Historical Occurrence of Gulf Of Mexico Bryde's Whale Calls at De Soto Canyon 2010-2013

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Executive Summary

The Gulf of Mexico (GOM) Bryde's whale (*Balaenoptera edeni*), estimated to have a population size of 33 individuals in US waters (CV 1.07, Waring et al. 2014), was recently listed as endangered under the US Endangered Species Act (ESA). The majority of modern sightings occur in waters between the 100 – 400 m depths in an area near the De Soto Canyon off northwestern Florida. Occurrence patterns from one year of long-term passive acoustic monitoring and two recent summer and fall surveys indicate the whales are found year-round within this primary habitat, but also suggest there may be seasonal movements throughout the habitat, and potentially out of the habitat.

The SEFSC and Scripps Institution of Oceanography have been collaboratively deploying long-term passive acoustic monitoring stations at five GOM sites 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 five sites, including the De Soto Canyon (DC) HARP in the primary GOM Bryde's whale habitat, have been continuously recording ambient noise and other acoustic events in the 10 Hz to 100 kHz frequency range, and these 8-year near-continuous recordings are available for analysis to better understand distribution and density trends of GOM Bryde's whales. The full analysis of the 8 years of historical data are covered across 2018-2020, with the 2018-19 focus on developing automated detectors and running and validating the automated detectors on data from the DC HARP in the core habitat collected between October 2010 and July 2014, to establish complete occurrence time-series for understanding seasonal and interannual trends and for future habitat modeling and density estimation. The work in 2020 will complete the historical analyses for August 2014 – June 2018, and start an extended data collection project.

Development and characterization of automated detectors of GOM Bryde's whale calls has been completed. Automated detectors for GOM Bryde's whale long-moan calls and downsweep pulse sequences were developed on training data from three days of the DC09 deployment and characterized on a 1% randomly selected test data subset of manually-reviewed 30-minute segments. The most effective detectors were spectrogram cross-correlation detectors developed in Ishmael. Thresholds were optimized to minimize miss rates without introducing an excessive number of false detections; false detections are removed in a subsequent validation step. The best long-moan detector had a miss rate of 6.5% and false detection rate of 26.4% on the test dataset. The best downsweep pulse sequence detector had a miss rate of 12.6% and a false detection rate of 69% on the test dataset. Downsweep pulse sequence false detections were typically associated with either pulsed long-moan calls or seismic airgun pulses.

The ambient noise analyses have been completed on the entire 8 year dataset. The underwater ambient soundscape at all sites had spectral shapes with higher levels at low frequencies compared to higher frequencies, owing to the dominance of ship noise and seismic airgun surveys at frequencies below 100 Hz and local wind and waves above 100 Hz. The years 2016 and 2017 had the lowest spectrum levels below 100 Hz while Dec 2013-June 2014 also had low levels. There appears to be a seasonal pattern in overall noise levels with lower noise levels in spring and summer compared to fall and winter, and this is typically most apparent above 100 Hz. This is likely due to the increased noise from wind and waves of winter storms. Spectral peaks around 100-300 Hz, which may be from fish chorusing, occur during spring 2011 and spring and summer 2013, and may have led to reduced detectability of GOM Bryde's whale calls at these times due to masking effects.

The automated detectors have been run on the complete 8-year dataset and the validation of the detections has been completed for the first deployment. In the 2010-2018 data at the De Soto Canyon site, GOM

Bryde's whale long moan calls were preliminarily detected in all seasons and all years with no apparent evidence of seasonality. Preliminary call detections ranged between 28,002 and 101,071 calls per deployment. Preliminary results indicate they were detected on nearly every day of every year and on between 67-95% of hours with recording effort. Validation of auto-detections yielded a 2.0% false detection rate for the long-moan call detector for the DC02 deployment and show a similar gap in detections in November 2010 as was found for downsweep pulse sequences by (Širović et al., 2014). Based on preliminary, pre-validated results, there appears to be an increase in hourly call detection rates at night compared to day for preliminary detections, and an increase in hourly call detection rates during fall, then summer with lower detection rates in late winter and late summer.

Preliminary results yielded between 6,803 and 23,067 Downsweep Pulse Sequence detections per deployment for deployments DC02-DC11. Preliminary detections occurred on 88-99% of days per deployment and 30-51% of hours per deployment. However, these preliminary detections represent a major overestimate as false detection rates for this detector are expected to be around 69%. Validation of auto-detections on the DC02 dataset indicated 97.6% false detections, with 218 true downsweep calls heard on only 12 days of the 110 days of data. Nearly 65% of the false detections during this deployment occurred over the course of a few days when ship noise was prevalent. For the DC02 dataset, true detections of downsweep pulse sequences (218) are 2 orders of magnitude lower than true detections of long-moan calls (22,278) during this time period.

During 2020, the project will continue and detections from 2014-2018 will be validated and results written up for peer-reviewed publication to improve understanding of the long-term variability in GOM Bryde's whale presence at this site. Further, to better understand the observed interannual variability in occurrence with respect to the entire core habitat, a new project will begin that expands passive acoustic monitoring to an additional 17 sites that should completely cover the core habitat. This study will provide further information to interpret the changes seen at this site over 8 years and to understand how call density varies seasonally throughout the core habitat.

Project Background

The SEFSC and Scripps Institution of Oceanography have been collaboratively deploying long-term passive acoustic monitoring stations at five Gulf of Mexico (GOM) sites since 2010 to monitor the impacts of the Deepwater Horizon oil spill and subsequent restoration activities on cetaceans (**Figure 1**). High-frequency Acoustic Recording Packages (HARPs), deployed at the five sites, including the De Soto Canyon (DC) HARP in the primary GOM Bryde's whale habitat, have been continuously recording ambient noise and other acoustic events in the 10 Hz to 100 kHz frequency range, and these 8-year near-continuous recordings are available for analysis to better understand distribution and density trends of cetaceans, potentially including GOM Bryde's whales. Data from the DC HARP site have only been evaluated for downsweep call sequences in the first year of data (Širović et al., 2014), and have not been evaluated for probable long-moan calls or constant tonal calls (Rice et al., 2014), which have also recently been recorded by SEFSC in the presence of GOM Bryde's whales. Over late 2018 through 2020, this project focuses on developing automated GOM Bryde's whale call detectors and analyzing the full 8 years of data from the DC HARP in the core habitat (Table 1), to establish complete occurrence time-series for understanding seasonal and interannual trends and for future habitat modeling and density estimation. The 2018-19 goals were to develop the detectors and run and validate them on the first 38 months of data collected between October 2010 and July 14. They 2020 goals are to complete the validation on the detector results on the remaining data and begin a new data collection project that builds upon these results to better understand temporal variability in occurrence.

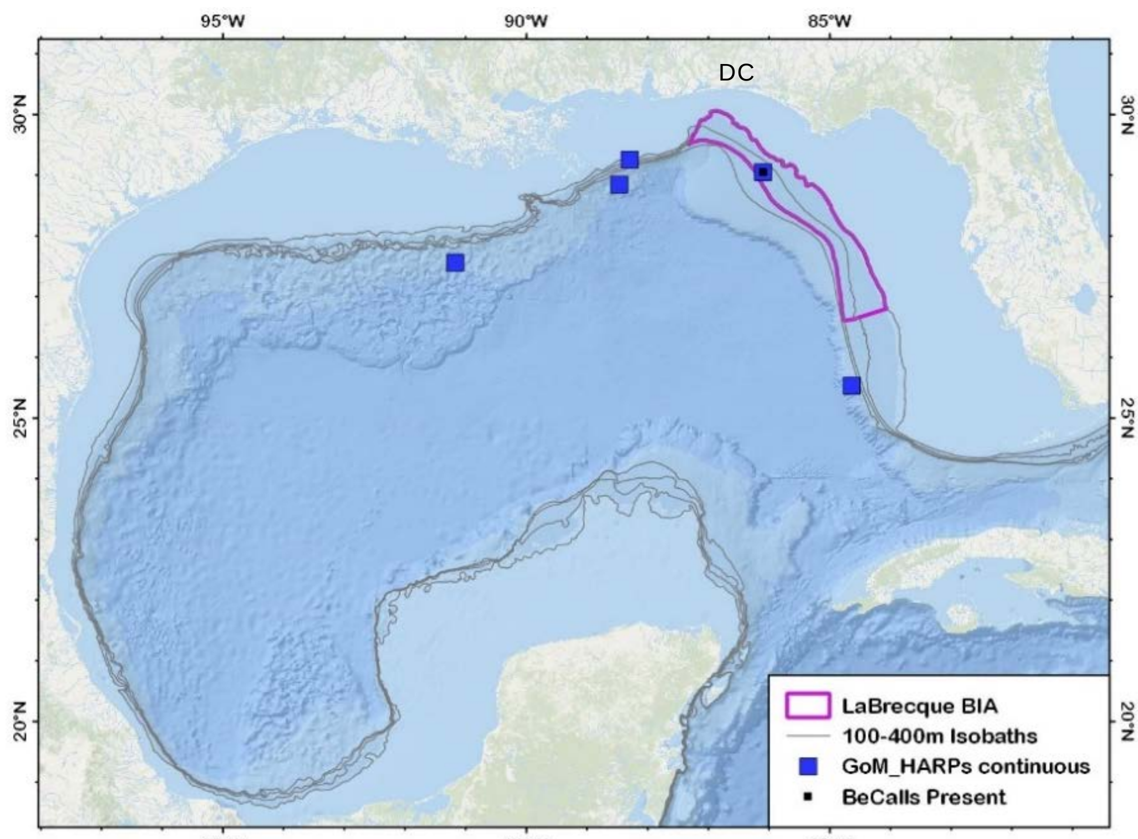


Figure 1. Historic long-term passive acoustic monitoring stations (HARPs) deployed in the Gulf of Mexico since 2010. The core habitat (BIA) of Gulf of Mexico Bryde's whales is indicated, including the De Soto Canyon (DC) site, where downsweep call sequences have previously been detected.

Table 1. Acoustic monitoring at site DC since October 2010. Asterisks indicate small gaps in the recording exist for these data sets. Rows in gray represent data sets to be analyzed in 2020.

Deployment	Start Date	End Date	# Days	# Hours
DC02	10/21/2010 0:00:00	2/6/2011 10:12:30	109.4	2626.2
DC03	3/21/2011 19:00:00	7/6/2011 2:01:14	107.3	2575.0
DC04	10/25/2011 23:59:59	3/1/2012 17:19:59 *	125.7	3015.5
DC05	3/3/2012 12:00:00	12/9/2012 8:32:59	281.9	6764.6
DC06	12/9/2012 20:00:00	9/25/2013 5:31:49 *	262.4	6289.6
DC07	12/18/2013 0:00:00	7/23/2014 5:31:59	218.2	5237.5
DC08	10/3/2014 0:00:00	5/25/2015 23:04:30	236	5663.1
DC09	8/3/2015 22:00:00	5/19/2016 4:18:44	290.3	6966.3
DC10	8/25/2016 0:00:00	7/18/2017 16:32:00	327.3	7854.0
DC11	7/17/2017 0:00:00	6/9/2018 00:43:00	328	7872.7

Gulf of Mexico Bryde's Whales

The GOM Bryde's whale (*Balaenoptera edeni*), estimated to have a population size of 33 individuals in US waters (CV 1.07, Waring et al., 2014), was recently listed as endangered under the US Endangered Species Act (ESA). 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., 2014). Occurrence patterns from one year of long-term passive acoustic monitoring and two recent summer and fall surveys indicate the whales are found year-round within this primary habitat, but also suggest there may be seasonal movements throughout the habitat, and potentially out of the habitat. 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' 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.

In the GOM, one call type has been definitively identified to free-ranging GOM Bryde's whales (Širović et al., 2014), and four additional call types have been proposed as likely candidates (**Figure 2**; Rice et al., 2014; Širović et al., 2014).

Gulf of Mexico Bryde's Whale Downsweep Pulse Calls

The positively identified call type is a pair of short-duration downsweeps 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 (Širović et al., 2014). Longer series of downsweeps (mean: 8 downsweeps, range: 2-25) with similar spectral and temporal features were detected in autonomous recordings and are presumed to be variants of the same call type (Rice et al., 2014; Širović et al., 2014). A third downsweep call type, higher in frequency (170 to 110 Hz), segmented, and typically occurring in repeated sequences of doublets, was also detected in autonomous recordings over a 5 day period and is proposed to be a possible Bryde's whale call (Širović et al., 2014).

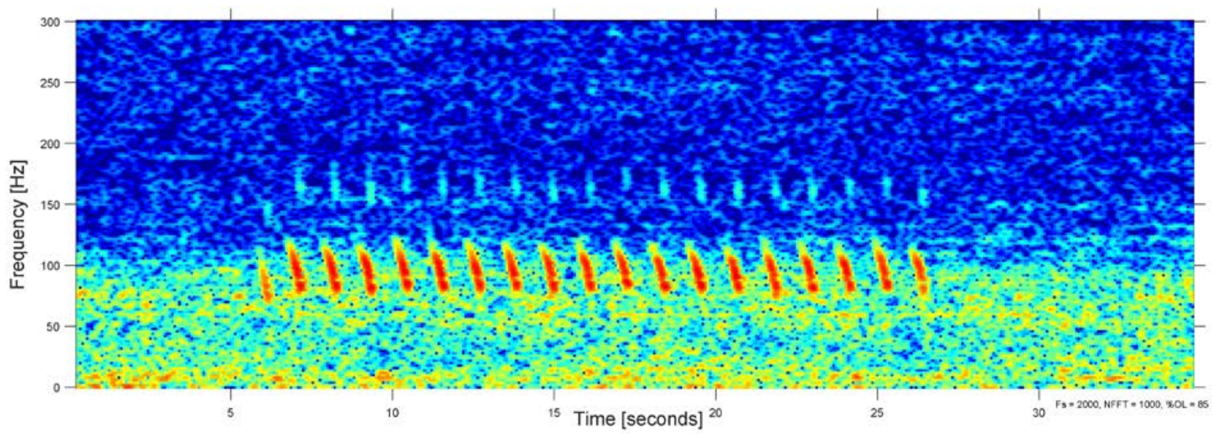


Figure 2. Spectrogram of a Gulf of Mexico Bryde's whale downsweep pulse sequence at site DC.

Gulf of Mexico Bryde's Whale Long Moan Calls

Two tonal call types detected on autonomous instruments are proposed as Bryde's whale calls based on baleanopterid-like features, movement patterns of tracked calls, and the known distribution of Bryde's whales. The long-moan call type is a long-duration, pulsed downsweep ranging from 208 to 43 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). 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). GOM Bryde's whales have been preliminarily validated as the source of both the downsweep sequences and long-moans using paired directional sonobuoy call localizations that match whale sighting locations (Soldevilla, unpublished data). LTSA analyses and detector development will focus on downsweep sequences and long-moans but have the flexibility to discover additional calls in the Bryde's whale repertoire.

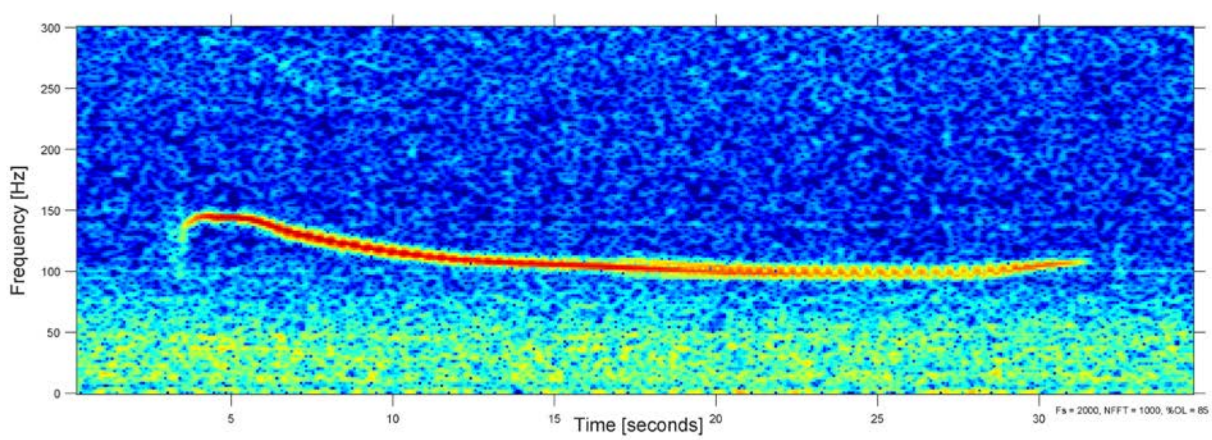


Figure 3. Spectrogram of a Gulf of Mexico Bryde's whale long moan call detected on the De Soto Canyon HARP.

Methods

High-frequency Acoustic Recording Package (HARP)

HARPs were used to record marine mammal sounds and characterize the low-frequency ambient soundscape in the GOM. 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. 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).

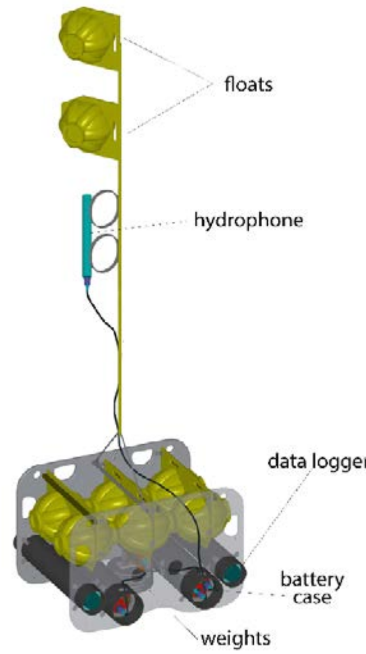


Figure 4. Schematic of a HARP seafloor package

Data Collected

No new data were collected as part of this historical data analysis project. Acoustic recordings have been collaboratively collected since 2010 by SEFSC and Scrips Institution of Oceanography at the De Soto Canyon site (29º 2.878' N 86º 05.847' W, 270 m depth) using HARPs sampling at 200 Hz. The De Soto Canyon site is located approximately in the center of the GOM Bryde's whale Biologically Important Area (BIA) which represents the core known habitat for these whales. This project includes the first half of ambient noise and whale call detection analyses for deployments DC02 to DC11 (**Table 1**) which include 2,286 days (54,874 hours) of data between 2010-2018.

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 GOM Bryde'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 to provide an effective bandwidth of 10 Hz to 1 kHz. LTSAs were created from the decimated data with a 1 Hz frequency and 5 s temporal resolution.

Low Frequency Ambient Soundscape

Hourly spectral averages and associated standard deviations were computed by combining ten 5 s (50 s) sound pressure spectrum levels calculated from each 75 s acoustic record. 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.

Gulf of Mexico Bryde's Whale Calls

Detector development

Four types of automated detectors were tested for effective detection of long-moan calls and downsweep sequences. Detectors were preliminary developed using a 2-day training dataset and a separate testing dataset was used to characterize miss rates and false detection rates on a novel dataset. The four detectors that were preliminarily developed included a tonal call detector in PAMGuard (Gillespie et al., 2008), spectrogram cross-correlation detectors in Ishmael (Mellinger & Clark, 2000), a Generalized Power Law detector in a custom Matlab software (Helble et al., 2012) and the Low Frequency Detection and Classification System in custom IDL software (Baumgartner & Mussoline, 2011). Early on in the development phases, it was determined that the Ishmael spectrogram cross-correlation detectors were most effective at detecting lower signal-to-noise-ratio calls and most effort was focused on fine-tuning these detectors to improve efficiency.

Training Data

The training dataset used in development of automated detectors for multiple GOM Bryde's whale call types consisted of 224 long-moan calls from the first two days of recordings from the DC09 deployment and 24 downsweep sequences from one day of recordings in the DC09 deployment. The training data were used to develop all four detectors and perform initial evaluations of their effectiveness and to fine-tune the numerous settings of the Ishmael spectrogram correlation detectors.

The 224 long-moan calls in the training data were used to measure various frequency and time features of the long moan call contour that were needed for input into the spectrogram cross-correlation detector. Frequency and duration measurements were taken from five different sections of each of the calls in order to create the proper contours in the detector. These sections included 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, Table 2**). Calls did not always include all sections due to differences in noise conditions and propagation effects. The measurements were used to develop and evaluate correlation strength of different combinations of these contour segments with similar features.

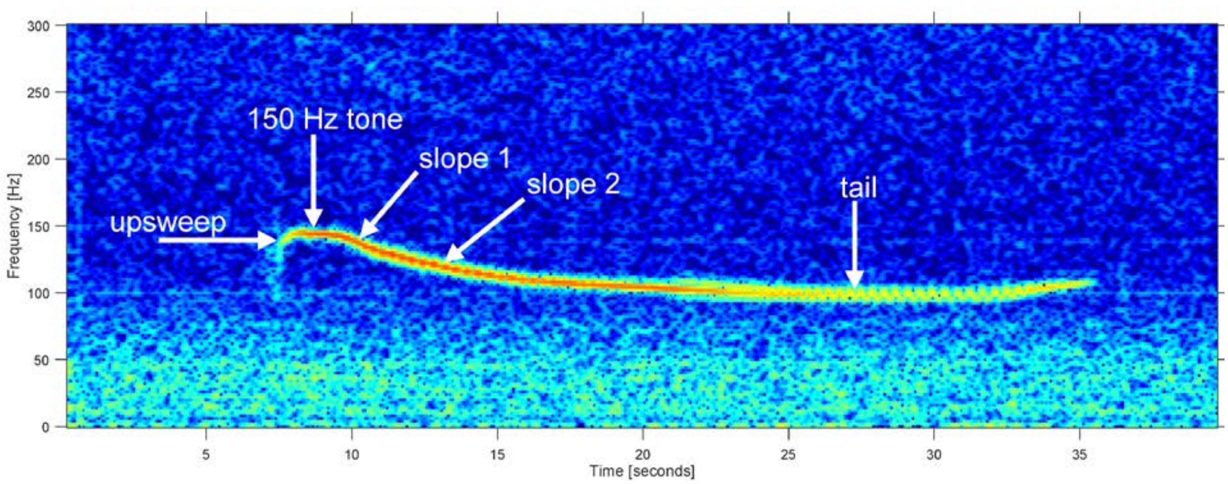


Figure 5. Five sections of a long moan call from which measurements were taken to create the contours in the long moan detector.

Table 2. Measurements taken from 224 long moan calls manually detected in the DC09 training data.

	n	Mean	Minimum	Maximum
Upsweep	96			
Start Frequency (Hz)		141.6	134.0	146.0
End Frequency (Hz)		146.6	144.0	149.0
Duration (s)		0.5	0.2	0.9
150 Hz Tone	220			
Start Frequency (Hz)		146.3	142.0	149.0
End Frequency (Hz)		145.4	141.0	150.0
Duration (s)		1.1	0.1	1.8
Slope 1	224			
Start Frequency (Hz)		145.2	141.0	148.0
End Frequency (Hz)		125.9	114.0	135.0
Duration (s)		1.5	0.4	3.0
Slope 2	189			
Start Frequency (Hz)		125.0	114.0	133.0
End Frequency (Hz)		113.3	104.0	127.0
Duration (s)		2.1	0.8	4.6
Tail	109			
Start Frequency (Hz)		111.8	103.0	120.0
End Frequency (Hz)		105.7	98.0	116.0
Duration (s)		2.6	0.0	10.2

We constructed the cross-correlation contour for the downsweep sequences based on call measurements for downsweep pulses reported in Rice et al. 2014 and Širović et al. 2014. These time and frequency features were measured for the 24 downsweep sequences in the training data and matched well with the values from the literature.

Table 3. Downsweep pulse measurements reported in Rice et al 2014 and Širović et al. 2014.

	Rice et al 2014	**Širović et al. 2014**
Start Frequency (Hz)	113.3	110 ± 4
End Frequency (Hz)	71.9	78 ± 7
Duration (s)	0.4	0.4 ± 0.1
Inter-pulse Interval (s)	0.8	1.3 ± 0.1

Testing Data

The novel test dataset used in detector evaluation and characterization consisted of 418 randomly selected 30-minute segments (209 hours total) from the DC09 deployment. A trained analyst manually scanned the spectrograms of each 30-minute segment and logged each long moan and downsweep sequence. The manual detections from this dataset included 1,753 long-moan calls and 87 downsweep sequences over a period encompassing 216 days. These manual detections were used as a ground-truth test dataset for each detector to characterize the expected % Missed Call and % False Detection rates given the known true detections from the manual detections.

Long Moan Detector Settings

The long-moan cross-correlation detector developed on the training dataset included a contour defined by 2 segments: the first segment was 1.1 s duration with starting and ending frequencies of 146 Hz and 145 Hz; the second segment immediately followed this with a duration of 3.7 s and starting and ending frequencies of 145 Hz and 112 Hz. Both segments had a contour width of 14 Hz as determined by measuring the instantaneous bandwidth of the frequency contour. An FFT frame size of 512 samples (no zero-padding) with a hop size of 50% was used to compute the spectrogram, and spectrogram equalization was enabled with 3 s spectral averaging. Detection function smoothing was enabled, while Teager-Kaiser sharpening of the detection function was not enabled. To count as a detection event, the minimum and maximum time that the detection function was required to remain above the threshold was 0.5 s and 3.0 s, respectively. The minimum time allowed between subsequent detection events was 0.5 s. A range of thresholds between 4 and 5.5 were evaluated and resulting detections were compared to the ground-truth data to determine miss and false positive rates for the training data. A threshold of 4.25, yielding 2.7% missed calls and 32.3% false positive detections, was determined to be the best balance between missed calls and false detections, with a preference for fewer missed calls, and was chosen as a starting point for the detector characterization on the testing data.

This detector was then run on the testing dataset, and evaluated with thresholds ranging between 3.75 and 5.5, to characterize its effectiveness on a novel dataset. The analyst reviewed all detections from detector runs at each threshold and compared them with the ground-truth test data results to validate if they were true or false detections. The ground truth dataset was also used to determine how many of the manually detected long-moan calls were missed for each run. The resulting characterization was evaluated to select the best threshold for the final detector.

Downsweep Pulse Sequence Detector Settings

The downsweep pulse sequence cross-correlation detector developed on the training dataset included a contour defined by a single segment of 0.4 s duration with starting and ending frequencies of 120 Hz and 80 Hz and a contour width of 20 Hz. An FFT frame size of 512 samples (no zero-padding) with a hop size of 50% was used to compute the spectrogram, and spectrogram equalization was enabled with 3 s spectral averaging. Neither detection function smoothing nor Teager-Kaiser sharpening of the detection function were enabled. To count as a detection event, the minimum and maximum time that the detection function was required to remain above the threshold was 0.1 and 40 s, respectively. The minimum time between detection events allowed was 0.4 s. To improve the specificity of the downsweep pulse detector in a soundscape environment containing frequent seismic airgun pulses, we incorporated the Ishmael sequence detector settings to find sequences of regularly occurring calls. Specifically, the minimum and maximum repetition period between individual pulse detections were set to 0.9 s and 1.1 s, respectively, allowing the entire pulse sequence to be detected as a single call. The window length for this step was 11 s with a hop size of 25%. Numerous thresholds between 7 and 35 were evaluated and resulting detections were compared to the ground-truth data to determine miss and false positive rates for the training data. A threshold of 10, yielding 0.0% missed calls and 0.0% false positive detections, was determined to be most effective and was used as the starting point for the detector characterization on the testing data.

This detector was then run on the testing dataset, and evaluated with thresholds ranging between 6 and 14, to characterize its effectiveness on a novel dataset. The analyst reviewed all detections for the run of each threshold and compared them with the ground-truth test data results to validate if they were true or false detections. The ground truth dataset was also used to determine how many of the manually detected downsweep pulse sequence calls were missed for each run. The resulting characterization was evaluated to select the best threshold for the final detector.

Automated call detections

Once the best detector thresholds were established based on the detector characterization results from the test dataset, each detector was run on the entire DC HARP dataset for deployments DC02 – DC11 using the selected threshold. Rather than selecting a threshold with equal miss and false alarm rates, the threshold selections were skewed toward reducing 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 step of removing false detections is feasible, while reviewing the entire dataset for missed detections is not; final results will underestimate total call detections. 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. For this report, we describe the pre-validation detector results for all DC HARP deployments. At this time, the validation steps have been completed for both call types for DC02 and final results are reported. Validation for the remaining deployments is ongoing and final results will be provided in the next project report.

Results

The preliminary results of acoustic data analysis at the GOM DC HARP site from October 2010 to June 2018 are summarized below. We describe the low-frequency ambient soundscape, the seasonal occurrence, and the relative abundance of GOM Bryde's whale signals.

Low Frequency Ambient Soundscape

• The underwater ambient soundscape at all sites had spectral shapes with higher levels at low frequencies compared to higher frequencies, owing to the dominance of ship noise and seismic airgun surveys at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand, 2009; **Figure 6 & Figure 7**).

• The years 2016 and 2017 had the lowest spectrum levels below 100 Hz while Dec 2013-June 2014 also had lower levels (**Figure 6**).

• There appears to be a seasonal pattern in overall noise levels with lower noise levels in spring and summer compared to fall and winter, and this is typically apparent above 100 Hz (**Figure 6 & Figure 7**). This is likely due to the increased noise from wind and waves of winter storms.

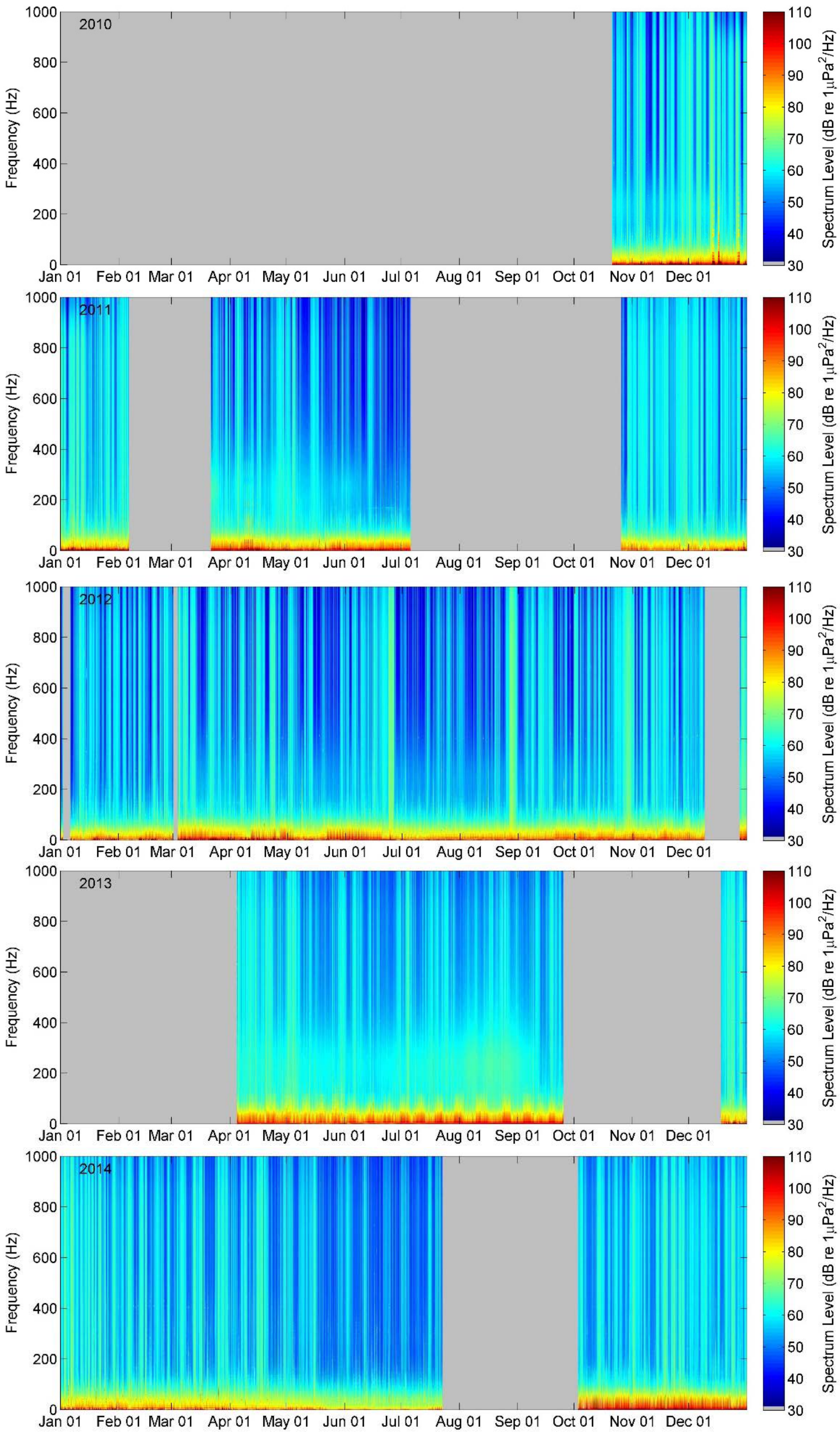
• Strong and brief peaks in broadband noise are evident at three times in summer and fall of 2012 (**Figure 6**) which coincide with the timing of Tropical Storm Debbie and Hurricane Isaac in the GOM, and unexpectedly with Hurricane Sandy which remained in the Atlantic.

• Fall noise levels across all frequencies were highest in 2014 (**Figure 6 & Figure 7**). Further investigation is needed to see if seismic surveys were operating closer to the DC site during these months.

• Noise levels across all frequencies were lowest in June 2017 (**Figure 6 & Figure 7**). No seismic surveys were operating in the GOM in June 2017. This may partially explain this reduction in noise levels, but it is surprising that the difference is greater at frequencies above 100 Hz than at the lower frequencies where seismic survey noise is typically dominant.

• Noise levels in the 100-200 Hz frequency band where GOM Bryde's whale calls occur were lowest in 2014 and 2017 and highest in 2010 and 2013 (**Figure 6 & Figure 7**).

• Spectral peaks around 100-300 Hz occur during spring 2011 and spring and summer 2013 (**Figure 6 & Figure 7**). These peaks may be from a currently unidentified biological source, such as a fish chorus.


2010
2011
2012
2013
2014
Frequency (Hz)
0
200
400
600
800
1000
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Spectrum Level (dB re 1μPa²/Hz)
30
40
50
60
70
80
90
100
110

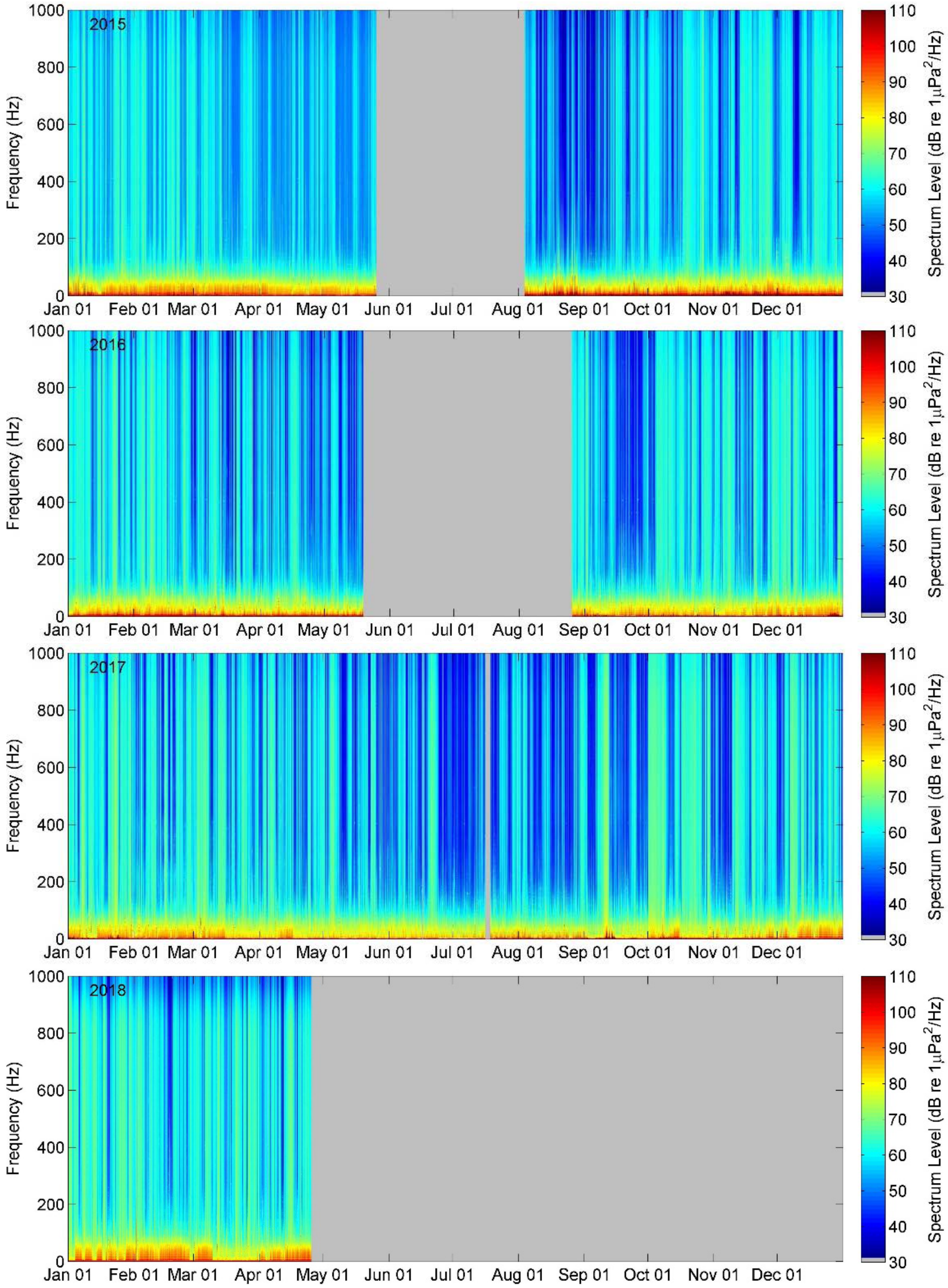


Figure 6. Hourly median long-term spectral average of 2010-2018 HARP deployments at the De Soto Canyon site showing recorded ambient noise levels from 10-1000 Hz. Gray indicates periods with no recording effort or corrupt data.

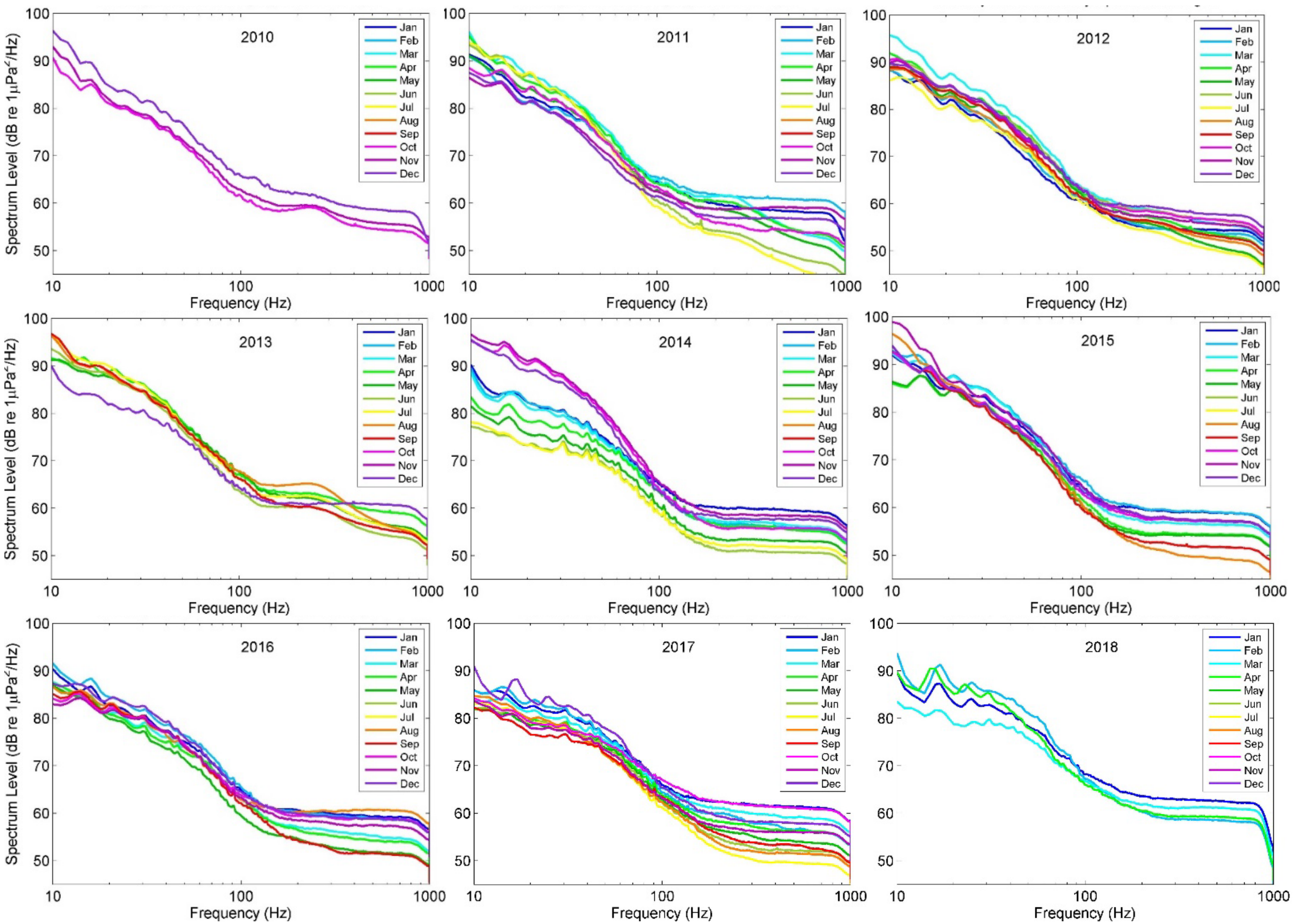


Figure 7. Monthly means of hourly spectral averages for 2010-2018.

Long Moan and Downsweep Pulse Sequence Detectors

Detector effectiveness was measured by characterizing the % Missed Calls and % False Detections from testing a range of thresholds on the 418 random 30-minute segments of the test dataset with known calls from manual review of the data.

The long-moan detector resulted in false detection rates between 2.9% and 52.5% and missed detection rates between 5.5% and 25.7.0% for thresholds between 3.75 and 8. The threshold of 4.5, with a 6.4% missed call rate and a 26.4% false detection rate (**Figure 8**), was selected as the detector that minimized 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 as well as tonal sounds from passing ships.

The downsweep pulse sequence detector resulted in false detection rates between 46.7% and 92.5% and missed detection rates between 9% and 26% for thresholds between 8 and 24. The threshold of 11, with a 12.6% missed sequences rate and a 69.1% false detections rate (**Figure 9**), was selected as the detector that minimized 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.

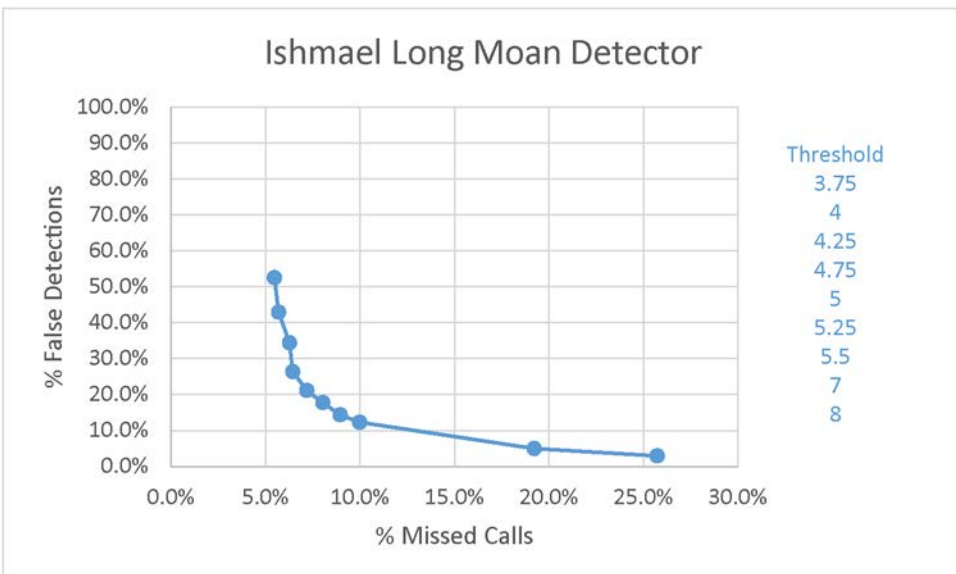


Figure 8. Performance of the long moan detector measured by the percentages of missed calls and false detections.

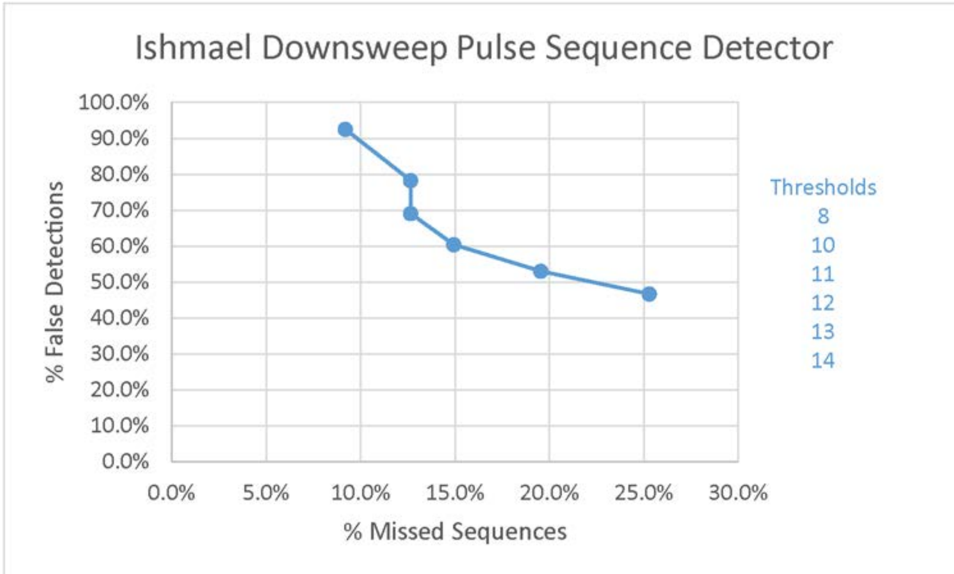


Figure 9. Performance of the downsweep pulse sequence detector measured by the percentages of missed calls and false detections.

Gulf of Mexico Bryde's Whale Long Moan Calls

GOM Bryde's whale long moan calls were detected in all seasons and all years with no apparent evidence of seasonality. Preliminary call detections ranged between 28,002 and 101,071 calls per deployment. Preliminary results indicate they were detected on nearly every day of every year and on between 67-95% of hours of recording effort. These results on daily presence will be re-evaluated once all detections have been validated. Detection ranges of these calls remains unknown; limited preliminary data suggests approximately 20 km ranges and possibly up to 70 km in some conditions. The core habitat is approximately 340 km long by 80 km wide along the shelfbreak.

• Validation of auto-detections yielded a 2.0% false detection rate for the long-moan call detector for the DC02 deployment.

• A gap in long-moan detections is evident in November 2010. A similar lack of downsweep sequence call detections was noted by (Širović et al., 2014), potentially indicating animals moved away from this site at this time.

• Fall 2014 and fall 2011 to winter 2012 have high numbers of preliminary call detections.

• Preliminary results indicate a slight diel pattern for long moan calls with increased call detections at night compared to day (**Figure 10** through **Figure 18**).

• Preliminary hourly call detection rates are highest during winter, with moderately high call detection rates during summer, and lower hourly call detection rates in spring and fall (**Figure 10** through **Figure 18**). The increase in call detection rates during summer may be related to lower levels of ambient noise at call frequencies during summer.

• There appears to be a crepuscular peak in pre-validated call detections in 2014 and 2015 that is not evident in others years. This pattern will be re-evaluated after validation work is completed.

Table 4. Number of long moan calls detected per deployment.

Deployment	Long Moan Call Detections	True Long Moan Calls	Days Present (%)	Hours Present (%)
Validated				
DC02	28,001	22,278	104 (94.6)	1882 (72.3)
Pre-Validated				
DC02	28,002	n/a	109 (100)	2340 (89.9)
DC03	36,215	n/a	108 (100)	2422 (94.9)
DC04	58,063	n/a	125 (97.7)	2844 (95.4)
DC05	47,542	n/a	282 (99.3)	5743 (85.1)
DC06	24,041	n/a	264 (98.1)	4265 (67.1)
DC07	48,109	n/a	218 (99.1)	4446 (85.3)
DC08	101,071	n/a	235 (99.6)	5338 (94.6)
DC09	72,709	n/a	291 (99.7)	6184 (89.0)
DC10	85,044	n/a	328 (100)	6331 (80.7)
DC11	122,874	n/a	320 (97.5)	6825 (86.7)

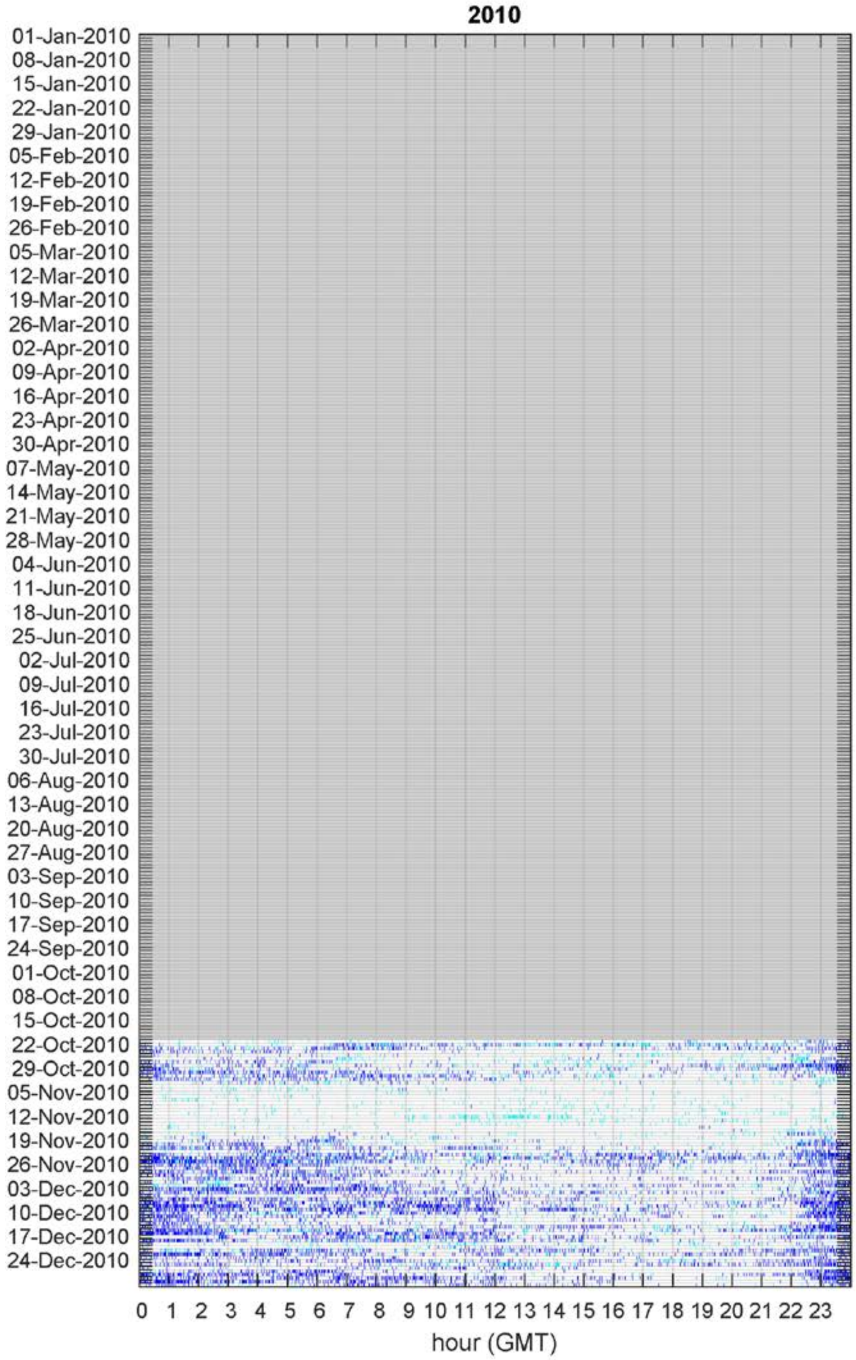


Figure 10. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2010. Cyan tick marks represent verified false detections while blue tick marks represent true long moan detections. The grayed area represents time periods without recording effort.

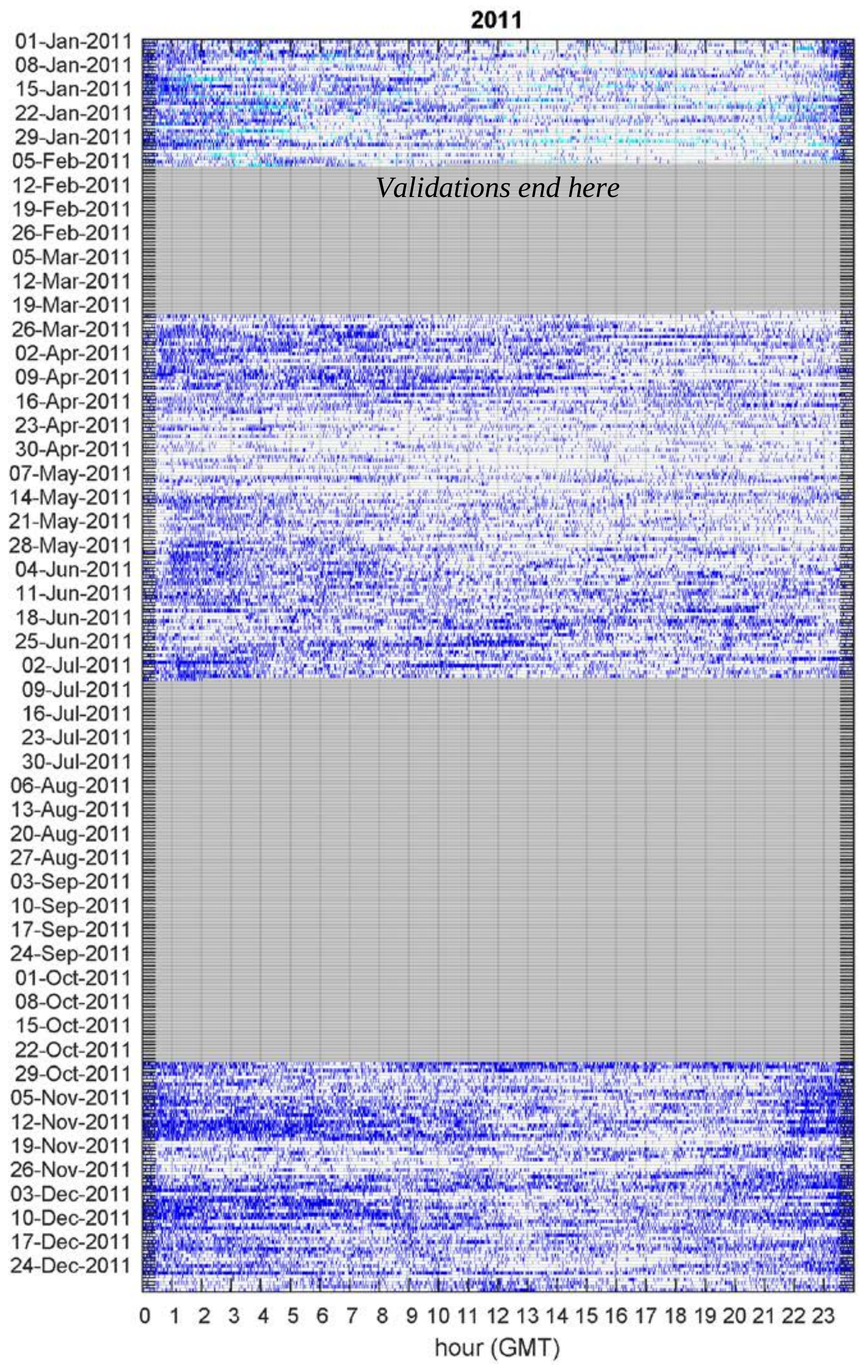


Figure 11. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2011. Cyan tick marks represent verified false detections while blue tick marks represent long moan detections. True detections have only been verified through February 6, 2011. The grayed area represents time periods without recording effort.

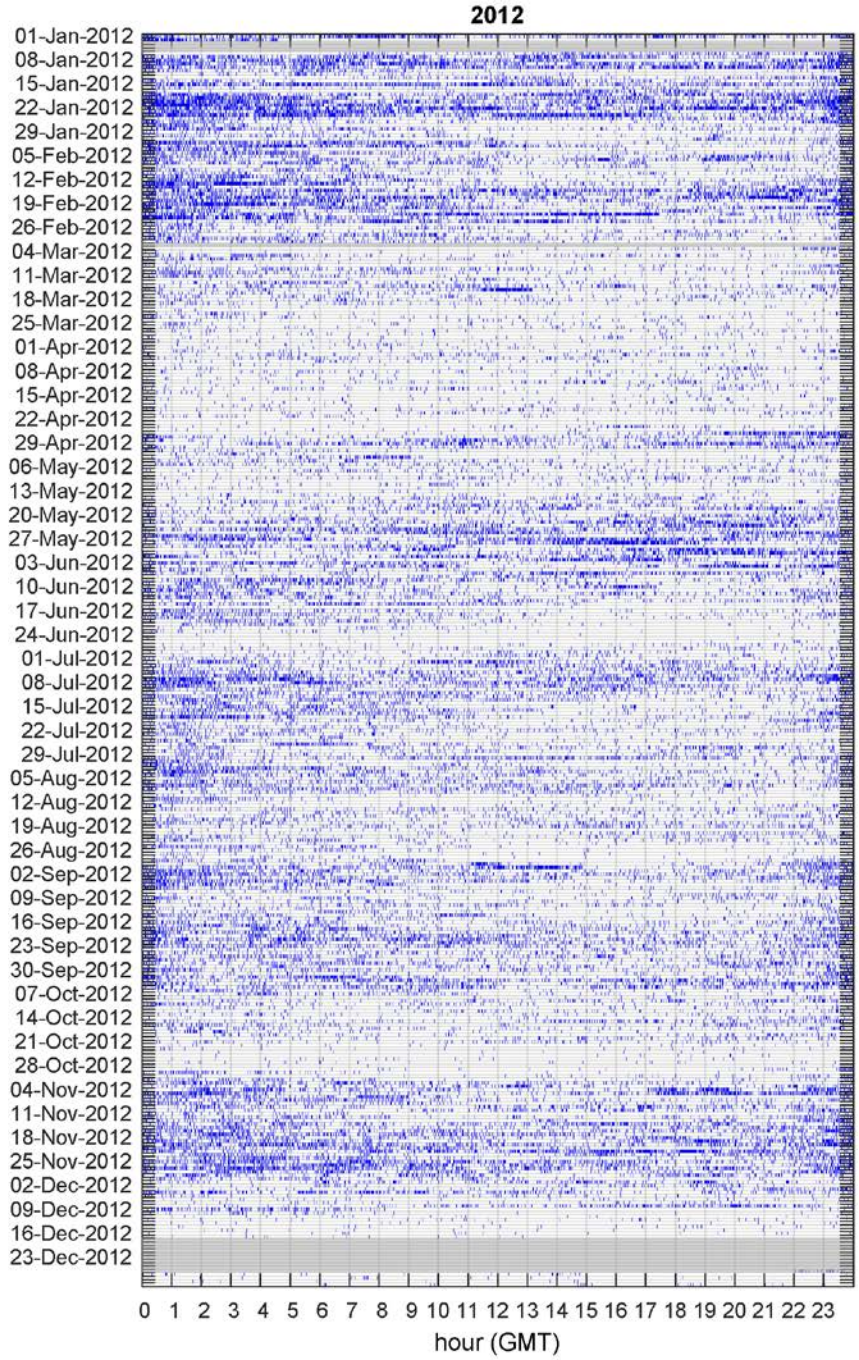


Figure 12. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2012. These detections have not yet been validated. The grayed area represents time periods without recording effort.

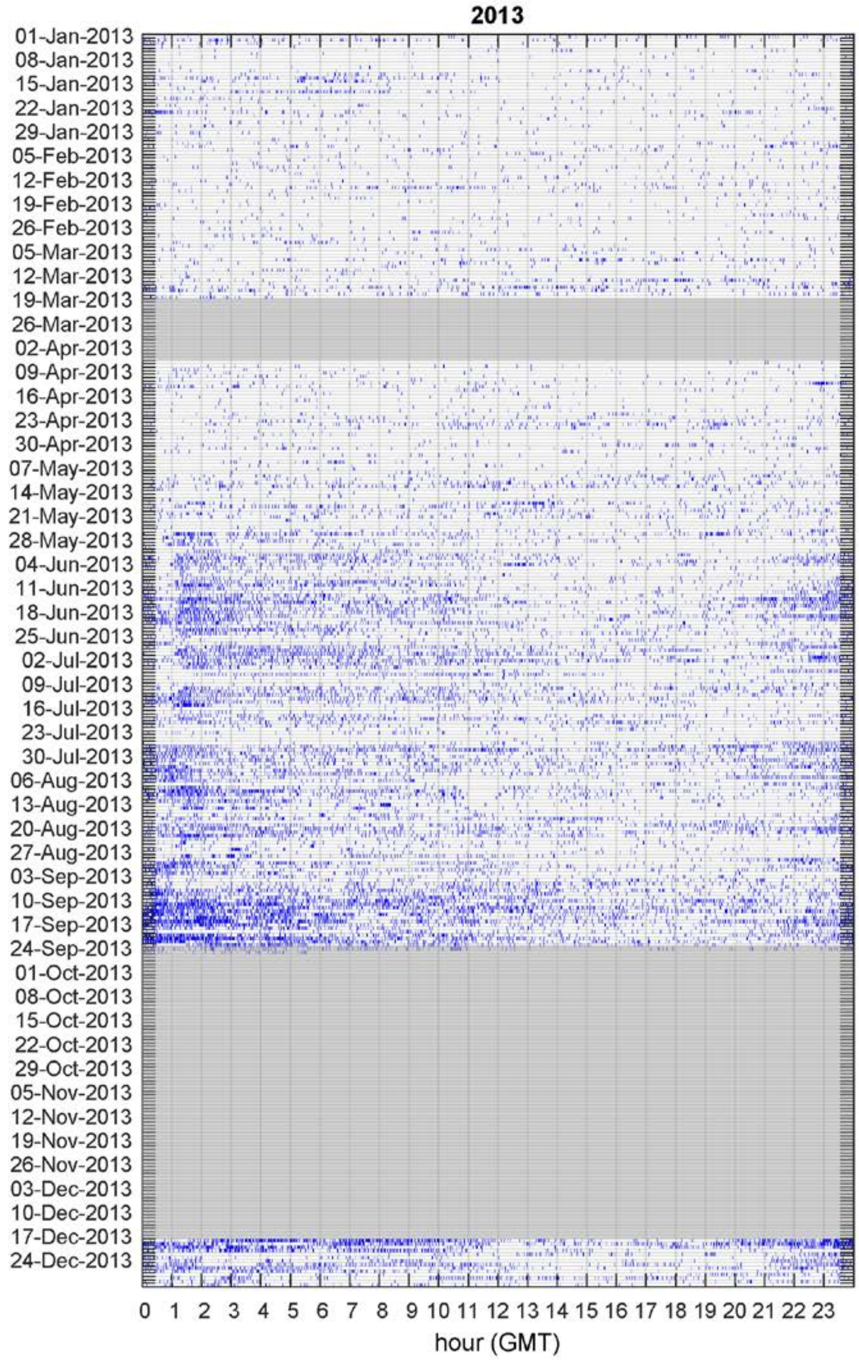


Figure 13. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2013. These detections have not yet been validated. The grayed area represents time periods without recording effort.

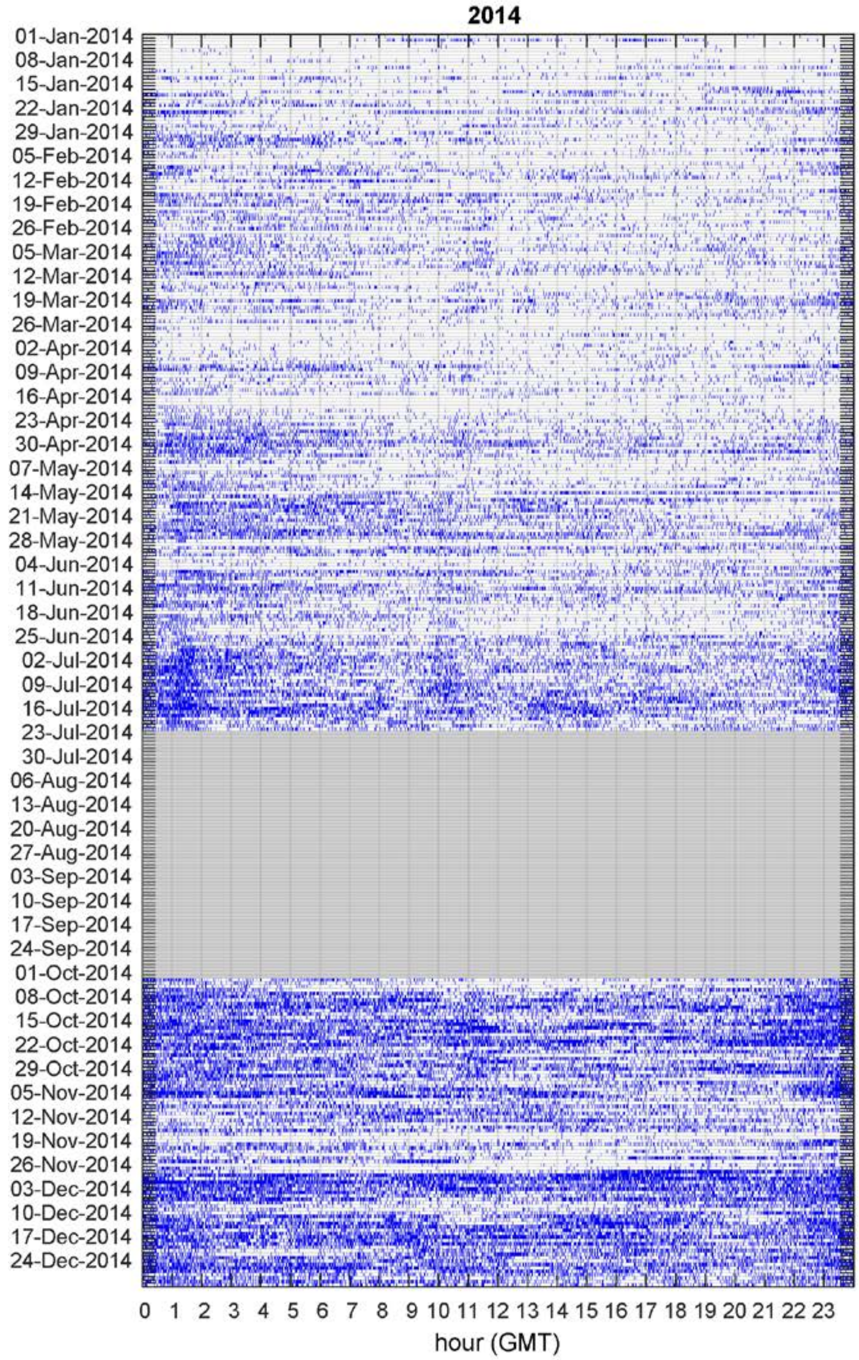


Figure 14. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2014. These detections have not yet been validated. The grayed area represents time periods without recording effort.

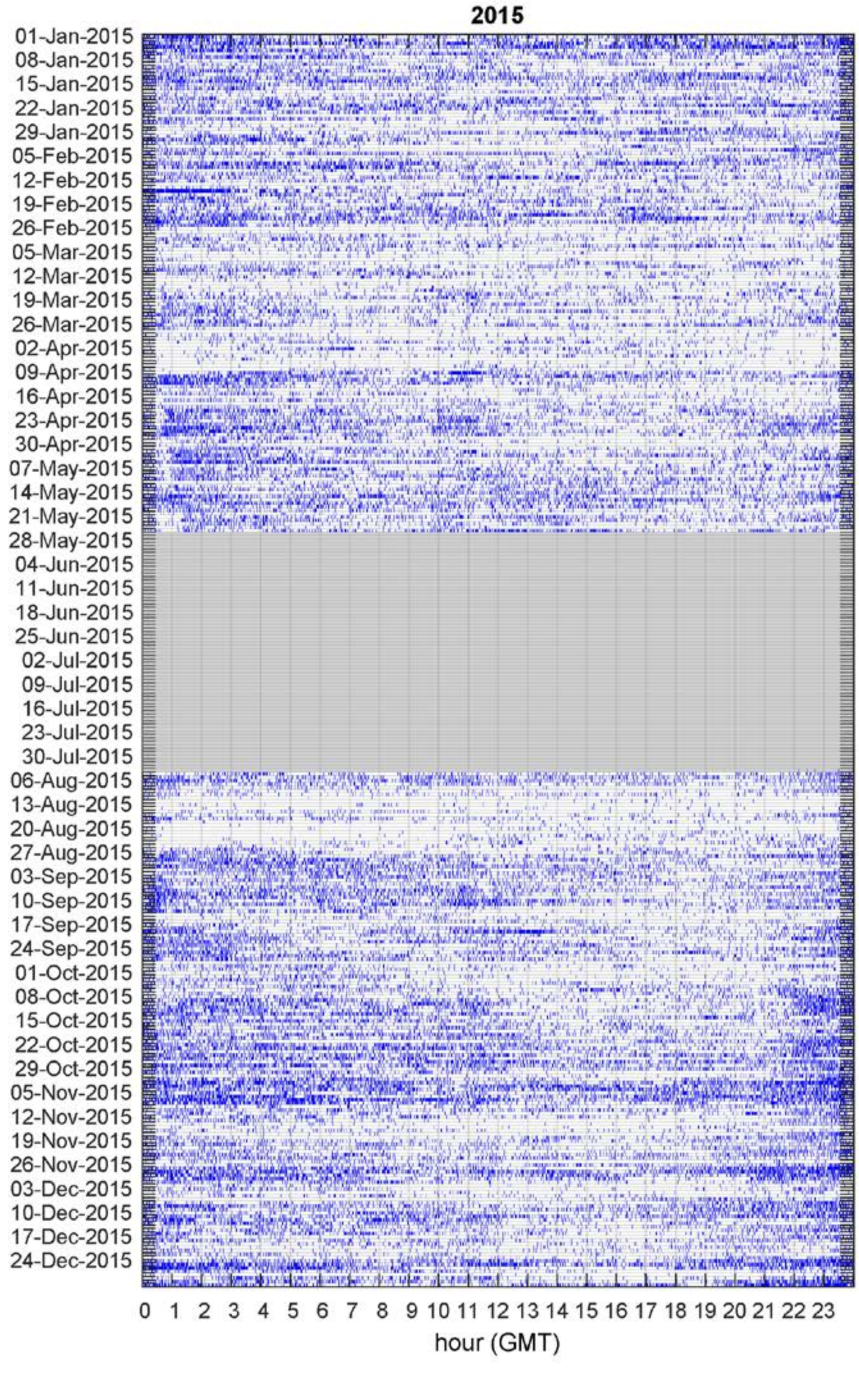


Figure 15. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2015. These detections have not yet been validated. The grayed area represents time periods without recording effort.

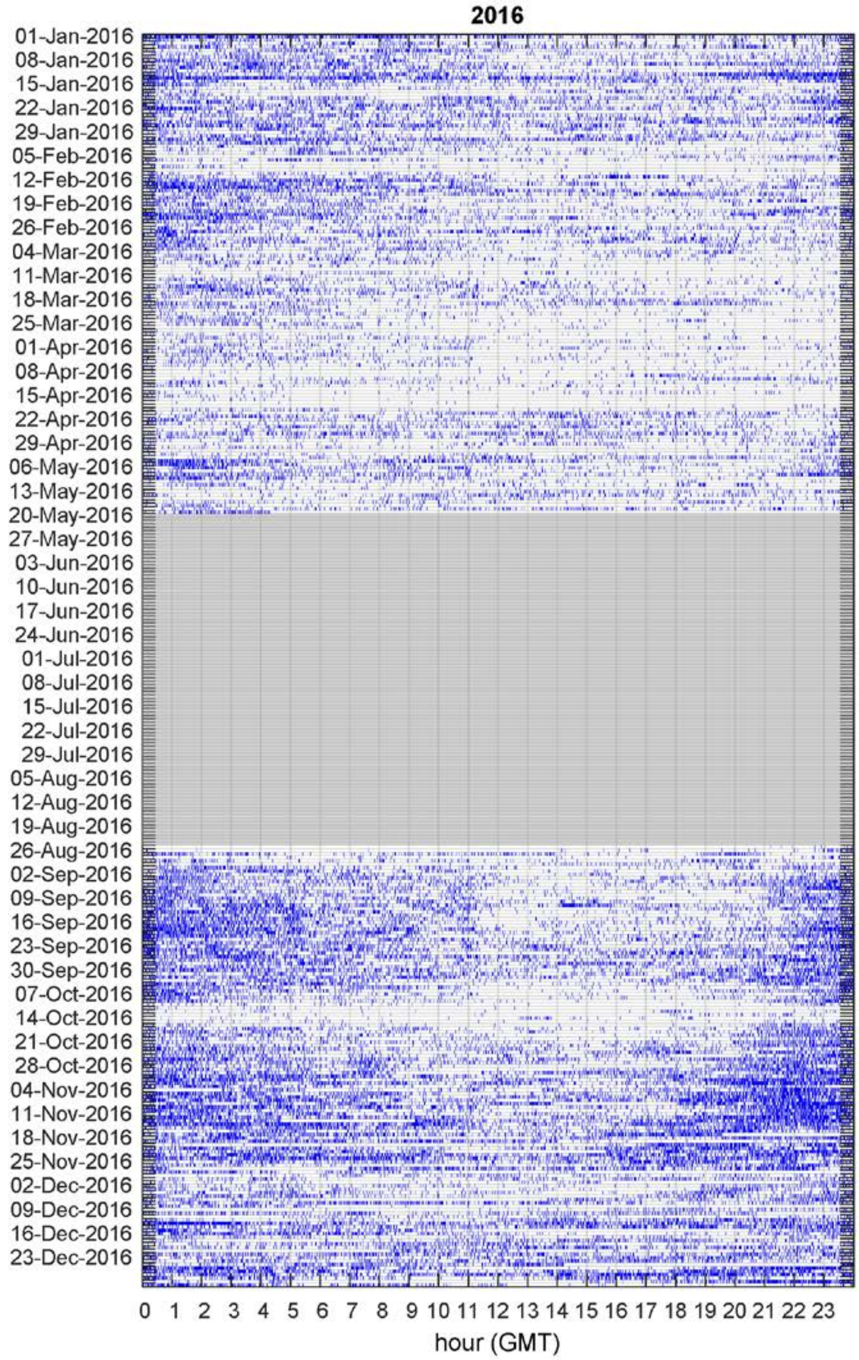


Figure 16. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2016. These detections have not yet been validated. The grayed area represents time periods without recording effort.

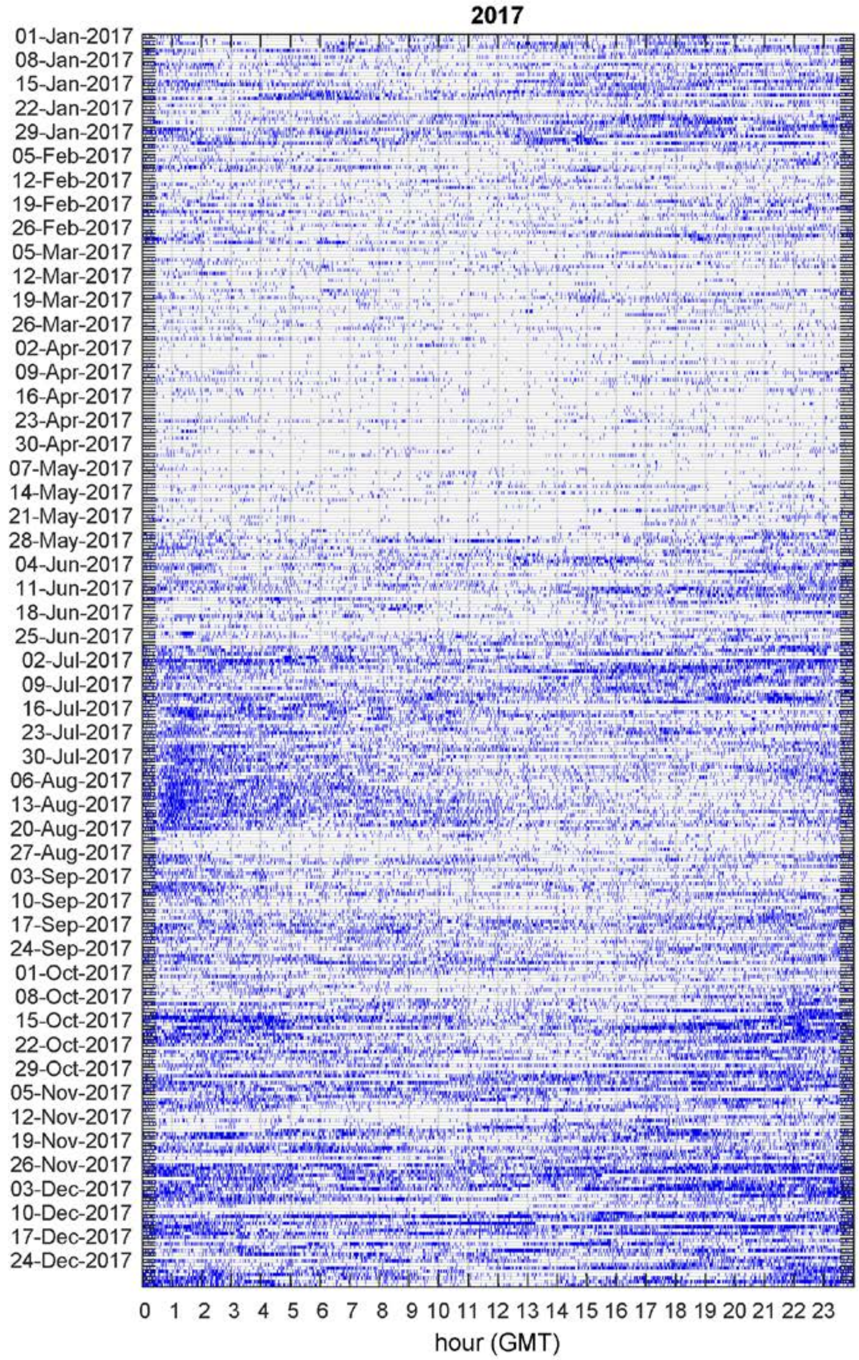


Figure 17. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2017. These detections have not yet been validated. The grayed area represents time periods without recording effort.

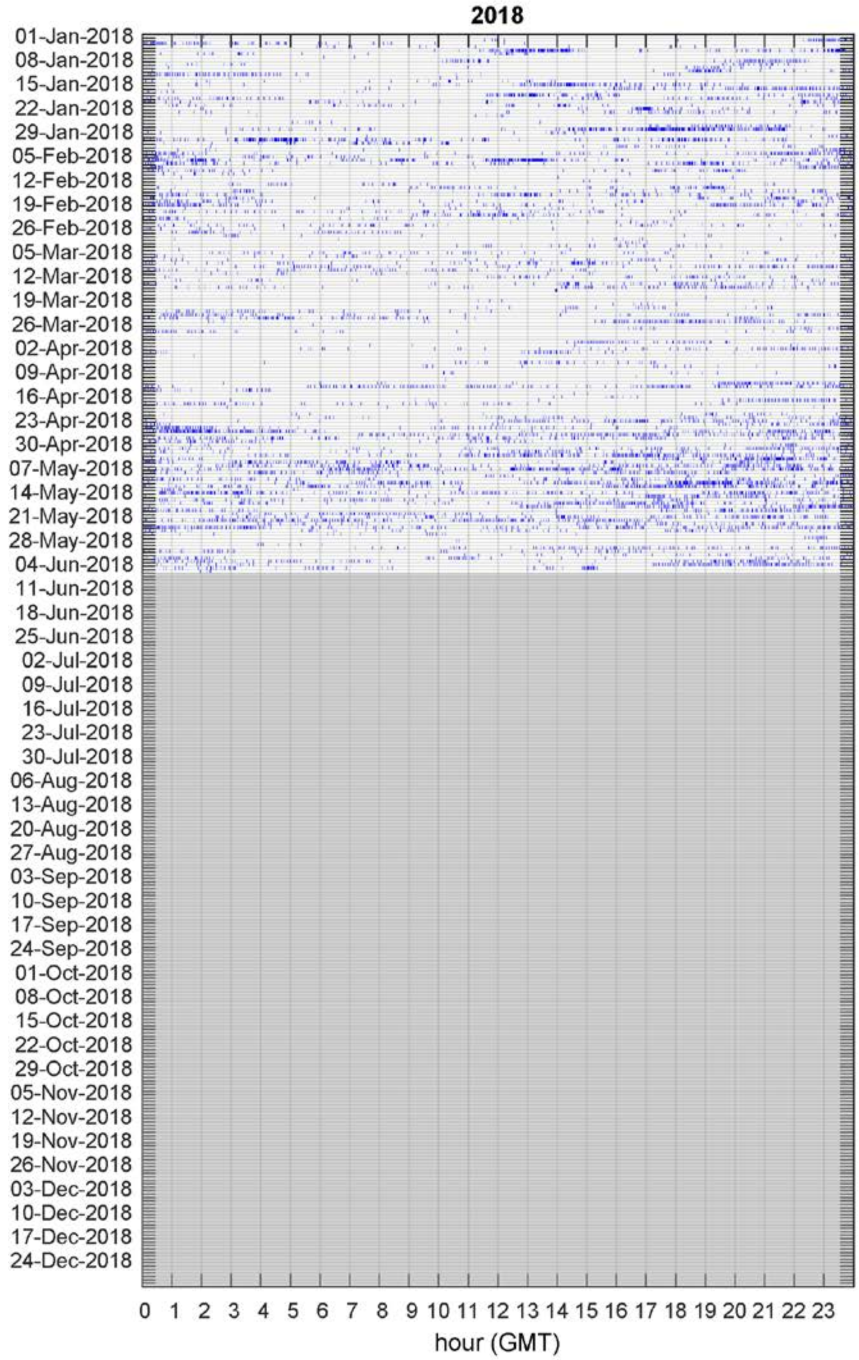
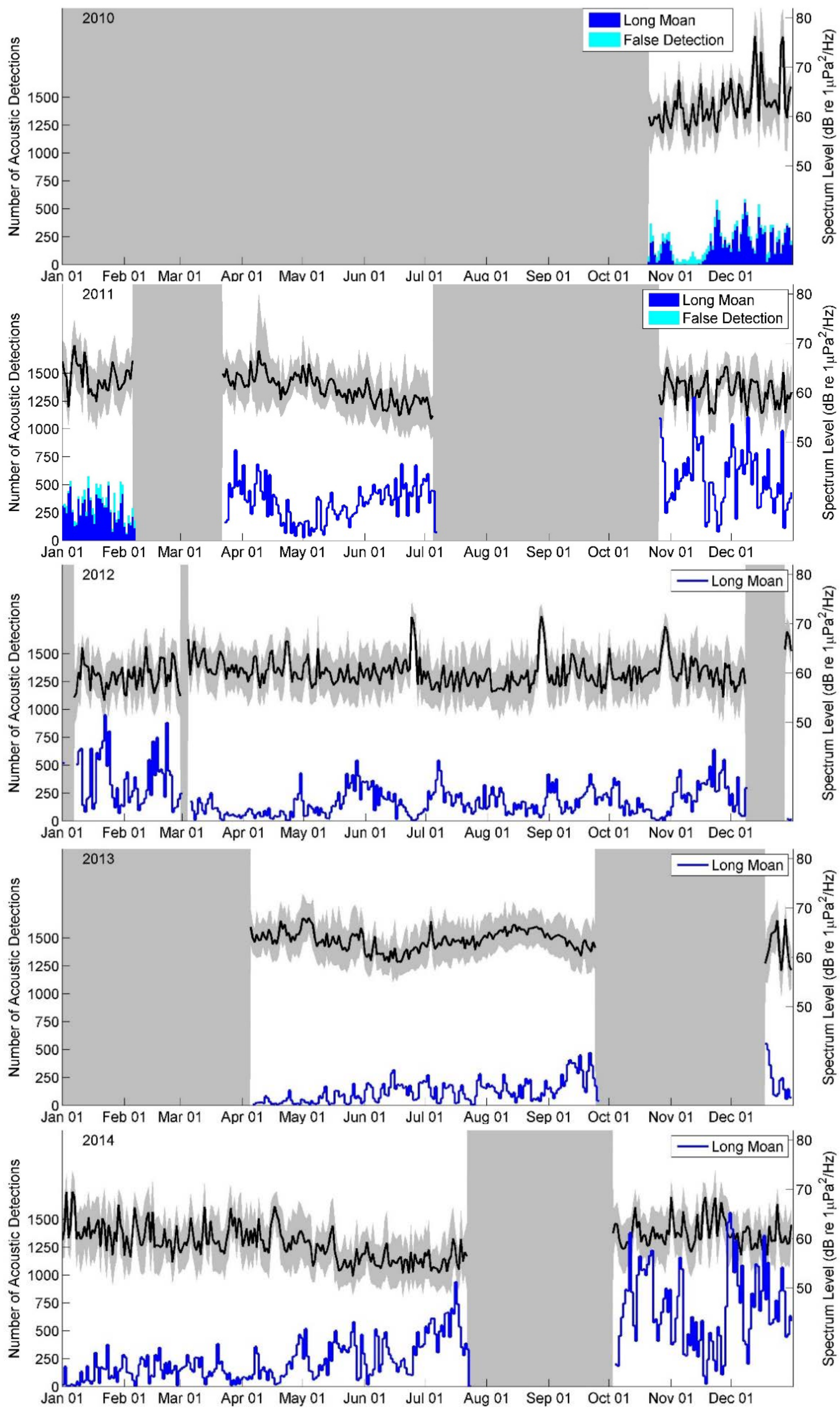


Figure 18. Gulf of Mexico Bryde's whale long moan calls in 1-minute bins in 2018. These detections have not yet been validated. The grayed area represents time periods without recording effort.



2010
2011
2012
2013
2014
Long Moan
False Detection
Number of Acoustic Detections
Spectrum Level (dB re 1μPa²/Hz)
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01

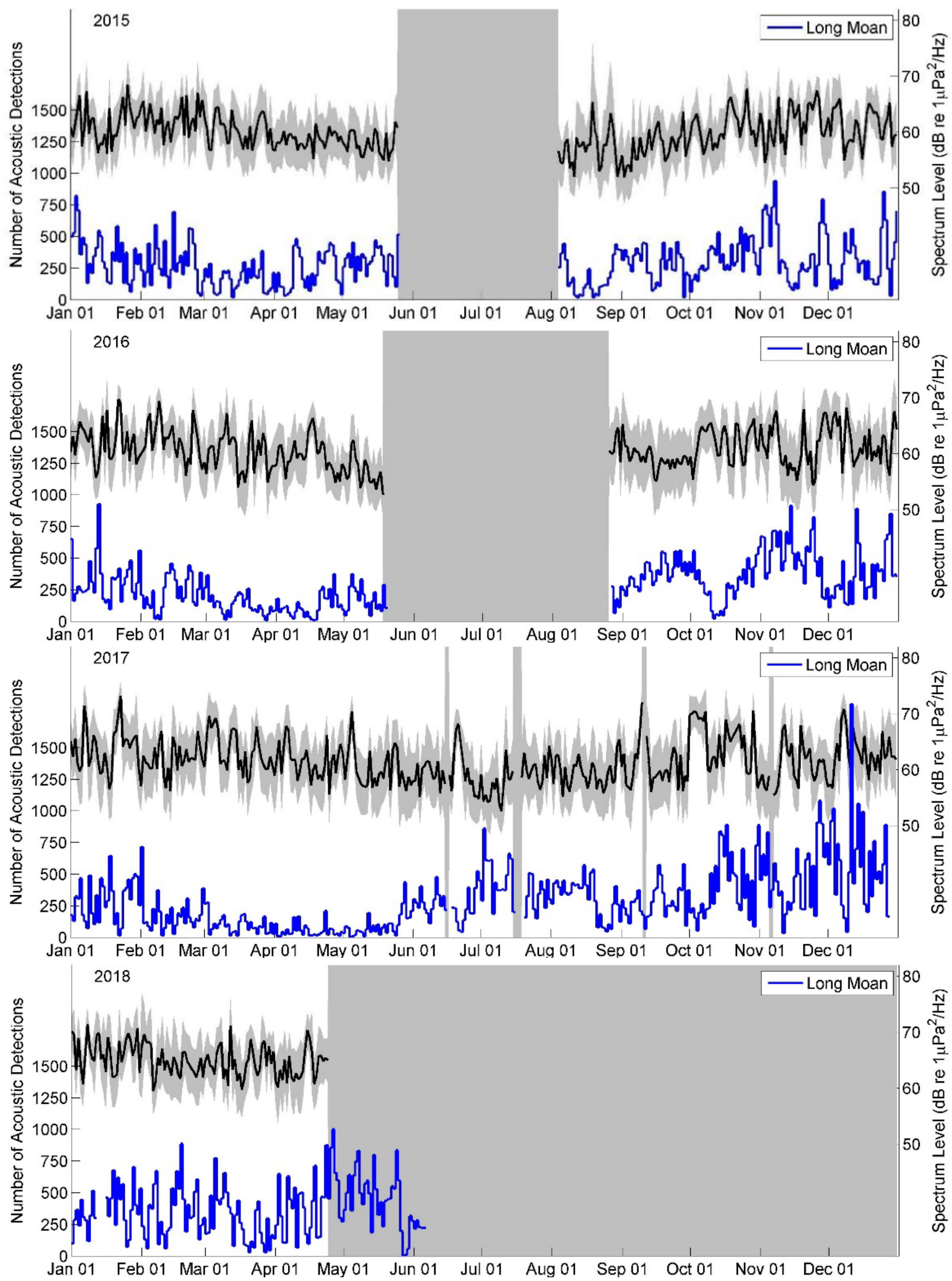


Figure 19. Daily total of long moan detections (blue) and daily average (black) and variance (gray) in noise levels in the 125 Hz frequency band. 2010 include validated detections and false alarms while remaining data represent pre-validated detections. Gray blocks indicate periods with no data.

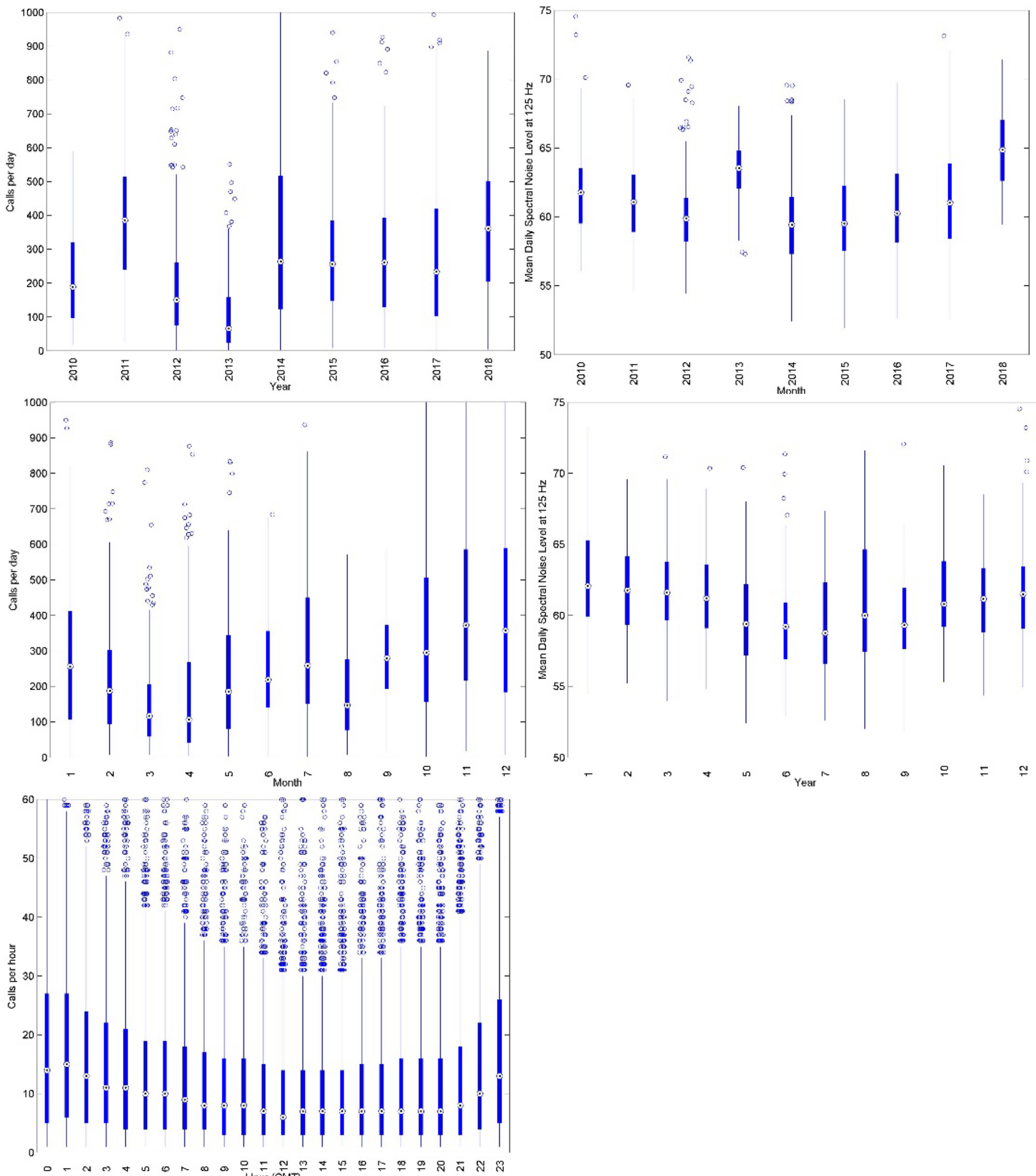


Figure 20. Preliminary comparisons of diel, seasonal, and interannual patterns in long-moan detections and noise.

The preliminary average long-moan call detections per day were lowest in 2013, and were low in 2010 and 2012 as well, while they were highest in 2011 and 2018 (**Figure 20**). Noise levels in the GOM Bryde's whale call frequency band were high in 2013 and 2018 (**Figure 20**); noise levels may have affected the ability to detect calls in 2013 through masking effects, though there doesn't appear to be a similar impact in 2018. These results will be reviewed once all calls have been validated.

Preliminary results indicate an increase in long-moan call detections per hour in fall with a smaller increase in late spring/early summer (**Figure 20**). Noise levels were generally lower in late spring/early summer which may account for the increase in call detections at that time (**Figure 20**).

Preliminary results indicate a slight diel pattern with an increase in hourly call detection rates from 22:00 to 3:00 GMT (17:00 to 22:00 CT) with a slight increase extending until 10:00 (5:00 CT) (**Figure 20**).

Gulf of Mexico Bryde’s Whale Downsweep Pulse Calls

Preliminary results yielded between 6,803 and 23,067 Downsweep Pulse Sequence detections per deployment for deployments DC02-DC07 (**Table 5**). Preliminary detections occurred on 88-98 % of days per deployment and 30-51% of hours per deployment (**Table 5, Figures 21-29**). These preliminary detections represent a major overestimate as false detection rates for this detector are expected to be around 69%. Extreme peaks in the time series likely represent periods with false detections from noise sources (**Figure 30**). Further development to improve this detector may yield better results. There were very few downsweep calls in the training dataset so redevelopment with more data may be sufficient, but given the pulsive nature of the calls and the high prevalence of seismic survey activity in the area, a machine learning approach may be more reliable.

- False detection rates for the DC02 dataset were 97.6%, with 218 true downsweep calls heard on only 12 days of the 110 days of data (**Table 5**). These false detection rates were much higher than expected based on the testing data characterization. Nearly 65% of the false detections occurred over the course of a few days when ship noise was prevalent.
- For the DC02 dataset, true detections of downsweep pulse sequences (218) are 2 orders of magnitude lower than true detections of long-moan calls (22,278) during this time period (**Tables 4, 5**).
- True downsweep detections were clusterd over two short periods one in late October 2010 (**Figures 21, 30**) and one in in late December 2010 – early Jan 2011 (**Figures 22, 30**).

Table 5. Number of downsweep pulse sequences detected per deployment.

Deployment	Downsweep Pulse Sequence Detections	True Downsweep Pulse Sequences	Days Present (%)	Hours Present (%)
Validated				
DC02	9,266	218	12 (11)	47 (1.8)
Pre-Validated				
DC02	9,266	n/a	105 (95)	907 (35)
DC03	6,803	n/a	103 (95)	1167 (46)
DC04	9,859	n/a	126 (98)	1531 (51)
DC05	13,666	n/a	269 (95)	2829 (42)
DC06	14,221	n/a	245 (91)	2425 (38)
DC07	6,941	n/a	193 (88)	1570 (30)
DC08	10,107	n/a	233 (99)	2360 (42)
DC09	8,066	n/a	281 (96)	2230 (32)
DC10	13,733	n/a	302 (92)	2829 (36)
DC11	23,067	n/a	310 (95)	3519 (45)

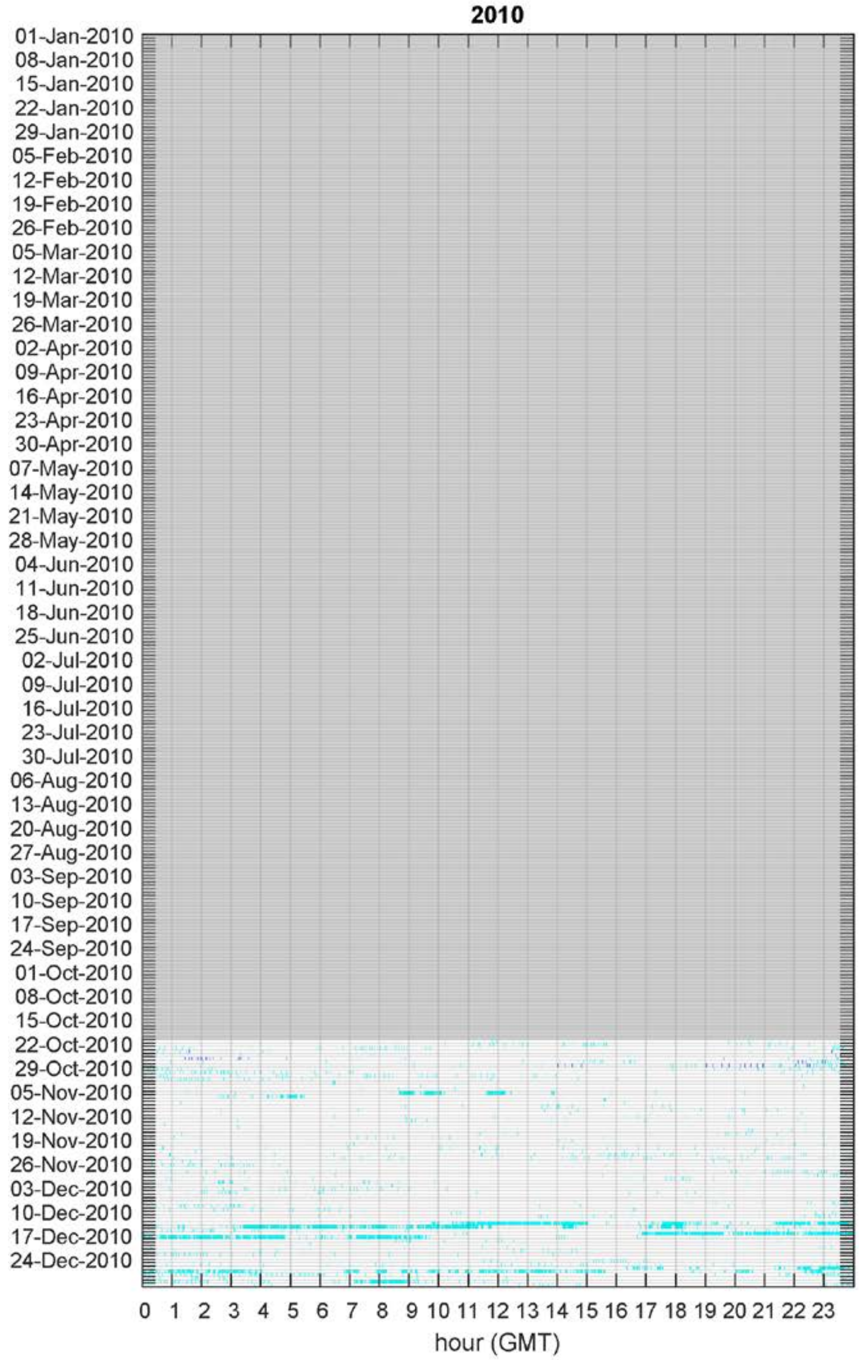


Figure 21. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2010. Cyan tick marks represent verified false detections while blue tick marks represent true pulse sequence detections. The grayed area represents time periods without recording effort.

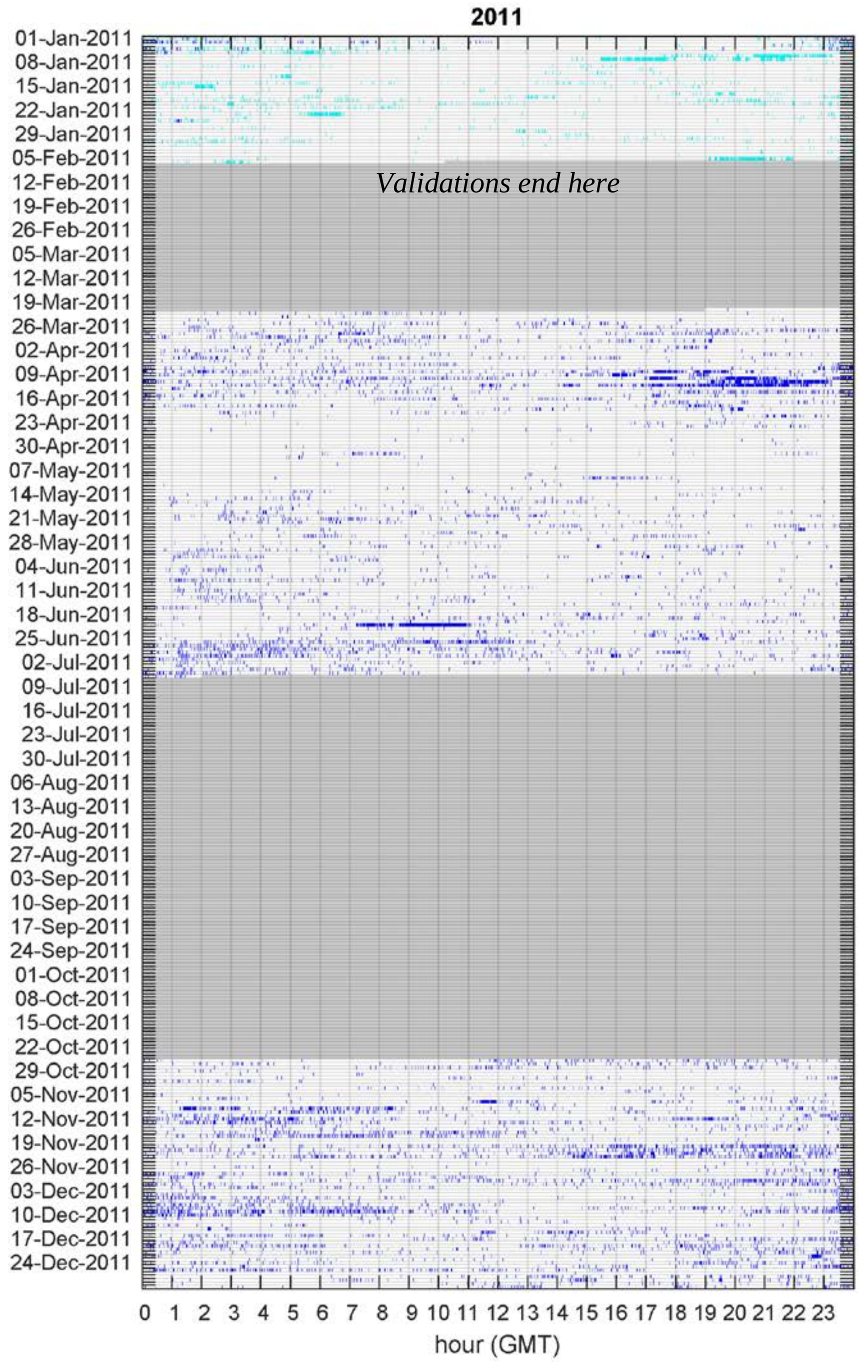


Figure 22. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2011. Cyan tick marks represent verified false detections while blue tick marks represent long moan detections. True detections have only been verified through February 6, 2011. The grayed area represents time periods without recording effort.

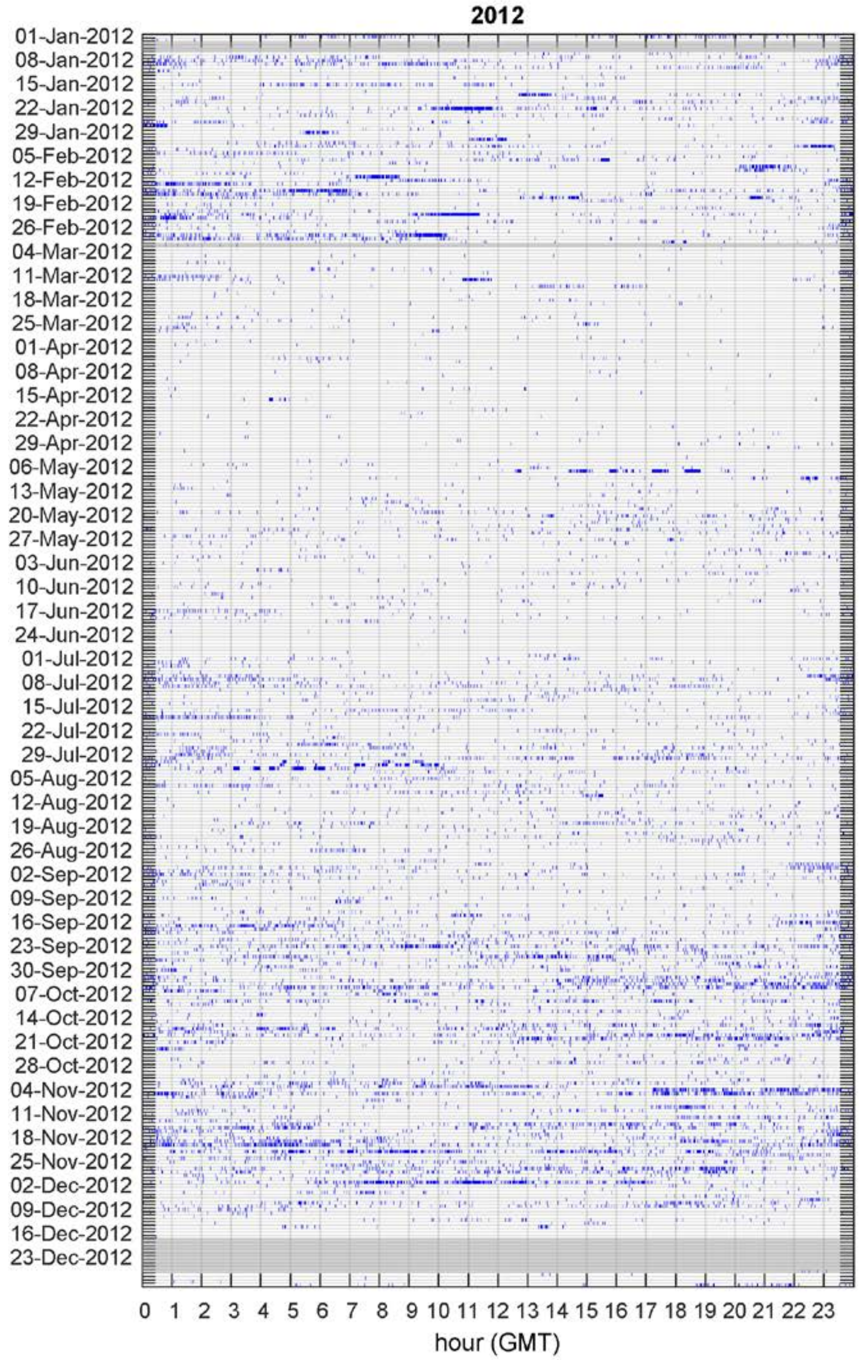


Figure 23. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2012. These detections have not yet been validated. The grayed area represents time periods without recording effort.

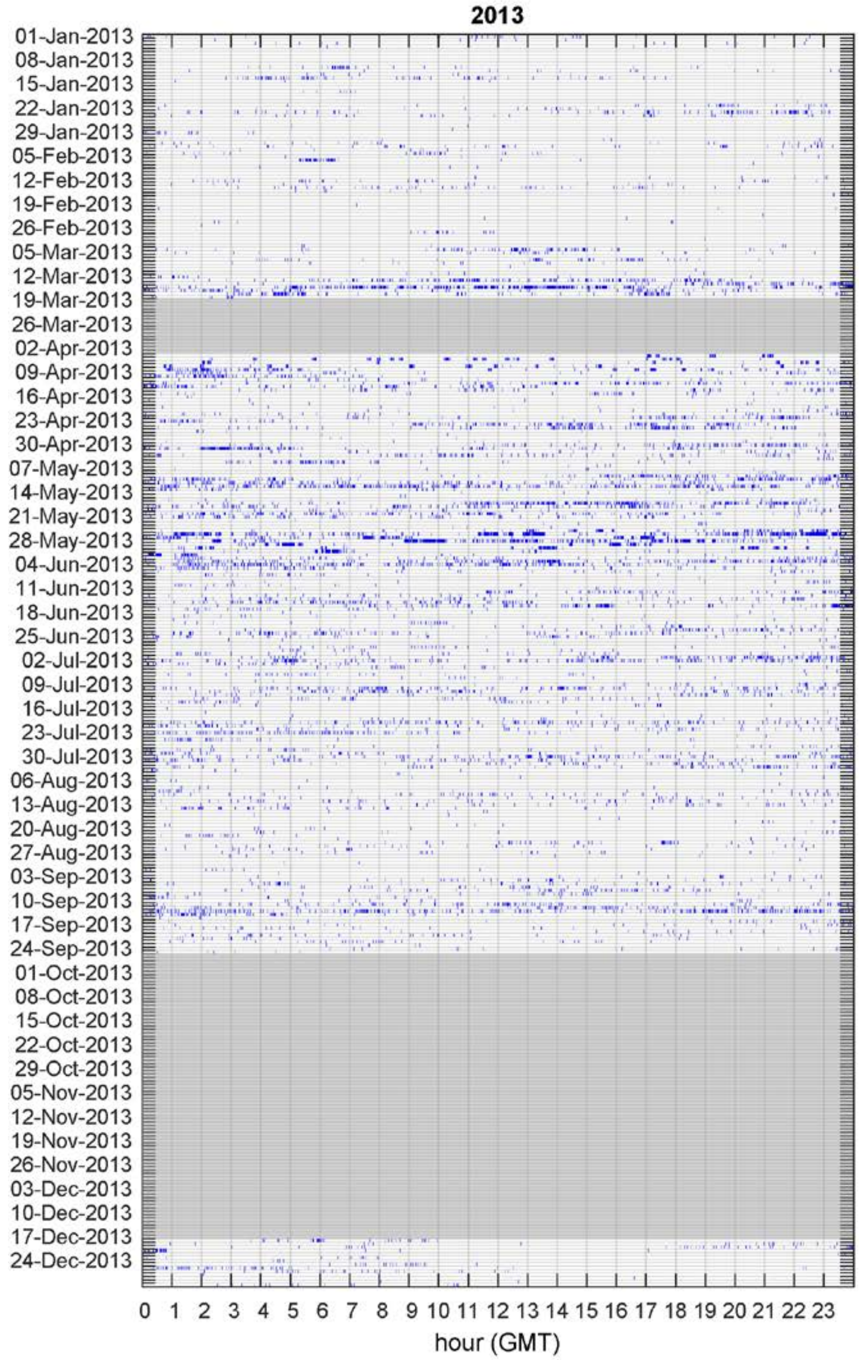


Figure 24. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2013. These detections have not yet been validated. The grayed area represents time periods without recording effort.

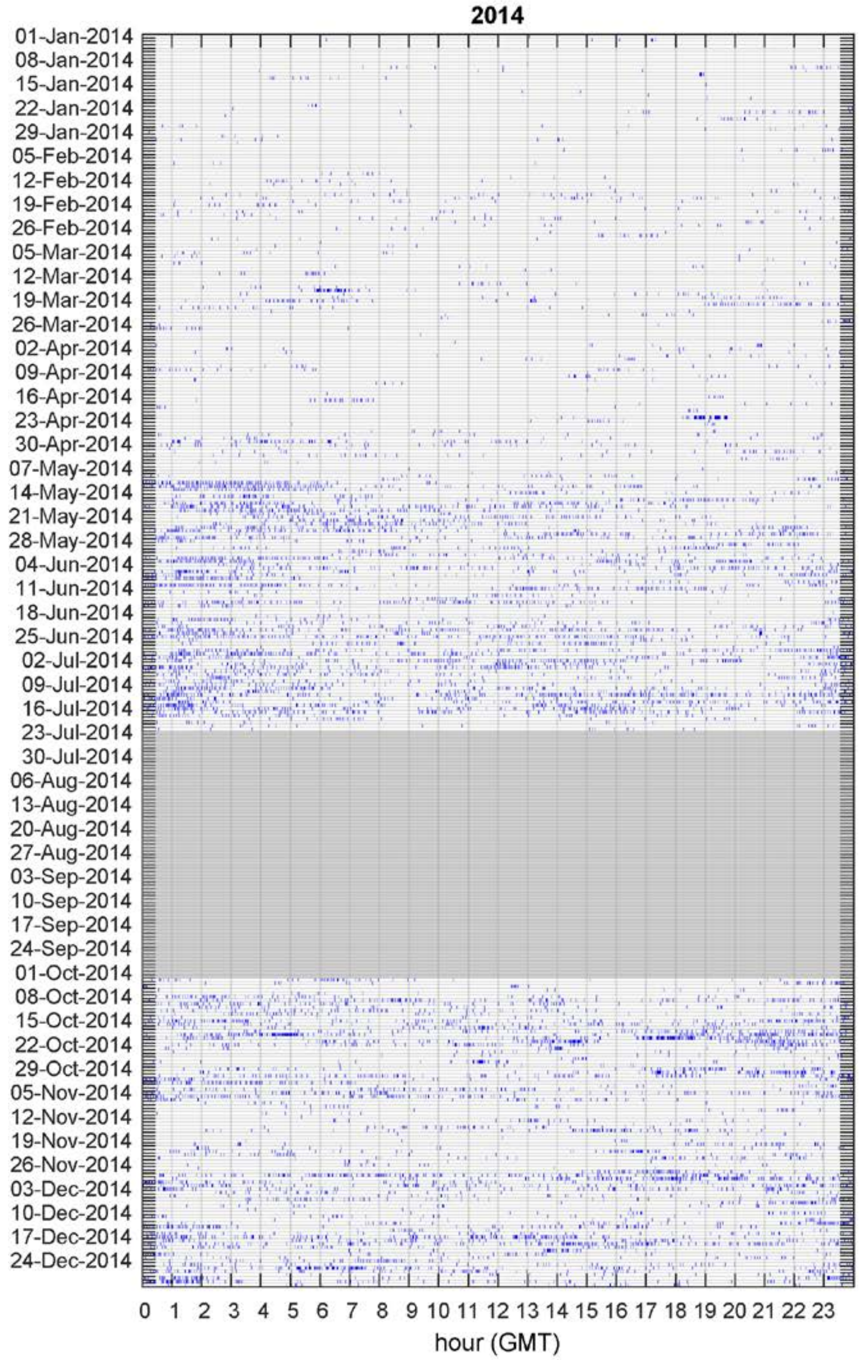


Figure 25. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2014. These detections have not yet been validated. The grayed area represents time periods without recording effort.

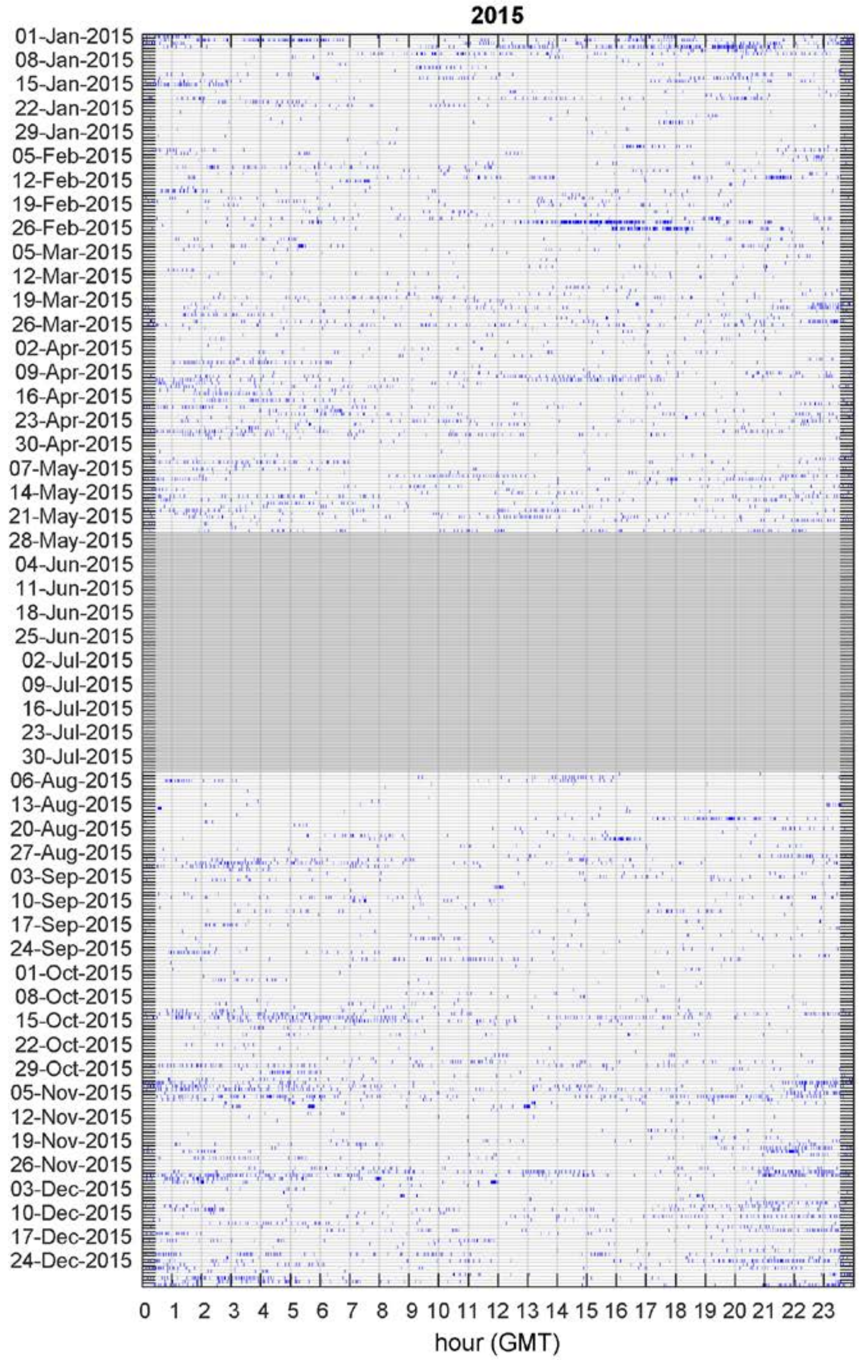


Figure 26. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2015. These detections have not yet been validated. The grayed area represents time periods without recording effort.

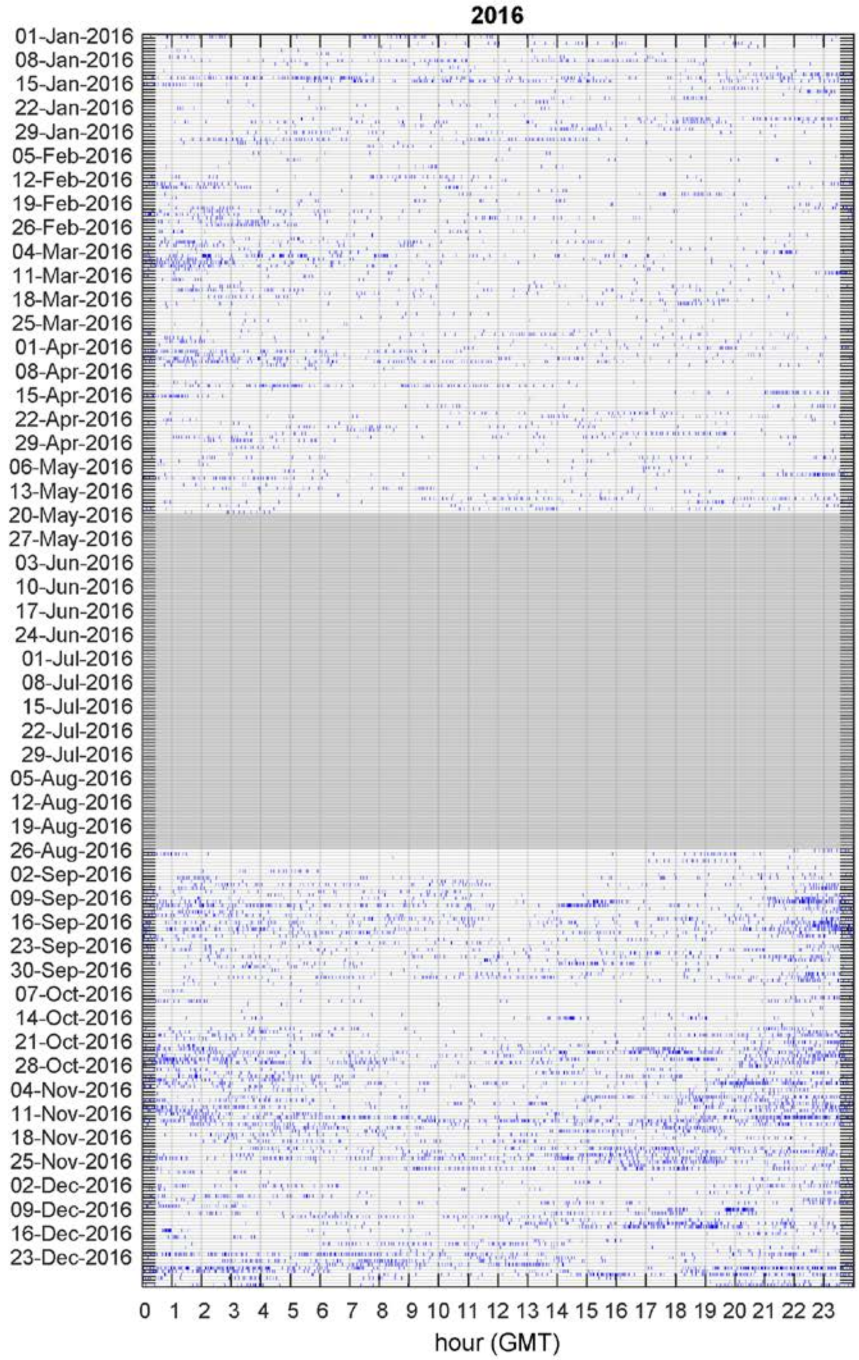


Figure 27. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2016. These detections have not yet been validated. The grayed area represents time periods without recording effort.

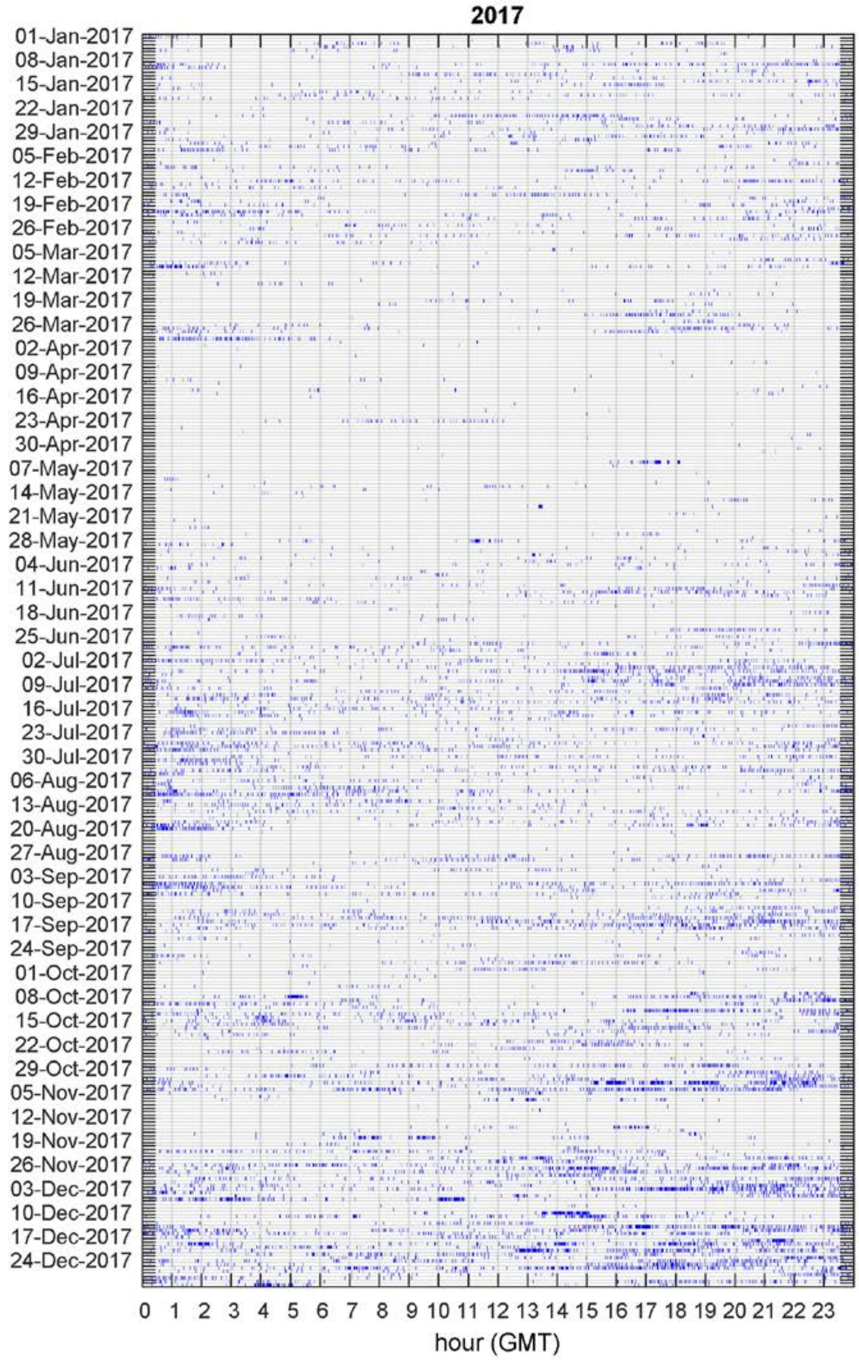


Figure 28. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2017. These detections have not yet been validated. The grayed area represents time periods without recording effort.

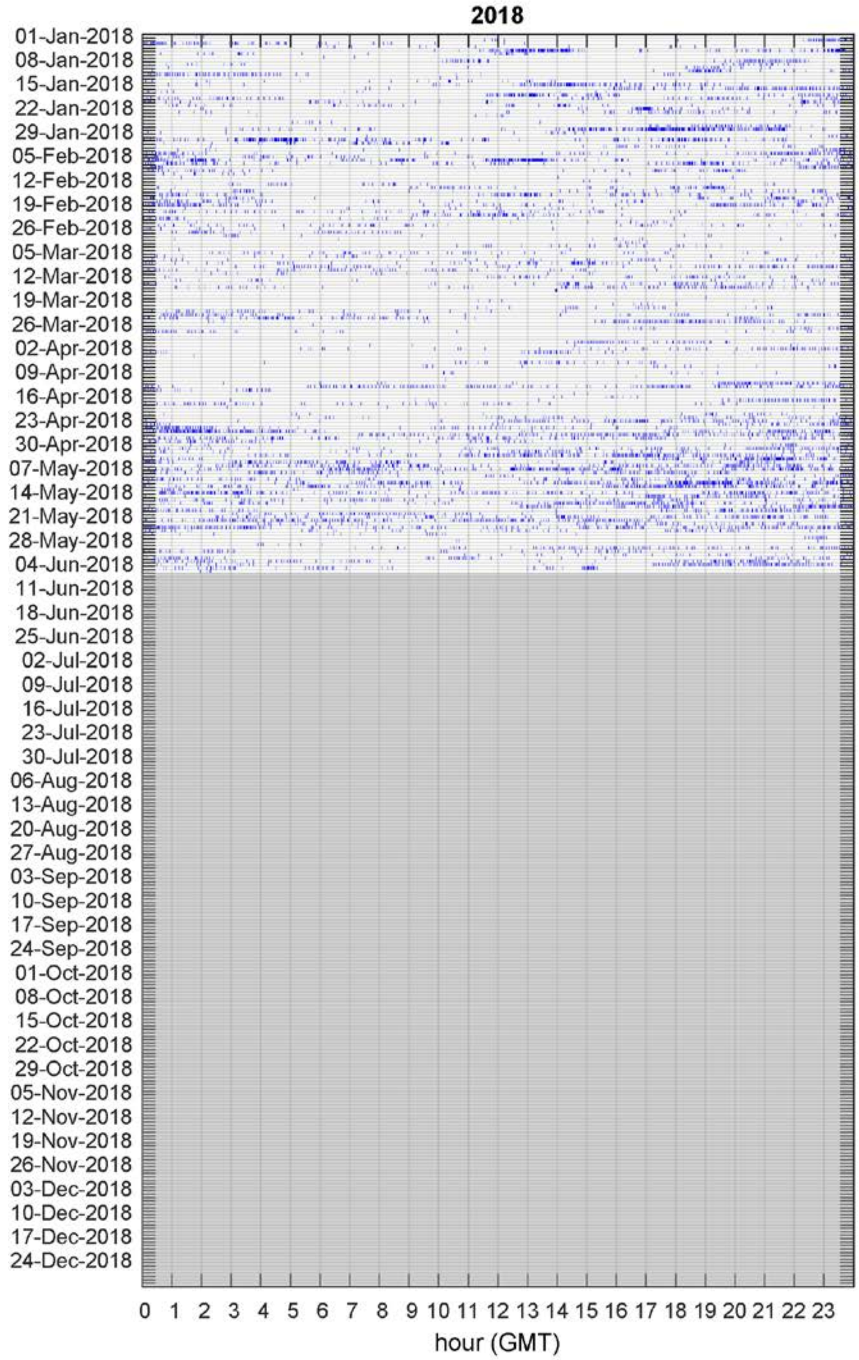
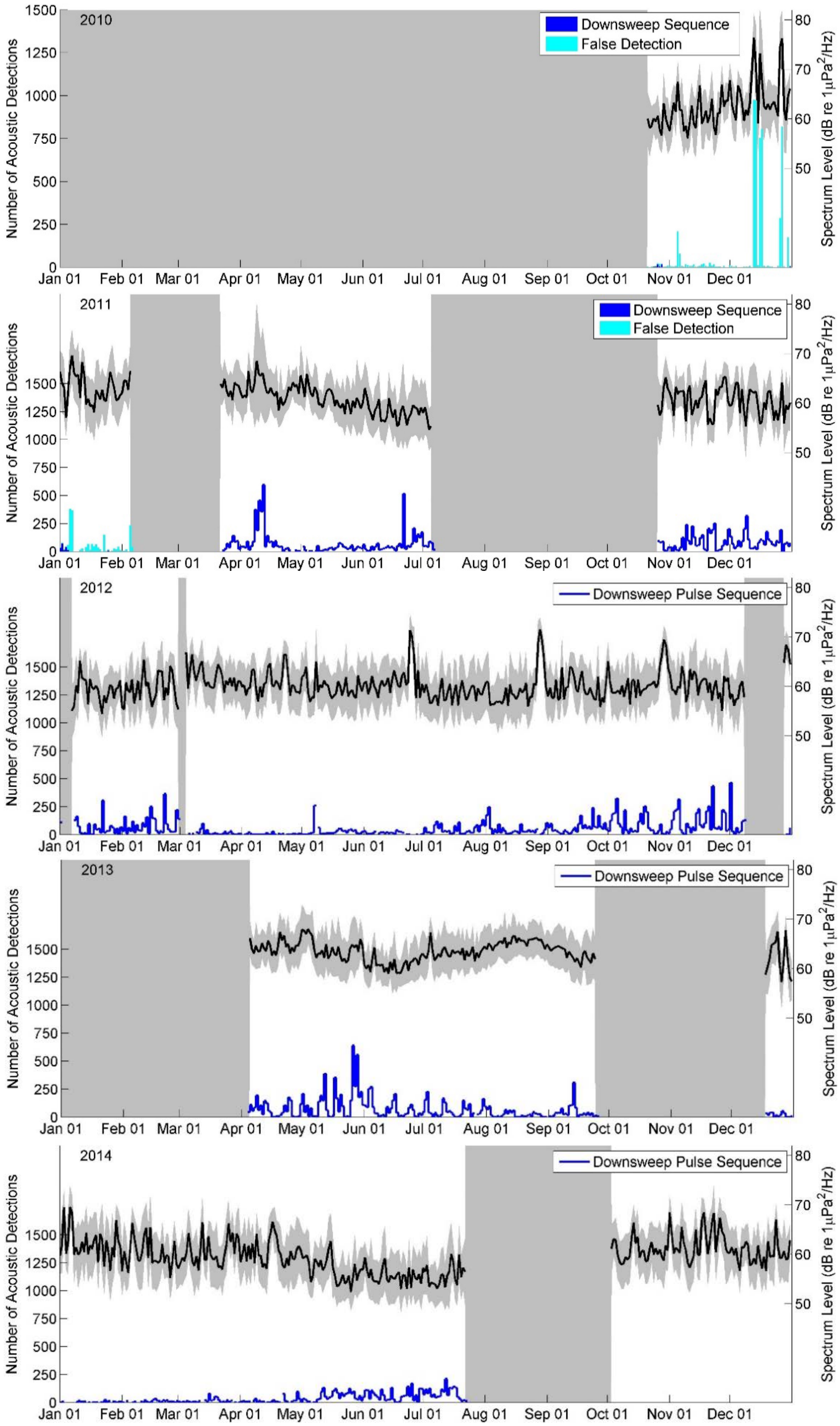


Figure 29. Gulf of Mexico Bryde's whale downsweep pulse sequences in 1-minute bins in 2018. These detections have not yet been validated. The grayed area represents time periods without recording effort.


2010
Downsweep Sequence
False Detection
2011
Downsweep Sequence
False Detection
2012
Downsweep Pulse Sequence
2013
Downsweep Pulse Sequence
2014
Downsweep Pulse Sequence
Number of Acoustic Detections
Spectrum Level (dB re 1μPa²/Hz)
0
250
500
750
1000
1250
1500
50
60
70
80
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01

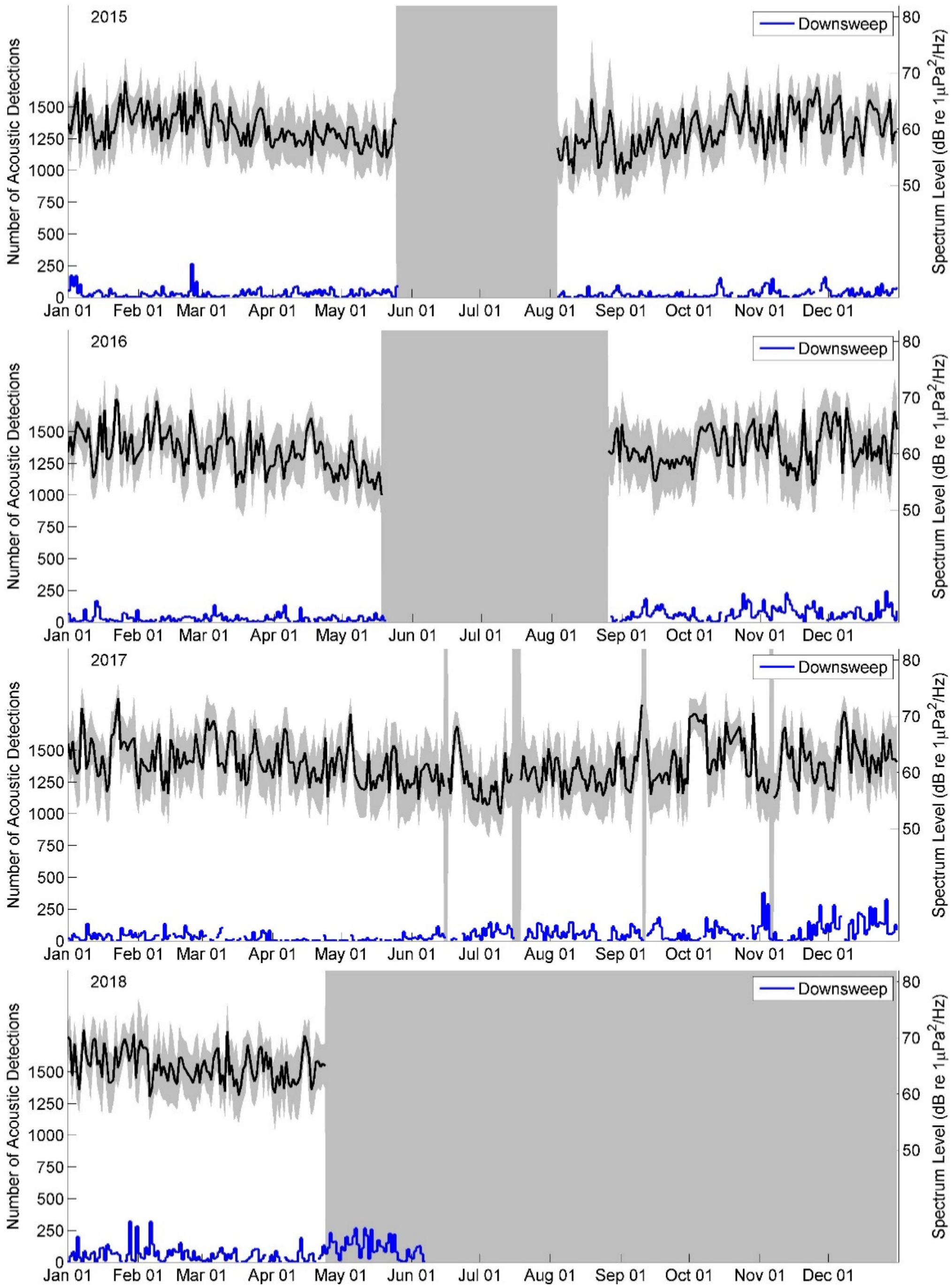


Figure 30. Pre-validated detections of Gulf of Mexico downsweep pulse sequences at the De Soto Canyon HARP site from 2010-2017. The expected false detection rate of this detector is 69% - detections require validation for accuracy. Validations are in progress.

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