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

2023 Annual Progress Report

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Executive Summary

The Rice's whale (*Balaenoptera ricei*; formerly Gulf of Mexico Bryde's whale) is estimated to have a population size of 51 individuals in U.S. waters (Garrison et al. 2020) and was listed as endangered under the ESA in 2019 (84 *Federal Register* 15446, 87 *Federal Register* 8981). The majority of modern sightings occur within waters between the 100- and 400-meter (m) isobaths within an area near the De Soto Canyon off northwestern Florida (Soldevilla et al. 2017; Rosel et al. 2021), an area defined as the Rice's whale core distribution area (Rosel and Garrison 2022). Occurrence patterns from long-term passive acoustic monitoring (PAM) over the 2010–2018 period and from summer and fall visual surveys during 2018 and 2019 indicate that the whales are found year-round within the core distribution area, but also suggest there may be seasonal movements throughout, and potentially out of, this area. High densities of anthropogenic activities occur throughout the Gulf of Mexico (GOM), including oil and gas exploration and extraction, fisheries, shipping, and military activities. Many of these activities, including U.S. Navy readiness training and testing, and Eglin Air Force Base activities, overlap with the whales' core distribution area. Understanding seasonal distribution and density of Rice's whales throughout the core distribution area will 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.

To improve management of human-based activities in the core distribution area of these endangered whales, the SEFSC began deploying a sparse array of 17 PAM units concurrent with one long-term HARP in May 2021. The PAM moorings were deployed in two lines of nine units each to nearly completely cover the core distribution area over a nearly 2-year period to improve understanding of seasonal and interannual distribution, movement patterns, and habitat use. The moorings use SoundTrap ST500 or ST600 STDs, calibrated long-term recorders capable of continuously recording underwater sound in the 20 Hertz to 48 kHz frequency range, including Rice's whale calls and ambient noise, for up to 6 months. Additionally, the study leverages a long-term HARP being deployed by the SEFSC, Scripps Institution of Oceanography, and collaborators, at the De Soto Canyon site in the core Rice's whale habitat over the August 2020 to July 2025 period. At this site, they have been continuously recording ambient noise and other acoustic events in the 10 Hertz to 100 kHz frequency range since 2010 to monitor the impacts of the Deepwater Horizon oil spill and subsequent restoration activities on cetaceans. Together with the sparse array of SoundTraps, these PAM deployments provide the necessary data to understand seasonal distribution and density of Rice's whales.

During 2023, data analyses were completed on recordings from the second and third deployments of SoundTraps (November 2021 to September 2022) as well as the concurrently deployed De Soto Canyon HARP recordings (August 2021 to June 2022). Automated spectrogram cross-correlation detectors for the downsweep-sequence and long-moan calls, developed under an earlier phase of this work, were run on all recordings. Given the critically endangered status of this species, automated detector thresholds are intentionally set low to minimize missed detections at the cost of increased false positive detections, and a subsequent manual validation step was 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 recovered from the November 2021 to April 2022 period, there were 1,835 instrument-days of recordings, 530,150 Rice's whale long-moan calls detected, and 65,901 Rice's whale downsweep sequences detected. The validation process was completed on the remaining two of the 15 moorings for long moan calls and on all 15 sites for downsweep sequences, yielding a total of 257,779 true long-moan calls and 13,231 true downsweep sequences. During this November 2021 to April 2022 period, true detections of Rice's whale long-moans occurred at 14 of the 15 sites, ranging from 368 to 55,529 calls per site, with call presence ranging from 30% to 100% of days. True detections of

downsweep sequences occurred at 10 of the 15 sites, ranging from 24 to 3,631 calls per site, with call presence ranging from 1% to 66% of days. A total of 11 moorings recovered from the April 2022 to September 2022 period yielded 1,552 instrument-days of recordings, 267,713 Rice's whale long-moan call detections, and 77,813 Rice's whale downsweep sequence detections. All calls were validated over the 11 moorings yielding a total of 141,134 true long-moan calls and 5,407 true downsweep sequences. During this April 2022 to September 2022 period, true detections of Rice's whale long-moans occurred at all 11 sites, ranging from 10 to 43,984 calls per site, with call presence ranging from 25% to 100% of days. True detections of downsweep sequences occurred at 8 of the 11 sites, ranging from 13 to 3,174 calls per site, with call presence ranging from 2% to 61% of days. The August 2021 to June 2022 HARP recordings yielded 285 days of recordings, 144,784 long-moan detections, and 24,285 downsweep sequence detections. The validation process yielded 110,887 true long moan calls and 4,314 true downsweep sequences, present on 99% and 42% of days, respectively. Similar to the May to September 2021 data, 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, and at the two southernmost sites near the Tampa shipping lane. High levels of seismic airgun activity during these two deployment periods led to higher false-positive rates than seen in the first deployment.

Final statistical analyses and manuscript writing are all that remain to be completed on this project. These analyses and the manuscript will include data from a fourth deployment funded by NOAA. Additional leveraging is incorporating sound propagation modeling and ambient noise analyses to estimate detection ranges for normalizing call detections across sites and over time prior to evaluating seasonal trends. Finally, data collected during this project are being leveraged under NOAA-funded projects to acoustically track calling Rice's whales throughout the core distribution area and to evaluate feasibility of using spatially explicit capture-recapture methods for density estimation.

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 distribution area 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 eight years of near-continuous DC HARP recordings (2010-2018) to understand Rice's whale seasonal and interannual occurrence patterns at this site. During the first phase of this project, SEFSC developed automated Rice's whale call detectors and analyzed eight years of historic data from the DC HARP in the core distribution area to establish complete occurrence time-series for understanding seasonal and interannual trends and for future habitat modeling and density estimation. Rice's whale call detections occurred throughout the year at this site with increased call detection rates during summer and fall compared to winter and spring.

In May 2021, the SEFSC implemented the second phase of this project to collect and analyze new passive acoustic data for at least one year over the entire Rice's whale core distribution area to understand seasonal distribution patterns, density, and whale movements throughout the core distribution area. 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 nine moorings each that nearly cover the Rice's whale core distribution area (**Figure 1**). The SoundTrap mooring survey design included three 5-month deployment periods to collect over a full year of recordings at each site. Analytical objectives include running the automated long-moan and downsweep-sequence detectors developed in phase 1 on all recordings, with thresholds set to minimize missed detections at the cost of increased false positives, then 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 of seasonal distribution and density of Rice's whales throughout the core distribution area 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.

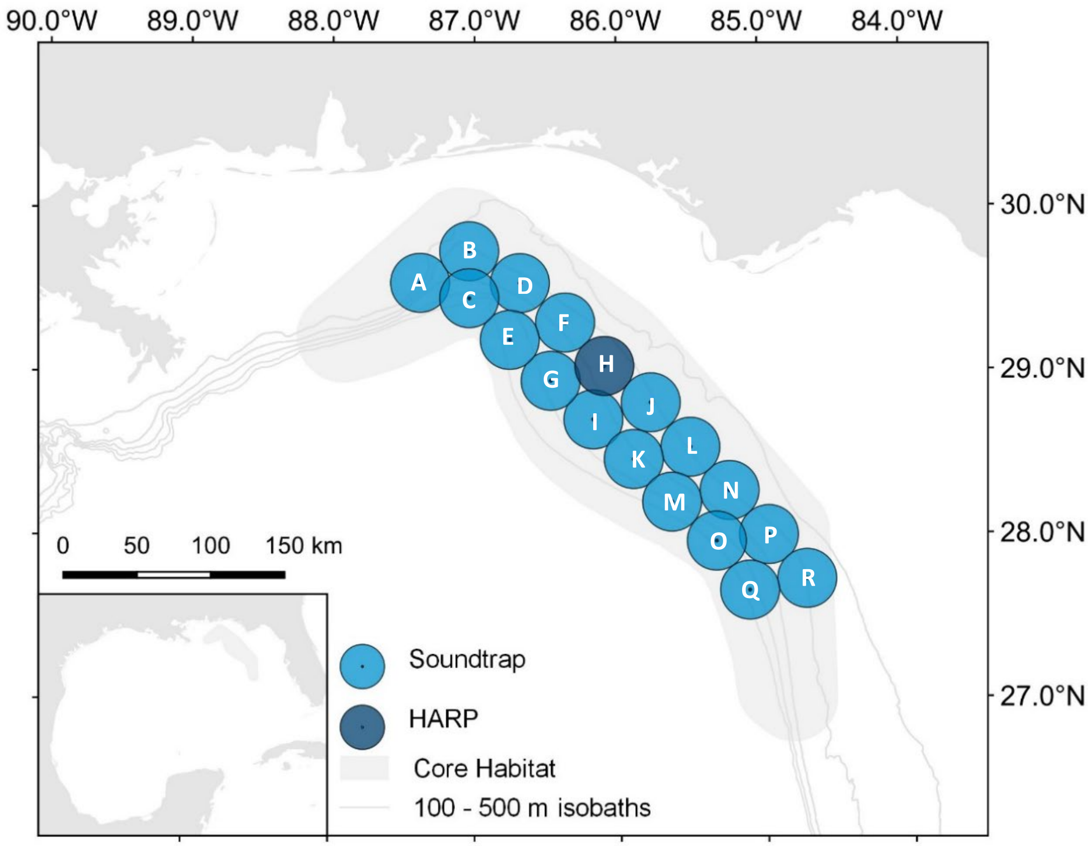

Figure 1. *Historic long-term passive acoustic monitoring station (HARP; dark blue) deployed in the Rice's whale core distribution area in the northeastern Gulf of Mexico since 2010, and sparse array passive acoustic monitoring stations (SoundTraps; light blue) deployed over the 2021-2023 period. Circles around passive acoustic stations indicate the expected acoustic coverage, assuming 20 km call detection distances. The NMFS core distribution area for Rice's whales is indicated as a shaded polygon. The long-term De Soto Canyon (DC) HARP site, where Rice's whale calls have previously been detected, was 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 meter (m) water depths near the De Soto Canyon off northwestern Florida (Soldevilla *et al.*, 2017; Rosel *et al.*, 2021), an area defined as the Rice's whale core distribution area (Rosel & Garrison, 2022). Occurrence patterns from long-term passive acoustic monitoring over the 2010-2018 period and two recent summer and fall surveys in 2018-2019 indicate the whales are found year-round within this core distribution area. Results also show decreased call detection rates in winter and spring, indicating there may be seasonal movements throughout the core distribution area, and potentially beyond it to areas like the recently identified habitat along the shelf break off Louisiana and Texas (Soldevilla *et al.,* 2022a, Soldevilla *et al.,* 2024). 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 distribution area. Many of these activities, including US Navy readiness training and testing and Eglin Air Force Base activities, overlap with the whales' core distribution area. Understanding seasonal distribution and density will improve understanding of potential impact of human activities in the core distribution area, 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 identified and definitively attributed to free-ranging Rice's whales (Rice *et al.*, 2014, Širović *et al.*, 2014, Soldevilla *et al.,* 2022b) 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 series of two or more 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.,* 2022b). 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.*, 2022b). 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.*, 2022b). Stereotyped variants of the long-moan that are common in the western Gulf are occasionally detected in the core distribution area as well (Soldevilla *et al.,* 2022a). The second tonal call type, 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).

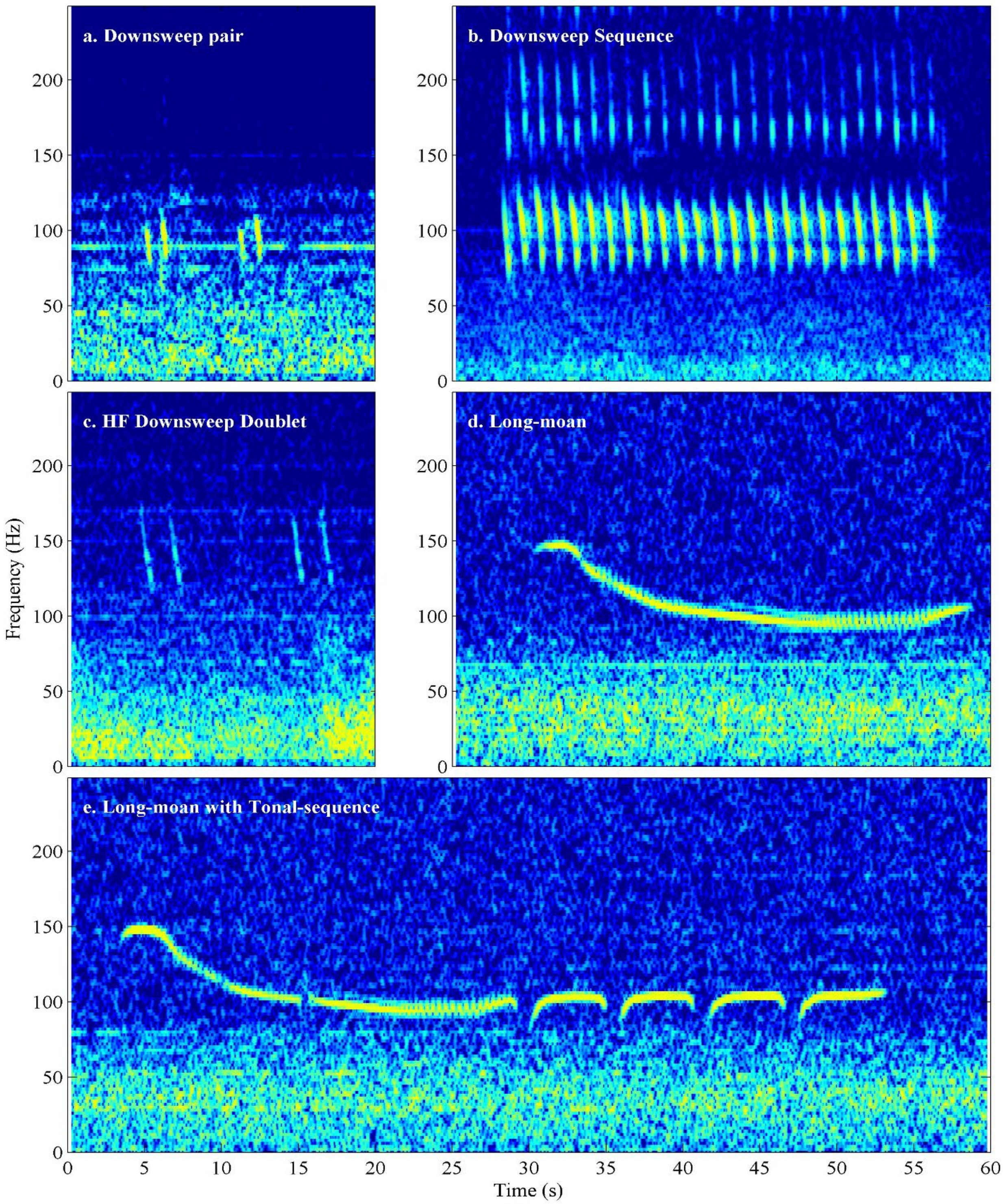

Figure 2. *Spectrograms of Rice's whale calls and potential calls*

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 2023. 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 4**). 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).

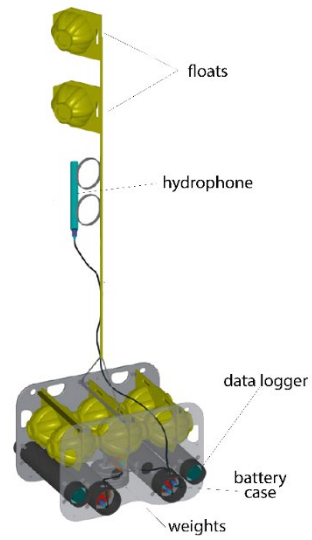

***Figure 3**. Schematic of a HARP seafloor package*

SoundTrap ST500 & ST600 (SoundTrap)

SoundTrap ST500 and ST600 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 distribution area in the northeastern GOM over the May 2021 to March 2023 period. The SoundTrap ST500 and ST600 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 six months. The SoundTraps were deployed in a small mooring configuration with the hydrophones suspended 3 m above the seafloor. The ST500 & ST600 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

Data were collected by SEFSC and Scripps from the historic DC HARP site (29° 2.878' N 86 ° 05.847' W, 270 m depth) during the August 2020 - 2023 period using HARPs sampling at 200 kHz, under funding from a *Deepwater Horizon* Restoration project. 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 DC HARP sampled over the periods from August 2020 to August 2021, August 2021 to July 2022, and September 2022 to July 2023.

Concurrent data were collected by SEFSC from a sparse array of up to 17 SoundTrap moorings deployed in two lines that nearly completed covered the core distribution area (**Figure 1**) during three deployments over the May 2021 to September 2022 period. A fourth deployment, funded by NOAA Office of Protected Resources (OPR), collected data over the September 2022 to March 2023 period. The SoundTraps sampled at 24 kHz over the periods: 1) May to October 2021; 2) November 2021 to April 2022; 3) May to September 2022; and 4) September 2022 to March 2023.

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 1, 50, and 99 percentiles of the average hourly spectrum levels at 100 Hz and 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. ST500 recorders purchased at the start of the COVID pandemic had reliability issues that affected recording quality. Hourly spectral averages were manually reviewed to identify periods of lower quality data. Spectral averages and Rice's whale call detections from these periods were removed from further analyses.

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 two-day training dataset and a separate testing dataset to characterize miss rates and false detection rates. In 2021, these detectors were run on spectrograms of recordings from all SoundTrap sites and the concurrent DC HARP recordings from the 1st deployment covering the May 2021 to November 2021 period. In 2022, the detectors were run on spectrograms of recordings from all SoundTraps and HARPs deployed over the 2nd and 3rd deployments covering the November 2021 to September 2022 period. In 2023, the detectors were run on spectrograms of recordings from all SoundTraps and HARP deployed over the 4th deployment covering period covering September 2022 to July 2023. 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 5**). 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.

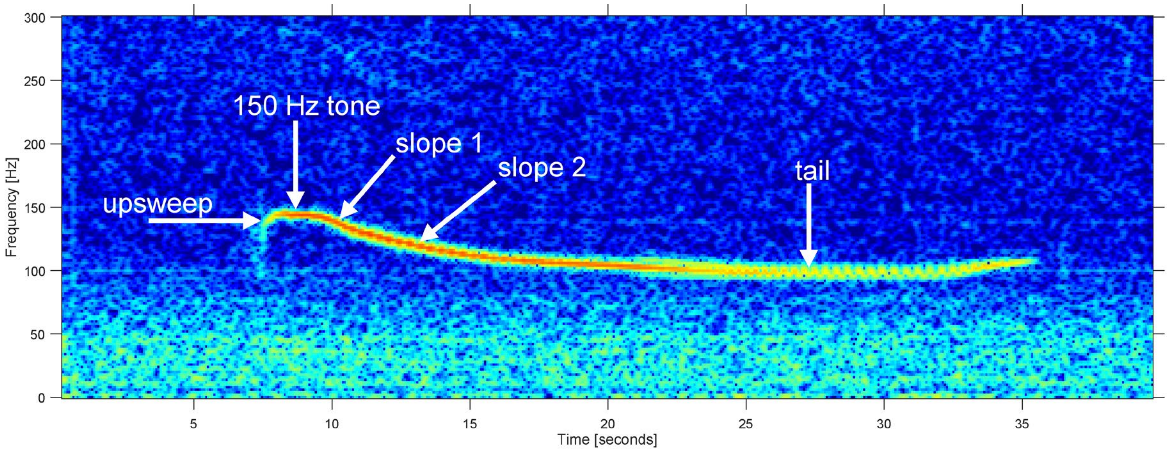

Figure 4. *Five sections of a long moan call. Two sections, the 150 Hz tone and slope 1 were used to create the contours in the long-moan detector.*

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

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 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. In 2021, all detections were manually validated for long-moan call detections at 12 of the 15 DC array sites from the first deployment over the May to September 2021 period. In 2022, manual validation of long-moan detections at the remaining 3 sites, and manual validation of downsweep sequence detections at all 15 sites were completed. Additionally, in 2022, manual validation of long-moan and downsweep sequence detections was completed for all 15 SoundTrap sites from the second deployment over the November 2021 to April 2022 period. In 2023, manual validation of long-moan and downsweep sequence detections was completed for the third SoundTrap deployment over the April to September 2022 period and for HARP recordings from the August 2021 to July 2023 periods. Funds were obtained from NOAA's OPR in FY24 to validate detections in the 4th SoundTrap deployment covering the period from September 2022 to March 2023, and validation of long-moan and downsweep sequence calls is currently in progress.

Results and Accomplishments

Moored Array Data Collection and Analyses

In March 2023, the SEFSC recovered 12 of 13 SoundTrap moorings from the fourth and final array deployment. One unit (site DCO) from the fourth deployment was not recovered as it did not come to the surface following release commands. The acoustic release communications indicated the release unit was horizontal rather than vertical, which suggests the float and potentially the SoundTrap were no longer present. The HARP at site DCH was recovered in July 2023 as part of the *Deepwater Horizon* Restoration passive acoustic monitoring project.

The acoustic recordings successfully recovered from the 12 SoundTraps from deployment 4 yielded a total of 1,399 instrument-days (33,572 hours) of recordings over the September 2022 to March 2023 period. The SoundTraps recorded for a median of 4.7 months each (range 0.2 to 5.6 months), with most recordings ending between late January to mid-March (some were still recording on recovery) and yielded good quality recordings throughout the deployment at 10 of the 12 sites. The ST500 deployed at site DCQ flooded and no recordings could be recovered. The ST500 at site DCF had power consumption issues and only recorded poor quality data for seven days. The ST500 at site DCM had connection issues with the hydrophone, with periodic signal dropouts during the first month followed by good quality recordings the remainder of the deployment. The ST500s deployed at sites DCB, DCC, DCJ, and DCP appear to have had hydrophone malfunctions that led to impulsive noise or high noise levels occurring periodically through the recordings. Data from all sites were QA/QC reviewed to remove low-quality data and retain useable recordings where possible. The HARP deployed concurrent with the 4th SoundTrap array deployment yielded 170 days (4,080 hours) of high-quality recordings over the September 2022 to March 2023 SoundTrap deployment period.

As noted above, technical challenges continue with the SoundTraps, including the ST500s built in the early days of the COVID pandemic and the ST600s built in summer 2021. While some of ST500 problems are associated with the internal lithium batteries remaining in a fully discharged state for an extended period due to inaccessibility during mandatory COVID closures in 2020-2021, other challenges are associated with hydrophone failures; this model is no longer being manufactured by Ocean Instruments due to reliability issues. The newer model ST600s are generally more reliable with respect to hydrophone quality and power consumption; however, instrument flooding, experienced by many NOAA and academic users, has affected this project as well with two ST600 flooding events. In all instrument failure cases, the SoundTraps exhibiting problematic behavior have been returned to the manufacturer and repaired prior to redeployment, except in a couple of cases when the failure was not evident until returning from sea.

The preliminary results of acoustic data analysis from recordings at the 18 DC array sites deployed during the first 3 deployments over the May 2021 to September 2022 period are summarized below. LTSAs and daily sound pressure spectrum levels have been calculated for all recordings at the 18 sites, the two automated spectrogram cross-correlation detectors have been run on all recordings from the 18 sites, and the resulting long-moan and downsweep sequence detections have been manually validated for all from the 18 sites. Automated detectors have been run on all recordings from the fourth deployment and the validation of long-moan and downsweep detections from the fourth deployment will be completed in 2024. Here we describe the low-frequency ambient soundscape, hourly and daily Rice's whale call presence, daily call detections per site, and map the monthly distribution of call rates and daily occurrence per site. Final statistical analyses of spatial distribution and variation in Rice's whale call occurrence and ambient noise levels will be completed following the completion of analysis from the fourth deployment, during 2024.

***Table 1**. Acoustic monitoring effort at 18 sites near De Soto Canyon during three deployments over the May 2021 to September 2022 period.*

			Deployment 1				**Deployment 2**				**Deployment 3**			
Site	**Latitude (°N)**	**Longitude (°W)**	**Start Time**	**End Time**	**Effort (Days)**	**Effort (Hours)**	**Start Time**	**End Time**	**Effort (Days)**	**Effort (Hours)**	**Start Time**	**End Time**	**Effort (Days)**	**Effort (Hours)**
DCA[6]	29.5640	-87.3815	5/2/21 00:58	9/28/21 23:57	150	3,599	11/17/21 13:02	4/2/22 00:13	135.5	3251	4/2/22 00:43	9/6/22 09:44	157.4	3777
DCB[2,5]	29.7579	-87.0380	5/2/21 03:32	9/10/21 18:30	131.6	3,159	11/11/21 13:00	-	-	-	4/10/22 17:53	9/9/22 17:35	152.0	3648
DCC[4]	-	-	-	-	-	-	11/16/21 23:04	4/1/22 09:34	135.4	3250	4/10/22 15:57	7/5/22 22:07	86.3	2070
DCD[4]	29.5626	-86.6830	5/2/21 06:05	8/24/21 03:43	113.9	2,734	11/11/21 16:58	3/27/22 05:47	135.5	3253	4/10/22 13:24	8/23/22 03:40	134.6	3230
DCE[3]	29.2153	-86.7550	5/2/21 08:31	10/2/21 19:53	153.5	3,683	11/16/21 20:05	11/26/21 00:18	9.2	220	4/4/22 20:05	9/2/22 03:26	150.3	3607
DCF[5]	29.3206	-86.3683	5/2/21 16:03	9/16/21 04:36	136.5	3,277	11/11/21 20:59	4/4/22 23:06	144.1	3458	4/4/22 23:00	-	-	-
DCG[3,4]	28.9647	-86.4710	5/2/21 18:41	8/23/21 02:47	112.3	2,696	11/16/21 17:16	3/30/22 22:52	134.2	3222	4/4/22 16:53	7/18/22 13:51	104.9	2517
DCH[1]	29.0554	-86.0965	5/1/21 00:00	8/23/21 01:05	114	2,737	8/23/21 06:00	6/3/22 18:23	284.5	6828	-	-	-	-
DCI[2,3]	28.7269	-86.1753	5/2/21 21:19	5/19/21 10:50	16.6	398	11/16/21 14:24	3/10/22 00:16	113.4	2722	4/2/22 12:27	9/11/22 08:13	161.8	3884
DCJ	28.8284	-85.7759	5/2/21 23:41	9/14/21 07:41	134.3	3,224	11/14/21 16:33	3/31/22 10:32	136.7	3282	4/4/22 19:04	9/21/22 07:33	169.5	4068
DCK	28.4830	-85.8975	5/3/21 02:12	9/16/21 15:51	136.6	3,278	11/14/21 19:42	4/1/22 17:18	137.9	3310	4/2/22 14:58	8/31/22 15:14	151.0	3624
DCL[5]	28.5542	-85.5043	5/3/21 04:52	9/22/21 19:53	142.6	3,423	11/14/21 23:30	4/3/22 23:50	140	3360	4/4/22 00:39	-	-	-
DCM[3]	28.2201	-85.6354	5/3/21 11:14	9/23/21 02:07	142.6	3,423	11/15/21 15:30	2/18/22 20:00	95.2	2285	4/2/22 18:25	9/2/22 03:40	152.4	3657
DCN	28.2865	-85.2375	5/3/21 13:50	9/21/21 00:10	140.4	3,370	11/15/21 12:28	4/3/22 20:58	139.4	3345	4/3/22 21:46	-	-	-
DCO[5]	27.9783	-85.3304	5/3/21 16:11	9/23/21 23:38	143.3	3,439	11/15/21 18:32	-	-	-	-	-	-	-
DCP[4,6]	28.0225	-85.0012	5/3/21 18:17	8/10/21 09:23	98.6	2,367	11/16/21 00:00	4/3/22 16:40	138.7	3329	4/3/22 18:39	6/1/22 11:27	58.7	1409
DCQ[4]	-	-	-	-	-	-	11/16/21 04:20	2/28/22 09:54	104.2	2502	4/3/22 13:46	4/13/22 05:34	9.7	232
DCR[5]	-	-	-	-	-	-	11/16/21 01:15	3/31/22 19:54	135.8	3259	4/3/22 14:53	-	-	-

[1] The 1st HARP at site DCH began recording in August 2020; only data collected concurrent with the SoundTrap array are included in these analyses. The 2nd HARP at DCH overlapped with all three deployments of the SoundTrap array, but are included in this and following tables as Deployment 2 for simplicity.
[2] These SoundTrap moorings had hydrophone or power malfunctions during deployment 1 and parts of the recordings are corrupted.
[3] These SoundTrap moorings had hydrophone or power malfunctions during deployment 2 and parts of the recordings are corrupted.
[4] These SoundTrap moorings had hydrophone or power malfunctions during deployment 3 and parts of the recordings are corrupted.
[5] The deployments with no end date at these SoundTrap sites had moorings that could not be recovered or flooded.
[6] Successive mooring deployment locations occurred within 25m, except at sites A & P. Deployment 3 at Site A was moved 6.5km southeast to deeper waters at 29.5675 N, -87.3229 W, as the original site was too shallow (85m). Deployment 2 at Site P was moved 3.6km southeast to the originally planned site location at 28.0137 N, -84.9703 W, as it was misplaced during the first deployment.

Low Frequency Ambient Soundscape

Across the three deployments, 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**). Seismic airgun surveys, with strong energy in the 10-70 Hz band showing distinctive energy peaks, dominate the low frequency band during the 2nd and 3rd deployments, while they were only evident in the first three weeks of May 2021 and in late August and September 2021 of the 1st deployment (**Figure 5**). Shipping noise is ubiquitous across all sites in the 30-100 Hz band when airgun noise doesn't mask it, and is particularly strong at the eight southernmost sites (**Figure 5**). The recorder at site DCA was deployed in 85 m depths, on the shelf, for deployments 1 & 2, while all other sites were deeper (180-450 m) 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**).

- While the 2021 Atlantic hurricane season was an unusually active one with seven named storms passing through the GOM during deployment 1, only one tropical storm (Tropical Storm Alex) passed through the Gulf during the 3rd deployment period in 2022. Similar to 2021, increases in broadband noise levels over the 100-1000 Hz band were evident across all sites during the storm on June 5-6 (**Figure 5**).
- Short-term increases in broadband noise levels in the 100-1000 Hz band associated with heavy weather were evident across sites during winter and spring, from Dec 2021 to May 2022 (**Figure 5**). During these periods, lower frequency noise levels associated with seismic surveys often decreased.
- 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. The soundscape only changed slightly at this site when moved to deeper waters (198 m) for deployment 3, when compared with noise levels during the same season from deployment 1.
- Similar to deployment 1 data from 2021, a comparison of sound pressure spectrum levels at site DCH deployment 2 (the fully calibrated HARP) and the SoundTrap sites from deployments 2 & 3 (factory calibrated at 250 Hz) shows that sound levels below 20 Hz 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 occurred nearly constantly and at higher levels during the 2nd and 3rd deployments compared the infrequent occurrence during the 1st deployment (**Figure 5**). The same airgun surveys were detected at nearly all sites across the array from late August 2021 through September 2022, with brief gaps in activity evident in March 2022 at southern sites and June of 2022 across sites. Airgun survey noise was limited at northernmost sites A & B.
- Diel date vs time plots of noise levels at 125 Hz (the center 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**). The slight diel differences seen at sites DCB and DCD during the 1st deployment are not evident during the 2nd and 3rd deployments. A tidal signal is evident during the 3rd deployment at site DCE (**Figure 6**). This may be related to fish chorusing since tidal strumming is not apparent in the long-term spectrogram (**Figure 5**).
- Large scale weather events described from long-term spectrograms are also evident in the 125 Hz diel plots (**Figure 6**), e.g., during April through June 2022, but these are not as apparent as the tropical storms and hurricanes seen during the 1st deployment (**Figure 6**)

- Noise levels at 125 Hz were generally higher at the shelf site DCA and at the eight southern sites, particularly the southern inshore sites (**Figure 6**). This was especially evident during the 2nd deployment.
- Shorter duration events, seen as brighter yellow or red spots in diel plots, represent ship passings, and are seen across all deployments at all sites, in particular the 5 southern inshore sites and the shallow DCA site (**Figure 6**).
- Time-series of the daily statistical distribution of average hourly sound pressure spectrum levels at 125 Hz (**Figure 7**) follow similar patterns of increased levels at the time periods described above. Daily spectrum levels are generally higher and more variable at the more southern sites compared to northern sites, with the exception of site DCA. At many sites, median noise levels track closely with the lowest 1st percentile noise levels, particularly at the northern sites.
- Noise levels at 100 Hz (the center frequency for Rice's whales downsweep sequences that typically range from 75 to 125 Hz) largely follow the same temporal patterns as those seen at 125 Hz, but at higher levels and with ship passing events occurring for longer durations (**Figures 8 & 9**).

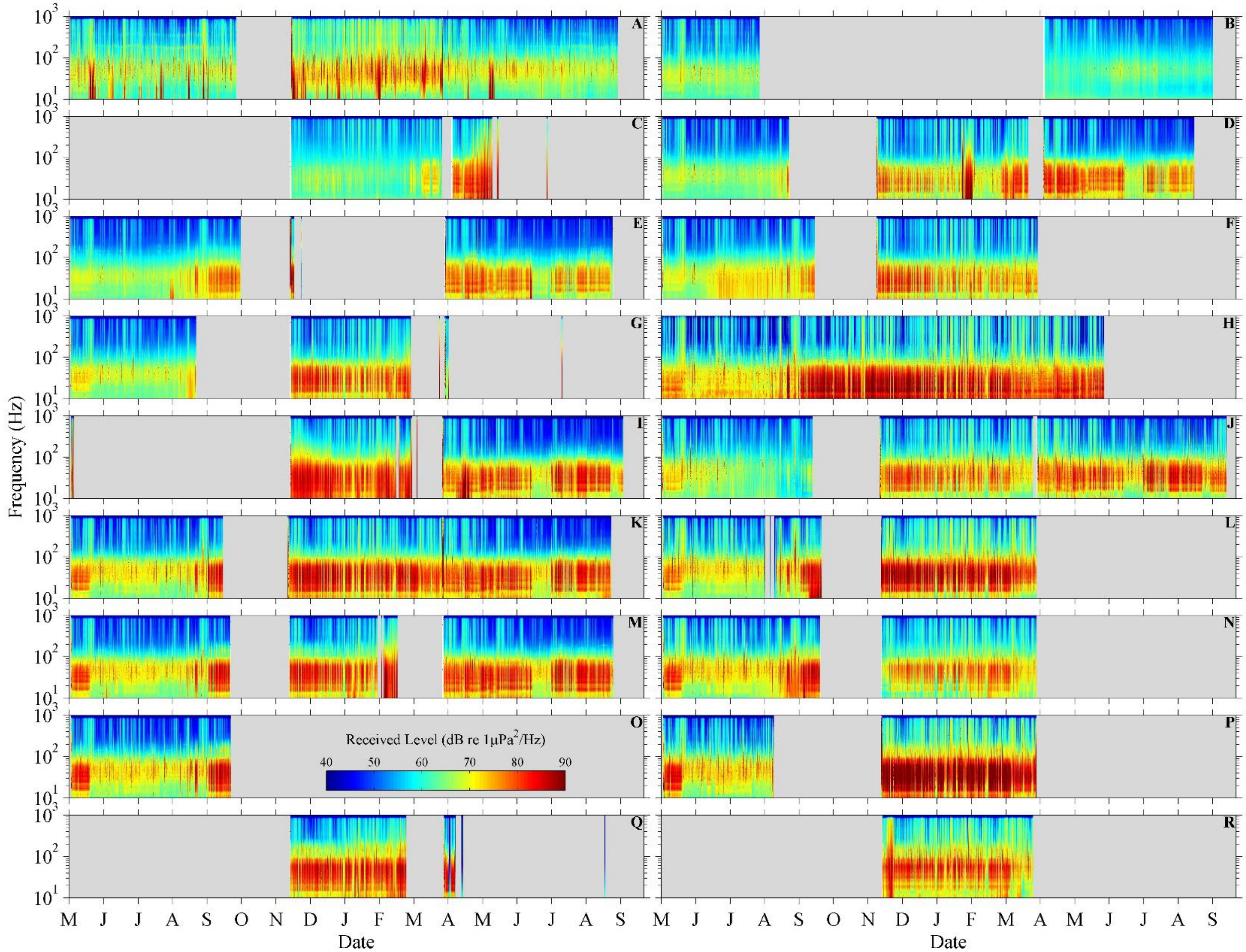

Figure 5. *Hourly median long-term spectral averages of the SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022 showing recorded ambient noise levels from 10-1000 Hz. Gray indicates periods with no recording effort.*

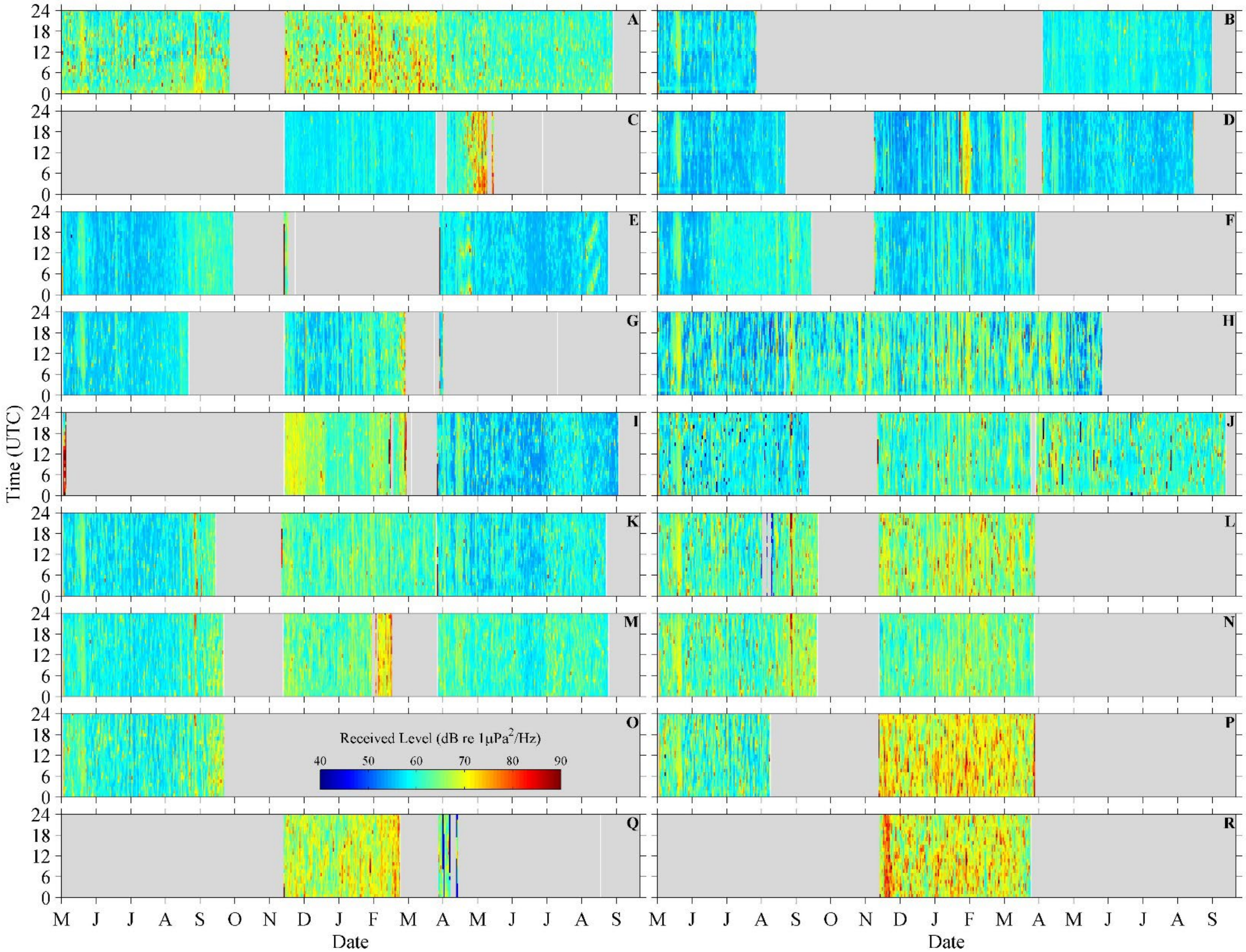

Figure 6. *Diel variation in hourly median sound pressure levels at 125 Hz (center frequency of long-moan calls) for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Gray indicates periods with no recording effort.*

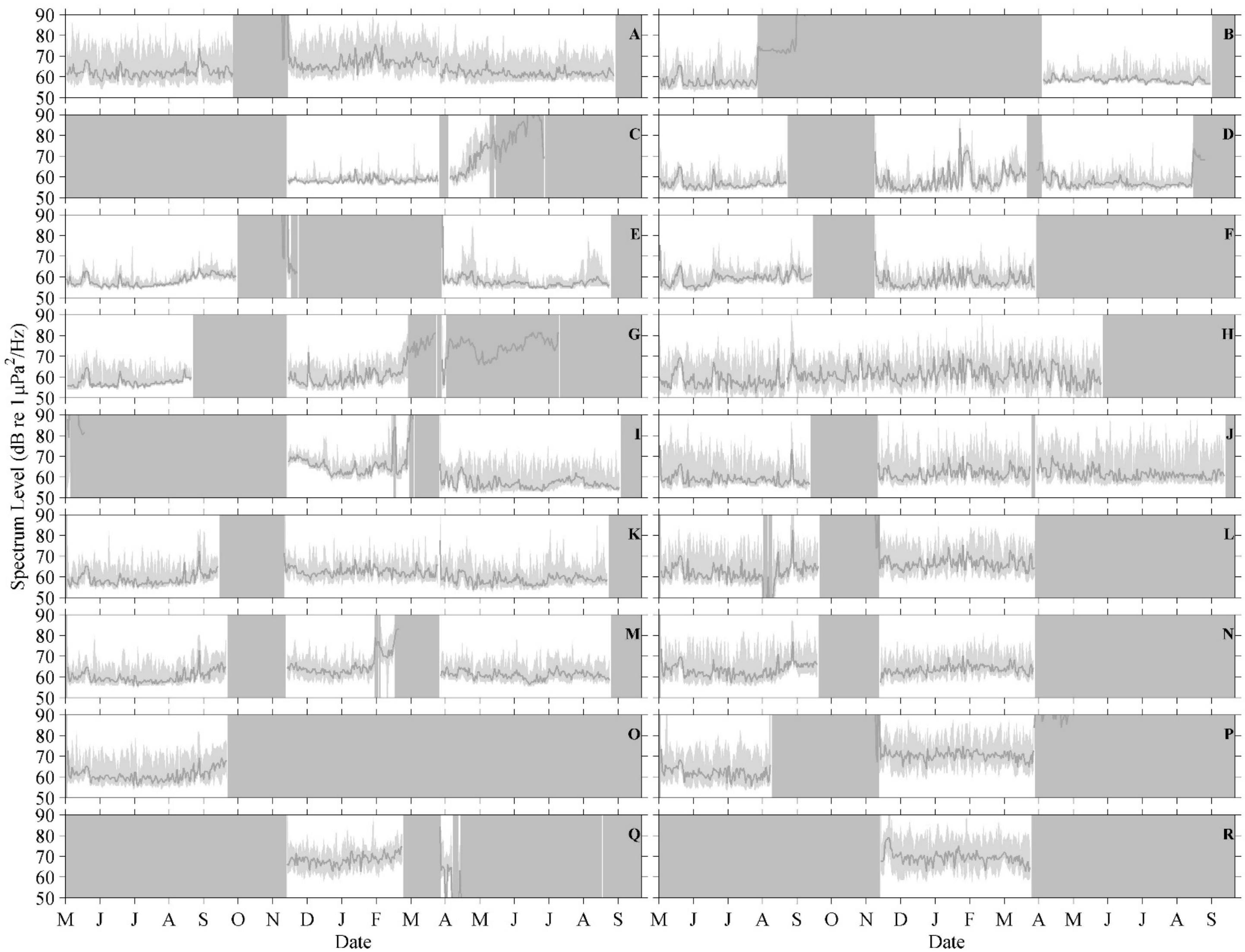

Figure 7*. Daily distribution (light gray shading: 1 – 99 percentile; gray line: 50 percentile) of average hourly sound pressure levels at 125 Hz (center frequency of long-moan calls) for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Dark gray indicates periods with no recording effort.*

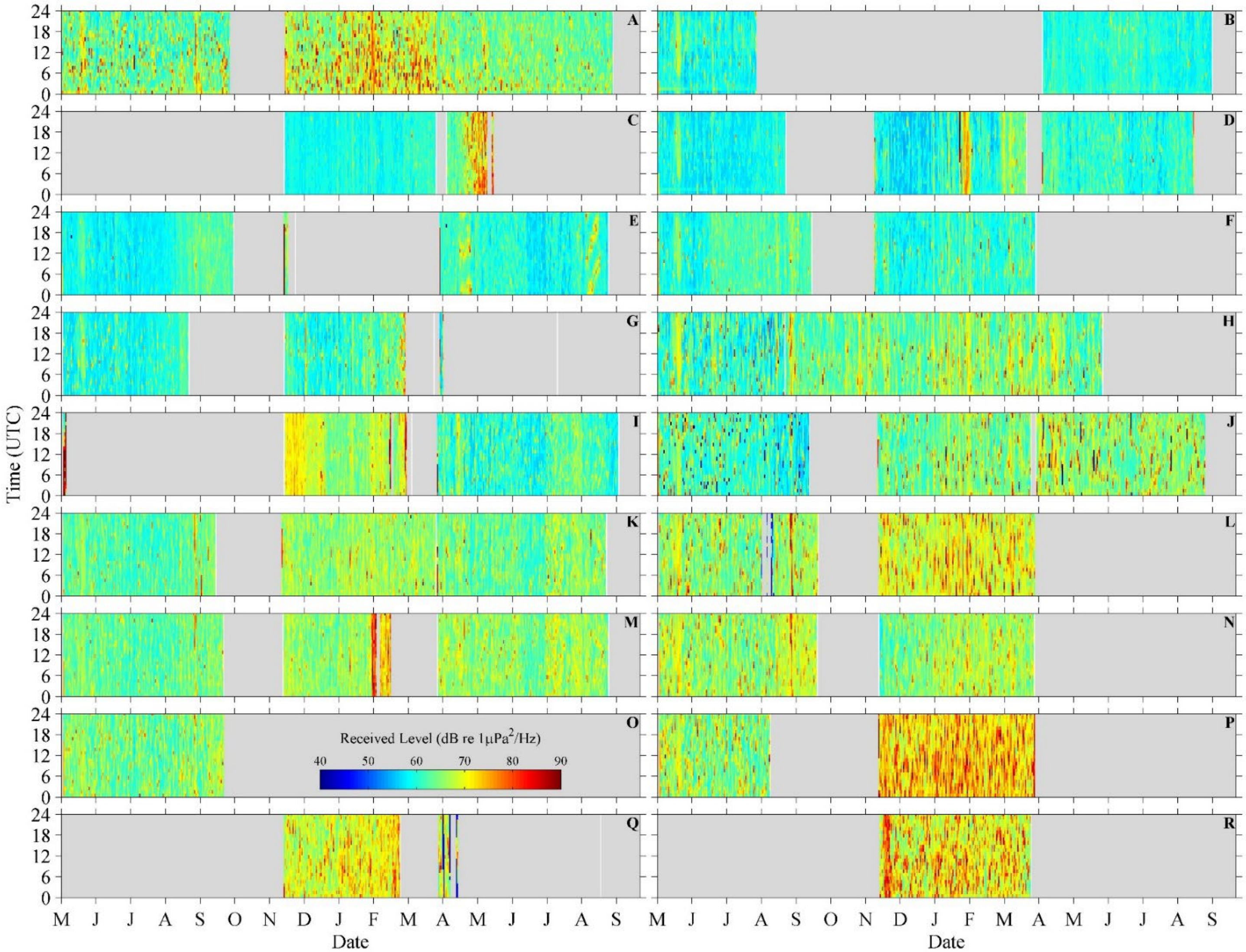

Figure 8*. Diel variation in hourly median sound pressure levels at 100 Hz (center frequency of downsweep sequence calls) for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Gray indicates periods with no recording effort.*

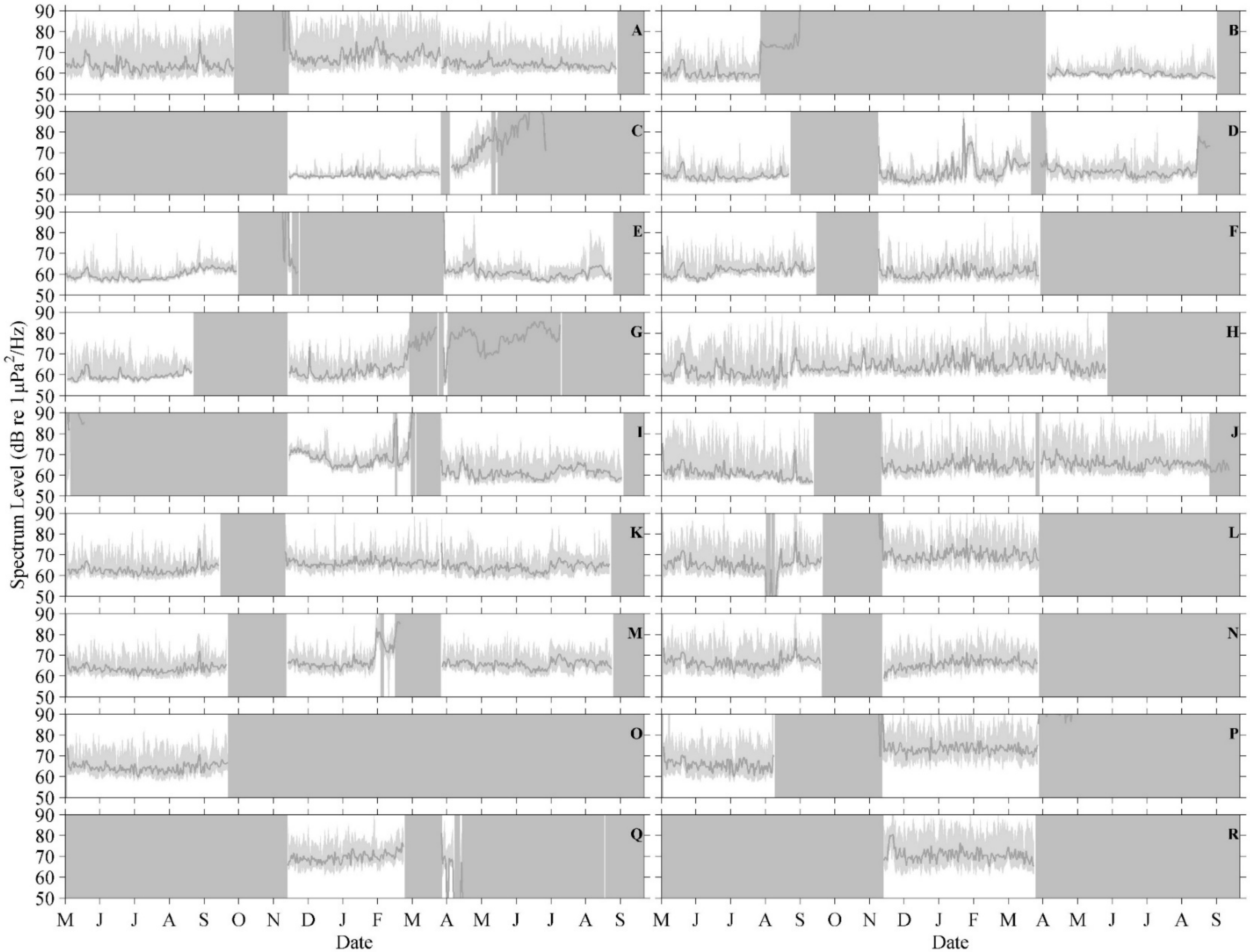

Figure 9. *Daily distribution (light gray shading: 1 – 99 percentile; gray line: 50 percentile) of average hourly sound pressure levels at 100 Hz (center frequency of downsweep sequence calls) for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Dark gray indicates periods with no recording effort.*

Rice's Whale Long-moan Calls

There were a total of 1,306,692 automated detections of Rice's whale long-moan calls in the quality-controlled recordings from the 18 sites in the DC array during the May 1, 2021 – September 21, 2022 period. Detections ranged between 21 and 84,575 per SoundTrap deployment, with 144,784 in recordings from the 2nd HARP deployment at DCH that spanned all three SoundTrap deployments (**Table 2**). Over the three deployment periods, 755,547 of the 1,306,692 detections were validated as true long-moan calls, with a range of 4 to 110,887 per deployment (**Table 2**). True long-moan call detections occurred at all sites, but were higher at inshore sites than offshore across both deployments (**Table 2**, **Figures 10, 11**). False detection rates per deployment averaged 32.5%, 45.4%, and 47.3% for the 1st, 2nd, and 3rd deployments respectively, and ranged between 13.2% and 100%. The sites with higher false positive rates (>50%) were the shallow site DCA and the other offshore sites where Rice's whale calls were less common, and the southernmost inshore sites DCP and DCR where vessel noise from the Tampa shipping fairway was common (**Table 2, Figure 11**). False detection rates also varied over time within sites, with increased rates at sites in the southern half of the array from September 2021 to March 2022 and at offshore sites in the middle of the array from July to September 2022, coincident with increased activity from seismic airgun surveys, which were the cause of most of the false detections (**Figure 11**).

Results indicate true long-moan calls were present during an average of 85% of days (range 46-99% of days) per site and during an average of 53% of hours (range 12-89% of hours) with recording effort per site across the three deployments from May 2021 to September 2022 (**Table 2**). Daily and hourly presence of Rice's whale calls per deployment were higher at inshore sites (mean: 93% of days, range 66-100%; mean 70% of hours, range 43-90%) than offshore sites (mean: 68% of days, range 0-100%; mean 32% of hours, range 0-74%). A preliminary comparison with potential detection ranges (**Figure 12**) as a function of noise levels at 125 Hz (e.g. **Figure 7**) indicates that masking effects of noise levels are not the primary driver for this inshore/offshore difference as noise levels are generally lower offshore leading to greater estimated detection ranges at offshore sites compared to inshore sites (future analyses will include site-specific sound propagation conditions). Preliminary results suggest potential seasonal movements between southern and northern sites as call rates and daily call presence vary across sites over time (**Figures 11, 13, 14, 15**) with higher occurrence and call detection rates at northern sites (DCB, DCD, DCF) in May through July 2021 compared to later months, and higher occurrence and call detection rates at southern sites (DCJ, DCL, DCN, DCP) during August 2021 through February 2022.

- The spectrogram cross-correlation detector for long-moan calls yielded a total of 1,306,692 detections in recordings from the 18 sites over the three deployments from May 2021 to September 2022, and ranged between 21 and 84,575 detections per SoundTrap deployment, with 144,784 detections in recordings from the year-long 2nd HARP deployment at DCH (**Table 2**).
- Validation of auto-detections of long-moan calls has now been completed on the HARP from the 2nd deployment and all 12 SoundTrap sites from the 3rd deployment, in addition to the previously completed 1st and 2nd deployments. Across the three deployments, true long-moan calls were detected at every site. There were higher numbers of true long-moan calls detected per deployment at inshore sites (mean: 33,242, range: 9,721 to 110,887) compared to offshore sites (mean: 5,389, range: 4 –19,147; **Table 2**, **Figures 10, 11, 13**).
- Across all validated detections across all sites and deployments during the May 2021 – September 2022 period, only 4 possible western long-moan variants were detected at site DCH, with 2 in September 2021, one in November 2021, and one in April 2022.

- Validation results from the 18 sites yielded false detection rates averaging 32.5%, 45.4%, and 47.3% for the 1st, 2nd, and 3rd deployments, respectively, and ranging between 13.2% and 100% for the long-moan call detector per deployment across the 18 sites over the May 2021– September 2022 period.
- The highest false detection rates (>90%) occurred during deployments 1 and 2 at site DCA, during deployment 3 at DCC, during deployments 2 & 3 at DCE, during deployment 2 at DCQ. At DCA, the mooring was deployed in 85 m water depth where Rice's whale calls were rare while fish chorusing and vessel noise were common – it was moved deeper for deployment 3 and the false detection rate dropped to 56%. Sites DCC and DCE are in deeper offshore waters near the canyon and true detections are generally uncommon in this area with false positives occurring during a period of high seismic survey activity. False detection rates also increased at the other offshore sites DCI, DCK, and DCM during this period during deployment 3. High false positive rates (93%) at site DCQ where calls were uncommon occurred when seismic survey noise was prevalent, with concurrently high false positive rates at site DCR (73%) just inshore of it and DCP (58%), one site to the north and inshore (**Figure 11**).
- Beyond the highest rates, false detection rates were generally higher at offshore sites (30-84%), where fewer true calls were detected, compared to inshore sites (generally 13-40% except at southernmost sites DCP and DCR near the Tampa shipping lane). False detections also varied over time within sites, with increased rates at sites in the southern half of the array from September 2021 to March 2022 and from July to August 2022, coincident with increased activity from seismic airgun surveys, which were the cause of most of the false detections (**Figure 11**). A similar effect was seen at site DCO in May 2021.
- Results indicate that true Rice's whale long-moan calls were present an average of 85% (range: 46 – 85%) of days per site, and were present in an average of 53% (range: 12 to 89%) of recording hours per site across the three deployments from May 2021 to September 2022 (**Table 2**). Percent of days and percent of hours present per deployment were generally higher at the inshore sites (mean 93%, range 66-100% of days; mean 71%, range 43-90% of hours) than the offshore sites (mean 68%, range 0 – 100% of days; mean 32%, range 0 – 74% of hours).
- Preliminary results of estimated maximum detection ranges of long-moan calls as a function of ambient noise conditions at 125 Hz (assuming call source level of 145 dB, detection threshold of 10 dB SNR, and 17logR geometric spreading loss at all sites) suggest detection ranges generally are higher at offshore sites where noise levels are lower (**Figure 12**). This suggests noise masking is not the cause of lower detection rates at offshore sites. Monthly sound propagation modeling at each site is being conducted using parabolic equation models to better estimate site-specific transmission loss effects on detection ranges.
- At the southern sites (DCK to DCR), call detections follow a similar temporal pattern, such as the peaks in call rates occurring in July and from November 2021 and to March 2022 (**Figures 10, 11, 13**). Prior analyses from this area indicate Rice's whale calls can be detected up to 75 km on some occasions. Preliminary results from an acoustic tracking project, which leverages the deployment 1 data, finds that calls detected at site DCL are also detected at sites DCJ, DCK, DCM, DCN, DCO, and DCP, suggesting that at least part of the explanation for these shared temporal occurrence patterns is that they represent the same whales detected on multiple instruments. These patterns may also be indicative of broader population movement patterns.

- Results suggest potential seasonal movement patterns with higher detection rates of true long-moan calls at northern sites in May through August of both 2021 and 2022, and higher detection rates at southern sites from September 2021 to March 2022 (**Figures 11, 13, 14, 15**). Spatial comparisons of percent of days per month present per site (**Figure 14**) and call detection rates per site (**Figure 15**) support the patterns observed in the time-series (**Figures 11, 13**). Additional data from the fourth deployment may help determine whether these potential seasonal patterns at southern sites are consistent beyond one year.
- Fewer long-moan calls were detected at the southern-most sites DCQ and DCR during the 2nd deployment than at the sites to the north of them (**Figures 11, 13**). This may indicate fewer whales occur here as the region approaches the known extents of the Rice's whale core distribution area, or this may be the effect of masking due to higher levels of shipping and seismic airgun noise at these sites. Rice's whale calls have been detected further south at a HARP site south of the Tampa shipping lane (Frasier *et al.,* 2024).

Table 2. *Number of long-moan calls automatically detected and true calls validated per site during the three SoundTrap and HARP deployments at 18 sites over the May 2021 – September 2022 period. Only 4 possible western Gulf long-moan variants were detected during this deployment period, all at site DCH between September 2021 and April 2022. Shaded sites are from the offshore line.*

	Deployment 1				**Deployment 2**				**Deployment 3**			
Site	**Automated Detections**	**Validated Calls**	**Days Present (%)**	**Hours Present (%)**	**Automated Detections**	**Validated Calls**	**Days Present (%)**	**Hours Present (%)**	**Automated Detections**	**Validated Calls**	**Days Present (%)**	**Hours Present (%)**
DCA	11,629	27	11 (7)	17 (0.5)	10,919	797	44 (32)	197 (6.1)	14,388	6,409	153 (97)	1,370 (36.3)
DCB	15,970	9,721	69 (78)	1,073 (51.0)	-	-	-	-	15,344	13,311	140 (92)	1,874 (51.4)
DCC					4,651	3,239	88 (64)	855 (26.3)	1,394	108	10 (25)	45 (5.5)
DCD	44,038	38,185	110 (96)	2,320 (84.9)	14,854	11,976	91 (66)	1,396 (43.3)	35,185	26,701	119 (88)	2,228 (69.0)
DCE	5,446	1,107	87 (56)	461 (12.5)	805	0	0 (0)	0 (0.0)	20,355	795	107 (70)	471 (13.1)
DCF	45,555	39,088	136 (99)	2,856 (87.2)	23,315	16,406	121 (83)	1,817 (52.6)	-	-	-	-
DCG	5,985	2,800	101 (89)	745 (27.6)	7,144	1,833	88 (80)	580 (22.3)	38	10	2 (40)	6 (9.8)
DCH	44,313	38,150	112 (98)	2,348 (86.4)	144,784	110,887	283 (99)	6,174 (90.4)	-	-	-	-
DCI	21	4	1 (33)	1 (5.9)	2,259	368	33 (30)	107 (4.2)	26,099	12,586	155 (95)	1,922 (49.5)
DCJ	21,655	16,448	130 (96)	2,074 (64.3)	50,555	35,185	134 (97)	2,404 (73.3)	57,920	43,984	171 (100)	3,366 (82.6)
DCK	14,451	8,124	120 (88)	1,402 (42.8)	34,730	10,277	132 (95)	1,752 (52.9)	42,836	19,147	152 (100)	2,642 (72.9)
DCL	36,731	27,262	133 (98)	2,263 (70.7)	73,323	55,529	140 (100)	2,799 (83.3)	-	-	-	-
DCM	26,368	10,459	135 (94)	1,730 (50.5)	37,041	12,895	88 (94)	1,613 (73.8)	49,056	17,228	154 (100)	2,710 (74.1)
DCN	39,943	28,990	134 (94)	2,354 (69.8)	69,727	50,639	138 (99)	2,930 (87.6)	-	-	-	-
DCO	32,624	11,439	131 (91)	1,763 (51.3)	-	-	-	-	-	-	-	-
DCP	19,316	13,943	96 (96)	1,441 (60.9)	84,575	35,824	137 (98)	2,541 (76.3)	-	-	-	-
DCQ	-	-	-	-	46,345	3,450	93 (89)	851 (33.9)	5,098	855	12 (86)	136 (60.7)
DCR					69,907	19,361	134 (99)	1,940 (59.5)				
Total	**364,045**	**245,747**			**674,934**	**368,666**			**267,713**	**141,134**		

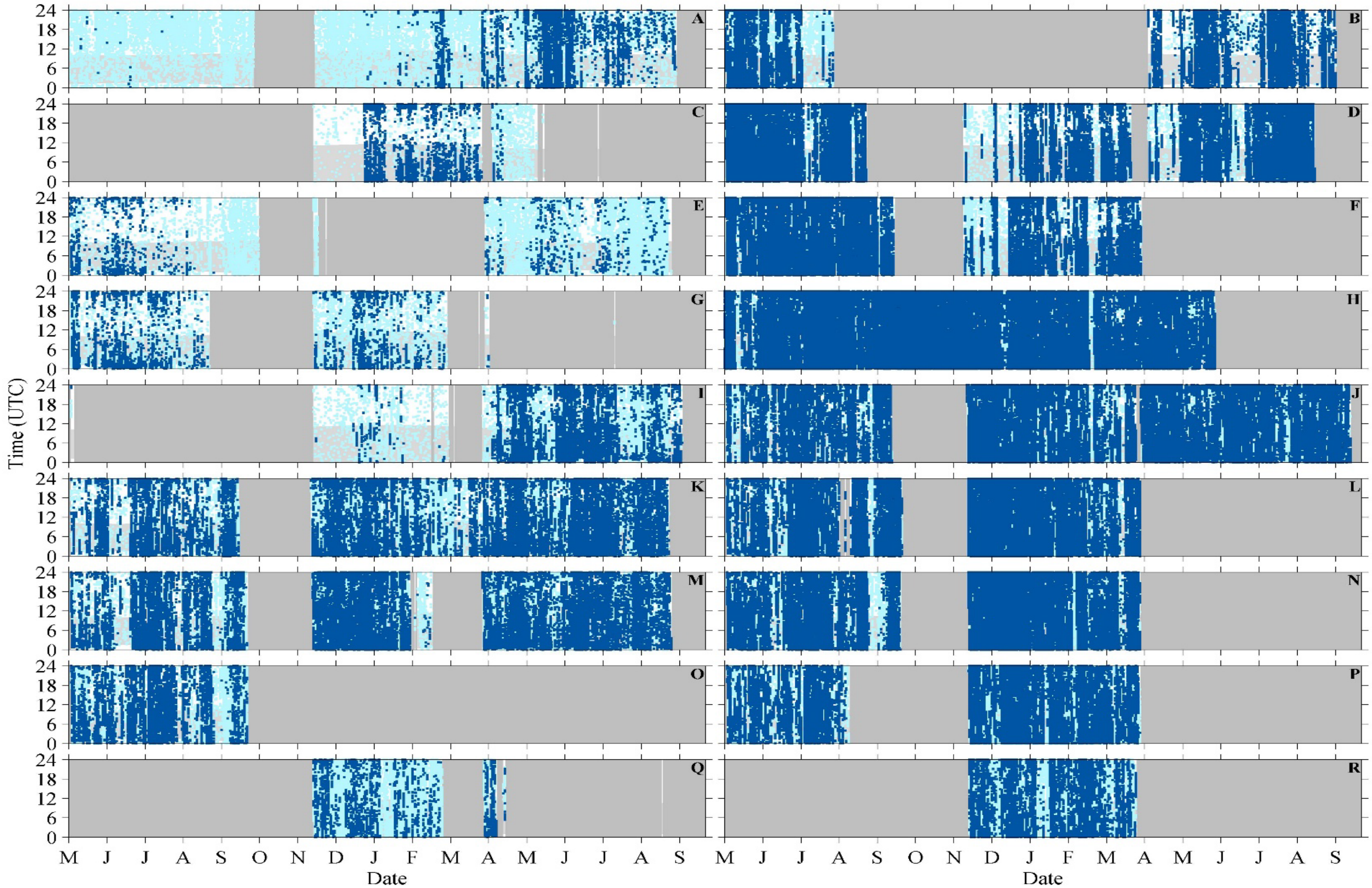

Figure 10. *Rice's whale long-moan call presence in 1-minute bins at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May 2021 to September 2022 deployment period. Light blue marks represent verified false detections; dark blue marks represent true long-moan detections. Night time is indicated by gray hourglass shading. The darker gray blocked area represents periods without recording effort.*

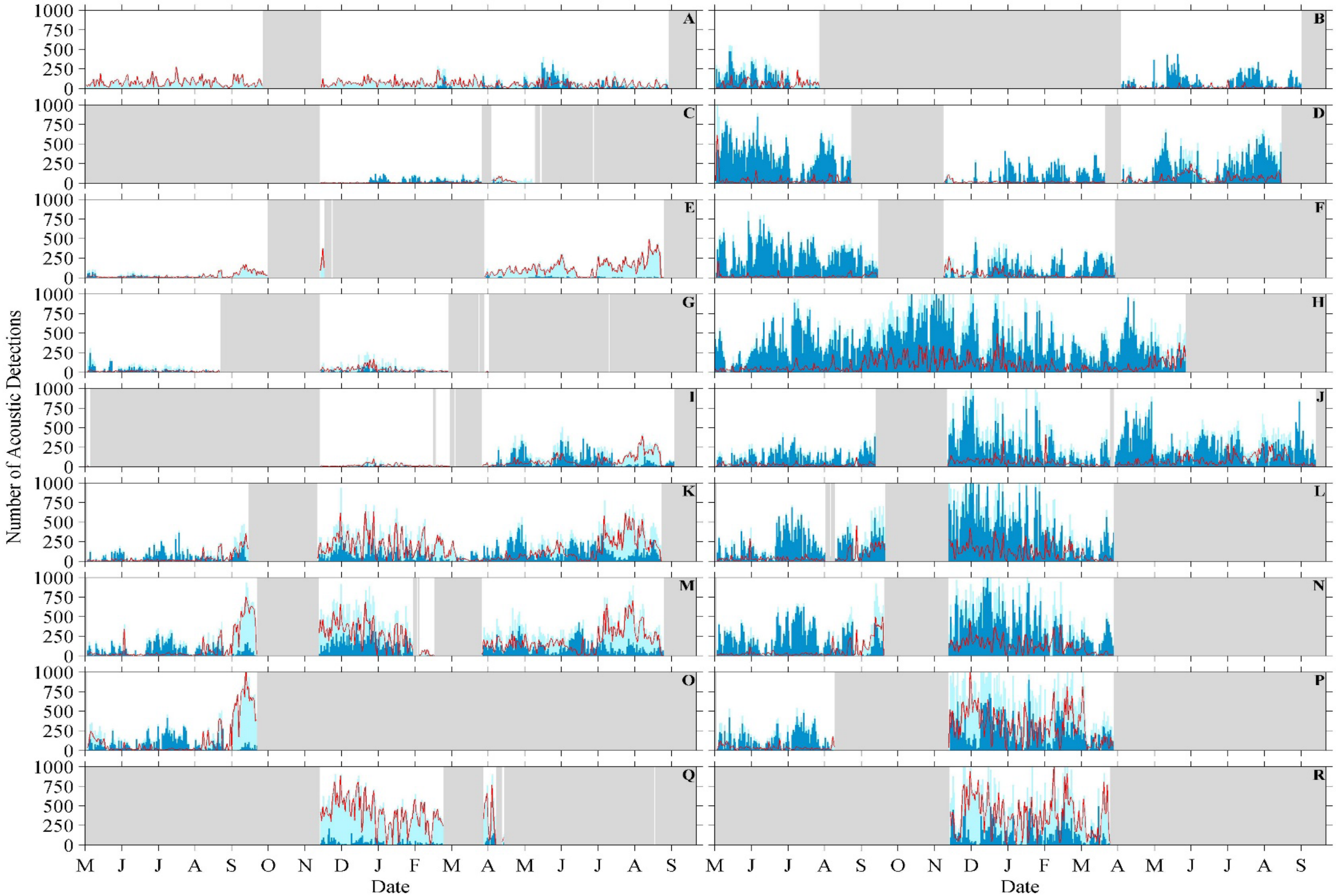

Figure 11. *Daily total of Rice's whale long moan detections (light blue = autodetections, dark blue = verified long-moans, red line = false detections) at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May 2021 to September 2022. Gray blocks indicate periods without recording effort.*

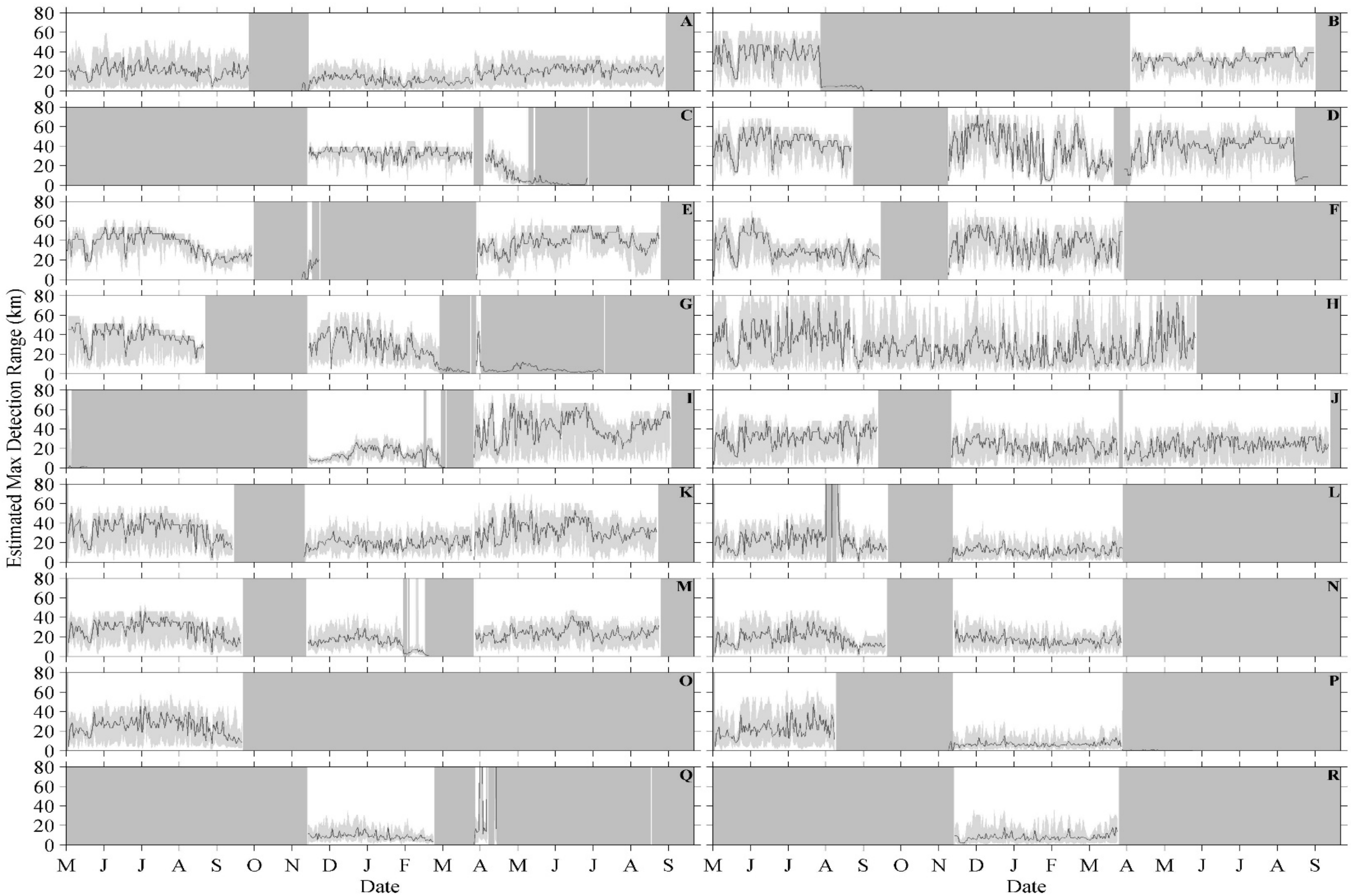

***Figure 12**. Example maximum detection ranges of long-moan calls as a function of ambient noise levels at 125 Hz for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Estimated example detection ranges calculated assuming a call source level of 145 dB, detection threshold of 10 dB signal-to-noise, and geometric spreading transmission loss at 17*logR; these assumptions require verification*

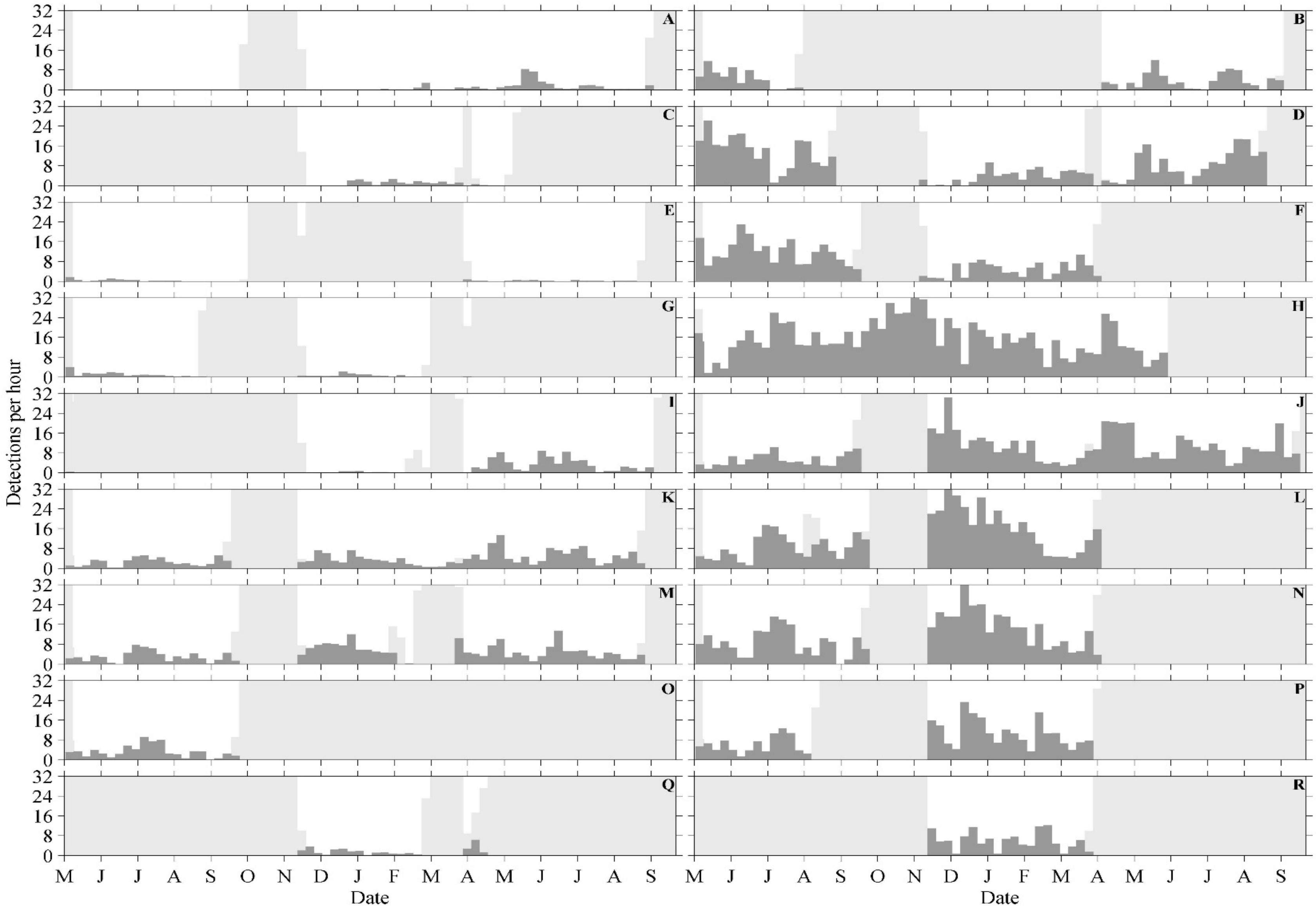

Figure 13. *Weekly Rice's whale long-moan calls per hour of effort at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May 2021 to September 2022. Dark bars represent validated long-moan detections. Light gray blocks indicate periods without recording effort.*

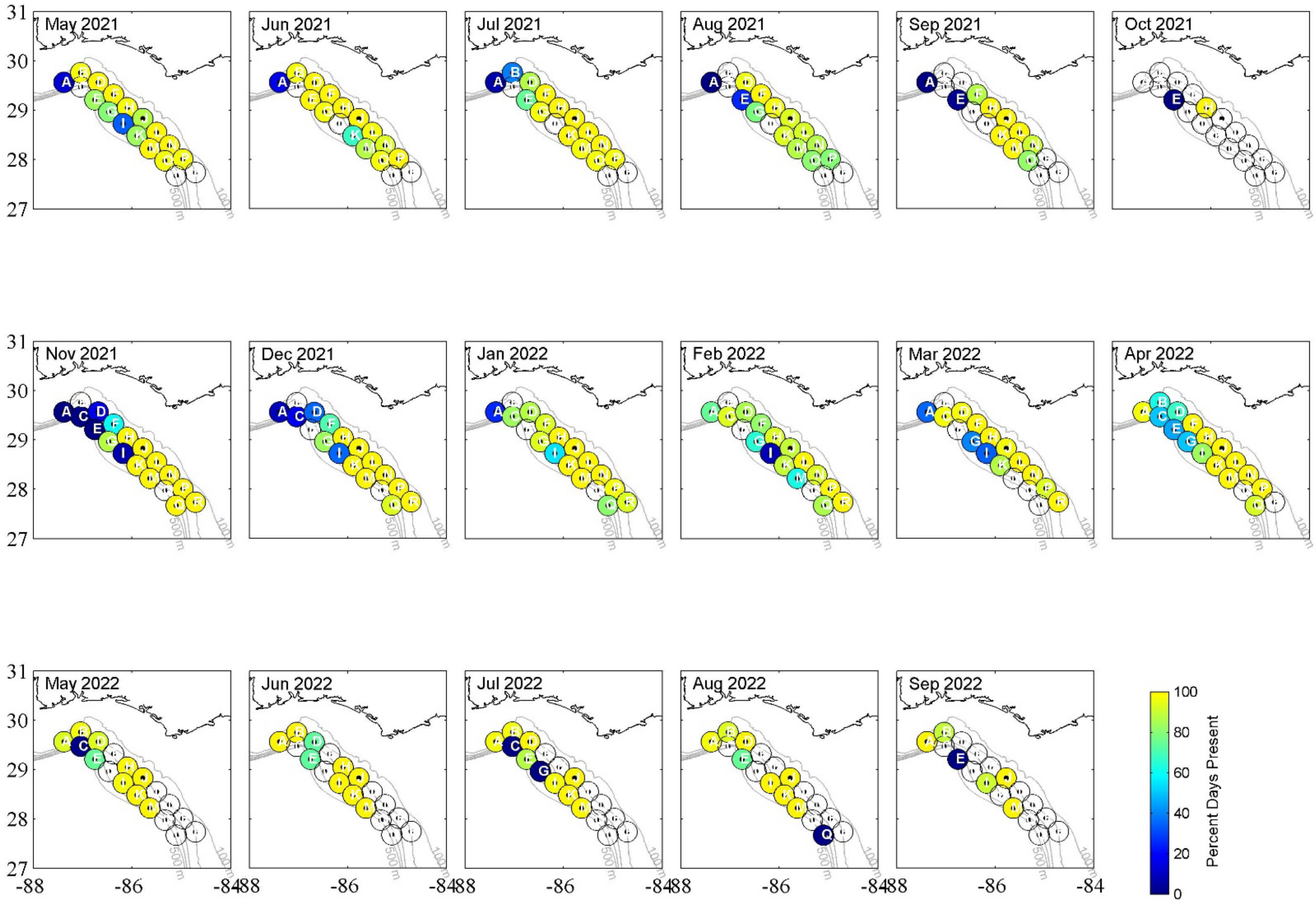

Figure 14 *Monthly Rice's whale long-moan presence, as percent of days, at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May 2021 to September 2022 deployment period. Color represents percent of days with calls present. Open circles with no color represent no data. Coastline and 100m isobaths up to 500m are indicated.*

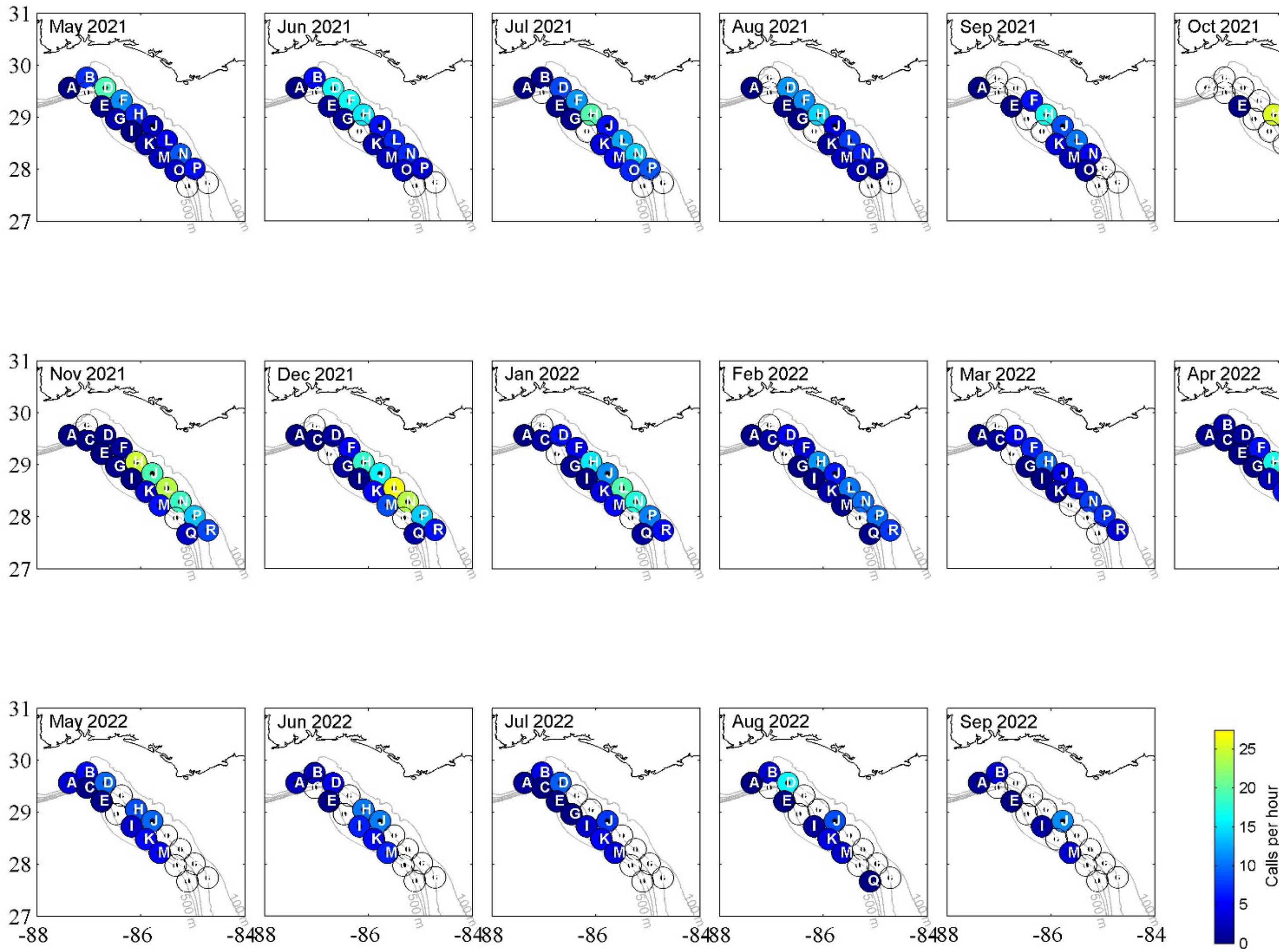

Figure 15*. Monthly average of Rice's whale long-moan call detection rates at 18 sites in the De Soto Canyon sparse array over the May 2021 to September 2022 deployment period. Color represents call detections per hour. Open circles with no color represent no data. Coastline and 100m isobaths up to 500m are indicated.*

Rice's Whale Downsweep Sequence Calls

There were a total of 224,060 automated detections of Rice's whale downsweep sequences in the quality-controlled recordings from 18 sites in the DC array during the May 1, 2021 to September 21, 2022 period. Detections ranged between 15 and 18,428 per SoundTrap deployment, with 24,285 in recordings from the 2nd HARP deployment at DCH, which spanned all three SoundTrap deployments (**Table 3**). Similar to previous analyses of the eight years of DC HARP recordings, downsweep detections were far less common than long-moan call detections (6x). Over the three deployment periods, 42,441of the 224,060 detections were validated as true downsweep sequence calls, with a range of 0 to 7,450 per deployment per site (**Table 3**), yielding 18x fewer true downsweep sequence calls than true long-moan calls. There were high false detection rates across sites over all three deployments (35-100%) due both to the rarity of true calls at many sites and to confusion with ubiquitous seismic airgun pulses and a long-moan call-type that includes heavy amplitude modulation in the tail. Similar to long-moan calls, true downsweep sequence detections were higher at inshore sites than offshore sites across both deployments (**Table 3, Figures 16, 17**). Noise levels are higher at 100 Hz (the center of the downsweep sequence call range) than at 125 Hz (the center of the long-moan call range), and hence preliminary estimates of detections ranges based on ambient noise levels indicate detection ranges will be smaller for downsweep sequences (**Figure 18**) than for long-moans (**Figure 12**), assuming similar source levels among call types. Similar to long-moans, these detection ranges as a function of noise levels are generally higher at offshore sites than inshore sites, so this does not explain the decreased call detections at offshore sites (**Figure 17**). Unlike long-moan calls, true downsweep sequence detections were not found at all sites across the three deployments, never being detected at either DCA or DCC. Sites DCE, DCG, and DCI each had at least one deployment with no true detections (**Table 3, Figures 16, 17, 19**). Similar to long-moan calls, there were suggestions of a seasonal movement between middle-habitat sites in the spring to summer and southern sites in the fall to winter (**Figures 17, 19, 20, 21**), though data from additional years (e.g. the 4th deployment) are needed to verify if this is a consistent pattern across years.

- There were 6x fewer downsweep pulse sequence call detections (224,060) than long-moan detections (1,306,692) over the 18 passive acoustic sites over the May 2021 to September 2022 period. Downsweep sequence detections ranged from 15 to 18,428 per SoundTrap deployment, with 24,285 detections in recordings from the year-long 2nd HARP deployment at DCH (**Tables 2, 3**).
- Validation of auto-detections of downsweep sequences has been completed on the HARP from the 2nd deployment and all 12 SoundTrap sites from the 3rd deployment, in addition to the previously completed 1st and 2nd deployments. Across the three deployments, true downsweep sequence detections did not occur at all sites during a given deployment, with northern sites DCA, DCB, and DCI lacking detections during deployment 1, sites DCA, DCC, DCD, DCE, and DCG lacking detections during deployment 2, and sites DCA, DCC, and DCG lacking detections during deployment 3 (**Table 3, Figures 16, 17, 19**).
- Detections of true downsweep pulse sequences per deployment were higher at inshore sites (mean: 1,909; range: 0 to 7,450) than offshore sites (mean: 291; range: 0 to 1,664) (**Table 3**).
- Validation results from the 18 sites yielded false detection rates averaging 72% , 87%, and 92% for the 1st, 2nd, and 3rd deployments, respectively, and ranging between 34% and 100% for the downsweep sequence detector per deployment across the 18 sites over the May 2021– September 2022 period.
- Highest false detection rates (90-100%) occurred in 22 of the 42 deployments, primarily at northern sites where downsweep calls were detected rarely or not at all, as well as at several offshore sites (**Figure 17**). Some false detections were due to confusion with a long-moan call type that is amplitude modulated throughout. Confusion with ubiquitous airgun pulses also affected the detector.

- False detection rates for downsweep sequences vary substantially over time (**Figure 17**), with increases across most sites during July to September 2022 associated with increased airgun activity.
- Results indicate that true Rice's whale downsweep sequences were present an average of 28% (range: 0 – 59%) of days per site, and were present in an average of 7% (range: 0 to 20%) of recording hours per site across the three deployments from May 2021 to September 2022 (**Table 2**). Percent of days and percent of hours present per deployment were generally higher at the inshore sites (average 34%, range 0-89% of days; average 11%, range 0-49% of hours) than the offshore sites (average 16%, range 0-54% of days; average 3%, range 0-13% of hours).
- Preliminary results of estimated maximum detection ranges of downsweep sequence calls as a function of ambient noise conditions at 100 Hz (assuming call source level of 145 dB, detection threshold of 10 dB SNR, and 17logR geometric spreading loss at all sites) show similar differences in detection ranges between offshore and inshore sites as long-moans at 125 Hz (generally larger at offshore sites where noise levels are lower; **Figure 18**), but these ranges are smaller for downsweep sequences than for long-moan calls as ambient noise levels are higher at 100 Hz than at 125 Hz (**Figure 12**). Monthly sound propagation modeling at each site is being conducted using parabolic equation models to better estimate site-specific transmission loss effects on detection ranges, and in-progress acoustic localization and tracking analyses are expected to yield improved estimates of long-moan and downsweep call source levels.
- Preliminary results suggest potential seasonal movement patterns with higher detection rates of true long-moan calls at sites in the middle of the array from May to August 2021 (this pattern is not strongly evident in May to August 2022 due to data gaps), and higher detection rates at southern sites from November to March (**Figures 17, 19, 20, 21**). Spatial comparisons of percent of days per month present per site (**Figure 20**) and call detection rates per site (**Figure 21**) support the patterns observed in the time-series (**Figures 17, 19**). Additional data from the 4th deployment may help determine whether these potential seasonal patterns are consistent beyond one year.

Table 3. Number of downsweep sequence calls automatically detected and true calls validated per site during the three SoundTrap and HARP deployments at 18 sites over the May 2021 – September 2022 period.

	Deployment 1				**Deployment 2**				**Deployment 3**			
Site	**Automated Detections**	**Validated Calls**	**Present (%)**	**Hours Present (%)**	**Automated Detections**	**Validated Calls**	**Present (%)**	**Hours Present (%)**	**Automated Detections**	**Validated Calls**	**Present (%)**	**Hours Present (%)**
DCA	1,828	0	0 (0)	0 (0.0)	1,615	0	0 (0)	0 (0.0)	2,045	0	0 (0)	0 (0.0)
DCB	1,406	0	0 (0)	0 (0.0)	-	-	-	-	1,180	30	3 (2)	18 (0.5)
DCC	-	-	-	-	1,442	0	0 (0)	0 (0.0)	1,903	0	0 (0)	0 (0.0)
DCD	8,605	69	5 (4)	19 (0.7)	3,068	0	0 (0)	0 (0.0)	18,428	105	9 (7)	26 (0.8)
DCE	353	3	2 (1)	3 (0.1)	227	0	0 (0)	0 (0.0)	11,790	13	4 (3)	5 (0.1)
DCF	7,164	1,378	38 (28)	257 (7.8)	6,640	492	23 (16)	112 (3.2)	-	-	-	-
DCG	176	37	6 (5)	15 (0.6)	1,621	0	0 (0)	0 (0.0)	15	0	0 (0)	0 (0.0)
DCH	15,932	7,450	102 (89)	1,319 (48.5)	24,285	4,314	120 (42)	969 (14.2)	-	-	-	-
DCI	18	0	0 (0)	0 (0.0)	479	24	1 (1)	7 (0.3)	10,636	160	24 (15)	62 (1.6)
DCJ	4,867	3,183	87 (64)	662 (20.5)	5,912	1,624	41 (30)	322 (9.8)	12,368	3,174	105 (61)	704 (17.3)
DCK	2,627	1,664	74 (54)	433 (13.2)	4,209	314	37 (27)	118 (3.6)	10,633	939	72 (47)	314 (8.7)
DCL	4,279	2,431	75 (55)	522 (16.3)	8,106	2,041	54 (39)	407 (12.1)	-	-	-	-
DCM	1,957	1,031	66 (46)	309 (9.0)	2,874	595	42 (45)	188 (8.6)	8,671	933	79 (51)	348 (9.5)
DCN	4,422	1,592	67 (47)	429 (12.7)	7,036	2,958	80 (57)	634 (19.0)	-	-	-	-
DCO	1,116	247	38 (26)	111 (3.2)	-	-	-	-	-	-	-	-
DCP	1,311	404	32 (32)	129 (5.5)	10,641	3,631	93 (66)	763 (22.9)	-	-	-	-
DCQ	-	-	-	-	4,325	150	37 (35)	75 (3.0)	144	53	7 (50)	21 (9.4)
DCR	-	-	-	-	7,706	1,402	73 (54)	363 (11.1)	-	-	-	-
Total	**56,061**	**19,489**			**90,186**	**17,545**			**77,813**	**5,407**		

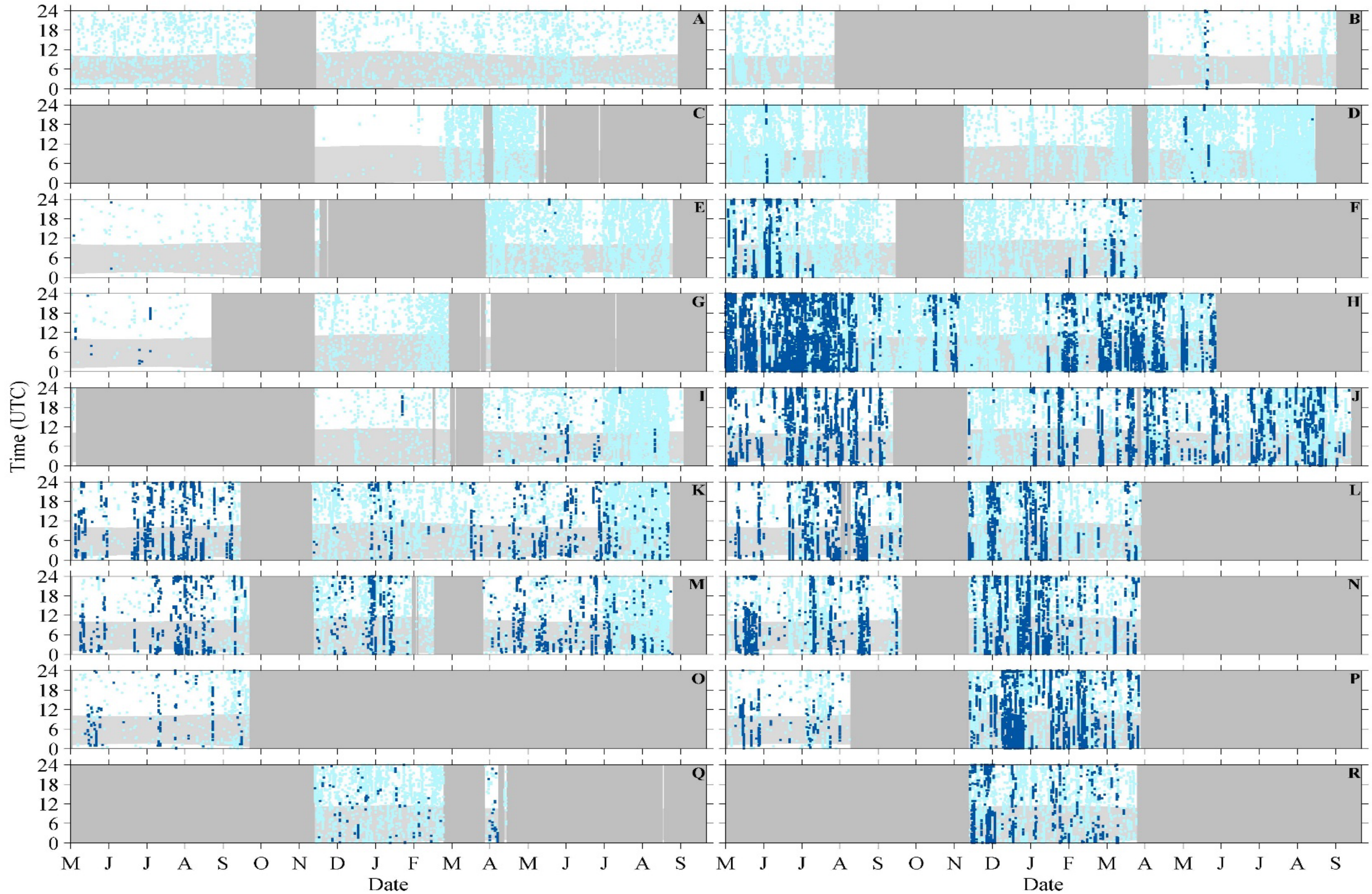

Figure 16. *Rice's whale downsweep sequence call presence in 1-minute bins at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May 2021 to September 2022 deployment period. Light blue marks represent verified false detections; dark blue marks represent true long-moan detections. The darker gray blocked area represents periods without recording effort.*

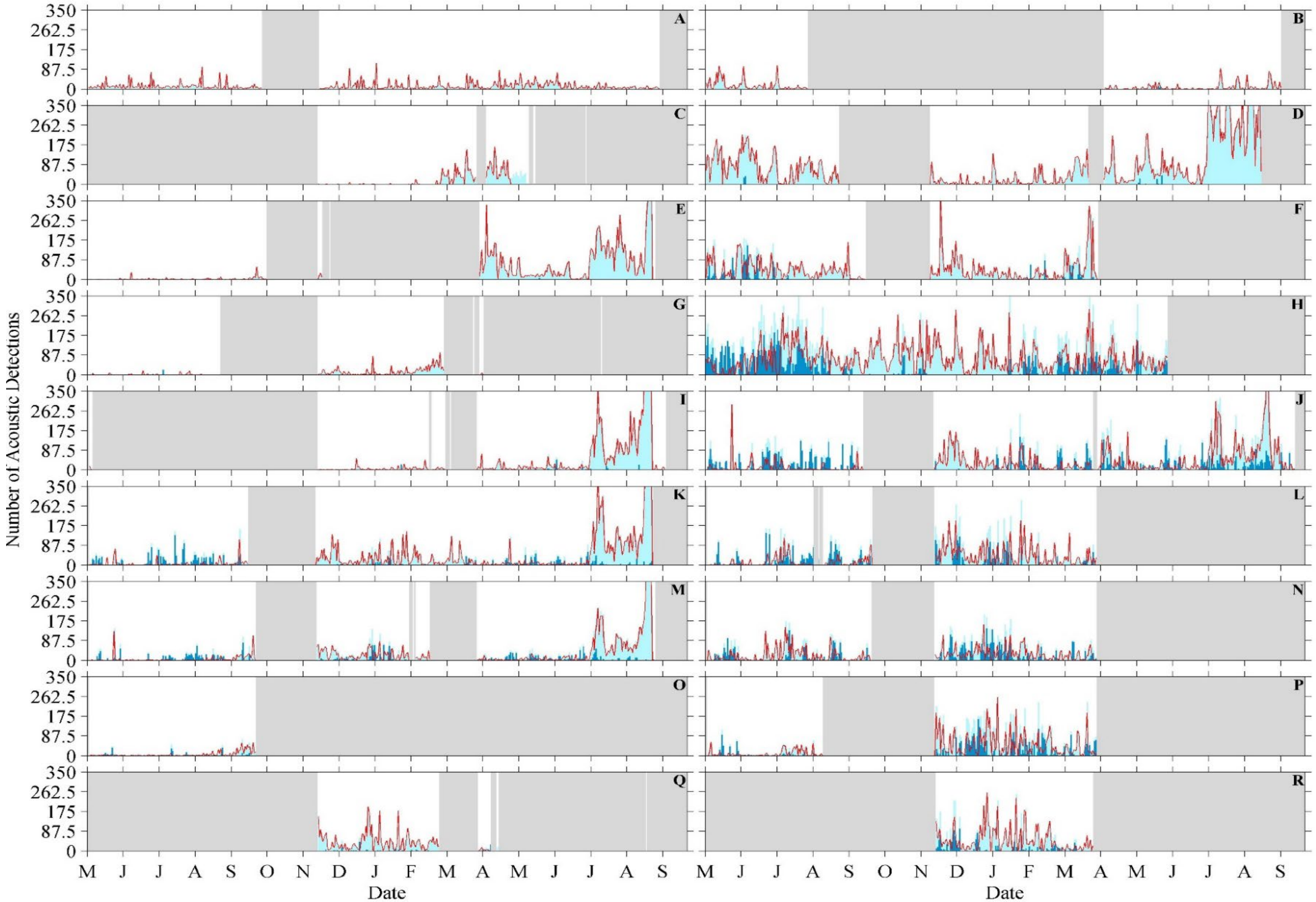

Figure 17*. Daily total of Rice's whale downsweep sequence detections (light blue = autodetections, dark blue = verified long-moans, red line = false detections) at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May 2021 to September 2022. Gray blocks indicate periods without recording effort.*

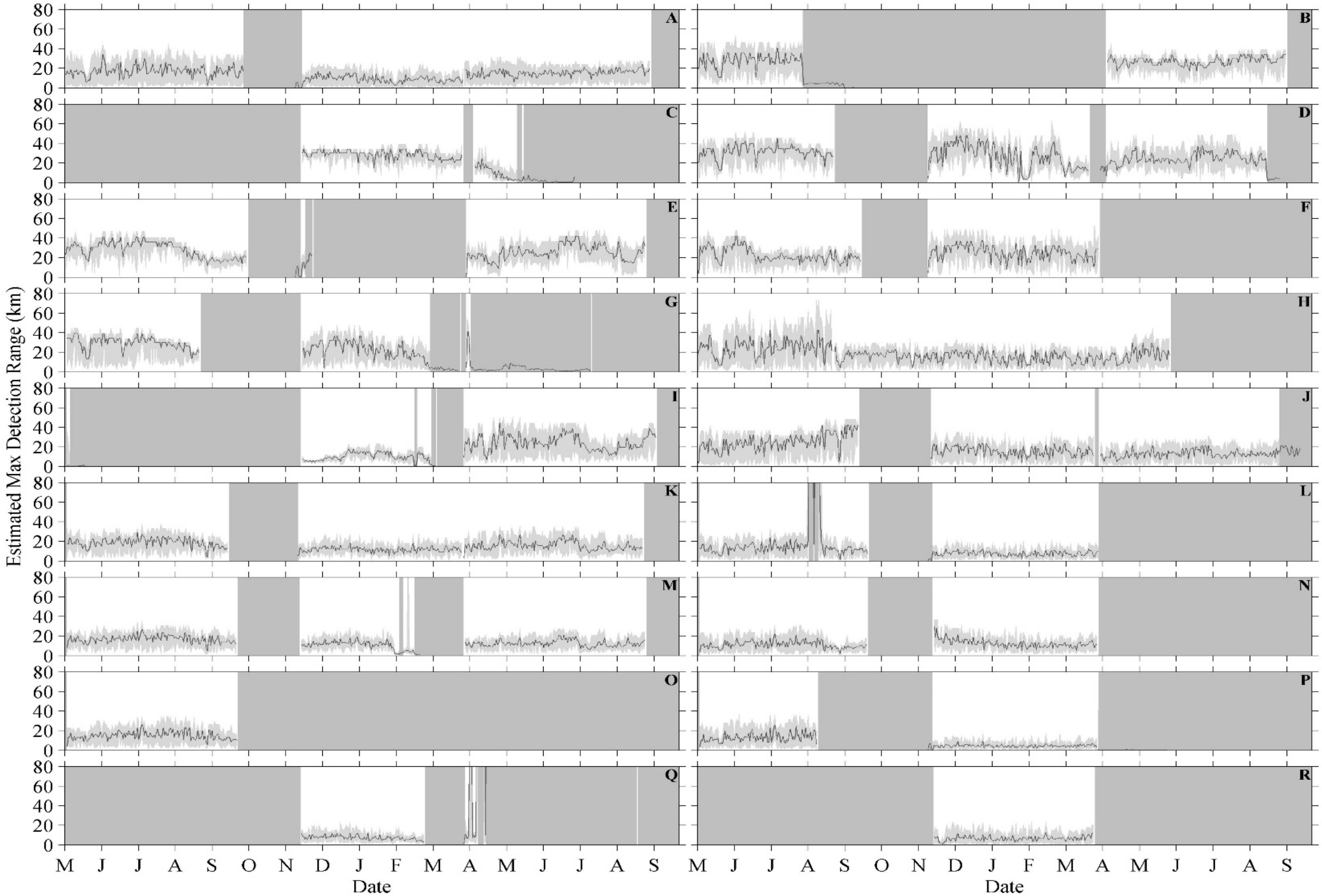

Figure 18. *Example maximum detection ranges of downsweep sequence calls as a function of ambient noise levels at 100 Hz for SoundTrap and HARP deployments at the De Soto Canyon (DC) array sites from May 2021 to September 2022. Estimated example detection ranges calculated assuming a call source level of 145 dB, detection threshold of 10 dB signal-to-noise, and geometric spreading transmission loss at 17*logR; these assumptions require verification.*

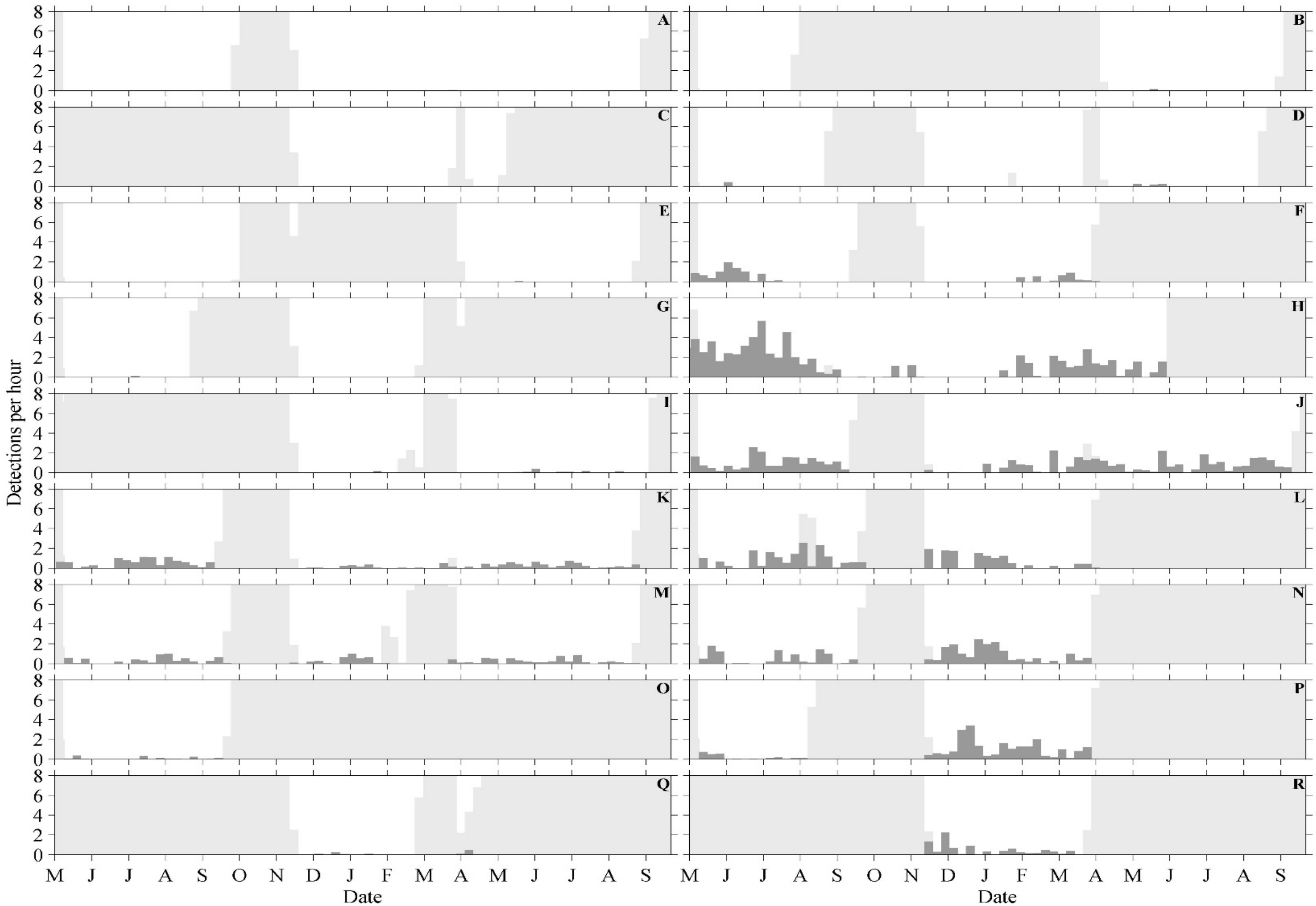

Figure 19. *Weekly Rice's whale downsweep sequence calls per hour of effort at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array from May 2021 to September 2022. Dark bars represent validated long-moan detections. Light gray blocks indicate periods without recording effort.*

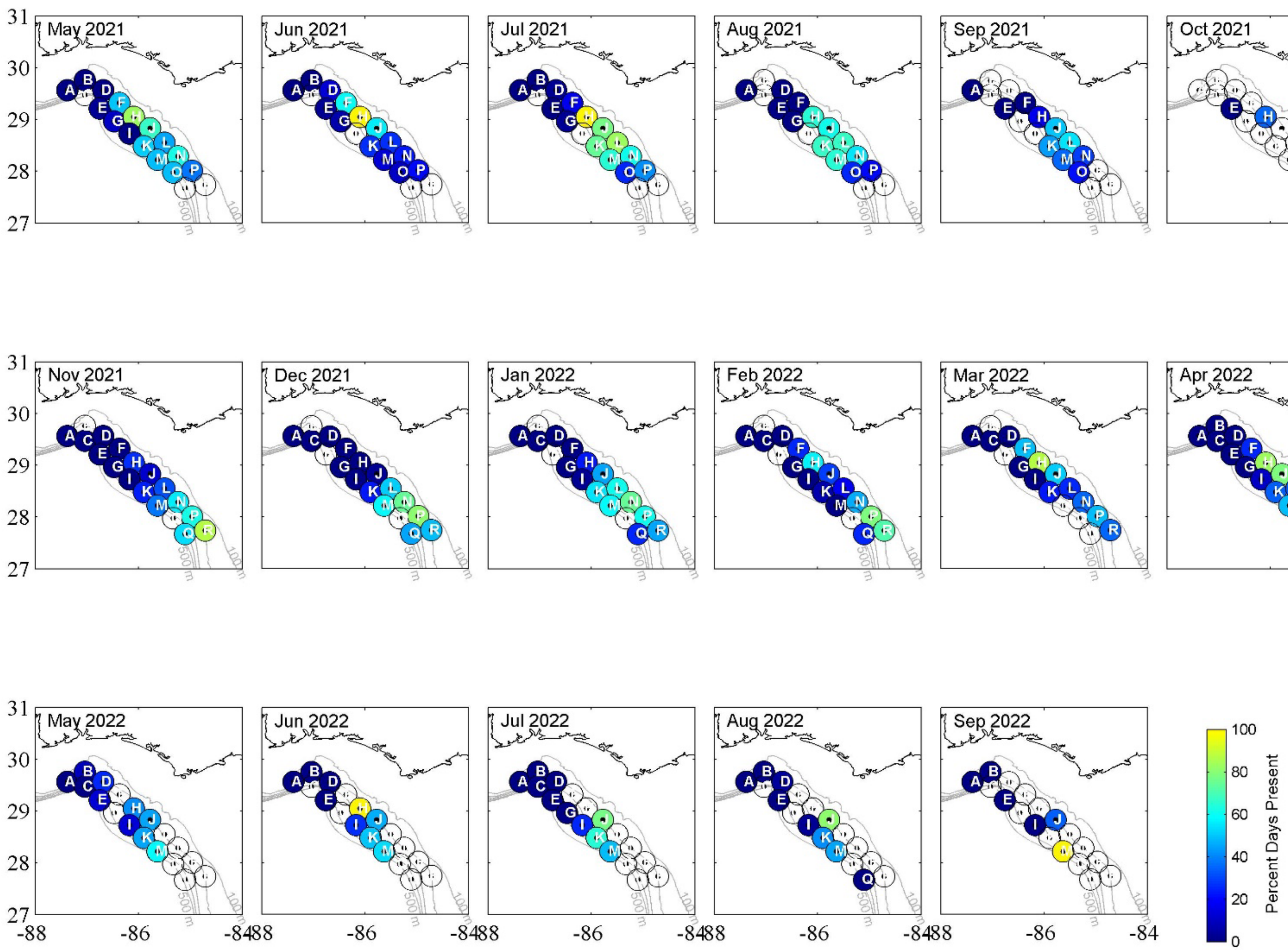

***Figure 20**. Monthly Rice's whale downsweep sequence presence, as percent of days, at 18 passive acoustic monitoring sites in the De Soto Canyon (DC) sparse array over the May 2021 to September 2022 deployment period. Color represents percent of days with calls present. Open circles with no color represent no data. Coastline and 100m isobaths up to 500m are indicated.*

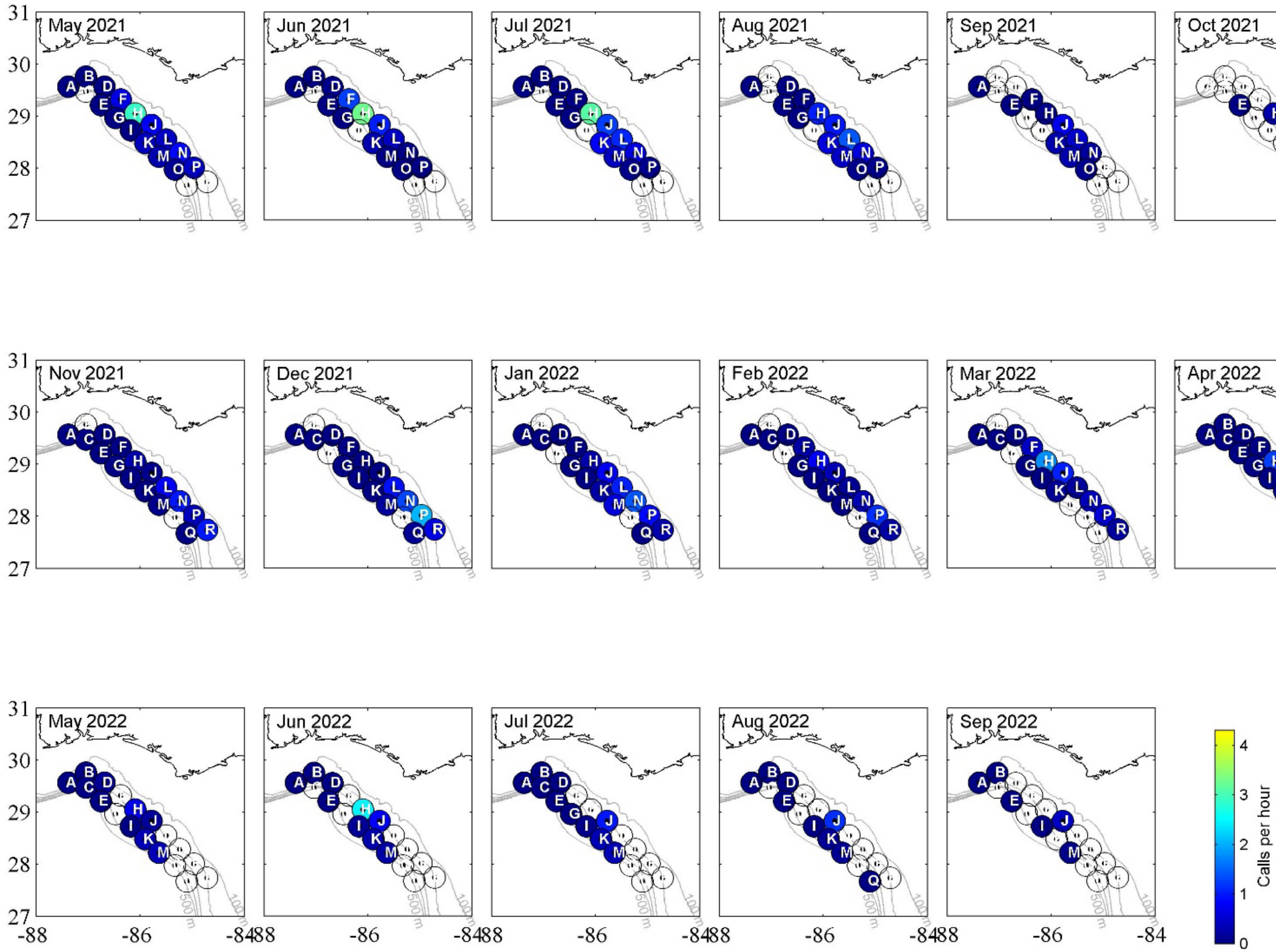

Figure 21. Monthly average of Rice's whale downsweep sequence call detection rates at 18 sites in the De Soto Canyon sparse array over the May 2021 to September 2022 deployment period. Color represents call detections per hour. Open circles with no color represent no data. Coastline and 100m isobaths up to 500m are indicated.

Next Steps

All data collection for this project is complete with the fourth and final deployment recovered in March 2023. The data processing phase of the Navy-funded deployments is now complete with automated detections and validation steps complete for the first, second, and third deployments. Analyses of the fourth deployment are in progress with completion expected in summer 2024 (funded by NOAA's OPR). Daily and monthly statistical distributions of sound pressure spectrum levels have been calculated for the first three deployments and will be calculated for the fourth deployment. Once all long-moan and downsweep sequence call detections have been validation for the fourth deployment, 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 core distribution area throughout the course of the year and whether they exhibited seasonal movement patterns throughout the year. Understanding seasonal and interannual distribution of Rice's whales throughout the core distribution area will improve understanding of potential impact of human activities on these whales and assist in developing effective mitigation measures as needed.

Data Leveraging and Future Opportunities

Several analytic efforts are underway that are leveraging data collected under this project to further improve our understanding of Rice's whale seasonal and interannual density and additional analytical projects could be developed to improve our understanding of the oceanographic and anthropogenic factors driving these patterns. To convert occurrence and distribution results into animal density, more information is needed on calling frequency and detection ranges and how they vary over time and space due to sound propagation conditions and ambient noise levels. Expanded analytical methods are being developed to leverage the SoundTrap array data to fill this need.

While the sparse array was designed to ensure near-complete acoustic coverage of the Rice's whale core distribution area, assuming minimum detection distances of 20 km based on prior findings, to understand seasonal distribution and movement patterns, further evaluation found calls are commonly detected on multiple neighboring instruments in the array. Under funding from NOAA's Ocean Acoustics Program, whale calls are being localized and tracked using time-difference-of-arrival (TDOA) methods, to obtain information on call detection distances, source levels, call rates, and swimming behavior, with automated localization algorithms in development. Under NOAA's SEFSC funding, monthly sound propagation areas are being estimated with parabolic equation models to improve understanding of oceanographic and noise impacts on detection ranges. Given the occurrence of the same call on multiple instruments, spatially-explicit capture-recapture (SECR) analyses could be conducted 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 impacts from anthropogenic activities in this core distribution 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. As detection distances, and how they vary over time, are better understood with the ongoing propagation modeling and tracking analyses, future studies could combine acoustic detections 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 distribution area, as needed to mitigate potential impacts from anthropogenic activities occurring in the area.

Finally, the data collection component of this project covers nearly two years to evaluate seasonal changes in Rice's whale distribution throughout the core distribution area. The anticipated results will characterize spatio-temporal variation for the May 2021 to March 2023 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 four-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 2021-2023 results and would yield a more robust dataset for developing the predictive habitat models described above.

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