Occurrence and Distribution of Rice's Whale Calls near De Soto Canyon, Gulf of Mexico

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Executive Summary

The Rice's whale (*Balaenoptera ricei*; formerly Gulf of Mexico (GOM) Bryde's whale) is estimated to have a population size of 51 individuals in U.S. waters (Garrison et al 2021) and was listed as endangered under the ESA in 2019 (84 FR 15446; 87 FR 8981). The majority of modern sightings occur in waters between the 100 – 400 m water depths in an area near the De Soto Canyon off northwestern Florida (Soldevilla et al. 2017, Rosel et al 2021). This primary distribution area is defined as the Rice's whale core habitat (Rosel and Garrison, 2022). Occurrence patterns from one year of long-term passive acoustic monitoring and two summer and fall visual surveys during 2018 and 2019 indicate the whales are found year-round within the core habitat, but also suggest there may be seasonal movements throughout, and potentially out of, this area. High densities of anthropogenic activities occur throughout the GOM, including oil and gas exploration and extraction, fisheries, shipping, and military activities; several of these activities overlap with the whales' primary habitat. Understanding seasonal distribution and density will improve understanding of potential impact of human activities in the core habitat and assist in developing effective mitigation measures as needed.

The Southeast Fisheries Science Center (SEFSC) and Scripps Institution of Oceanography have been collaboratively deploying long-term passive acoustic monitoring stations throughout the GOM since 2010 to monitor the impacts of the Deepwater Horizon oil spill and subsequent restoration activities on cetaceans. HARPs deployed at the De Soto Canyon (DC) site in the core Rice's whale habitat have been continuously recording ambient noise and other acoustic events in the 10 Hz to 100 kHz frequency range, and 8 years of near-continuous recordings (2010–2018) were the focus of 2019-2021 analyses to better understand Rice's whale seasonal and interannual occurrence patterns. In 2019-2020, the focus of this project was on developing automated detectors for Rice's whale calls and analyzing eight years of near-continuous HARP recordings to establish complete occurrence time-series for understanding seasonal and interannual trends and for future habitat modeling and density estimation. In 2021, the project focus expanded to deploy a sparse array of 17 PAM units concurrent with the one long-term HARP to cover the Rice's whale core habitat and provide the necessary data to understand seasonal distribution and density.

During 2021, work focused on 1) preparing a manuscript to submit for peer-review describing the seasonal and interannual occurrence patterns from eight years of DC HARP data and 2) implementing the new field data collection project. The draft manuscript describes the automated detectors for long-moan and downsweep-sequence call types and the resulting occurrence time-series from the eight years of DC HARP data, which show year-round occurrence of both Rice's whale call types, with decreased call detections during late winter and early spring in some years. The high percentage of time Rice's whale calls are present throughout this 8-year period strongly supports the definition of this area as their core habitat, as based on sightings from visual surveys of the northern Gulf primarily conducted during summer and fall months. Seasonal and interannual variation in call detection rates described here may reflect 1) variation in ambient noise conditions or sound propagation conditions that impact detection ranges of the calls, and hence the HARP sampling area, 2) variation in call behavior, and 3) variation in spatio-temporal distribution and density of whales throughout the core habitat related to oceanographic variation. This temporally rich time series will be available for comparison with the spatially rich data from the new 2021-2022 field project and will improve interpretation of habitat use. To improve management of human-based activities in the core habitat of these endangered whales, further research is needed to understand and predict seasonal and interannual movement patterns and the factors driving this variation.

In May 2021, the new field project was implemented with 17 Soundtrap ST500 STD moorings deployed concurrent with the long-term DC HARP, in two lines of 9 PAM units each, to nearly completely cover the core habitat for approximately one year to improve understanding of seasonal and interannual movement

patterns and habitat use. The Soundtrap ST500 STDs are calibrated long-term recorders capable of continuously recording underwater sound in the 20 Hz – 48 kHz frequency range, including Rice's whale calls and ambient noise, for up to 6 months. SEFSC deployed 14 autonomous passive acoustic recording instruments in the northeastern habitat of the Rice's whale in May 2021, and recovered them and redeployed 17 instruments in November 2021. The instruments each recorded for a median of 4.5 months, with most recordings ending in September 2021. SEFSC will service the 17 moorings again in March-April 2022, and will recover the instruments in August 2022, yielding 12-15 months of near-continuous recordings across sites. The concurrently deployed DC HARP will have three deployments spanning this period 1) Aug. 2020 – Aug. 2021; 2) Aug. 2021 – July 2022; and 3) July 2022 – July 2023. Data from the first HARP deployment have been recovered, yielding 3.5 months of concurrent data from May 1 – Aug 23, 2021.

During 2021-2022, data analyses were begun on the Soundtrap recordings (May – Sept 2021) as well as the concurrently deployed DC HARP recordings (May - Aug 2021). Automated spectrogram cross-correlation detectors for the downsweep-sequence and long-moan calls, developed under the 2019 work, were run on all recordings. Given the critically endangered status of this species, automated detector thresholds are intentionally set to minimize missed detections at the cost of increased false positive detections, and a subsequent manual validation step is conducted to remove false positive detections. This semi-automated process is both more efficient and consistent than a complete manual detection process and more accurate than a fully automated process. Across the 15 moorings deployed during the May-September period, there were a total of 1,867 days of effort recorded, a total of 365,977 Rice's whale long-moan calls detected, and a total of 58,130 Rice's whale downsweep sequences detected. The validation process has been completed for long-moan calls from 12 of the 15 moorings, yielding a total of 141,931 true long-moan call detections out of 239,471 auto-detections validated to date. During the May – Sept 2022 period, true detections of Rice's whale long-moans occurred at all 12 of the manually validated sites, ranging from 7 to 38,375 calls per site. Higher numbers of detections occurred at the inshore sites. Manual validation results indicate false detection rates for the long-moan detector vary by site and over time within sites, with higher false-positive rates at offshore sites compared to inshore sites. Across the 12 validated sites, the daily occurrence of Rice's whale long-moan calls varied by site as well, with calls present on 7 to 95 percent of days per site over the May to September 2022 period.

Planned work for the remainder of the project includes completing validation and statistical analyses from the first deployment, completing field work and conducting analyses on the second deployment, and conducting field work and analyses for the third deployment. The manual validation process will be completed for long-moans on data from the remaining 3 sites and for downsweep sequences at all sites, and the detectors will be run and validated on the Soundtrap data from the second and third deployment cycles, and on the concurrent DC HARP data collected from Sept. 2021-July 2022. Additionally, ambient noise analyses, monthly occurrence mapping, and evaluation of diel and seasonal changes in call occurrence and ambient noise impacts on call detection will be conducted.

Project Background

The NOAA's Southeast Fisheries Science Center (SEFSC) and Scripps Institution of Oceanography (Scripps) have been collaboratively deploying long-term passive acoustic monitoring stations throughout the Gulf of Mexico (GOM) since 2010 to monitor the impacts of the Deepwater Horizon oil spill and subsequent restoration activities on cetaceans. High-frequency Acoustic Recording Packages (HARPs) deployed at the De Soto Canyon (DC) site in the Rice's whale core habitat have been continuously recording ambient noise and other acoustic events in the 10 Hz to 100 kHz frequency range. During 2019-2021, SEFSC conducted analyses of 8 years of near-continuous DC HARP recordings (2010-2018) to understand Rice's whale seasonal and interannual occurrence patterns at this site. Data from the DC HARP site had previously only been evaluated for downsweep call sequences in the first year of data (Širović et al. 2014), and had not been evaluated for long-moan or tonal-sequence calls (Rice et al. 2014), which have recently been verified as calls produced by Rice's whales (Soldevilla *et al.*, accepted). Over late 2018 through 2020, the first phase of this project focused on developing automated Rice's whale call detectors and analyzing 8 years of historic data from the DC HARP in the core habitat to establish complete occurrence time-series for understanding seasonal and interannual trends and for future habitat modeling and density estimation. The 2021 goal for the first phase of the project was to develop a manuscript for peer-review based on the results from the 8 years of Rice's whale call detections.

Additionally, in 2021, the SEFSC implemented the second phase of this project to collect and analyze new passive acoustic data for one year over the entire Rice's whale core habitat to understand seasonal distribution patterns, density, and whale movements throughout the core habitat. To achieve this goal, the SEFSC developed a survey design using an array of 17 moored Soundtrap acoustic recorders deployed concurrent with the long-term DC HARP, with two lines of 9 moorings each that nearly cover the Rice's whale core habitat (**Figure 1**). The Soundtrap mooring survey design included two 6-month deployment periods to collect a full year of recordings at each site. Analytical objectives include running the automated long-moan and downsweep-sequence detectors develop in phase 1 on all recordings, with thresholds set to minimize missed detections at the cost of increased false positives, and conducting a manual verification step to remove all false positive detections and improve accuracy of the final results. Products to be developed include time-series of daily presence and total call detections by call type and site, time-series of ambient noise levels per site, and monthly maps of call detection rates and daily presence per site. These products to improve the understanding of seasonal distribution and density of Rice's whales throughout the core habitat are needed to improve understanding of potential impact of human activities in this area, improve the accuracy and precision of impact assessments, and assist in developing effective mitigation measures as needed.

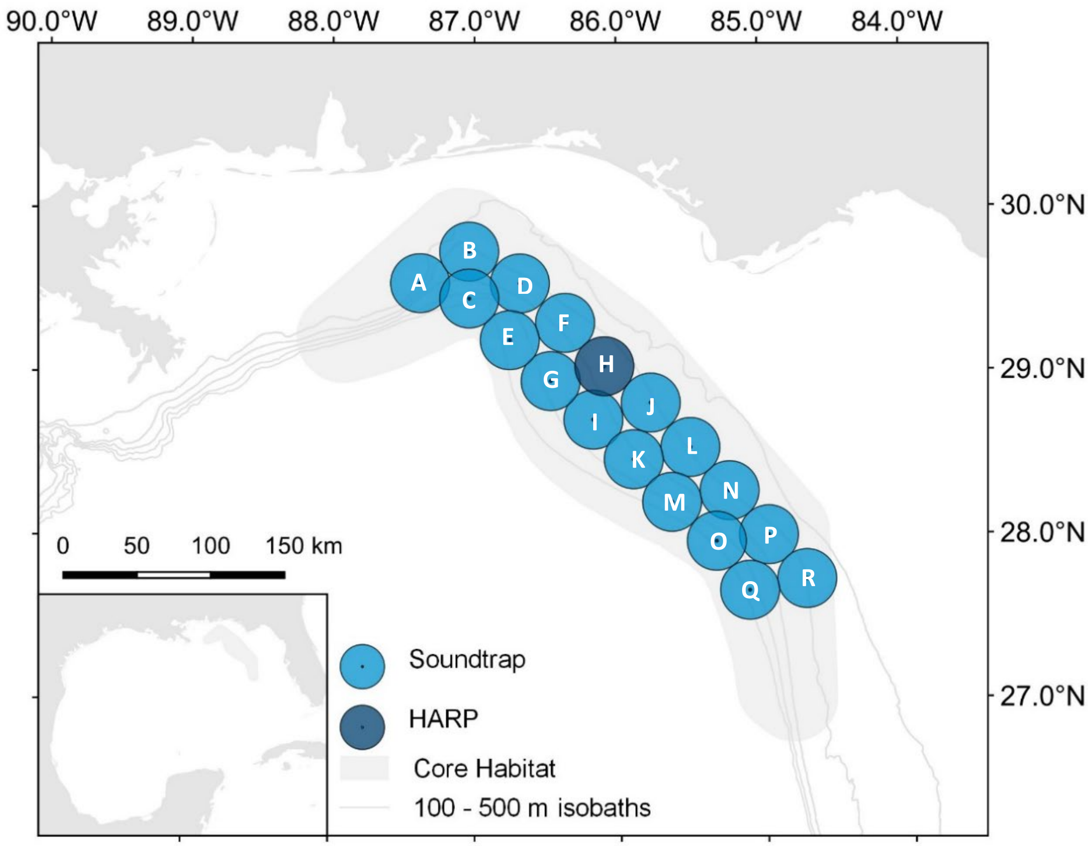

Figure 1. *Historic long-term passive acoustic monitoring station (HARP; dark blue) deployed in the Rice's whale core habitat in the northeastern Gulf of Mexico since 2010 and 2021-2022 passive acoustic monitoring stations (Soundtraps; light blue). Circles around passive acoustic stations indicate the expected acoustic coverage with 20 km call detection distances. The NMFS core habitat of Rice's whales is indicated. The long-term De Soto Canyon (DC) HARP site, where Rice's whale calls have previously been detected, is being deployed concurrent with the Soundtrap array under a Deepwater Horizon Restoration project.*

Rice's Whales

The Rice's whale (*Balaenoptera ricei*; formerly Gulf of Mexico Bryde's whale), estimated to have a population size of 51 individuals in US waters (CV 0.53, Garrison *et al.*, 2020), was listed as endangered under the US Endangered Species Act (ESA) in 2019. The majority of modern sightings occur in waters between the 100 – 400 m water depths in an area near the De Soto Canyon off northwestern Florida (Soldevilla *et al.*, 2017; Rosel *et al.*, 2021). This primary distribution area has been defined as the Rice's whale core habitat (Rosel & Garrison, 2022). Occurrence patterns from one year of long-term passive acoustic monitoring in 2010-2011 and two recent summer and fall surveys in 2018-2019 indicate the whales are found year-round within this core habitat, but also suggest there may be seasonal movements throughout this core habitat, and potentially beyond it into a broader range than is currently documented. High densities of anthropogenic activities occur throughout the GOM, including oil and gas exploration and extraction, fisheries, shipping, and military activities and several of these activities overlap with the whales' core habitat. Many of these activities, including US Navy readiness training, testing, and ship shock trials, and Eglin airforce base activities, overlap with the whales' core habitat. Understanding seasonal distribution and density will improve understanding of potential impact of human activities in the core habitat, improve the accuracy and precision of impact assessments, and assist in developing effective mitigation measures as needed.

Rice's Whale Calls

Long-term, broad-coverage passive acoustic monitoring is a highly effective tool for investigating whale seasonal and interannual occurrence patterns. In the GOM, three call types have been definitively identified to free-ranging Rice's whales (Rice *et al.*, 2014, Širović *et al.*, 2014, Soldevilla *et al.,* accepted) and one additional call type has been proposed as a likely candidate (Širović *et al.*, 2014; **Figure 2**).

Downsweep Pulse Calls

Rice's whales produce downsweep pulse sequence calls made up of pairs and longer series of short-duration downsweeps (mean: 8 downsweeps, range: 2-25) ranging from 110 ± 4 to 78 ± 7 Hz, with a mean duration of 0.4 ± 0.1 s, an inter-pulse interval of 1.3 ± 0.1 s, and source levels of 155 ± 14 dB re: 1 µPa at 1 m (Rice *et al.*, 2014, Širović *et al.*, 2014, Soldevilla *et al.,* accepted). A second downsweep call type, higher in frequency (170 to 110 Hz), segmented, and typically occurring in repeated sequences of doublets, also has been detected in autonomous recordings and is proposed to be a possible Rice's whale call (Širović *et al.*, 2014).

Tonal Calls

Rice's whales produce two tonal call types: long-moan calls and tonal-sequence calls (Rice *et al.*, 2014, Soldevilla *et al.*, accepted). The long-moan call type is a long-duration, amplitude-modulated downsweep ranging from 150 to 75 Hz with a mean center frequency of 107 Hz, mean 22.2 s duration, and 3.4 pulse/s amplitude pulse rate (Rice *et al.*, 2014, Soldevilla *et al.*, accepted). The tonal-sequence consists of 1-6 narrow-band constant-frequency tones in sequence following some long-moans, with individual tonals having a mean center frequency of 103 Hz and mean 3.6 s duration (Rice et al. 2014).

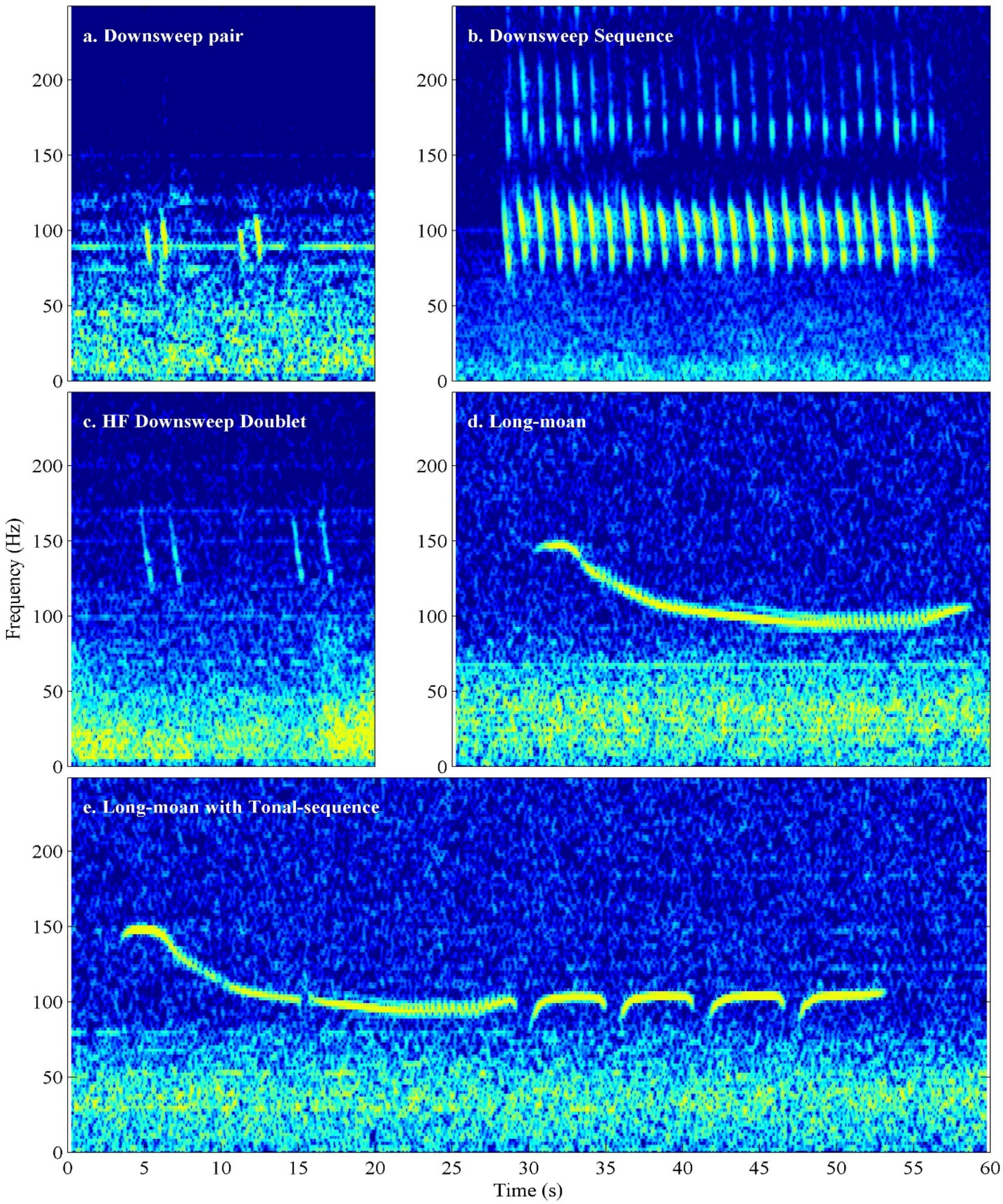

Figure 2. *Spectrogram of Rice's whale calls and potential calls*

Methods

Acoustic Recording Instrumentation

High-frequency Acoustic Recording Package (HARP)

HARPs were used to record marine mammal sounds and characterize the low-frequency ambient soundscape in the GOM at the DC HARP site from 2010 through 2021. HARPs can autonomously record underwater sounds from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. The HARPs were deployed in either a seafloor mooring or a seafloor package configuration with the hydrophones suspended 10 m above the seafloor (**Figure 3**). Each HARP is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations (Wiggins & Hildebrand 2007).

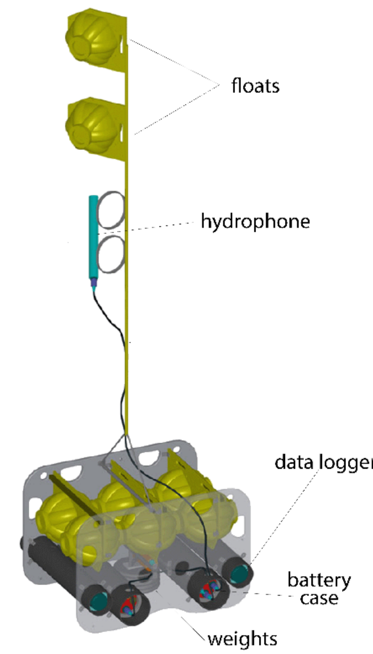

***Figure 3**. Schematic of a HARP seafloor package*

Soundtrap ST500 (Soundtrap)

Soundtrap ST500 STD recorders (Ocean Instruments Inc.) were deployed as a sparse array to record marine mammal sounds and characterize the low-frequency ambient soundscape throughout the Rice's whale core habitat in the northeastern GOM over the May 2021 to August 2022 period. The Soundtrap ST500 STDs are calibrated long-term recorders capable of continuously recording underwater sound in the 20 Hz – 60 kHz frequency range, including Rice's whale calls and ambient noise, for up to 6 months. The Soundtraps were deployed in a small mooring configuration with the hydrophones suspended 3 m above the seafloor. The ST500 STD recorders are factory calibrated at 250 Hz. The Soundtrap moorings use a Vemco VR2AR acoustic release that allows opportunistic collection of transmissions from Vemco-acoustic-tagged fish and reptiles that pass by the mooring.

Data Collected

Historic data analyzed during the first phase of this project include acoustic recordings collaboratively collected by SEFSC and Scripps at the DC HARP site (29º 2.878' N 86 º 05.847' W, 270 m depth) during the 2010-2018 period using HARPs sampling at 200 kHz. The DC HARP site (DCH) is located approximately in the center of the Rice's whale core distribution area (**Figure 1**; Rosel & Garrison, 2022). The first phase project analyses included ambient noise and whale call detection analyses for deployments DC02 to DC11 which included 2,226 days (53,424 hours) of data between 2010-2018.

New data collection for the second phase of this project began in May 2021. A sparse array of 14 Soundtrap moorings were deployed concurrent with the DC HARP in two lines that nearly completed covered the core habitat (**Figure 1**). The first deployment of 14 Soundtraps sampled at 24 kHz over the May 1 to Oct. 2, 2021 period. The concurrent HARP deployment, funded under a *Deepwater Horizon* Restoration project, recorded over the August 2020 to August 2021 period. The second phase project analyses include ambient noise and whale call detection analyses for recordings from the 14 Soundtrap sites and the May to August 2021 recordings from the DC HARP. A sparse array of 17 Soundtrap moorings deployed in November 2021 are due to be recovered in April 2022. The DC HARP is concurrently deployed over the August 2021 – July 2022 period.

Data Analysis

Recording over a broad frequency range of 10 Hz to 100 kHz allows detection of the low-frequency ambient soundscape, baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. Because analyses were focused on the Rice's whale and ambient noise, only the low-frequency data were required for these analyses. The HARP recordings were decimated by a factor of 100 and the Soundtrap recordings were decimated by a factor of 12 to provide an effective bandwidth of 10 Hz to 1 kHz. Long-term spectral averages (LTSAs) were created from the decimated data with a 1 Hz frequency and 5 s temporal resolution.

Low Frequency Ambient Soundscape

All recordings were converted to sound pressure levels using factory calibration values for Soundtrap recordings and calibration values obtained from full-system calibrations conducted at the U.S. Navy's Transducer Evaluation Center in San Diego, CA for HARP recordings. Hourly spectral averages and associated standard deviations were computed by combining sound pressure spectrum levels calculated from each acoustic record per hour. System self-noise was excluded from these averages. Time series of the daily mean and standard deviation of the noise level at 125 Hz were developed from these data. They were also combined to obtain monthly spectral averages to evaluate longer term changes in the ambient soundscape and its potential impacts on baleen whale call detectability.

Rice's Whale Calls

Automated Call Detectors

During prior work conducted in 2018-2019, spectrogram cross-correlation detectors for long-moan calls and downsweep pulse sequences were developed in Ishmael (Mellinger & Clark 2000) using a 2-day training dataset and a separate testing dataset to characterize miss rates and false detection rates. In 2019-2020, these detectors were run on spectrograms of recordings from all 10 DC HARP deployments. In 2021, these detectors were run on spectrograms of recordings from all 14 Soundtrap sites and the concurrent DC HARP recordings. For all analyses, spectrograms were calculated using an FFT frame size of 512 samples, no zero-padding, 50% overlap, and spectrogram equalization with 3 s spectral averaging.

Long Moan Detector Settings

Long-moan call contours contain five sections which include the preliminary upsweep, the approximately 150 Hz tone, the first part of the downsweep (slope 1), the second part of the downsweep (slope 2), and the long nearly constant frequency tail (**Figure 4**). The cross-correlation contour kernel for the long-moan call focused on the 150 Hz tone and slope 1, the most consistent parts of the frequency-modulated tonal call. The kernel contour is defined by a 1.1 s tone from 146 Hz to 145 Hz followed by a 3.7 s downsweep from 145 Hz to 112 Hz, each with a 14 Hz contour bandwidth. Detection function smoothing was enabled. The detection threshold was set to 4.5, and minimum and maximum detection durations were 0.5 s and 3.0 s, respectively. The minimum time allowed between subsequent detection events was 0.5 s. The threshold of 4.5, yielding a 6.4% missed call rate and a 26.4% false detection rate on a test dataset, was selected to minimize miss rates without excessive false detection rates. Missed detections were typically associated with calls with low signal to noise ratios. The majority of false alarms were associated with disk write noise from the recording instrument and tonal sounds from passing ships.

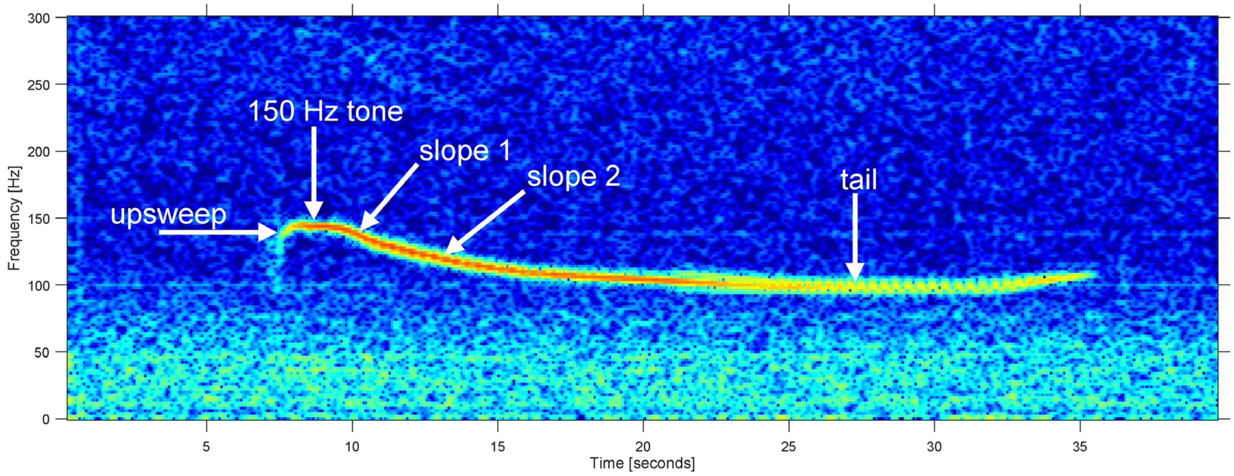

Figure 4. *Five sections of a long moan call. Two sections, the 150 Hz tone and slope 1 were used to create the contours in the long-moan detector.*

Downsweep Pulse Sequence Detector Settings

The *Ishmael* downsweep pulse sequence detector used the regular sequence feature to detect sequences of individual downsweep pulses as a single call. The cross-correlation contour kernel was defined as a single 4 s downsweep from 120 Hz to 80 Hz, with a 20 Hz contour bandwidth. For regular sequences, the minimum and maximum repetition period between individual pulse detections were set to 0.9 s and 1.1 s, respectively, and an 11 s window with 75% overlap was used. The detection threshold was set to 11, and minimum and maximum detection durations were set to 0.1 s and 40 s, respectively. The minimum time allowed between detection events was 0.4 s. The threshold of 11, yielding a 12.6% missed sequences rate and a 69.1% false detection rate on a test dataset, was selected to minimize miss rates without excessive false detection rates. Missed detections were typically associated with calls with low signal to noise ratios. The majority of false alarms were associated with long-moan calls with strongly pulsed tails and seismic survey airgun pulses with unusually short inter-pulse intervals or strong multipath effects.

Validation of automated call detections

In 2019-2020, each detector was run on the entire DC HARP dataset for deployments DC02 – DC11. In 2021, each detector was run on all Soundtrap recordings and concurrent DC HARP recordings. Given the critically endangered status of Rice's whales, automated detector thresholds were intentionally set to minimize missed detections at the cost of increased false positive detections, rather than selecting a threshold with equal miss and false alarm rates. The threshold selections aimed to reduce missed detections as much as possible while balancing the need to keep false detections within a reasonable number. Therefore, these preliminary detections require a follow-up step to manually validate the detections and remove all false detections for a final dataset. This semi-automated process is both more efficient and consistent than a complete manual detection process and more accurate than a fully automated process. In the validation step, each automated detection is manually reviewed and scored as a true or false detection, and false positive rates are calculated as the percentage of false positives to total detections. At this time, all detections have been manually validated for long-moan call detections at 12 of the 15 DC array sites from the May to September 2021 deployments. Manual validation at the remaining 3 sites is in progress, and manual validation of downsweep sequence detections at all 15 sites is planned for 2022.

Results and Accomplishments

Manuscript Preparation

During 2021, work from the first project phase focused on finalizing the work by preparing a manuscript to submit for peer-review that describes the seasonal and interannual occurrence patterns from eight years of historic DC HARP data. The drafted manuscript describes the automated detectors for long-moan and downsweep-sequence call types and the resulting occurrence time-series from the eight years of DC HARP data, which highlight the year-round occurrence of both Rice's whale call types and decreased call detections during late winter and early spring in some years. The high percentage of time Rice's whale calls are present year-round throughout this 8-year period strongly supports the definition of this area as Rice's whale core habitat, which was based on sightings from visual surveys of the northern Gulf primarily conducted during summer and fall months. The seasonal and interannual variation in call detection rates described may reflect 1) variation in ambient noise conditions or sound propagation conditions that impact detection ranges of the calls, and hence the HARP sampling area, 2) variation in call behavior, and 3) variation in spatio-temporal distribution and density of whales throughout the core habitat related to oceanographic variation. The draft manuscript is currently being revised to include results from 8 years of recordings at a nearby HARP site at Main Pass (MP), and will be submitted for peer-review in summer 2022. This temporally rich time series from the first phase of the project will be available for comparison with the spatially rich data from the second phase 2021-2022 field project and will improve interpretation of habitat use.

Moored Array Data Collection and Analyses

In May 2021, the SEFSC deployed 14 Soundtrap moorings from NOAA's *R/V Gordon Gunter*. In November 2021, the SEFSC recovered the 14 Soundtrap moorings from the first deployment and deployed 17 Soundtrap moorings for a second deployment from NOAA's *R/V Southern Journey*. A trip aboard the *R/V Southern Journey* is planned for the first 2 weeks of April 2022 to recover the Soundtraps from the second deployment and to deploy Soundtraps for the third and final deployment, to be recovered in August or September 2022. Concurrent HARP recordings are being collected over the Aug 2020 – Aug 2021, Aug 2021 – July 2022, and July 2022 – July 2023 periods at the long-term DC HARP site as part of the *Deepwater Horizon* Restoration passive acoustic monitoring project.

In November 2021, the acoustic recordings were successfully recovered from all 14 Soundtrap moorings deployed in May 2021, while the acoustic recordings from the DC HARP (DCH) were successfully recovered in August 2021, yielding a total of 1,867 instrument-days (44,807 hours) of recordings over the May – October 2021 period (**Table 1**). The Soundtraps recorded for an average of 4.5 months each (range 0.5 to 5.1 months), with recordings ending between late August to early October, yielding high quality recordings throughout the deployment at 12 of the 14 sites. The Soundtrap at site DCB had high-quality recordings until a hydrophone malfunction in August that corrupted some recordings over the August – September period. The Soundtrap at site DCI had a hydrophone malfunction and only recorded for 17 days. The Soundtrap at site DCL experienced issues on data transfer during data offload over August 2 – August 13 and lost 183 hours (7.6 days) of data during this period. Data from these three sites are undergoing QA/QC to remove low-quality data and retain useable recordings if possible.

The Soundtraps were originally built and shipped in the early days of the COVID pandemic. The mandatory closures during this period led to the Soundtraps being placed into storage for an extended period of time. Stored Soundtrap internal lithium batteries should be charged every 3-6 months to prevent them remaining in a fully discharged state for an extended period; however, this could not be done during COVID closures. Three Soundtraps exhibited unusual behavior prior to the May 2021 cruise and were not deployed at that time. These were returned to the manufacturer and repaired in time for the November cruise. The three Soundtraps with hydrophone failures and data transfer issues were also returned to the manufacturer and repaired following the November 2021 recovery.

Table 1. *Acoustic monitoring at 15 sites near De Soto Canyon over the May to September 2021 period. * The HARP at site DCH began recording in August 2020; only data collected concurrent with the Soundtrap array are included in these analyses. +These two Soundtrap moorings had hydrophone malfunctions and parts of the recordings are corrupted*

Site	Start Date \ Time	End Date \ Time	Latitude	Longitude	Duration (Days)	Duration (Hours)
DCA	2 May 2021 00:58	28 Sep 2021 23:57	29.5640	-87.3815	150.0	3,599
DCB+	2 May 2021 03:32	10 Sep 2021 18:30	29.7579	-87.0380	131.6	3,159
DCD	2 May 2021 06:05	24 Aug 2021 03:43	29.5626	-86.6830	113.9	2,734
DCE	2 May 2021 08:31	2 Oct 2021 19:53	29.2153	-86.7550	153.5	3,683
DCF	2 May 2021 16:03	16 Sep 2021 04:36	29.3206	-86.3683	136.5	3,277
DCG	2 May 2021 18:41	23 Aug 2021 02:47	28.9647	-86.4710	112.3	2,696
DCH*	1 May 2021 00:00	23 Aug 2021 01:05	29.0554	-86.0965	114.0	2,737
DCI+	2 May 2021 21:19	19 May 2021 10:50	28.7269	-86.1753	16.6	398
DCJ	2 May 2021 23:41	14 Sep 2021 07:41	28.8284	-85.7759	134.3	3,224
DCK	3 May 2021 02:12	16 Sep 2021 15:51	28.4830	-85.8975	136.6	3,278
DCL	3 May 2021 04:52	22 Sep 2021 19:53	28.5542	-85.5043	142.6	3,423
DCM	3 May 2021 11:14	23 Sep 2021 02:07	28.2201	-85.6354	142.6	3,423
DCN	3 May 2021 13:50	21 Sep 2021 00:10	28.2865	-85.2375	140.4	3,370
DCO	3 May 2021 16:11	23 Sep 2021 23:38	27.9783	-85.3304	143.3	3,439
DCP	3 May 2021 18:17	10 Aug 2021 09:23	28.0225	-85.0012	98.6	2,367

The preliminary results of acoustic data analysis from recordings at the 15 DC array sites deployed from May 2021 to October 2022 are summarized below. At this time, LTSAs and daily sound pressure spectrum levels have been calculated for all 15 sites, the two automated spectrogram cross-correlation detectors have been run on recordings from all 15 sites, and the resulting long-moan detections have been manually validated for 12 of the 15 sites. The validation of long-moan detections from the remaining 3 sites and of the downsweep-sequence detections at all 15 sites will be completed in 2022, along with analyses of newly collected data from the second and third deployments. Here we describe the low-frequency ambient soundscape, the hourly and daily call presence of Rice's whale long-moan calls, the daily long-moan call detections per site, and map the monthly distribution of call rates and daily occurrence per site. Final statistical analyses of spatial variation in Rice's whale call occurrence and ambient noise levels will be completed following the completion of data collection and analysis, over 2022-2023.

Low Frequency Ambient Soundscape

The low-frequency soundscape in the 10-800 Hz range showed strong similarities across most of the sites in the DC array. Long-term spectrograms of the full deployment at each site show that the 100-800 Hz band is primarily dominated by wind and wave noise with broadband noise level increases seen across all sites at the same time (**Figure 5**). Shipping noise is ubiquitous across all sites in the 30-100 Hz band, and is particularly strong at the six southernmost sites (**Figure 5**). Seismic airgun surveys were evident in the first three weeks of May and in late August and September, with strong energy in the 10-70 Hz band showing distinctive energy peaks. More distant airgun surveys were also apparent in long-term spectra of southern sites in mid-June to mid-July (**Figure 5**). The recorder at site DCA was deployed in 85 m depths, on the shelf, while all other sites were deeper (180-450m) and the soundscape at this site was distinctly different from other sites, with less seismic airgun noise, more shipping noise, and the presence of biological noise from fish, including diel chorusing (e.g. bands around 200 and 400 Hz; **Figure 5**). Long-term spectral averages also give a quick look into data quality, and the issues described above at sites DCB, DCI, and DCL are evident in these figures (**Figure 5**).

- The 2021 Atlantic hurricane season was an unusually active one and 7 named storms passed through the GOM. Increases in broadband noise levels over the 100-1000 Hz band were evident across all sites during these events (**Figure 5**). In particular, noise levels were increased over these periods: 1) June 19-22 (Tropical Storm Claudette); 2) August 11-17 (Tropical Storm Fred); 3) August 26 – Sept 1 (Hurricane Ida); and 4) Sept. 8 – 9 (Tropical Storm Mindy).
- Additionally, increased broadband noise levels associated with heavy weather were evident prior to hurricane season with high noise levels in the 100-1000 Hz band during May 15 – 21 (**Figure 5**).
- Site DCA, the shallowest site at 85 m and the only site on the shelf, had a different soundscape than all the other sites (**Figure 5**). The soundscape was characterized by more shipping noise, less seismic survey noise, and high levels of biological activity including diel fish choruses.
- A comparison of sound pressure spectrum levels at site DCH (the fully calibrated HARP) and the Soundtrap sites (factory calibrated at 250 Hz) shows that sound levels below 20 kHz drop off more rapidly on the Soundtraps than on the HARP, indicating that ambient noise quantification from Soundtraps is inappropriate at these lower frequencies (**Figure 5**).
- Seismic survey noise in the 10-70 Hz range was evident across all sites during the May 2021 to Sept. 2021 deployment period with high noise levels in the 10-100 Hz (**Figure 5**). The same airgun surveys were detected at all sites across the array during early May and late August through September.
- Diel date vs time plots of noise levels at 125 Hz (the middle frequency for Rice's whales long-moans that typically range from 150 to 100 Hz) show how 125 Hz noise levels vary by time of day and day of the year (**Figure 6**). Sites DCB and DCD show some diel differences with lower noise levels during the night than during the day and increased noise levels at sunrise and sunset.
- Large scale weather events described from long-term spectrograms are also evident in the 125 Hz diel plots (**Figure 6**) with the May storms and Hurricane Ida in late August evident across all sites, and Tropical Storm Claudette in late June evident at central and northern sites (**Figure 6**)
- Noise levels at 125 Hz began increasing in northern offshore waters (sites DCE and DCG) in mid-August and September, while noise levels increased at site DCF beginning in late June (**Figure 6**).
- Noise levels at 125 Hz were generally higher at the shelf site DCA and at the six southern sites, particularly the southern inshore sites (**Figure 6**). At the six southern sites, noise levels at 125 Hz increased beginning in September.
- Shorter duration events, seen as brighter yellow or red spots in diel plots, represent ship passings, and are seen at all sites, in particular the 3 southern inshore sites and the shallow DCA site (**Figure 6**).
- These diel plots suggest indicate sporadic missing data at site DCJ (**Figure 6**). QA/QC will be conducted to evaluate this issue.

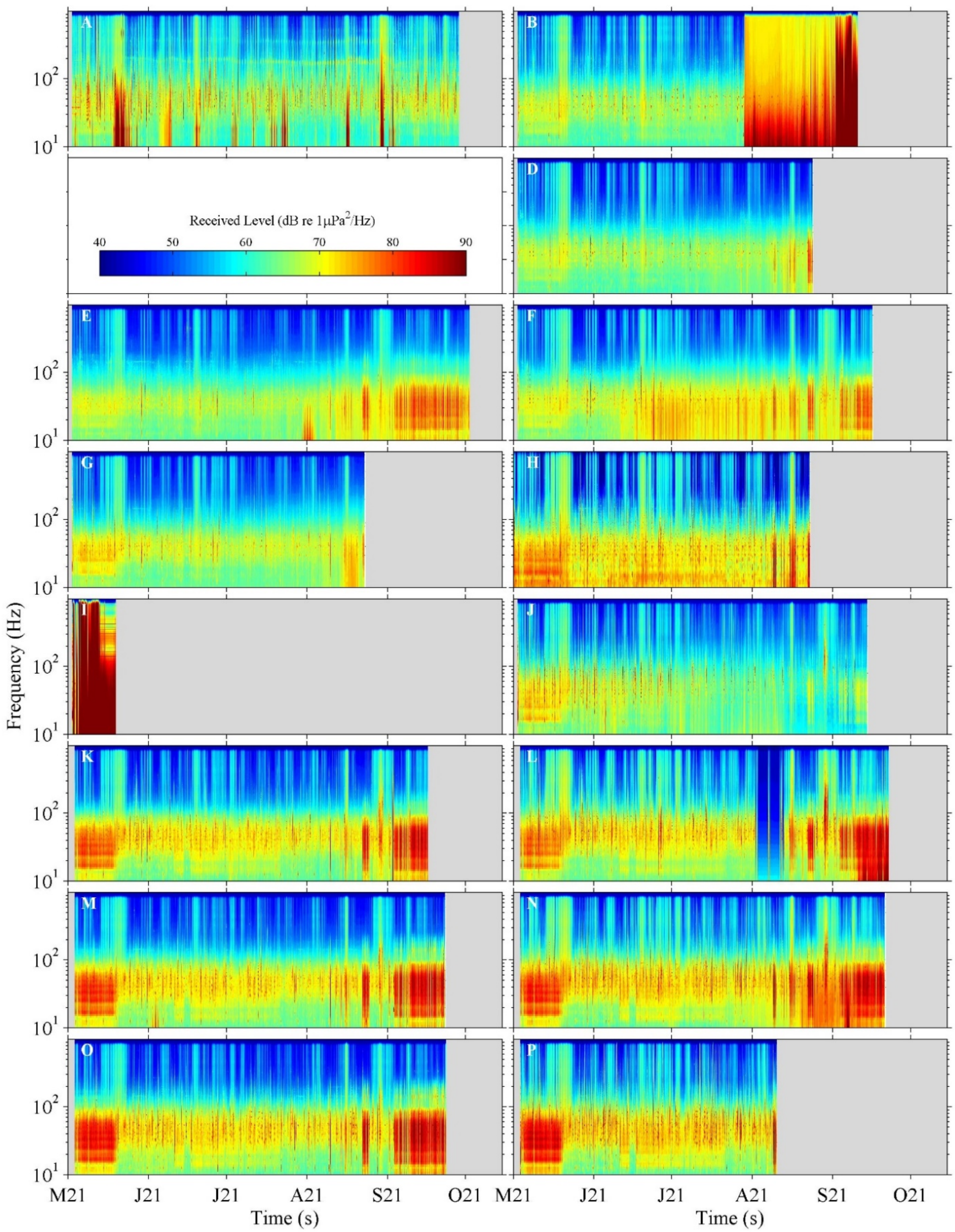

Figure 5. *Hourly median long-term spectral averages of the Soundtrap and HARP deployments at the De Soto Canyon (DC) array sites showing recorded ambient noise levels from 10-1000 Hz. Gray indicates periods with no recording effort. Dark yellow and red periods at sites DCB and DCI and dark blue periods at site DCL represent periods with poor quality data that are currently undergoing QA/QC to salvage any good quality recordings; poor quality recordings will be removed.*

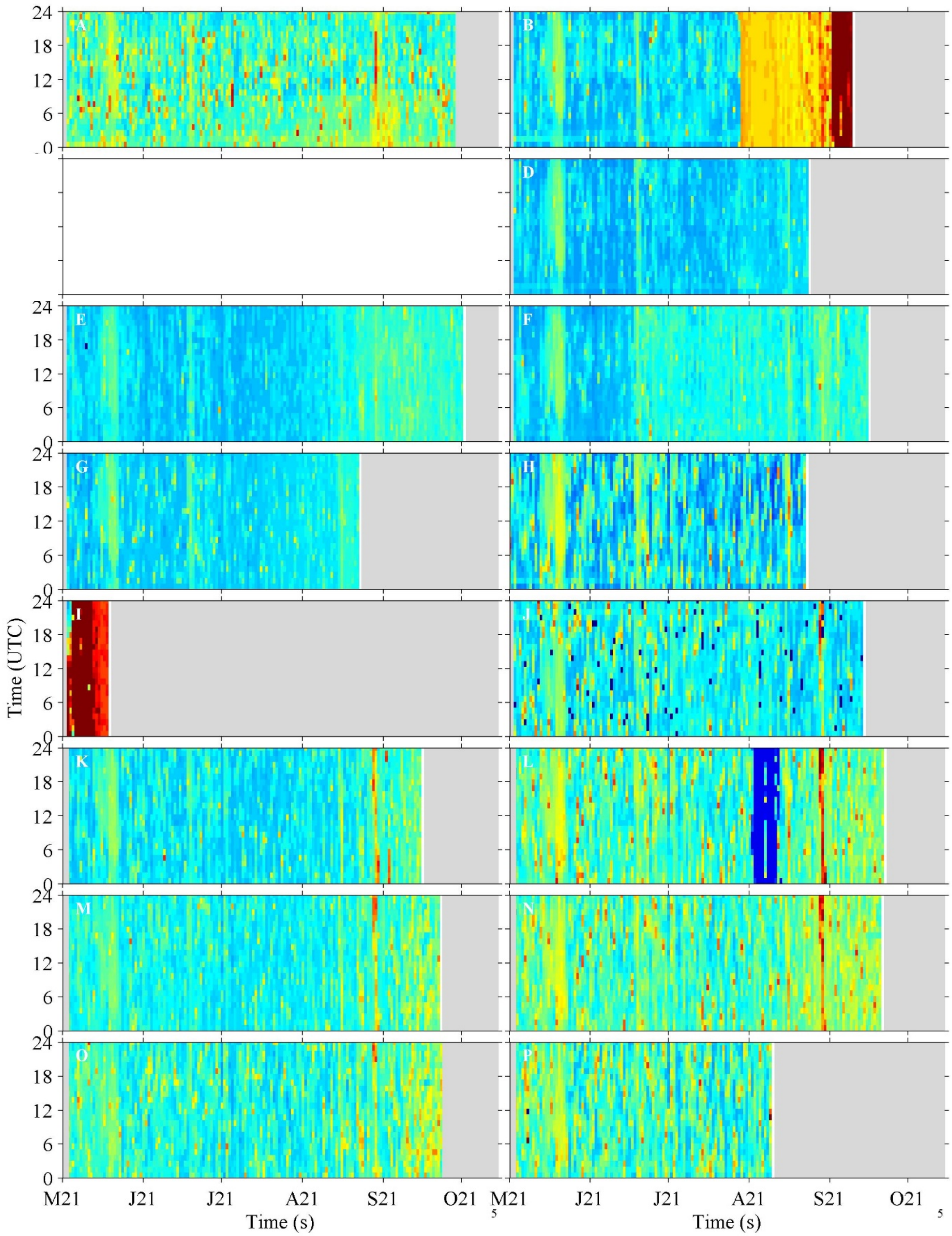

Figure 6. *Diel variation in hourly median sound pressure levels at 125 Hz at the 15 sites in the De Soto Canyon (DC) array. Gray indicates periods with no recording effort. Dark yellow and red periods at sites DCB and DCI and dark blue periods at site DCL represent periods with poor quality data that are currently undergoing QA/QC to salvage any good quality recordings; poor quality recordings will be removed.*

Rice's Whale Long-moan Calls

There were a total of 365,977 automated detections of Rice's whale long-moan calls in recordings from the 15 sites in the DC array during the May 1 – Oct. 2, 2021 period, ranging between 434 and 45,573 detections per site (**Table 2**). Over the 12 sites for which automated long-moan detections have been manually validated, 141,931 of the 239,471 detections were validated as true long-moan calls, with a range of 7 to 38,375 per deployment (**Table 2**). False detection rates per deployment averaged 36.6% and ranged between 11.2 and 99.2%. The two sites with highest false positive rates were site DCI with the bad hydrophone (7 true calls, 97.2% false positives) and site DCA in shallower waters (27 true calls, 99.2% false positives) where vessel noise and fish calls were common. Call detections were higher at inshore sites than offshore sites, while the false positive rates were higher at the offshore sites (**Table 2**, **Figures 7, 8**).

Preliminary results indicate true long-moan calls were present during an average of 71% of days (range 7-95% of days) per site and during an average of 38% of hours (range 0.5-69% of hours) with recording effort per site during the May to September 2021 deployment (**Table 2**). Daily and hourly presence of Rice's whales were also higher at inshore sites (mean: 84% of days, range 61-95%; mean 54% of hours, range 37-69%) than offshore sites (mean: 62% of days, range 7-93%; mean 26% of hours, range 0.5-51%). These numbers are likely biased low as the remaining 3 sites undergoing validation are inshore sites. Preliminary results suggest spatial variation in call rates and daily call presence over time (**Figures 9, 10, 11**) with higher occurrence and call detection rates at northern sites in May and June compared to later months, and higher occurrence and call detection rates at southern sites during July. Spatio-temporal variation will be re-evaluated upon completing the validation at the remaining 3 sites and with the addition of new data from the second and third array deployments.

- The spectrogram cross-correlation detector for long-moan calls yielded a total of 365,977 detections in recordings from the 15 sites from the first deployment, and ranged between 434 and 45,573 per site
- Validation of auto-detections of long-moan calls has been completed on 12 of the 15 sites. True long-moan calls were detected at every site, with higher numbers of detections at inshore sites (10,208 to 38,375) compared to offshore sites (7 – 11,439; **Table 2**, **Figures 7-9**).
- At the 12 validated sites, no western long-moan variants were detected during the May – September 2021 period (**Table 2**).
- Validation results from 12 of the 15 sites yielded false detection rates averaging 36.6% and ranging between 11.2% and 99.2% for the long-moan call detector across the 15 sites from the May – Sept 2021 deployment.
- The highest false detection rates occurred at 2 sites, DCA (99%) and DCI (97%). At DCA, the mooring was deployed in 85 m water depth where fish chorusing and vessel noise were high. Site DCI had a hydrophone malfunction, and was unreliable for the 17 days of recordings, though some true long-moan calls were still detected.
- Beyond these, false detection rates were higher on offshore sites (35-71%), where fewer true calls were detected, than inshore sites (11-32%). False detections also varied over time within sites, with higher false detections at southern sites during September when there was high activity from seismic airguns. A similar effect was seen at site DCO in May.
- Preliminary results indicate that true Rice's whale long-moan calls were present an average of 71% (range: 7 – 95%) of days per site at the 12 validated sites, and were present in an average of 38% (range: 0.5 to 69%) of recording hours per site (**Table 2**). Percent of days and percent of hours present were generally higher at the inshore sites (61-95% of days; 37-69% of hours) than the offshore sites (7 – 93% of days; 0.5 – 50% of hours).

- At the five southernmost sites at which detections have been validated, call detections follow a similar temporal pattern, with the strongest peak in call rates occurring in July (**Figures 8, 9**). Prior analyses from this area have indicated Rice's whale calls can be detected up to 75 km on some occasions. Further analyses are needed to determine whether these shared temporal occurrence patterns represent the same whales detected on multiple instruments or broader movement patterns.
- Preliminary results suggest a potential increase in true long-moan call detections at northern sites in May to June compared with later months (**Figures 7, 8, 9**), but the few call detections at the offshore sites that have been validated, along with hydrophone issues at site DCB, and ongoing processing of sites DCD and DCF limit the ability to make this inference. This possibility needs to be reviewed following completion of manual validations at DCD and DCF and QA/QC of the August and September data from site DCB
- Increased noise in the 125 Hz band during stormy weather in late May (**Figures 5, 6**) does not appear to have affected call detections (**Figure 7**), while there does appear to be a decrease in call detections associated with increased noise levels during Hurricane Ida in late August (**Figures 6, 7**) that may be an effect of masking or a behavioral change.
- Preliminary results indicate the percent of days per month with Rice's whale calls present varied by site and month (**Figure 10**). Patterns will be re-evaluated once validation at sites DCD, DCF, and DCL is complete.
- Similarly, preliminary results suggest call rates vary by site and month, with higher call detection rates generally occurring at the southern sites, and at site DCH in particular (**Figure 11**). Patterns will be re-evaluated once validation at sites DCD, DCF, and DCL is complete.

Table 2. *Number of long-moan calls detected and true long-moan calls validated per site during the May – Sept. 2021 deployment. No western Gulf long-moan variants were detected during this deployment. Shaded sites are from the offshore line.*

Site	Long-moan Call Detections	True Long-moan Calls	Western Long-moan Calls	Days Present (%)	Hours Present (%)
	Automated	*Validated*			
DCA	11,641	27	0	11 (7)	17 (0.5)
DCB	16,927	10,208	0	80 (61)	1,159 (36.7)
DCD	44,085	TBD	TBD	TBD	TBD
DCE	5,455	1,107	0	87 (56)	461 (12.5)
DCF	45,573	TBD	TBD	TBD	TBD
DCG	5,991	2,800	0	101 (89)	745 (27.5)
DCH	44,678	38,375	0	113 (76)	2,364 (67.1)
DCI	434	7	0	2 (11)	4 (1.0)
DCJ	21,655	16,448	0	130 (95)	2,074 (65.6)
DCK	14,452	8,124	0	120 (87)	1,402 (42.5)
DCL	36,848	TBD	TBD	TBD	TBD
DCM	26,372	10,459	0	135 (93)	1,730 (50.1)
DCN	39,946	28,991	0	134 (94)	2,355 (69.2)
DCO	32,636	11,439	0	131 (90)	1,763 (50.7)
DCP	19,321	13,946	0	96 (95)	1,442 (60.0)

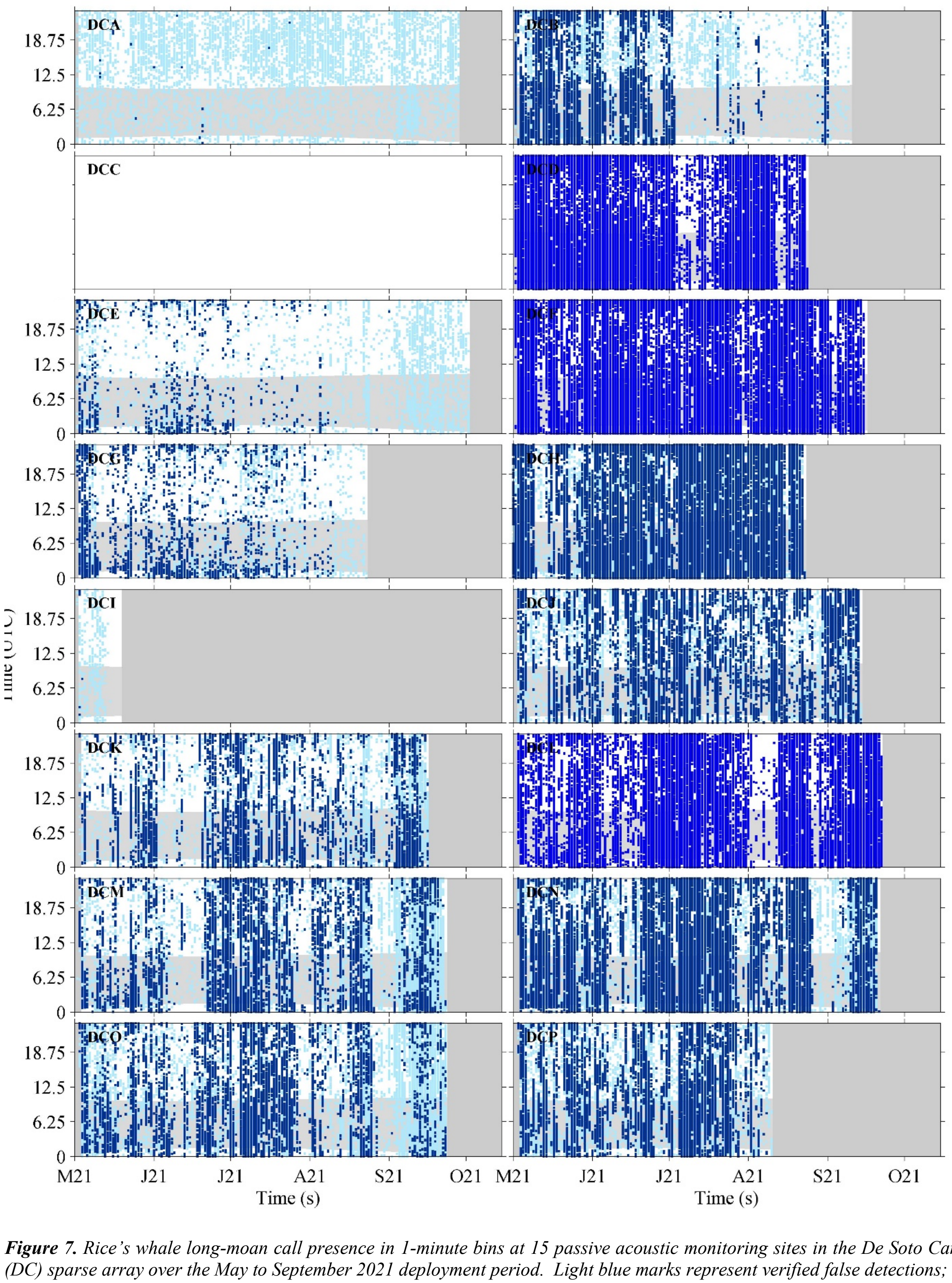

Figure 7. *Rice's whale long-moan call presence in 1-minute bins at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May to September 2021 deployment period. Light blue marks represent verified false detections; dark blue marks represent true long-moan detections. Medium blue marks at sites D, F, and L represent long-moan detections that have not yet been validated. Night time is indicated by gray hourglass shading. The gray blocked area represents periods without recording effort.*

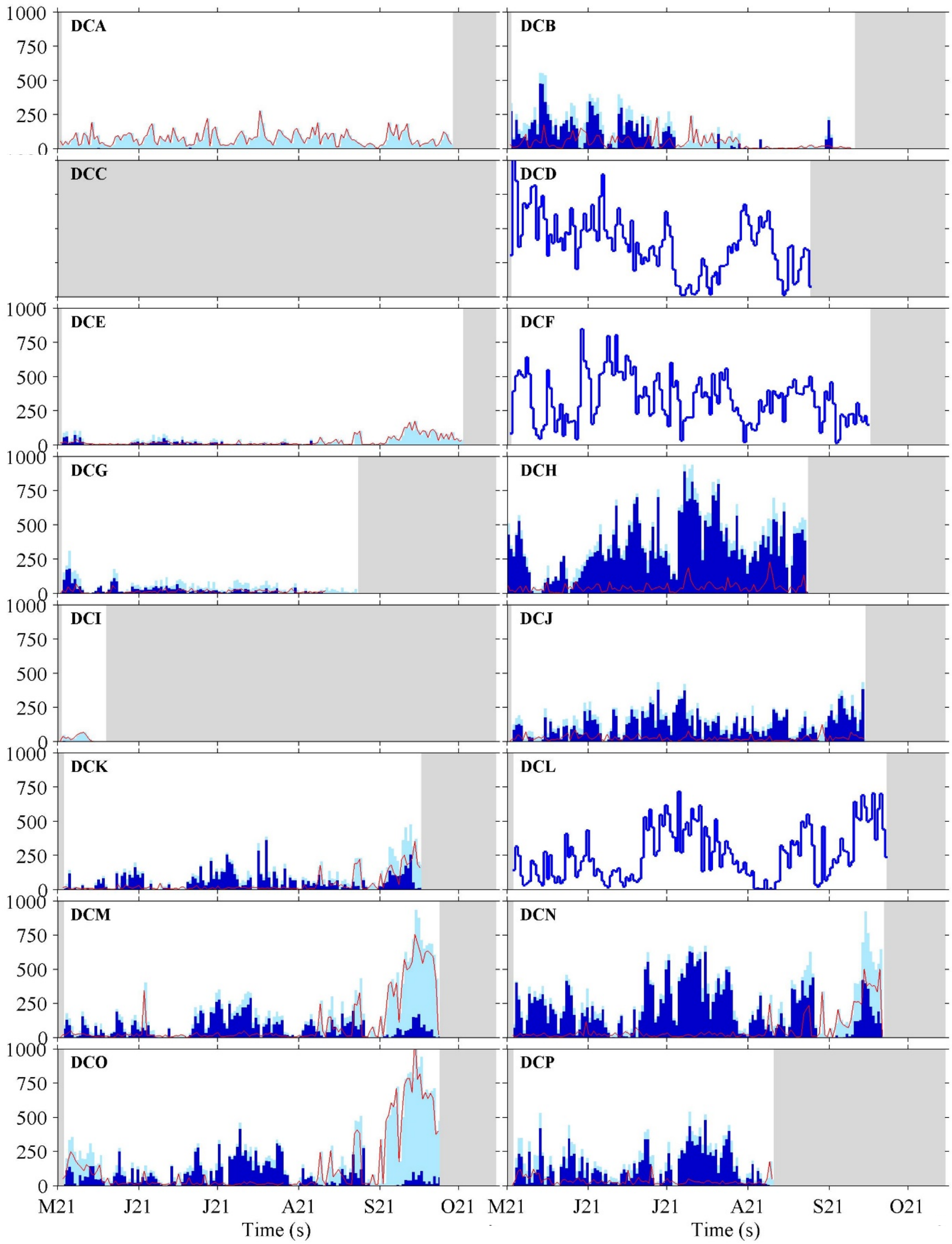

__Figure 8__. Daily total of Rice's whale long moan detections (light blue = autodetections, dark blue = verified long-moans, red line = false detections) at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May to September 2021. Gray blocks indicate periods without recording effort. Medium blue lines at sites D, F, and L represent long-moan detections that have not yet been validated.

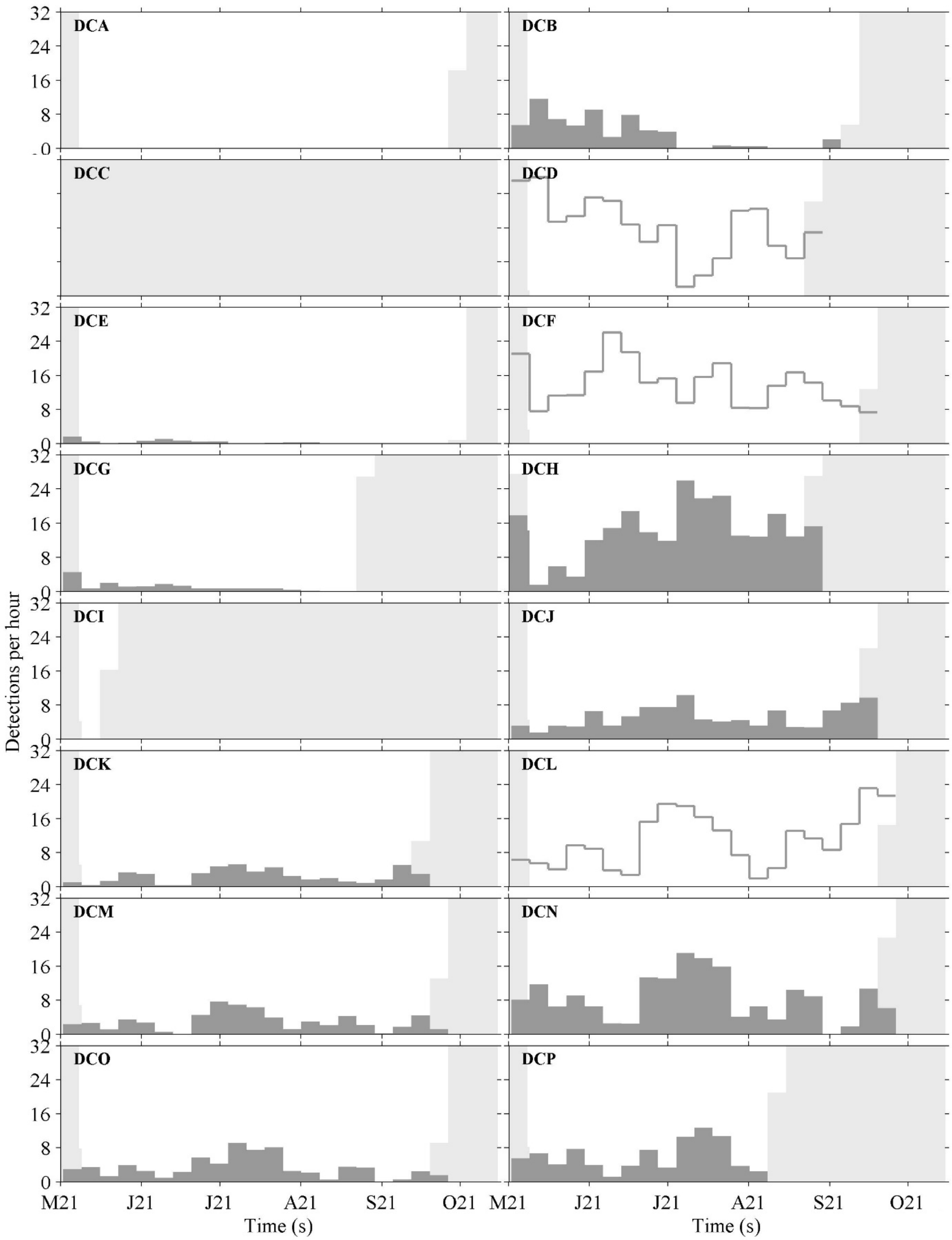

Figure 9. *Weekly Rice's whale long-moan calls per hour of effort at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May to September 2021. Dark bars represent validated long-moan detections; dark gray lines at sites D, F, and L represent long-moan detections that have not yet been validated. Light gray blocks indicate periods without recording effort.*

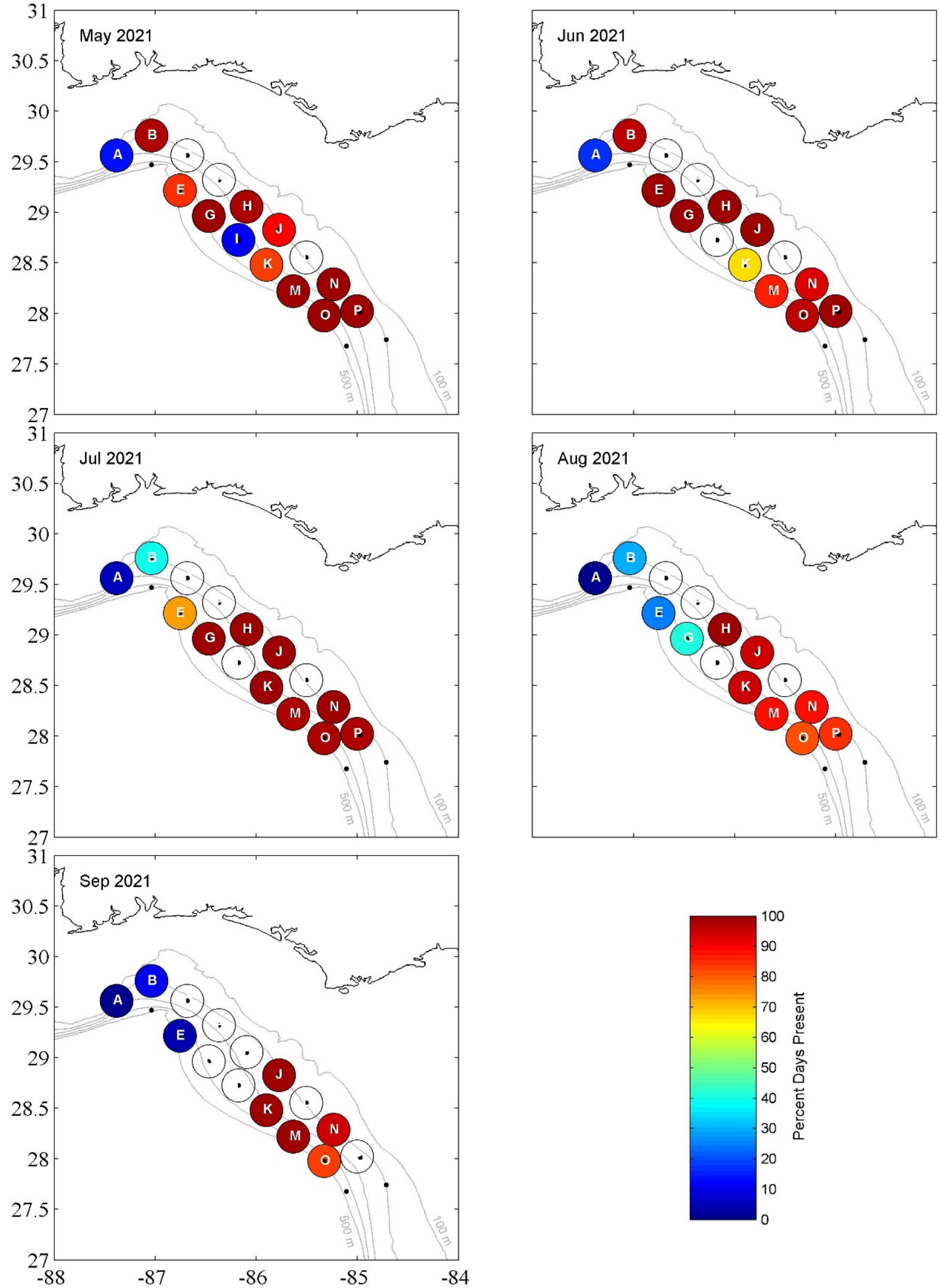

Figure 10 *Monthly Rice's whale long-moan presence, as percent of days, at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May to September 2021 deployment period. Color represents percent of days with calls present. Open circles with no color represent no data; Sites D, F, and L are being validated and maps will be updated once complete. Coastline and 100m isobaths up to 500m are indicated.*

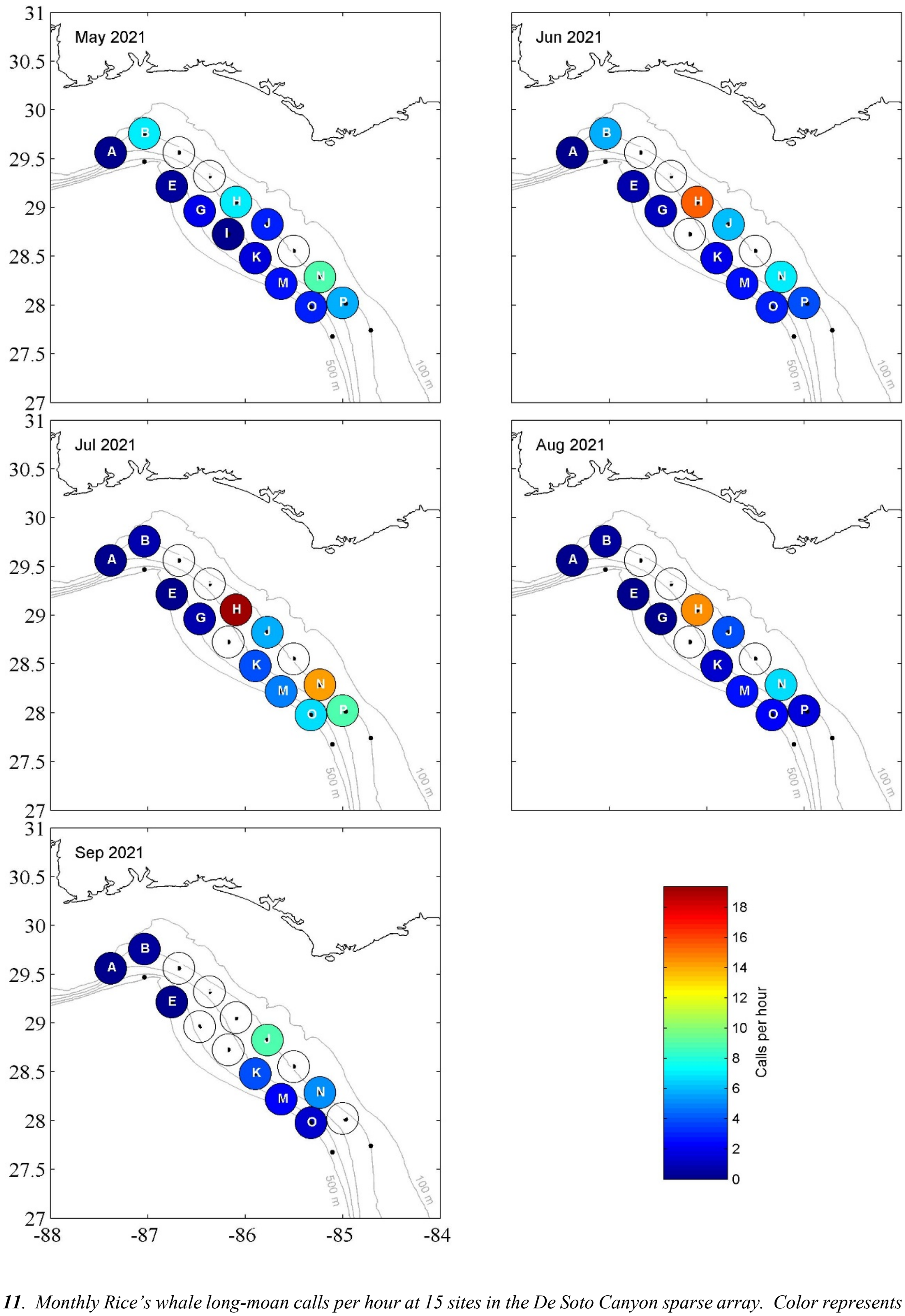

Figure 11. *Monthly Rice's whale long-moan calls per hour at 15 sites in the De Soto Canyon sparse array. Color represents calls per hour. Open circles with no color represent no data; Sites D, F, and L are being validated and maps will be updated once complete. Coastline and 100m isobaths up to 500m are indicated.*

Rice's Whale Downsweep Sequence Calls

There were a total of 58,130 Rice's whale downsweep sequences detected in recordings from 15 sites in the DC array during the May to September 2021 deployment period, ranging between 176 and 16,013 detections per site (**Table 3**). Similar to previous analyses of the 8-years of DC HARP recordings, downsweep detections were far less common than long-moan call detections (6x). The automated downsweep sequence detection results presented here are preliminary and need to be manually validated. These preliminary detections likely represent a major overestimate as previous analyses have shown high false detection rates (66-99%) due to confusion with ubiquitous seismic airgun pulses and long-moan calls with heavy amplitude modulation. Similar to long-moan calls, preliminary downsweep detections were found at all sites, throughout the recording period, and occur in higher numbers at inshore sites than offshore sites (**Table 3**, **Figures 12, 13, 14**); these results will be re-evaluated upon completion of manual validation.

- There were many fewer downsweep pulse sequence call detections (57,130) than long-moan detections over the 15 passive acoustic sites (over 6x more long-moans), with an average of 3,875 downsweep sequence detections per site, and a range from 176 to 16,013 detections (**Tables 2, 3**).
- Preliminary detection rates of downsweep pulse sequences were higher at inshore sites (mean: 6,081, range: 1,311 to 16,013) than offshore sites (mean: 1,354, range: 176 to 2,628) (**Table 3**).

Table 3. *Number of downsweep sequences detected per deployment. Downsweep sequence detections at all sites have not yet been validated.*

Site	Downsweep Sequence Detections	Days Present (%)	Hours Present (%)	True Downsweep Detections
	Automated			*Validated*
DCA	1,828	147 (98)	685 (19)	TBD
DCB	1,926	112 (85)	655 (21)	TBD
DCD	8,610	111 (97)	1521 (56)	TBD
DCE	353	85 (55)	195 (5)	TBD
DCF	7,166	135 (98)	1509 (46)	TBD
DCG	176	42 (37)	69 (3)	TBD
DCH	16,013	116 (78)	1986 (56)	TBD
DCI	1,421	16 (89)	249 (60)	TBD
DCJ	4,867	122 (89)	957 (30)	TBD
DCK	2,628	117 (85)	624 (19)	TBD
DCL	4,335	121 (84)	902 (26)	TBD
DCM	1,957	113 (78)	526 (15)	TBD
DCN	4,422	121 (85)	985 (29)	TBD
DCO	1,117	115 (79)	406 (12)	TBD

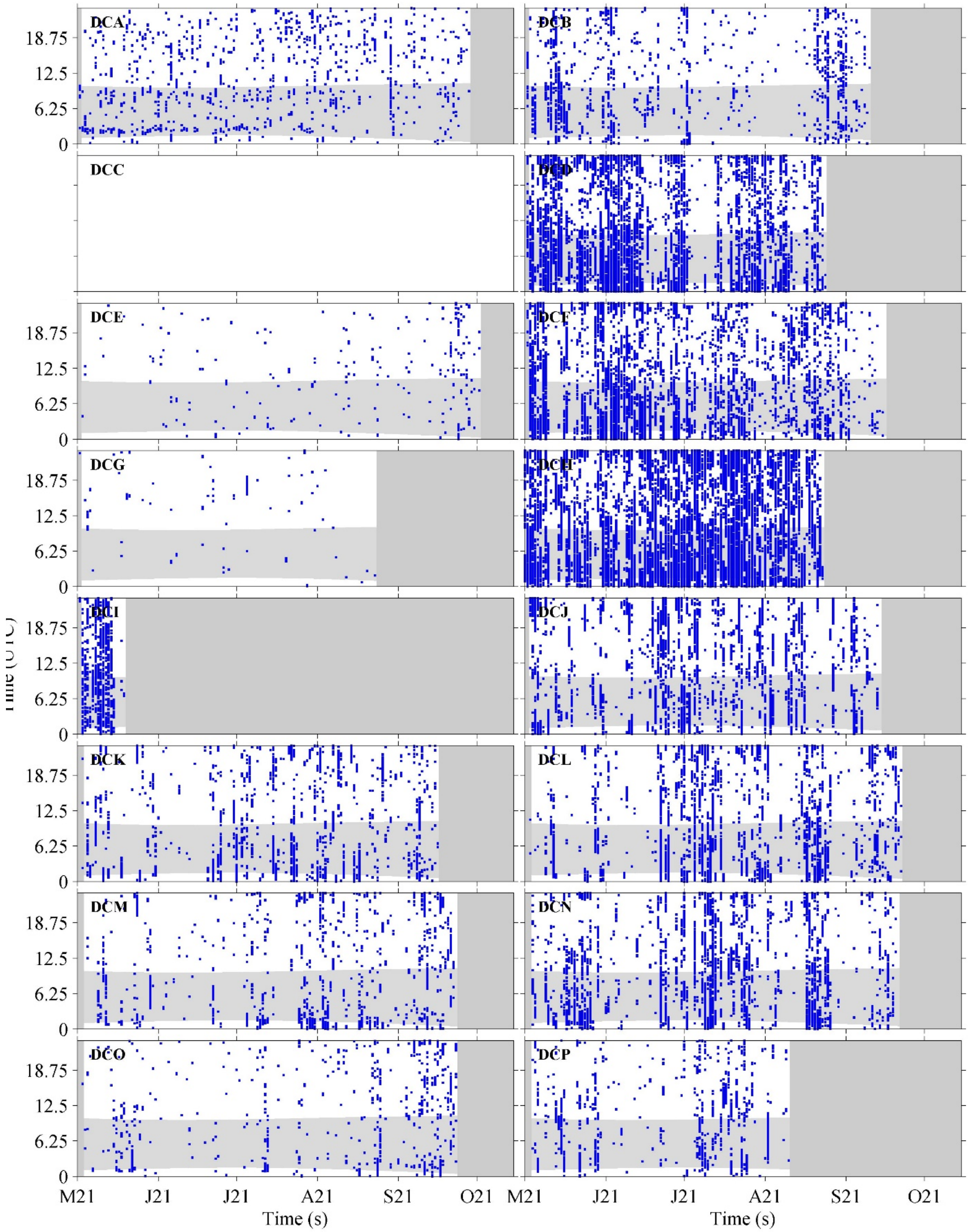

Figure 12. *Rice's whale downsweep sequence call presence in 1-minute bins at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May to September 2021 deployment period. Blue marks represent downsweep detections that have not yet been validated. Night time is indicated by gray hourglass shading. The gray blocked area represents periods without recording effort.*

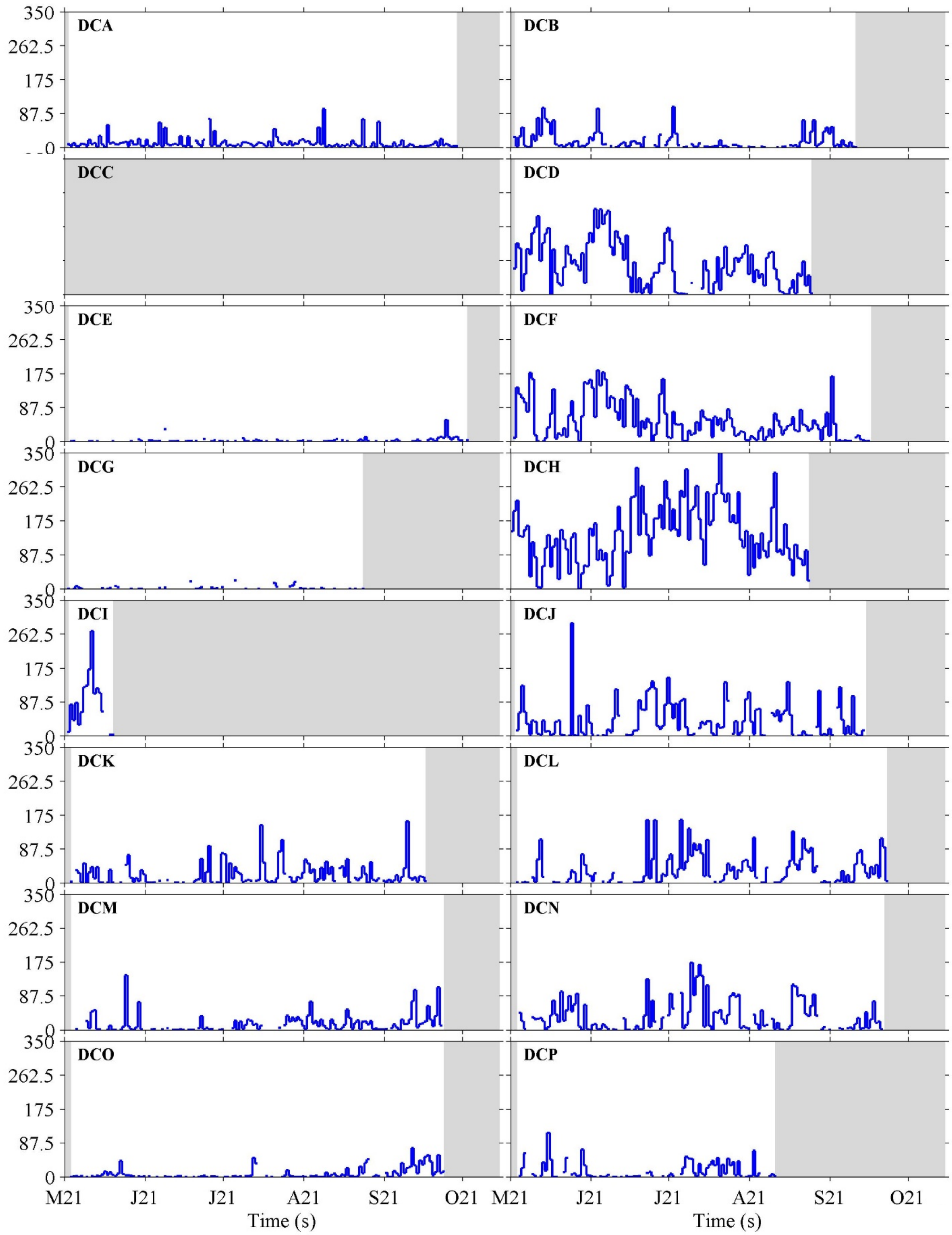

Figure 13. *Daily total of Rice's whale downsweep sequence detections at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May to September 2021. Medium blue lines represent downsweep detections that have not yet been validated. Gray blocks indicate periods without recording effort.*

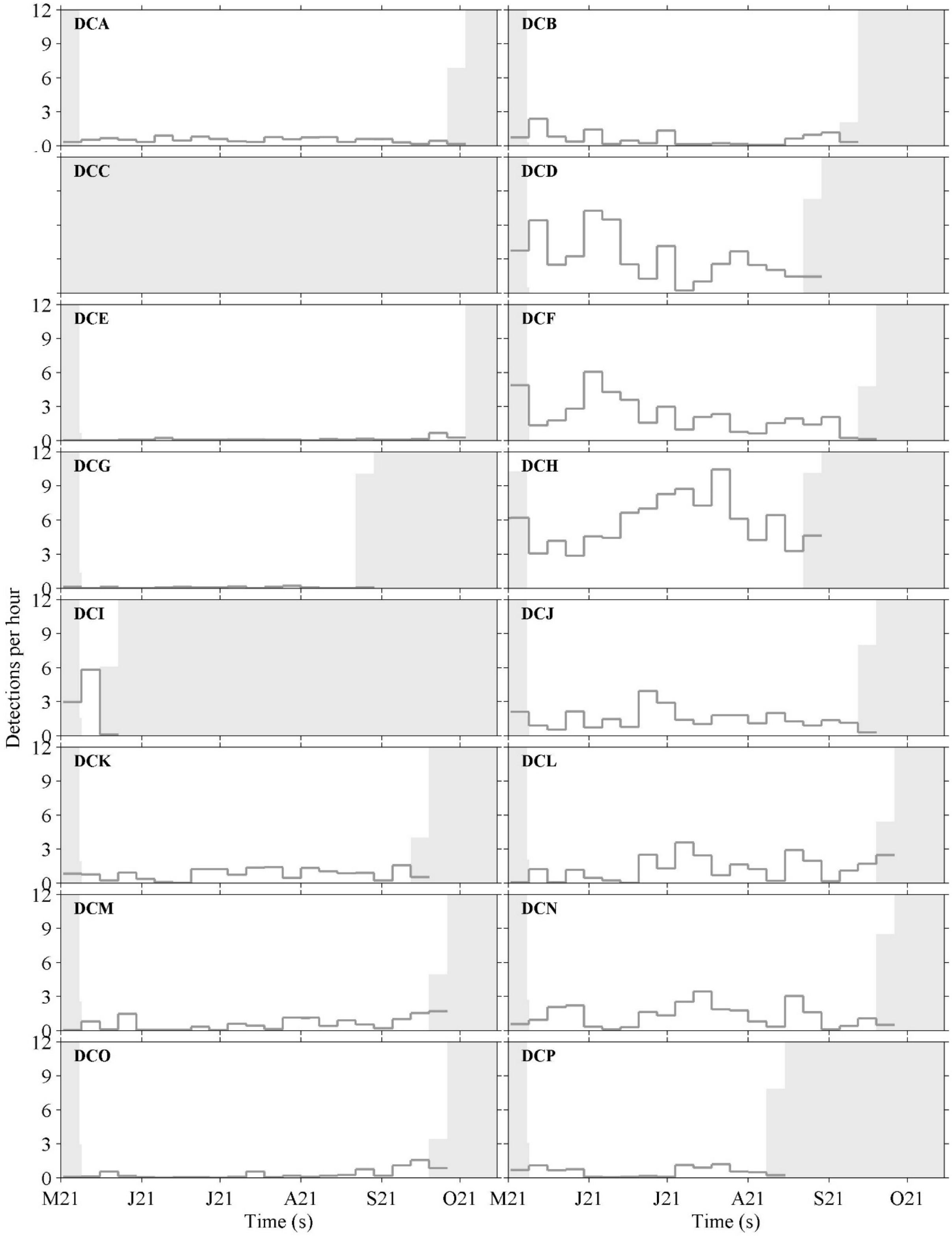

Figure 14. *Weekly Rice's whale downsweep seqeunce calls per hour of effort at 15 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May to September 2021. Dark gray lines represent downsweep detections that have not yet been validated. Light gray blocks indicate periods without recording effort.*

Vemco Acoustic Tag Detections

Opportunistic data collection of transmissions from Vemco-acoustic-tagged fish and reptiles that pass by the mooring was possible due to the use of Vemco VR2AR acoustic releases. Tag detections occurred at all sites with a total of 365 transmissions received (range: 3 – 79 per site) from 25 unique tagged individuals. (range: 1 – 7 per site). Vemco tag IDs have been uploaded to the iTag orphan tag database, and three of the 25 individuals have been identified. A bull shark was detected at site DCK on June 17, a scalloped hammerhead was detected at site DCB on May 14, and a greater amberjack was detected at site DCN during two non-consecutive days in May and at DCP on one day each in October and November.

Next Steps:

The data collection part of the second phase of this project is nearly two-thirds complete, with instrument servicing planned for April 1, 2022. The third deployment of the array will cover the April to August 2022 period. The data processing part of this phase is nearly one-quarter complete with automated detections and validation steps for the first deployment nearing completion. Data processing needs to be completed at 3 sites for long-moan calls and at all sites for downsweep calls from the first deployment. Upon recovery of the second and third deployment recordings, similar automated detection with manual validation analyses will be completed. Daily and monthly statistical distributions of sound pressure spectrum levels will be calculated. Once all detections have been validated across the three deployments, statistical analyses will be conducted to evaluate diel, seasonal, and spatial variation in call occurrence over the DC array, and to evaluate the impacts of varying ambient noise levels on call detection. These analyses will provide crucially important data for understanding how Rice's whales are utilizing the habitat throughout the course of the year and whether they exhibited seasonal movement patterns throughout the year. Understanding seasonal and internannual distribution of Rice's whales throughout the core habitat will improve understanding of potential impact of human activities on these whales and assist in developing effective mitigation measures as needed.

Future Opportunities:

Several future analytical projects could be completed using the data collected under this project to further improve our understanding of Rice's whale seasonal and interannual density patterns and the oceanographic and anthropogenic factors driving them. To convert occurrence and distribution results into call or animal density, more information is needed on call detection ranges and how they change over time and space due to varying sound propagation conditions and ambient noise levels. Preliminary analyses of the data collected under this project suggest potential for obtaining this information with expanded analytical methods. The second phase study design included a sparse array to ensure near-complete acoustic coverage of the Rice's whale core habitat, assuming minimum detection distances of 20 km based on prior findings, to understand seasonal distribution and movement patterns. Initial review of recordings from neighboring instruments in the array indicates that on numerous occasions the same call from a given whale can be detected on multiple instruments. One test case has been evaluated which shows that a whale could be localized using time-difference-of-arrival (TDOA) methods, yielding a detection distance estimated at 37 km. Further analysis using TDOA localization methods may yield information on call detection distances, source levels, and dive behavior. Additionally, the occurrence of the same call on multiple instruments can be used in spatially-explicit capture-recapture (SECR) studies to estimate density and detection distances, providing complementary results to evaluate detection distances and how they change over time along with density estimates. Further, to permit and mitigate anthropogenic activities in this core habitat area where these endangered whales consistently occur year-round, predictive habitat models describing the factors driving spatio-temporal occurrence will be important to assess and predict when and where the whales might be found to determine if we can better predict finer-scale spatial occurrence. If detection distances, and how they vary over time, can be better understood, acoustic detections can be combined with oceanographic data to evaluate if variation in the position of the Loop Current and its eddies, or Mississippi River outflow may impact animal distribution as well as sound propagation conditions and associated call detection distances. Developing predictive habitat models incorporating environmental proxies of prey occurrence, ambient noise levels, and modeled detection distances with passive acoustic detections as the response variable will help determine which dynamic factors drive the occurrence of calling Rice's whales throughout the core habitat, as needed to mitigate potential impacts from anthropogenic activities occurring in the area.

Finally, the data collection component of this project covers one-year to evaluate seasonal changes in Rice's whale distribution throughout the core habitat. The anticipated results will characterize spatio-temporal variation for the May 2021 to August 2022 period. To make further inferences about whether these trends represent general seasonal changes, we suggest a minimum of three-years of data collection to evaluate consistency in seasonal cycles over time. At this time it remains unknown whether factors driving temporal variation in Rice's whale occurrence and distribution follow typical 4-season cycles or are more nuanced with respect to oceanographic conditions including the position of the Loop Current and its eddies and variation in Mississippi River outflow. Three years of broad coverage passive acoustic data collection would provide the information needed to assess generality of the 2021-2022 results and would additionally yield a robust dataset for developing the predictive habitat models described above.

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