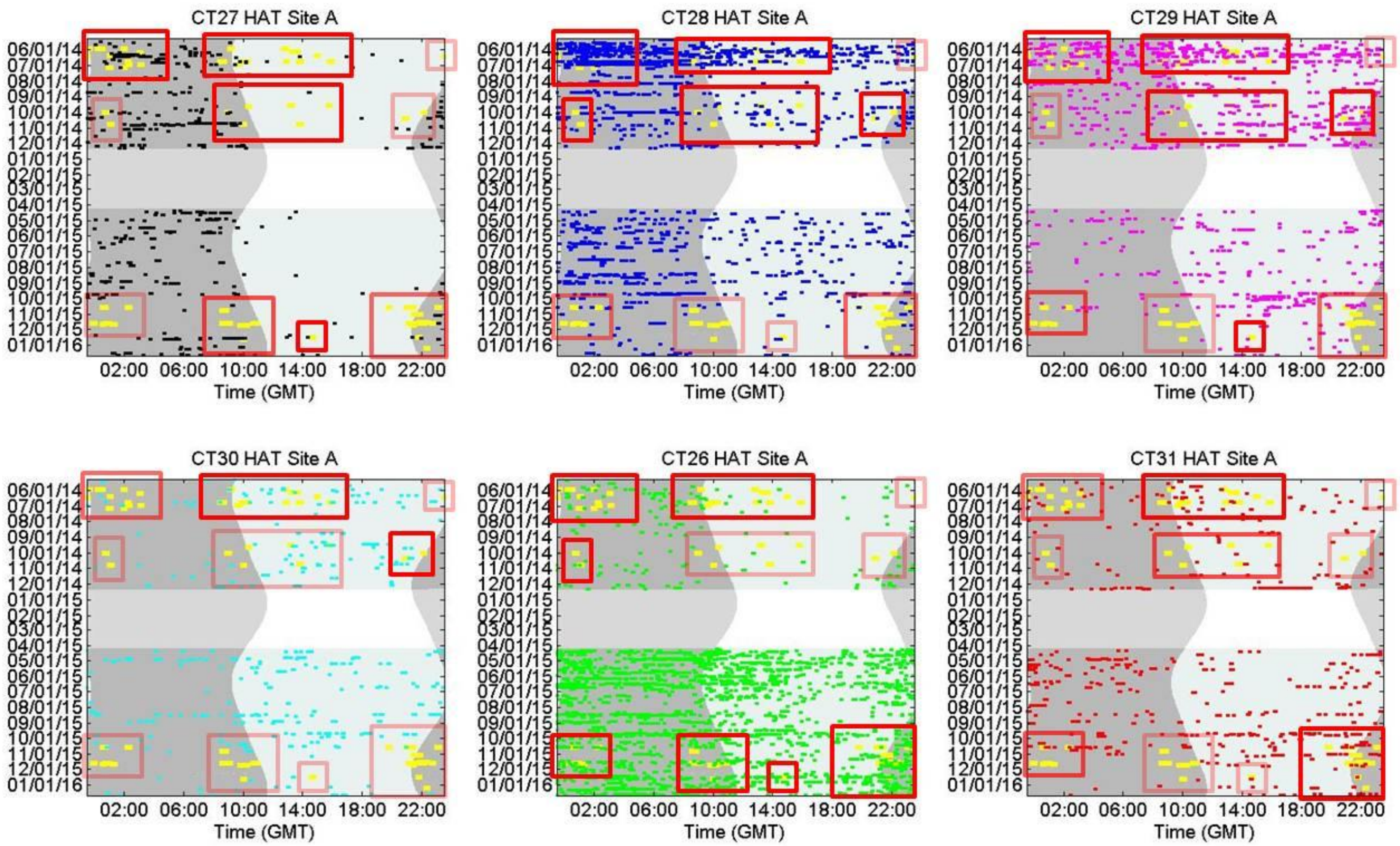

Figure 50. Group G click types and their co-occurrence with detections of satellite tagged short-finned pilot whales at Cape Hatteras Site A. The different colored horizontal bars represent the different templates except for yellow, which represents the detections of satellite tagged pilot whales within 5 nm of the HARPs. The red boxes are highlighting the detections of satellite tagged animals, with darker shades of red indicating higher co-occurrence and lighter shades of red indicating lower co-occurrence.

As seen above, the ***Group G*** click types show up consistently when comparing times that satellite tagged pilot whales were within 5 nm of the HARPs.

IV. Discussion

A merged template database was run on all of the HARP datasets from Norfolk Canyon, Cape Hatteras, Onslow Bay, and Jacksonville. The only difference was one template click type – from ***Group D*** – which was only run on the Norfolk Canyon datasets. This one Norfolk Canyon click template was only used when classifying clicks for that site because it seemed similar enough to three other click type groupings (***Group A***, with its notch in general, and ***Groups B and C***, with its peak frequency) that the amount of misclassification may have increased at the other sites, where it was not a recurrent click type. The logic behind using a merged template database versus one for each of the four main geographical locations or for shallow versus deep sites (which were both also tested previously but which results are not included here) was to be more useful and consistent for species identification as well as more useful for applying to future datasets.

The last datasets included in this report from Jacksonville Site D (JAX13D) and Norfolk Canyon Site A (NFC02A) have different hydrophone frequency responses than previous datasets. While the transfer function should make click spectra comparable, these hydrophones may have been able to detect clicks from farther away with their improved sensitivity. Thus, any differences in numbers of detections for those datasets should be viewed with caution. Also, the data at the beginning of JAX13D have sections that are of poor quality. Because all of the click detections and click classifications were done automatically without manual review, it is certain that misclassifications have occurred, especially since some of the templates and groupings used here are very similar to each other and would be hard to assign manually. It seems that during these poor quality periods of JAX13D, misclassifications occurred frequently (see ***Groups O and R***). One also needs to be cautious when interpreting the results from Jacksonville Site B, as data from that particular site was inundated with snapping shrimp, which may have resulted in more misclassifications than normal. The groupings were done manually, with the possibility that some “merged” click types should not have been included within the specified group.

Finally, it is important to note that multiple species could share a click type and a single species could produce multiple click types, perhaps differing depending on behavioral state, depth, or prey type. Pilot whales seem to be an example of a single species that produces multiple click types.

A. Temporal Patterns

Diel and seasonal patterns for each click type were described in the results section. Here, we highlight some of the interesting patterns observed.

At Onslow Bay Site A (located near the shelf break), ***Group A*** click types show a strong seasonal crepuscular pattern, with a strong pulse of longer-duration and clustered click events in the late night-dawn-early morning period. This diel pattern was not seen at the other Onslow Bay sites for ***Group A*** click types, even for data collected concurrently at different sites (see Figure 51, with red box showing concurrent deployments), suggesting perhaps the species that produced these click types moved toward the shelf break area (which runs along the 200-m isobaths in Onslow Bay) at that time. In addition, the longer duration click events detected during this period at this shallower site suggests that either animals were moving toward the shelf break area, were staying in this shallow area for longer periods of time, were composed of larger group sizes, and/or were from a migratory species. As detections for this click type grouping appear year-round at Onslow Bay Site A, a migratory species does not seem as likely. If the longer events were due to animals staying in the area for longer periods, it seems likely that these extended click events are indicative of a behavioral change, either reflecting movement into the area or a change in vocal behavior, such as an increase in foraging or a shift in prey distributions. It is important to note that shallower sensors typically have shorter click detection ranges than deeper sensors due to signal propagation, which typically results in shorter acoustic encounters in shallow environments. The longer encounters reported here at shallower sites are probably not attributable to detection probability differences. The question then remains as to whether this pulse resulted from a certain species moving into this area to feed, or reflects animals staying longer and foraging on prey aggregated during that time of the year. Similar horizontal movements have been described for Hawaiian spinner dolphins (Benoit-Bird and Au 2003), dusky dolphins in the south Atlantic (*Lagenorhynchus obscurus*, Würsig and Würsig 1980), and striped dolphins in the northwestern Mediterranean Sea (Gannier 1999).

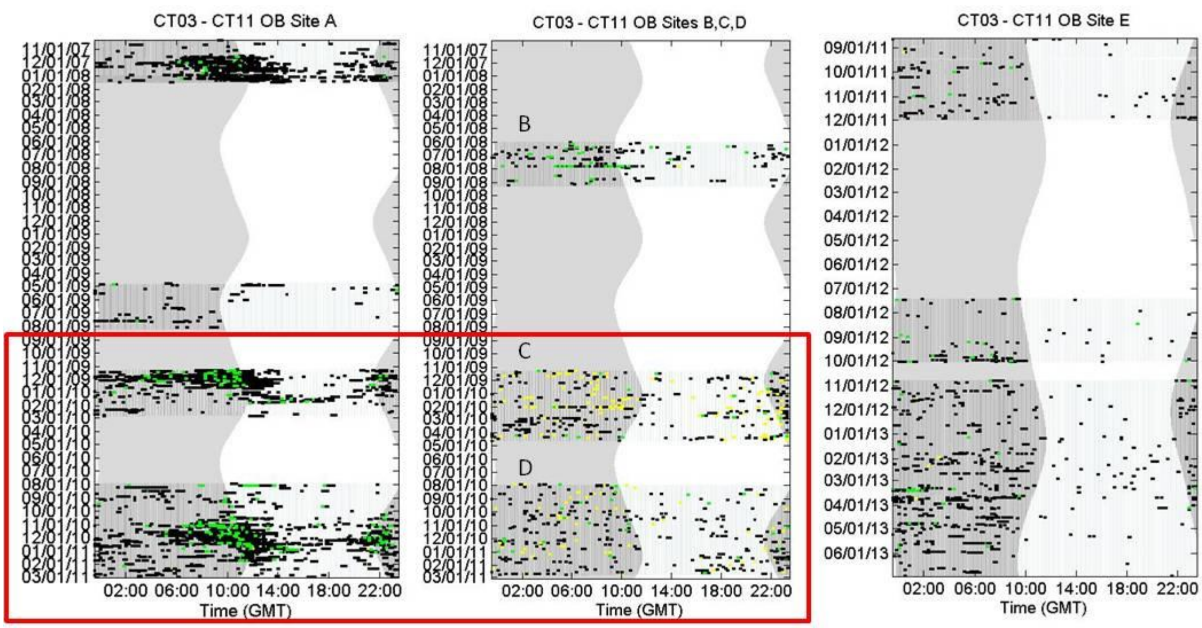

Figure 51. ***Group A* click types detected at the different sites of Onslow Bay. Concurrent recordings from different sites are shown within the red rectangle. Sites B, C, and D are combined in the middle plot. Notice the different diel pattern observed at Site A versus Sites B, C, D, and E. Dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections in five-minute bins are represented by the black and colored dots/horizontal bars.**

Groups B, F, and P as well as CT31 from ***Group G*** all showed a crepuscular pattern at Jacksonville Site D. For ***Group F***, the crepuscular pattern was seen for CT20 and CT24 only. The diel plots in Figure 52 show these patterns.

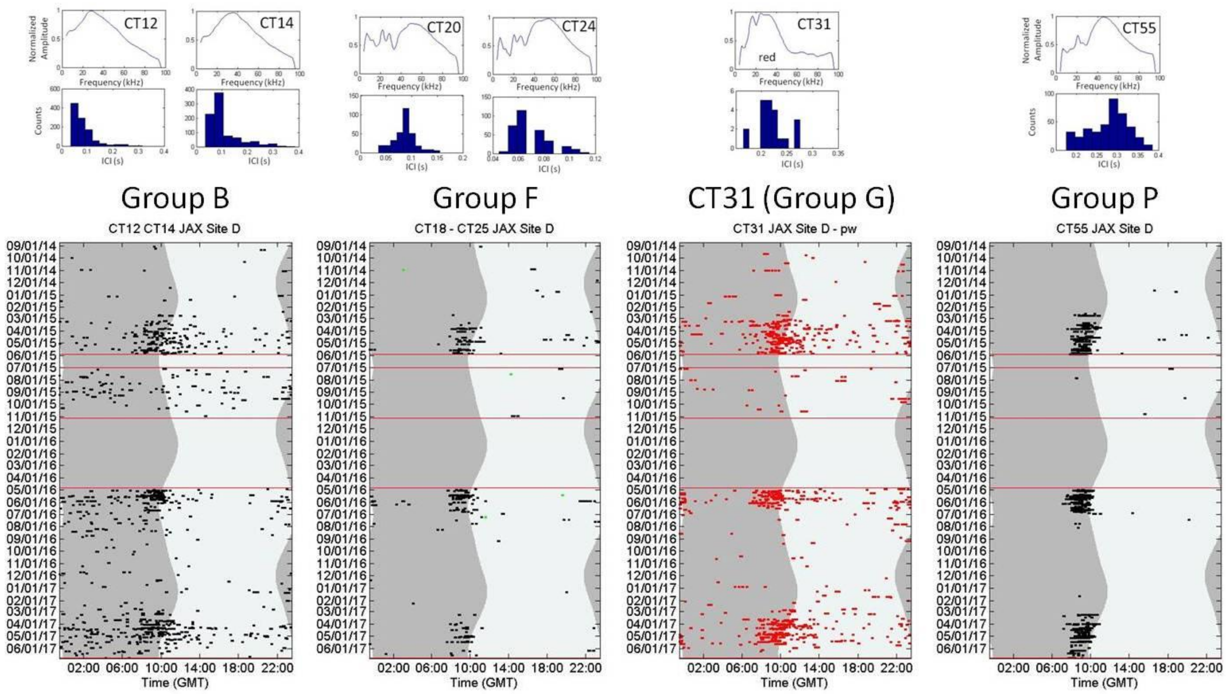

Figure 52. The groups of click types that showed crepuscular patterns at Jacksonville Site D. Above the group name, the mean frequency spectrum of click clusters (top panel) and distribution of inter-click intervals (ICIs) (bottom panel) within click clusters for the click types that displayed crepuscular patterns within each group are shown. Below the group name, the click detections in five-minute bins at the various HARP deployment locations are shown. For these plots, dark gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil). Recording/analysis effort is indicated by lighter gray shading or red horizontal lines. Detections are represented by the black or red dots/horizontal bars.

There are some similarities between some of the click type spectra, although the ICIs are quite different (compare ***Group F*** with ***Group P***). It is possible there were misclassifications for these groups during the automated process. If these were not misclassified, however, perhaps these groups are showing a similar crepuscular pattern to the occurrence of clicks due to the aggregation of prey during spring at that site. For ***Groups B and F*** and CT31, the diel patterns at the shallower Jacksonville sites were different (either nocturnal or no diel pattern) than the crepuscular pattern of click occurrence at Site D. This could indicate that the species producing these click types showed a horizontal movement toward deeper waters during that time of day (dawn) during a specific time of year (spring). ***Group P*** was only seen at Jacksonville Site D. It is possible this group normally is found in deeper waters and moved more inshore at that time to forage on aggregated prey.

B. Click Types and Possible Species Producing Them

For the shallow water Onslow Bay (Site A) and Jacksonville sites (Sites A, B, C), the dominant click types fall under ***Groups A, B, and C***. Year-round visual surveys (aerial- and vessel-based) indicate that the two most common cetacean species in the shallower sites of Onslow Bay (A, B, C, D; Read et al. 2014) and Jacksonville (A, B, C) are bottlenose dolphins and Atlantic spotted dolphins, so it is likely that the clicks from ***Groups A, B, and C*** are produced (and possibly shared) by one or both of them. ***Groups B and C*** have similar peak frequencies and overall shape (although ***Group C*** shows a steeper upward slope between ~10-35 kHz), but they were kept separate due to the different diel patterns observed at Jacksonville Site D. When comparing temporal patterns, there also appears to be considerable co-occurrence of ***Group A*** with CT15 (green) and CT16 (magenta) from ***Group C*** at all sites, possibly due to classifier confusion. The co-occurrence of these groups should be examined statistically.

An objective of this work was to compare click types found at the Jacksonville shallow water (Sites A, B, C) versus deep water (Site D) sites to determine if a click type consistent with known Atlantic spotted dolphin distributions could be identified. Based on findings from visual surveys in the area, indications of a possible match would include abundant detections at the shallow sites with no or few detections at sites deeper than 200 m. Focusing on the dominant click type groups, there are many detections of ***Group C*** click types at Jacksonville Site D, even during the day when visual surveys rarely detected Atlantic spotted dolphins in such deep waters. Therefore, ***Group C*** does not seem to be solely produced by Atlantic spotted dolphins if at all. The number of ***Group A*** click type detections is considerably lower at the deeper site, although not absent. ***Group B*** also seems to be detected slightly less at Jacksonville Site D. However, for this group, most detections at Site D showed a crepuscular pattern of occurrence in contrast to the more nocturnal pattern at Site C and lack of obvious diel patterns at Sites A and B. Thus, perhaps the species producing ***Group B*** click types moved horizontally into deeper waters at dawn during certain times of the year as mentioned previously. In any case, the difference in diel patterns of ***Groups A and C*** (mostly nocturnal) versus ***Group B*** (crepuscular pattern seasonally) at Jacksonville Site D could mean two things – 1) that at least two different species are producing these groups of click types or 2) the groups of click types are from a single species (such as described below for pilot whales) or shared by multiple species but the actual click spectra and ICI differ because of dive depth, prey differences, or behavioral changes. This conclusion is also supported by differences in diel patterns of click types from ***Groups A, B, and C*** at Onslow Bay Site A (located near the shelf break). While there was a strong seasonal crepuscular pattern for ***Group A*** click types at Onslow Bay Site A (detailed above, Figure 51), there was no such diel pattern at that site for click types from ***Groups B and C*** (with the possible exception of the first deployment which should be examined further). Further analysis should address the impact (in any) that classifier confusion has on these conclusions.

Group D click types are somewhat similar to ***Groups A, B, and C*** click types, as mentioned previously. From the Norfolk Canyon temporal figures for these four groupings, one can see co-occurrence, especially for ***Group A*** (both deployments) and ***Group C*** (second deployment). The species that produce(s) ***Group D*** click type is/are not known but it is suspected that these clicks are produced by bottlenose dolphins and/or Atlantic spotted dolphins.

Groups E, F, and M are occasionally or often times associated with low-frequency narrow-band calls and/or low-frequency burst-pulses. This is based on a review of comments in spreadsheets made for manual detections for the Onslow Bay datasets as well as a quick look at some of those instances. Low-frequency narrow-band calls have been found to be associated with bottlenose dolphins (Schultz *et al.* 1995, Simard *et al.* 2011), although other species may also produce these sounds. ***Groups E and M*** often times occurred together, although this was not statistically examined.

Group G click types represent click types thought to be produced by pilot whales (probably short-finned pilot whales as long-finned pilot whales are thought to occur north of Cape Hatteras). As mentioned previously, it is thought that this grouping represents pilot whale click types as they have low peak frequencies, seem to be associated with pilot whale-like calls and occasionally social buzzes (although CT26 and CT31 still needs to be reviewed for these associations), and show up consistently when comparing times that satellite tagged pilot whales were within 5 nm of the HARPs. As discussed previously, there are interesting differences in diel patterns for each of the different click types, which may be related to dive depth, prey, and/or behavioral state. It seems likely that ***Group G*** may be over-represented due to misclassifications (probably due to snapping shrimp) at Jacksonville Site B.

Group H, represented by one click type (CT32), also may be produced by pilot whales. It is very similar to the spectral shape of CT26 (***Group G***) and appears to occur with that click type at JAX Site D. Its ICI is longer than the other click types thought to be produced by pilot whales, though.

The two click types that make up ***Group I*** are similar with peaks and notches. CT01 was a template taken from Cape Hatteras, while CT02 was a template taken from a shallow water Onslow Bay site (Site C). It was originally thought common dolphins might produce these click types, given that it appeared to have a seasonal component (winter/early spring) in Hatteras and Onslow Bay. The few detections in JAX do not support this, although it is possible they are misclassifications. It is also interesting that these click types disappear from Hatteras more or less starting in 2014 and never really show up in Norfolk Canyon (which had its first deployment in 2014). Whether this shows a change in click type from a species or something else is unknown. Note that the ICI distribution for CT02 was copied from CT01 for this one example as CT02 was manually extracted from the Onslow Bay Site C dataset. This should be fixed in future runs.

Group K, represented by one click type (CT34), is also somewhat similar to ***Group I*** and one of the templates from the Southern California HARP from 2007. Despite more detections during the winter/spring seasons, detections do occur year round in Cape Hatteras, which is not expected for common dolphins. Detections also occurred in Jacksonville, although they also could be due to misclassifications.

Group P, represented by one click type (CT55), was a template created from the Jacksonville Site D datasets. Minus a single detection at Cape Hatteras Site A, it is only found at Jacksonville Site D. It has a very distinct crepuscular temporal pattern, similar to that of CT31 (***Group G*** – possible pilot whale). Its ICI is longer than that measured for the possible pilot whale click types of ***Group G***, and shorter than the peak ICI of ***Group H***. It seems likely that this click type is produced by a blackfish species or possibly rough-toothed dolphins.

Finally, ***Group R*** is made up of templates from Cape Hatteras Site B. Their ICIs are longer than those of the possible pilot whale click types from ***Group G***. There are similarities between the click types of ***Group R*** and CT30 (***Group G***) and CT55 (***Group P***). The detections at the start of the third Jacksonville Site D dataset should be ignored, as they are likely due to the poor quality data at the beginning of that deployment. It seems likely the ***Group R*** click types are produced by a blackfish species.

Overall, this work shows that there are categories of unidentified odontocete clicks that show promising structure for future classification as algorithms are developed further. Continuing to explore the satellite tag data and detections of those tagged animals on the HARP array can also help in identification of click types.

C. Future Considerations and Directions

Although the results presented here are not clear cut and contain lots of complicating factors, they do show that there is promise for future classification of at least some unidentified odontocete clicks. An obvious next step for this work is to look at the co-occurrence of different click types, which would help to determine if similar click types could be merged. This targeted review of subsets of the data would improve understanding of click type variability within and between encounters. Several similar click type templates were used here (see ***Group F*** for instance or CT29 and CT30 from ***Group G***) which could likely be merged without changing the results as the algorithm should assign them to the remaining similar template. There were also click types that perhaps should not have been included. For example, CT61 from ***Group T*** showed similarities to other click types and may have muddled the results. Manual review of a subset of the data would allow a more robust, semi-supervised classification strategy. Ideally, a smaller number of templates would be used. In addition, co-occurrence of click types that are not as similar could indicate that the same species are producing them as well, but might be a result of different click beam angles (on-axis versus off-axis clicks) or behavioral states of the animals themselves. Once co-occurrence of click types has been examined and click types merged, we recommend looking for seasonal and spatial patterns of occurrence of click types in conjunction with information on seasonal and spatial occurrence of odontocete species from aerial surveys. Not all species are found at each site and some species occur only seasonally.

Templates were only created for recurring click types found in each dataset. Thus, rare species likely are not represented. Adding new and different templates found in HARP data from more northern sites (such as those collecting data for the NOAA NEFSC Passive Acoustic Research Group) could help in identifying click types for animals that are rare in our study areas or even those that migrate seasonally, such as common dolphins.

It is also possible that the click detector included buzzes, which would affect the mean click characteristics used in the classification steps. This should be looked into and if buzzes are found to be included, improving one step of this automated process to isolate buzz clicks as separate from other clicks could help in the overall classification. Also improving the automatic false positive removal and/or introducing a manual cleaning step to reduce the influence of non-target sounds, such as snapping shrimp, is also suggested.

While some species (*e.g.*, Risso's dolphins) are known to produce clicks with strong frequency peaks (Soldevilla *et al.* 2008), species that produce shorter clicks with indistinct spectral features are more difficult to distinguish. As mentioned previously, it is possible, and perhaps likely, that multiple species produce clicks that are similar enough to be lumped into a single click type. A future step to examine this possibility would be to combine the HARP array data with visual sighting information, perhaps developing algorithms to achieve this comparison of datasets. On future visual surveys and tagging operations that take place in Cape Hatteras, it will be important to make sighting records of all delphinid species that occur within 2 km of the HARP array, and then identify clicks produced at that location and time within the HARP acoustic records. This will allow us to possibly associate specific click types to a particular species. This will not only allow us to examine how much variability is coming from individual animals and species, but also will assist in determining if multiple species (such as bottlenose dolphins and Atlantic spotted dolphins) share common click types. Of course, it is important to note that even if we find no overlap in click types, we would not be able to rule out the possibility that different species still share click types.

The different diel patterns for the different click types that are thought to be produced by pilot whales may be indicative of behavioral changes reflected by shifting ICIs. A next step would be to statistically characterize the average peak frequency for the different possible pilot whale click types as a function of time of day (and dive depth if possible from the tracking array data). Also continuing to further explore the possibility of multiple click types for pilot whales by examining the acoustic record for click types produced by satellite tagged pilot whales that approach within 2 km of the HARP array system in Cape Hatteras is important and recommended. Using the tracking array to look at specific depths of different click types would provide further information on the context in which various types are produced.

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