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Acoustic Detection of Endangered North Pacific Right Whale (*Eubalaena japonica*) Along the Eastern Bering Shelf, 2012-2018

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EXECUTIVE SUMMARY

The Alaska Fisheries Science Center's Marine Mammal Laboratory has maintained a network of subsurface long-term passive acoustic recorder moorings along the eastern Bering Sea shelf to monitor marine mammal species, including the endangered North Pacific right whale (NPRW; *Eubalaena japonica*), using passive acoustic monitoring (PAM). Here we report NPRW PAM data collected on the eastern Bering shelf from May 2012 to December 2018.

Data were collected from 57 deployments of subsurface moorings among seven sites. All PAM data were manually processed for NPRW vocalizations by analysts using an in-house MATLAB package, *SoundChecker*. These PAM data were collected on a duty cycle (i.e., the recorder was powered on and off to preserve battery life, resulting in periodic data collection), and thus PAM data were standardized to daily calling activity (CA; %), defined as the percentage of daily sampled 10-minute sound clips with NPRW vocalizations present. Note that CA is not a measure of number of calls or of calling individuals.

Resulting daily CA was plotted with sea ice concentration data for each mooring to explore trends in distribution over the study period. The number of days with NPRW vocalizations (CA > 0%) was also plotted by month, site, and year to define seasonality over the dataset. Daily CA data were subsampled to the period consisting of 15 May to 31 December for statistical analysis to maximize the amount of consistent recording effort of unambiguous NPRW CA across mooring sites and years. Kruskal-Wallis rank-sum tests quantified differences in mean CA among years by site and among sites by year for the subsampled period. Annual maps of the percentage of days with calls by site were also created to visualize spatial trends.

We found that NPRW calling occurred in all sampled years and exhibited a latitudinal gradient in CA that peaked during fall months in the right whale Bering Sea Critical Habitat (BSCH). Right whale vocalizations were also detected north of the BSCH in all sampled years at sites PM04 and BS02 in the southeastern Bering Sea (SEBS; ≤ 60°N) as well as in the majority of sampled years at SEBS site PM05. Detections in the northern Bering Sea (NBS; > 60°N) were sparse and intermittent.

Ice extent influenced which mooring locations had calling. More calling occurred at BSCH sites following more extensive sea ice extent (2012, 2017). In contrast, higher CA and a higher percentage of days with calls occurred at SEBS sites north of the BSCH following winters with lower ice extent (2014-2016). In the NBS, there was a pulse in fall calling in 2016 that corresponded to CA pulses at all southward sites, supporting a fall distribution that spanned nearly the entire study area during this low-ice year.

Ice extent also influenced the timing of calling. Calls were heard later in the open water season during reduced ice extent years at both BSCH sites and PM04 in the SEBS. In 2018, following an unseasonably warm winter with markedly low ice extent, lower and more intermittent CA was observed across sites in fall months compared with prior years.

Together, these results reflect annual variability in NPRW acoustic occurrence within and among sites on the eastern Bering shelf and suggest observed variability may be linked to sea ice extent. As the Arctic climate continues to change, it is imperative that monitoring at these mooring sites is maintained, while adding other sites or platforms along the Bering Shelf, Slope, and Basin.

CONTENTS

INTRODUCTION

The North Pacific right whale (NPRW; *Eubalaena japonica*) is endangered due to extensive commercial whaling in the 19th and 20th centuries (Ivashchenko and Clapham 2012, Smith et al. 2012). These whaling records comprise the bulk of distribution data for this rare species, suggesting a historical habitat range extending from 20° N (subtropical geographic zone) to 60° N (south of St. Matthew Island in the Bering Sea). Little is currently known about the seasonal distribution of NPRW and the potential impact of changing climate conditions, particularly on feeding grounds. Scientific data collected in the 1990s and 2000s support a right whale core feeding ground on the southeastern Bering Sea (SEBS) shelf (Shelden et al. 2005, Munger et al. 2008, Zerbini et al. 2015), resulting in designation of the Bering Sea right whale critical habitat (BSCH) in 2008 (73 FR 19000, April 8, 2008). Genetic analyses support that animals observed in this area belong to the critically endangered remnant eastern population (Wade et al. 2011, LeDuc et al. 2012, Pastene et al. 2022). Given the rarity of this species combined with the remoteness of the Bering Sea and lack of dedicated funding, passive acoustic monitoring (PAM) has been the primary tool to monitor for NPRW in this region. The Alaska Fisheries Science Center's Marine Mammal Laboratory (AFSC-MML) has been monitoring the distribution of NPRW in the eastern Bering shelf using PAM since 2006. This report presents AFSC-MML PAM data collected on the eastern Bering shelf from May 2012 to December 2018.

METHODS

Data Collection

Our analysis used passive acoustic data from an existing network of underwater moorings with long-term passive acoustic recorders maintained by AFSC-MML (Appendix Table A-1). We used data from seven of these sites on the eastern Bering Shelf from May 2012 through

December 2018 (Table 1 and Appendix Table A-1, Fig. 1). Sites were labeled based on the current Bering Sea critical habitat (BSCH) boundary and oceanographic features as follows: within the BSCH (hereafter BSCH; Site PM02 and BS03), north of the BSCH within the southeastern Bering Sea (≤ 60°N; hereafter SEBS; Site PM04, BS02, and PM05), and within the northern Bering Sea (> 60°N; hereafter NBS; Site BS01 and PM08) (Stabeno et al. 2012a; Fig. 1).

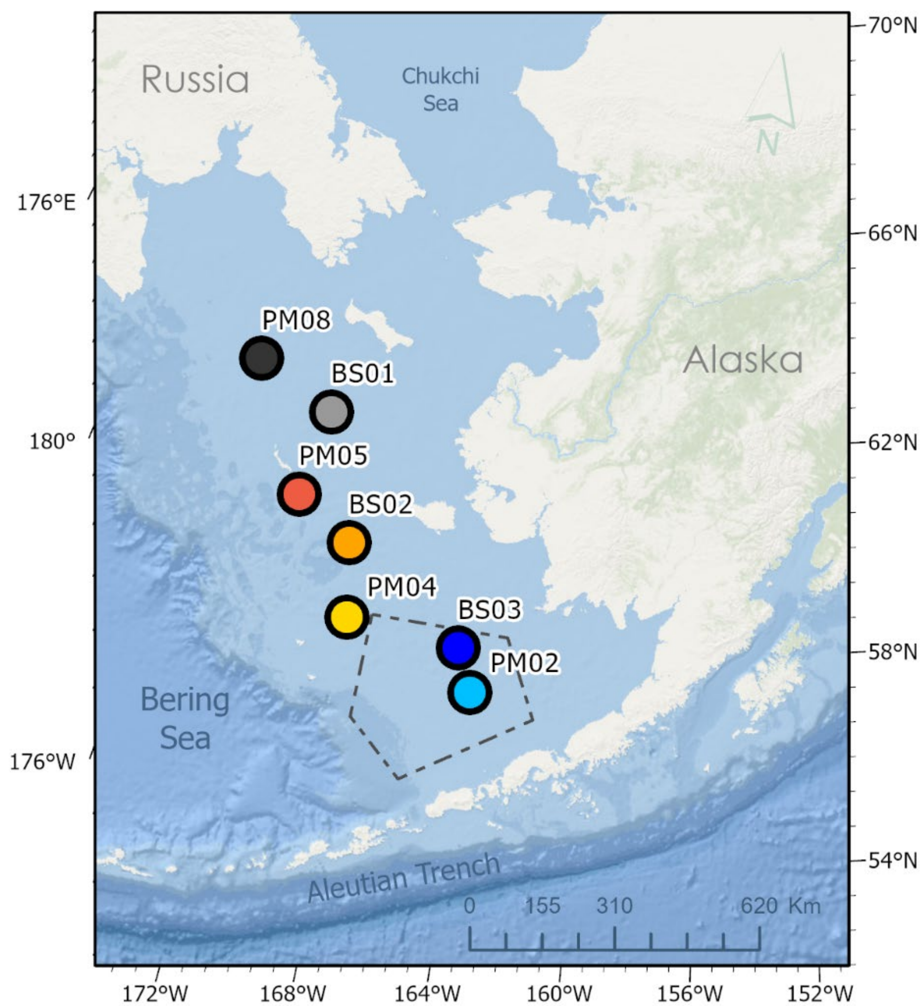
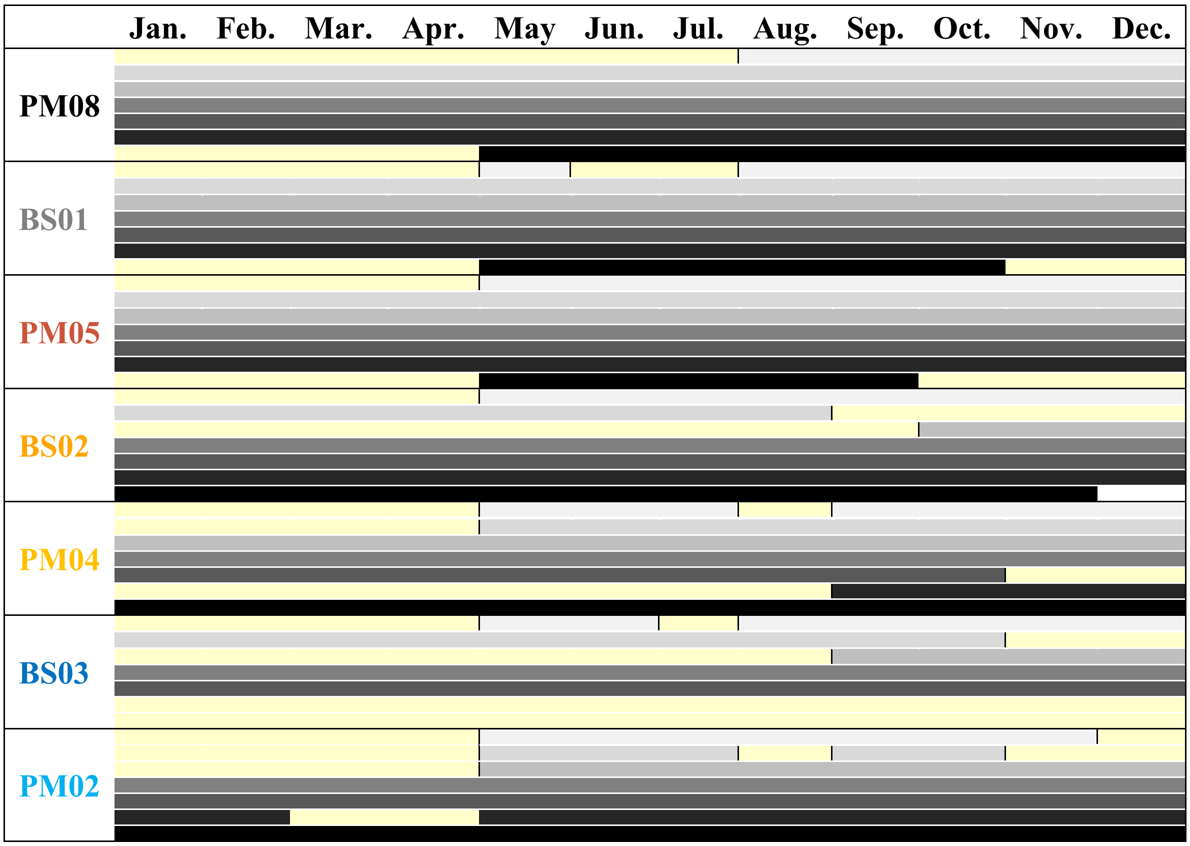


Figure 1. -- Mooring sites on the eastern Bering shelf; symbol colors denote region: current Bering Sea critical habitat, denoted by dashed line (BSCH; blues), southeastern Bering Sea shelf above the BSCH (SEBS; warm tones), and northern Bering Sea (NBS; grays). "PM" moorings are located along the 70-m isobath and "BS" moorings are located along the 50-m isobath.

Table 1. -- Effort table. Sites with passive acoustic data by month and year, 2012-2018, shown as grayscale (lightest gray = 2012, darkest gray = 2018). Months with zero days of available data denoted with pale yellow background. Note that the table does not indicate effort days per month; refer to Appendix Table A-1 and Appendix Tables C-1, C-3, C-5, C-7, C-9, C-11, and C-13.



Data were collected from 57 deployments of subsurface moorings (an average of 8 deployments per site; Tables 1 and Appendix Table A-1). Each mooring had a passive acoustic recorder, either an Autonomous Underwater Recorders for Acoustic Listening device (AURAL, Multi-Électronique, Rimouski, QC, Canada) or an Ecological Acoustic Recorder (EAR; Lammers et al. 2008) (Appendix Table A-1); both are 16-bit instruments. The recorders were attached to sub-surface, bottom-mounted moorings along the 50 and 70 m isobaths of the eastern Bering Sea shelf (Fig. 1) that were replaced every 6 or 12 months (Appendix Table A-1). The sampling rate, duty cycle, depth, and recording period of each mooring are included in Appendix Table A-1.

The AURAL recordings had a flat (±3 dB) frequency response from 10 Hz to 7.8 kHz for the 16 kHz sampling rate and 10 Hz to 3.9 kHz for the 8 kHz sampling rate. The EAR recordings have a flat (±1.5 dB) frequency response across all frequencies for the 4 kHz sampling rate (Lammers et al. 2008). System sensitivity for the AURALs is - 63.7 dB counts/μPa (-164 dB V/ μPa hydrophone sensitivity, 16 dB gain, and 84.3 dB count/V), and for the EARs is - 57.6 dB (-193.5 dB V/ μPa hydrophone sensitivity, 47.5 dB gain, and 88.4 dB count/V). Dynamic range for both the AURALs and the EARs is 90 dB. AURALs have a spectral noise floor of approximately 52-55 dB re 1 μPa2/Hz (Kinda et al. 2013 and empirically derived); the spectral noise floor for the EARs is 52-53 dB re 1 μPa2/Hz (M. Castellote, AFSC-MML pers. comm.).

Processing of Acoustic Data

Raw data (.wav files) were divided into 10-minute standardized .wav files, converted to 225-second spectrograms (one of three frequency bands, see below), and analyzed using an in-house MATLAB program *SoundChecke*r (Wright et al. 2018). *SoundChecker* produces a GUI (Graphical User Interface) that allows for visual and auditory processing of all data by trained analysts (Fig. 2).

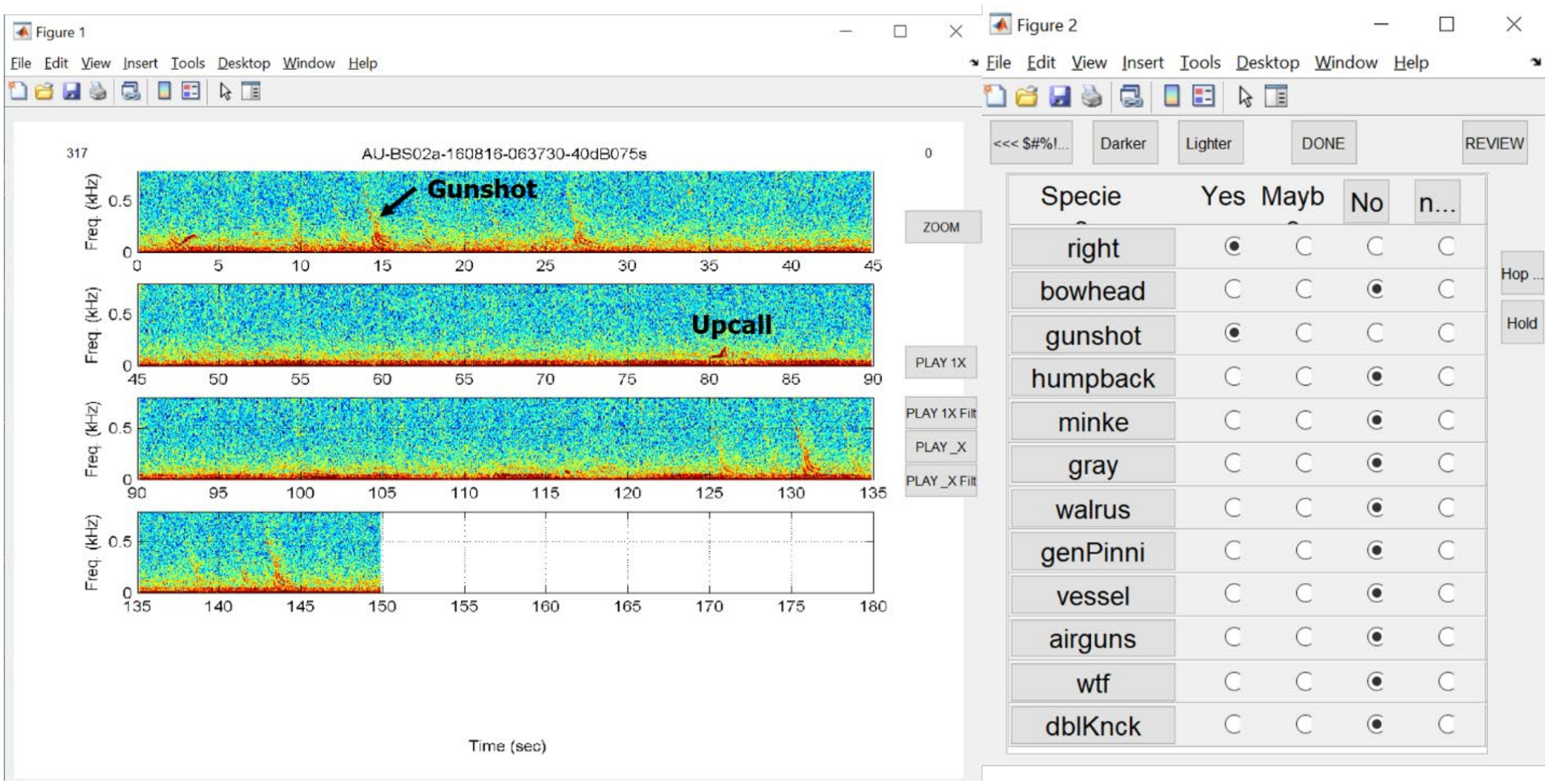


Figure 2. -- Screenshot of *SoundChecker* GUI showing NPRW upcalls and gunshots.

Analysts are assigned to one of three frequency bands for processing of a given mooring using *SoundChecker*: low-frequency (0-250 Hz), mid-frequency (0-800 Hz) or high frequency (0-N Hz, where N = sampling rate/2). NPRW vocalizations are identified by analysts looking at spectrograms of the mid-frequency band (0-800 Hz) and confirmed by listening to the call, if necessary. For each spectrogram of the *SoundChecke*r GUI in the mid-frequency band, an analyst manually identifies the presence of seven possible species – NPRW, bowhead whale (*Balaena mysticetus*), humpback whale (*Megaptera novaeangliae*), gray whale (*Eschrichtius robustus*), walrus (*Odobenus rosmarus divergens*), minke whale (*Balaenoptera acutorostrata*), and unidentified pinniped, in addition to two additional biological sounds – double knocks and gunshot calls, and two anthropogenic sounds – vessel and seismic airgun.

We used two primary call types to identify NPRW: upcalls and gunshot calls (McDonald and Moore 2002, Wright et al. 2018, Crance et al. 2019; Fig. 2). NPRW upcalls are frequency modulated (FM) upsweeps predominantly between 80 and 160 Hz and 1-1.5 second duration that occur in bouts of irregular length (McDonald and Moore 2002). Upcalls are believed to be contact calls that are produced by both sexes of all three species of right whale (Clark 1982, Matthews et al. 2001, McDonald and Moore 2002). NPRW gunshot calls are short (< 1 s) broadband calls that can occur in pattern (Crance et al. 2019). Gunshot calls are also produced by both sexes of all species of right whale, but the proportion of gunshot calls is much higher for NPRW (Crance et al. 2017). The function of gunshot calls for NPRW is unclear but patterned gunshots could be linked to reproduction (Crance et al. 2019).

In addition to NPRW, bowhead and humpback whales produce upsweeps similar to the NPRW upcall, and bowhead whales produce non-patterned gunshot calls (Thompson et al. 1986, Stafford and Clark 2021). We used call characteristics (e.g., fundamental frequency, call interval and duration, variability in call type, and patterning) and contextual clues (e.g., season, bout characteristics, association with conspecific sounds, and proximity to non-conspecific sounds) to identify NPRW from other species. For each spectrogram, the analyst would mark 'yes' for a given signal type if at least one signal that could be confidentially attributed to said signal type was present, 'maybe' if possible sounds of a given signal type are present, and 'no' for the absence of a given signal type (Wright et al. 2018). We sometimes encountered individual calls or small groups of calls that fit our call characteristic criteria but had minimal contextual information (e.g., isolated calls, no association with conspecific sounds or proximity to non-conspecific sounds). These detections were marked 'yes' and flagged as ambiguous. Only 'yes' detections of NPRW vocalizations, including those with the ambiguous flag, are presented in this report.

Analytical Methods

Daily Calling Activity

Given the variety of duty cycles used among moorings (Appendix Table A-1), results of individual 225-second spectrograms were collated to the 10-minute .wav file resolution and were then converted to a daily Calling Activity (CA; %) metric:

$$Daily\ CA = \#\ yes\ 10\ min.\ sound\ clips\ day^{-1} / \#\ total\ 10\ min. sound\ clips\ day^{-1}\ ,$$

defined as the daily percentage of 10-minute sound clips with yes detections (Wright et al. 2018). Note that CA is not a measure of the number of calls or individual animals nor a direct measure of habitat use, as animals could be present but not calling. It is a measure of the acoustic occurrence on the sampled day.

Ice Concentration Data

We overlaid daily CA with daily sea ice concentration at each site. Sea ice concentrations were averaged from NASA's National Snow and Ice Data Center (NSIDC) Near-Real-Time and Bootstrap products which are derived from the Scanning Multichannel Microwave Radiometer (SMMR) on the Nimbus-7 satellite and from the Special Sensor Microwave/Imager (SSM/I) sensors on the Defense Meteorological Satellite Program's (DMSP) -F8, -F11, and -F13 satellites (DiGirolamo et al. 2022). These data are provided on a 25 km grid. To find the closest values for a given point, spherical math was used to approximate a box around the point. The haversine equation was then used in Python to calculate which points in the box were within 15 nautical miles (nm) of the given point. The values for these data points were then averaged.

Removing Calls During Ice and Bowhead Presence

FM upsweeps and individual gunshots matching our description of NPRW upcalls and gunshots occurred during periods of ice cover with bowhead presence (Fig. 3). Given the similarity in call repertoire between the two species (Stafford and Clark 2021), species-specific identification of these calls was unfeasible. Consequently, we omitted from each mooring the period spanning from the first day of either bowhead presence (> 0 CA) or ice occurrence (> 15% ice concentration) to the last day when either was present (Wright et al. 2023). For moorings without ice or bowhead calling (Fig. 3), all days are presented.

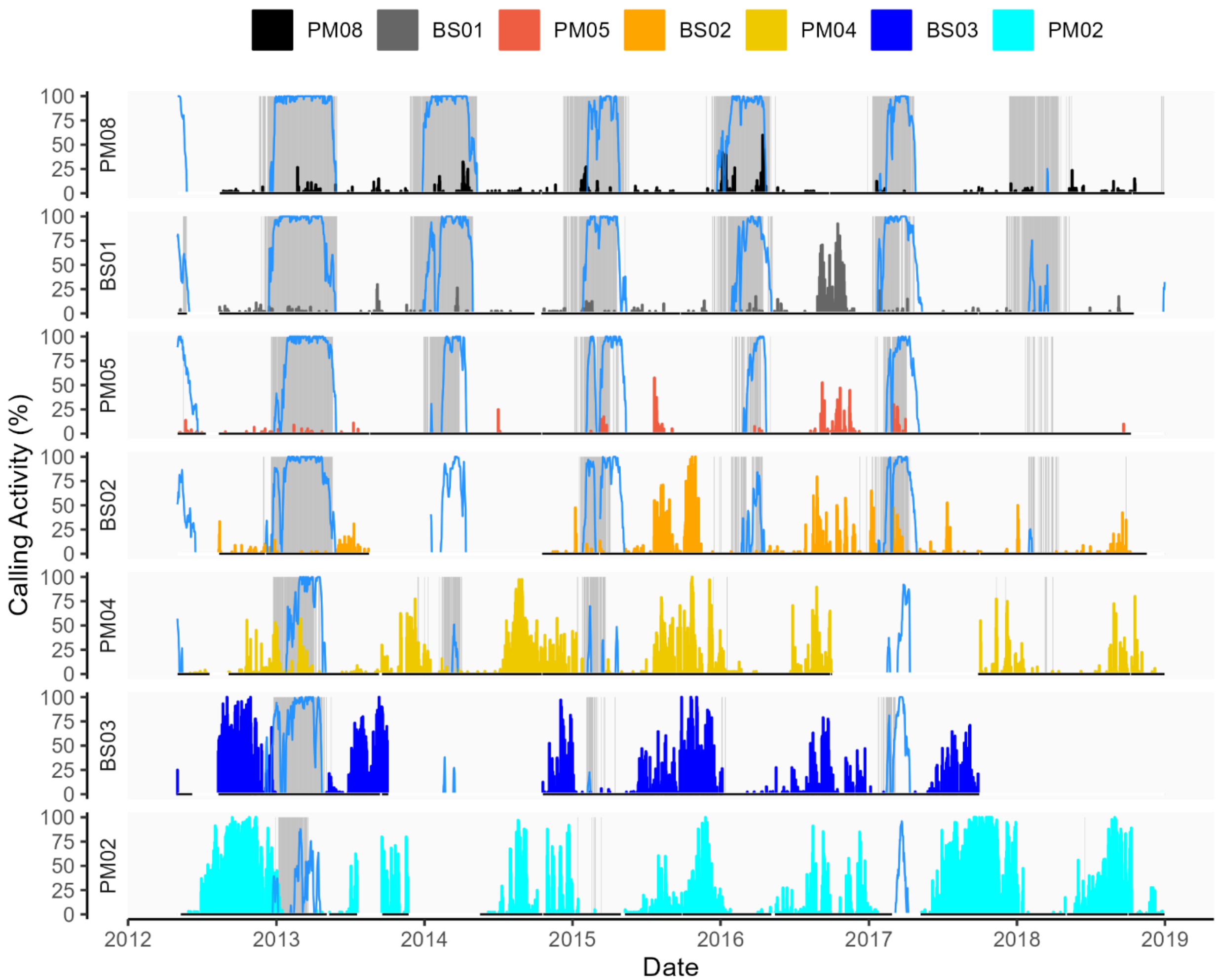


Figure 3. -- Daily calling activity (CA; %) of NPRW vocalizations from 15 May 2012 to 31 Dec. 2018 by station (row; colors correspond to Fig. 1). Also shown is the daily sea ice concentration (thick blue line; %) and days with bowhead presence (gray shading). Effort indicated by black horizontal lines. Note that bowhead presence is not CA.

Calling by Month

We created plots of the number of days with NPRW calls (i.e., number of days with CA > 0) by month for each site and year to visualize monthly trends in calling occurrence. Gaps in the data prevented comparing months across sites using statistical analyses.

Statistical Analyses

Data Included

Given funding constraints and recorder malfunctions, gaps in the time-series exist for each site (Appendix Table A-1), prohibiting inclusion of all data in statistical analysis. Moreover, timing and extent of sea ice changed dramatically over the study period (Stabeno and Bell 2019), resulting in some mooring sites having years without ice presence (Fig. 3). This made it difficult to delineate open water seasons, making comparisons across sites and calendar years unrealistic. Consequently, we subset the data to a period where mean differences in NPRW acoustic occurrence could be statistically compared. This period spanned from 15 May to 31 December, which contained the largest amount of consistent recording effort across mooring sites and years (Fig. 4). For each site, we limited the calendar years included in analysis to those with ≤ 5 days of missing data for the May to December subset period to minimize the confound of sample size differences (Appendix Table A-1, Fig. 4). As aforementioned, days spanning ice and/or bowhead whale presence within the period were removed.

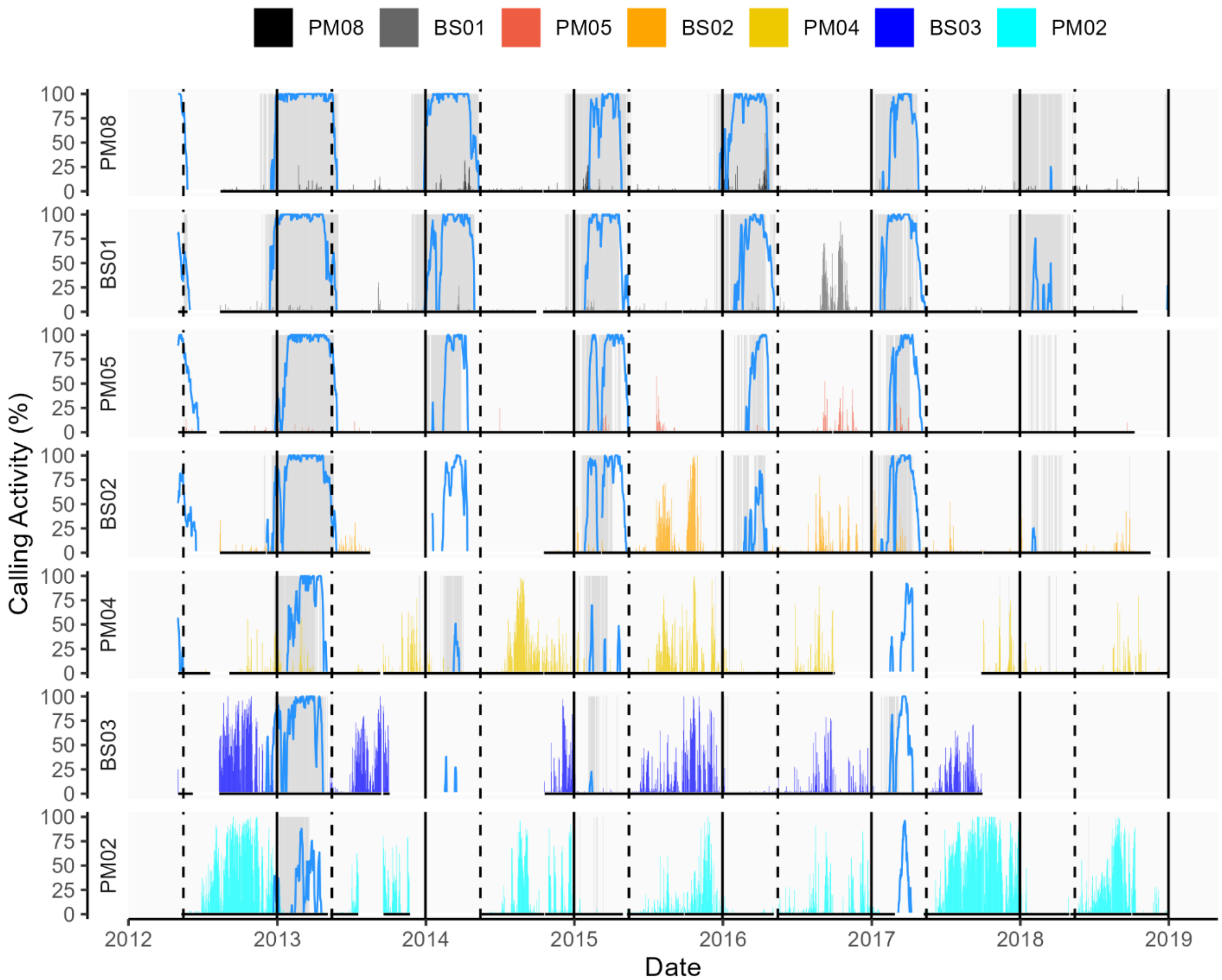


Figure 4. -- Daily calling activity (CA; %) of NPRW vocalizations from 15 May 2012 to 31 Dec. 2018 by station (row; colors correspond to Fig. 1). Also shown is the daily sea ice concentration (thick blue line; %) and days with bowhead presence (gray shading). Note that bowhead presence is not CA. Black dashed lines denote 15 May and solid lines denote 31st Dec. of each calendar year.

We tested for mean differences among years by site and among sites by year using Kruskal-Wallis rank sum tests (hereafter K-W tests) and post-hoc analysis. We used K-W tests as data did not meet normality or homoscedasticity assumptions to run Analysis of Variance. K-W tests were run in the R base package *stats* (R Core Team 2023). Post hoc analysis of K-W tests consisted of Dunn's tests using R package *PMCMRplus* (Pohlert 2023) with Holm's correction to control for familywise error rates. K-W tests and post hoc analyses assumed an $\alpha < 0.05$.

Tables of mean estimates include bootstrapped 95% confidence intervals (CI) instead of standard deviation or standard error given the non-Gaussian data structure. We calculated the bootstrapped 95% CI using 1,000 bootstrap samples with replacement in R package *boot* (Davison and Hinkley 1997, Canty and Ripley 2022).

CA Thresholds

To compare spatial variability in NPRW calling, we computed the percentage of days with 'yes' detections (hereafter, PoD) for the 15 May to 31 December period by CA threshold, defined as follows: all CA (> 0%; i.e., at least one processed 10-minute bin had a 'yes' right whale acoustic detection on the sampled day), medium CA (≥ 50%; i.e., more than half of the processed 10-minute bins had 'yes' right whale detections), and high CA (≥ 80%; i.e., more than 80% of processed 10-minute bins had 'yes' right whale detections). Histograms of overall detections guided thresholds (Figs. S1 and S2). These data are presented as maps of PoD for each CA threshold, with corresponding tables in Appendix E.

RESULTS

Results are presented below in two sections: general (all seasons, all sites) and subset data (15 May to 31 December for sites with ≤ 5 missing days for a given calendar year). As aforementioned, for both cases ambiguity was removed by excluding time periods with either bowhead whale detections or ice concentrations > 15%.

General NPRW Occurrence Patterns and Their Relations to Sea Ice

NPRW vocalizations were detected in all sampled years and sites, except for PM05 in 2017 (Fig. 5), and comprised a latitudinal gradient in daily CA and the number of days with calls that peaked at BSCH sites across most years (Figs. 6 and 7). Across the study period, the highest CA occurred between August and November for BSCH and SEBS sites except for BS02 2013 (June; sampling ended Aug. 17), PM02 2018 (July), and PM04 2018 (July) (Fig. 5). In contrast, the month with the most days with calls at BSCH and SEBS sites varied from June to December depending on the site and year (Figs. 7 and 8). Overall lower CA and intermittent calling occurred at sites PM02 and PM04 sites in fall 2018, which included an absence of calls from late November to mid-December followed by a return of calling until the end of sampling (Fig. 5). In the NBS, low CA (< 25%) and intermittent occurrence (< 10 days) were observed over the study period, with the exception of high CA (≥ 80%) and number of days (>20 days) in fall 2016 at BS01 (Figs. 5 and 8). Overall, the fall 2016 BS01 data line up temporally with acoustic detections at all southward sites (Figs. 5 and 6) and included patterned gunshots believed to be produced exclusively by NPRW in this region (Crance et al. 2019). Together, these data support a pulse in NPRW CA in summer and fall months across the majority of the study area in 2016, extending from PM02 to BS01 (Figs. 6 and 8). The month with the most days with calls at NBS sites varied by site, ranging from June to November at site BS01 and May to September at site PM08 (Figs. 7 and 8).

Sea ice concentration varied across site and year (Fig. 5). Sea ice was absent at the most southward site, PM02, in the winters of 2013-14, 2014-15, 2015-16, and 2017-18. Ice was also absent at sites BS03 and PM04 in 2015-16 and 2017-18 and absent at site PM05 in 2017-18. For all of these corresponding moorings except PM05, calling occurred past December 31st (Figs. 5

and 8). In addition, calling extended past December 31st at PM02 2016-17 and did not overlap with ice presence. The latest open water calling occurred in March 2016 at PM04 (Figs. 5 and 8).

In general, calling relative to ice retreat, defined as the last day with sea ice concentration ≥ 15% (Serezze et al. 2009, 2016; Stroeve et al. 2012; Escajeda et al. 2020), varied by site (Fig. 5). Calls were recorded within 2 weeks of ice retreat across most years at SEBS site BS02. In addition, calls were recorded within 2 weeks of ice retreat in spring 2013 at BSCH site PM02 and SEBS site PM05 as well as in spring 2015 and 2016 at NBS site BS01. For the remaining sites, the onset of seasonal calling lagged ice retreat by one month to several months depending on year and location. Calling relative to ice formation, defined as the first day with sea ice concentration ≥ 15% (Serezze et al. 2009, 2016; Stroeve et al. 2012, Escajeda et al. 2020), also varied by site (Fig. 5). Calls were detected within 2 months prior to ice formation across moorings, with the majority of detections within one month of ice formation (Fig. 5). As previously mentioned, days spanning ice and bowhead presence were removed; the extent of NPRW calling during this period is unknown.

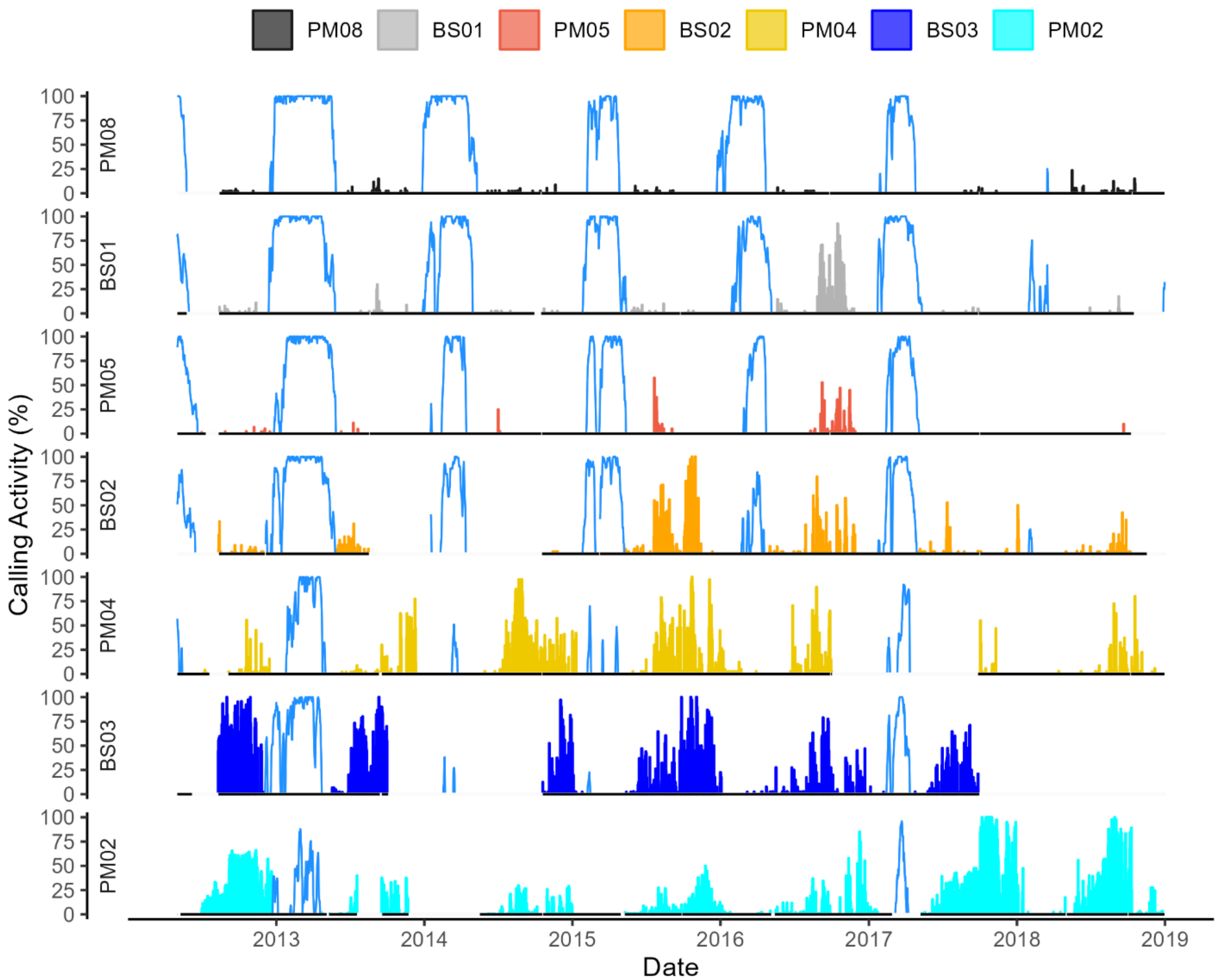


Figure 5. -- Daily calling activity (CA; %) of NPRW vocalizations by site (row; colors correspond to Fig. 1) from May 2012 through Dec. 2018. Also shown is the daily ice concentration (0-100%; thick blue line) on the same scale as CA (0-100%). Gaps in sampling denoted with breaks in black horizontal bar for each site. Days with calls spanning the period of ice or bowhead whale calls were excluded (Fig. 3).

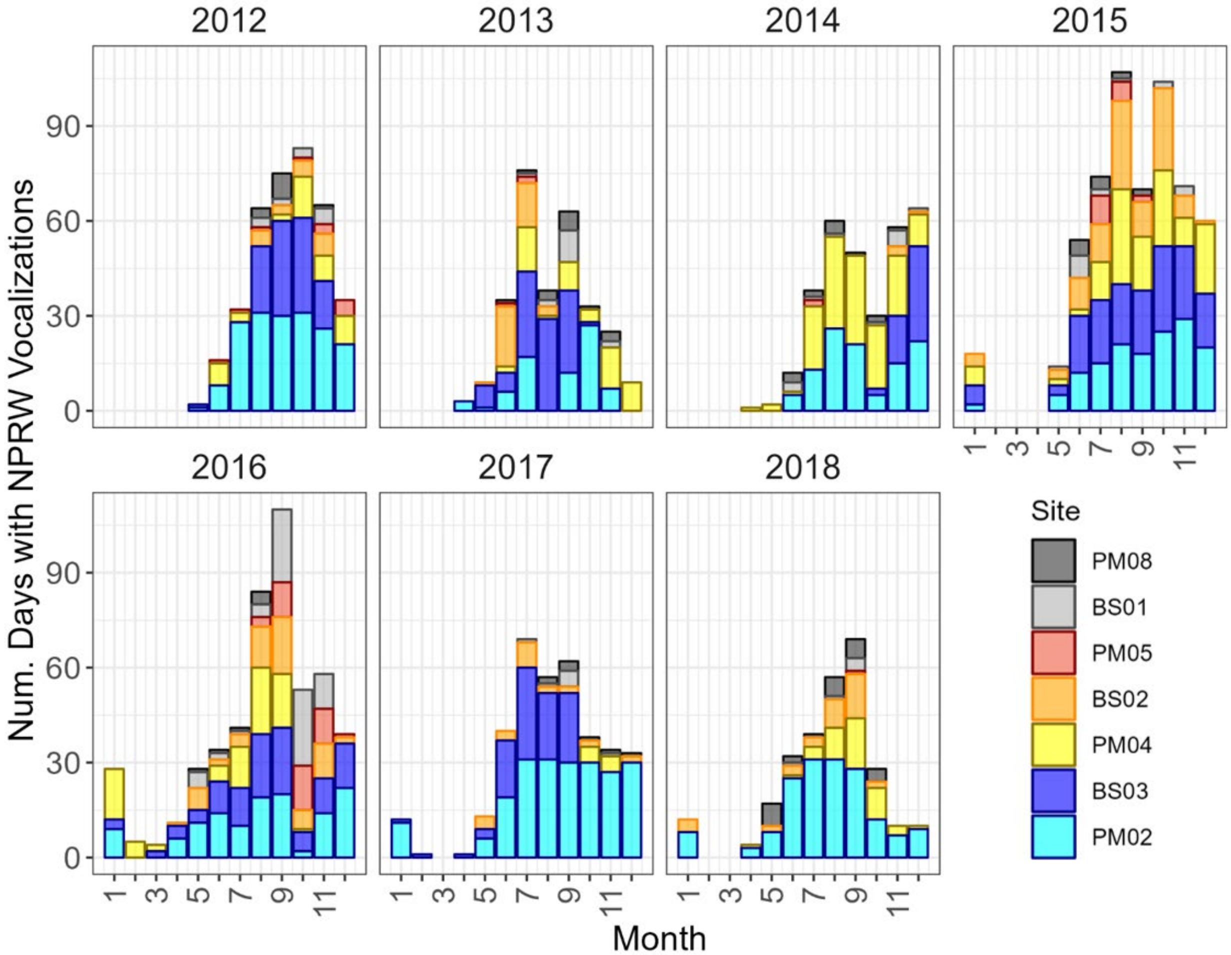


Figure 6. -- Stacked bar chart. Number of days with NPRW calls by month (Jan. =1, Feb. = 2, etc.) and site (colored bar; colors correspond to Fig. 1) for each year (box), 2012 to 2018. Note that not all days were recording at each site and year. Refer to Appendix Table A-1 for recorder deployment and retrieval dates.

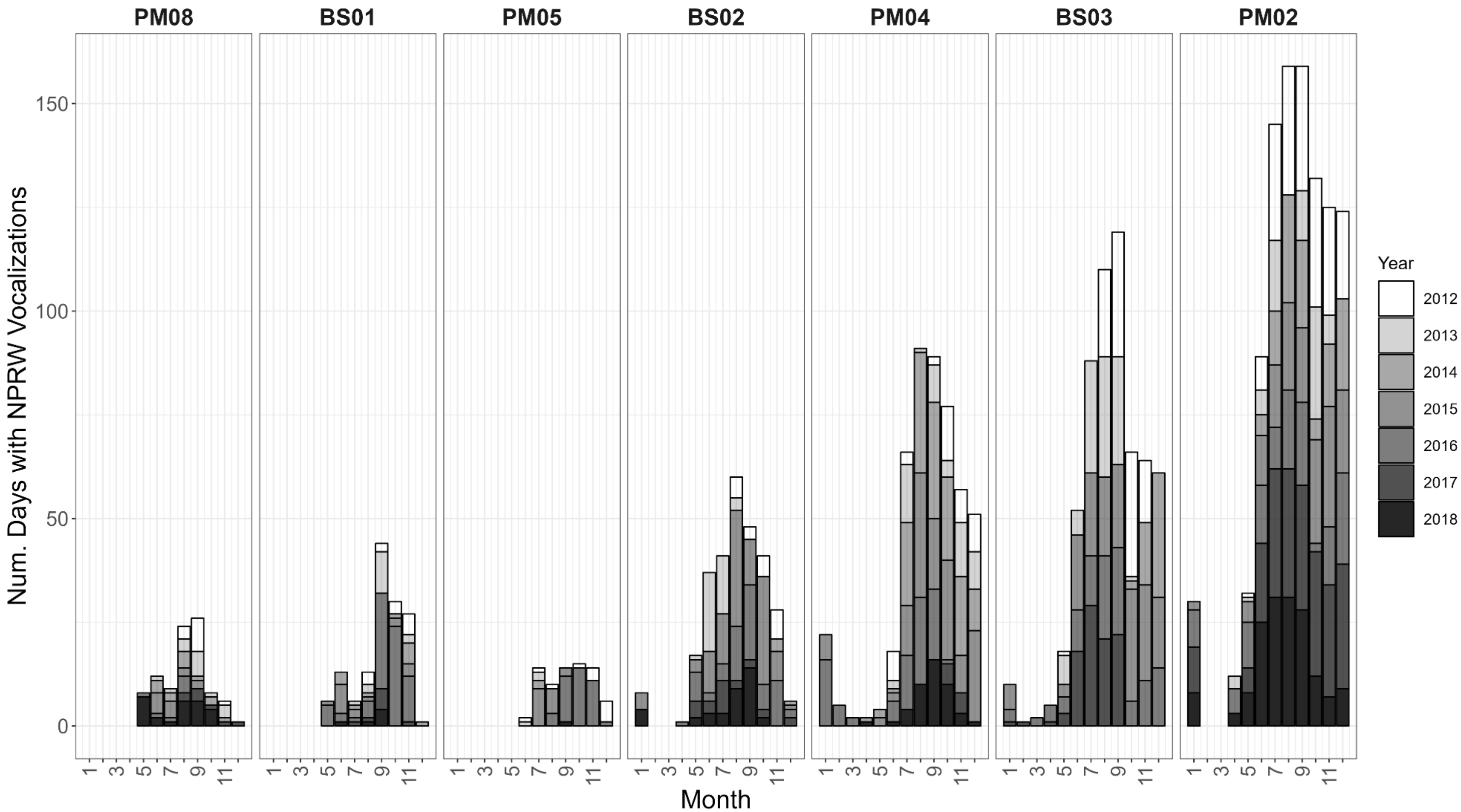


Figure 7. --Stacked bar chart. Number of days with NPRW calls by month and site for each year (bar transparency), 2012 to 2018. Refer to Appendix Table A-1 for recorder deployment and retrieval dates.

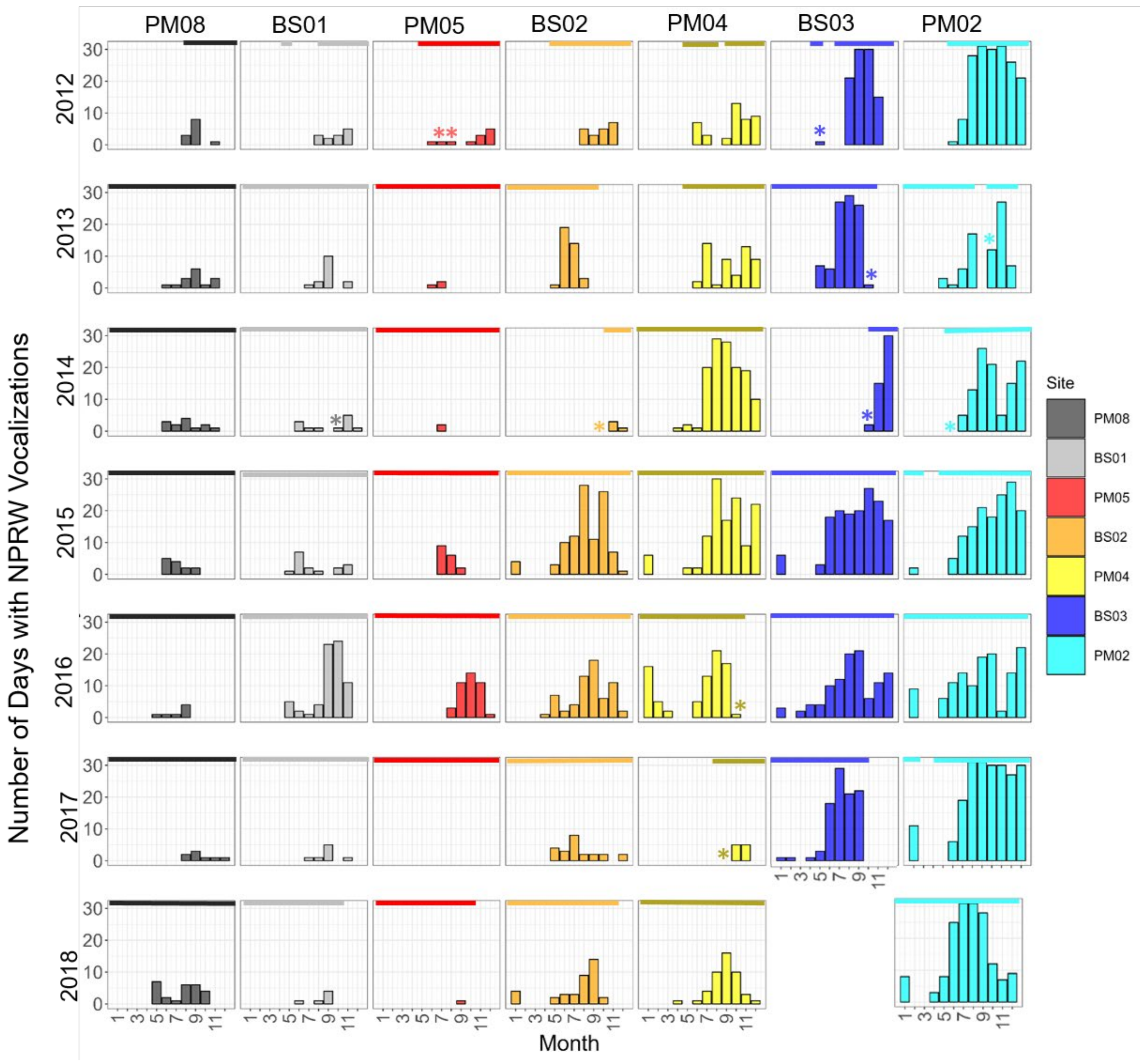


Figure 8. -- Number of days with NPRW calls by month (columns) and site (boxes; colors correspond to Fig. 1) for each year (row), 2012 to 2018. Horizontal bars denote months with recording effort. Asterisk indicates months with < 50% of days sampled. Refer to Appendix Table A-1 for recorder deployment and retrieval dates. Plots (Appendix Figs. C-1 – C-7) and tables (Appendix Tables C-1 – C-14) of each mooring are presented in Appendix C.

Seasonal Period 15 May to 31 December

Percentage of Days with Calls (PoD)

The highest PoD occurred at PM02 in 2017 (88%) followed by PM02 in 2012 (79%; Fig. 9). By site, the highest PoD occurred in 2014 for PM04 (56%), 2015 for BS03 (63%) and BS02 (45%), 2016 for PM05 (18%) and BS01 (31%), 2017 for PM02 (88%), and 2018 for PM08 (11%). In contrast, the lowest PoD occurred in 2014 for PM02 (47%), 2016 for BS03 (41%) and PM08 (3%), 2017 for BS02 (9%), PM05 (0%), and BS01 (4%), and 2018 for PM04 (20%: Fig. 10). Across sites, PoD decreased at BSCH sites and increased at SEBS and NBS sites in 2015 and 2016 compared with 2017 (Fig. 9).

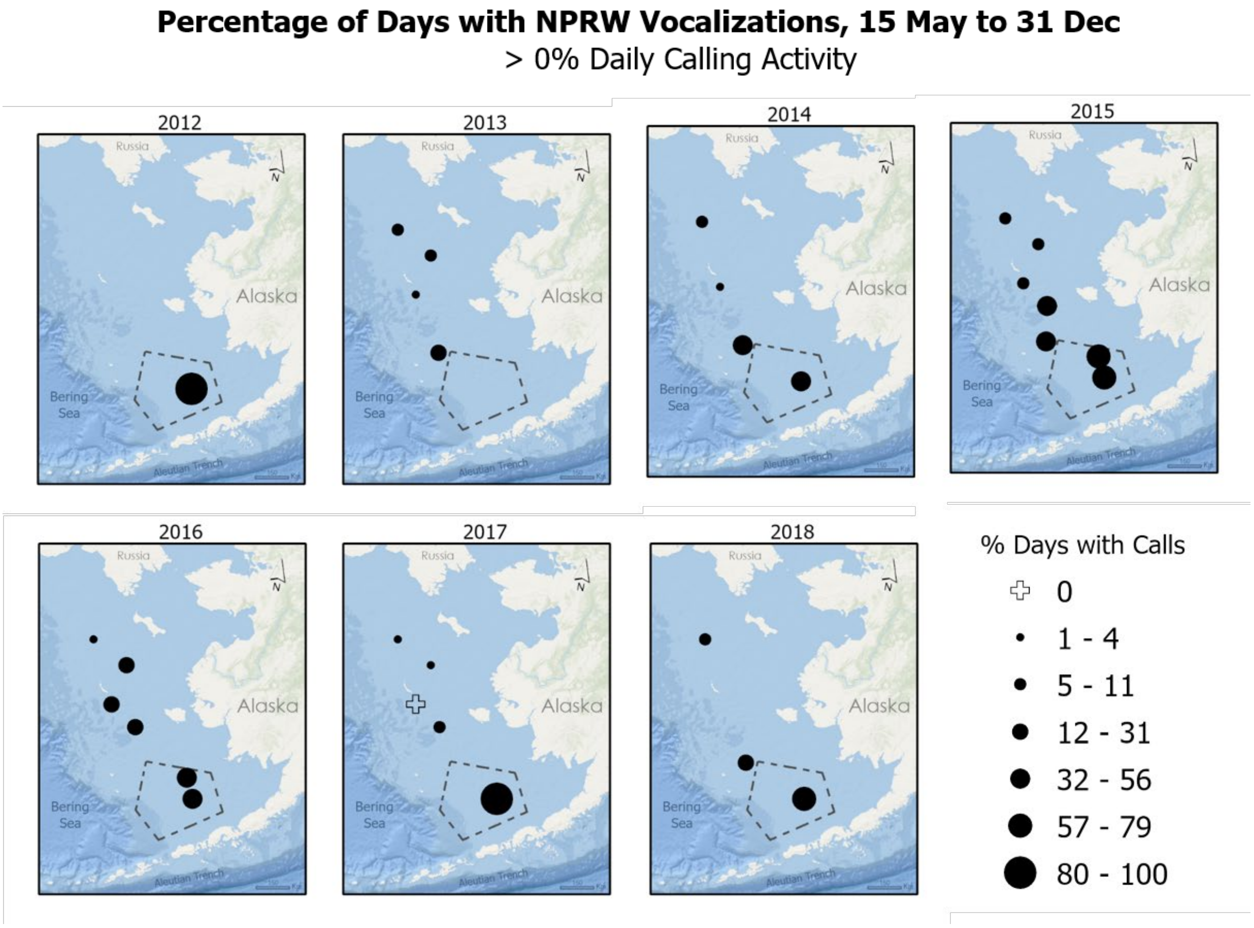


Figure 9. -- Percentage of days with daily calling activity (CA, %) > 0 for NPRW vocalizations during 15 May to 31 Dec. period by site and year, 2012 to 2018; refer to Figure 1 for all site locations. Moorings with zero days of calling denoted with cross; moorings with no symbol had > 5 days of missing data during the period for a given year (see Appendix Table A-1). CA label thresholds defined using natural breaks.

Calling Activity Trends

Trends in CA were similar to PoD across years and sites. For example, higher CA occurred at BSCH sites in 2017 compared with 2015 and 2016 while SEBS and NBS sites showed an opposite trend. Similarly, the highest CA occurred at PM02 in 2017 (52.2% [47.9, 56.4; 95% credible interval]) followed by PM02 in 2012 (42.4% [37.7, 47.3; Table 2, Fig. 10). The highest CA by site occurred in 2014 for PM04 (17.1% [14.0, 20.5]), 2015 for BS02 (15.0% [11.9, 18.4]) and BS03 (19.0% [16.0, 22.4]), 2016 for PM05 (2.6% [1.7, 3.7]) and BS01 (9.2% [6.7, 12.1]), 2017 for PM02 (52.2% [47.9, 56.4), and 2018 for PM08 (0.6% [0.3, 0.9]; Table 2, Fig. 11). The lowest CA by site occurred in 2016 for PM02 (9.8% [7.4, 12.1]), BS03 (7.8% [5.8, 10.2]), and PM08 (0.1% [0, 0.2]), 2017 for BS02 (0.9% [0.3, 1.5]), PM05 (0% [0, 0]), and BS01 (0.1% [0, 0.2]), and 2018 for PM04 (3.1% [1.9, 4.7]; Table 2, Fig. 10).

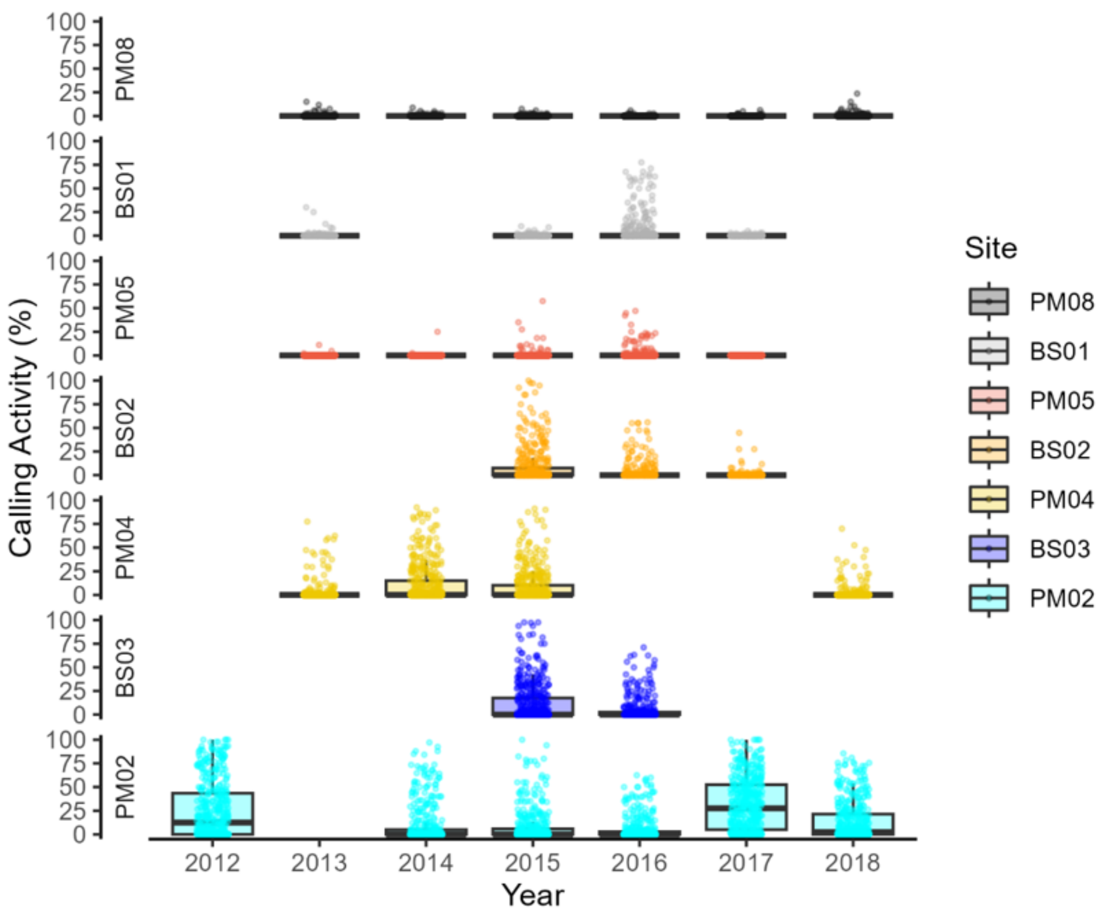


Figure 10. -- Boxplot illustrating NPRW daily calling activity (CA; %) for 15 May to 31 Dec. period by year (2012-2018) and site (colors correspond to Fig. 1). Each box represents the interquartile range (IQR) with the median indicated by a horizontal line inside the box. Whiskers extend to 1.5 times the IQR. Raw data points are overlaid using jittered points to provide a comprehensive view of the distribution within each group. Note that moorings with > 5 days missing for a given year were excluded (Fig. 3).

Table 2. -- Mean [95% bootstrapped confidence interval] daily calling activity (CA, %) for NPRW vocalizations detected for period 15 May to 31 Dec. by site, 2012 – 2018.

Year	PM08	BS01	PM05	BS02	PM04	BS03	PM02
2012	--	--	--	--	--	--	42.4 [37.7, 47.3]
2013	0.4 [0.2, 0.7]	0.6 [0.2, 1.4]	0.1 [0, 0.2]	--	4.8 [3.1, 6.7]	--	--
2014	0.2 [0.1, 0.4]	--	0.1 [0, 0.5]	--	17.1 [14.0, 20.5]	--	16.3 [12.6, 19.9]
2015	0.2 [0.1, 0.4]	0.3 [0.2, 0.6]	1.2 [0.5, 2.1]	15.0 [11.9, 18.4]	14.6 [11.8, 17.9]	19 [16.0, 22.4]	13.9 [11.2, 17.1]
2016	0.1 [0, 0.2]	9.2 [6.7, 12.1]	2.6 [1.7, 3.7]	5.2 [3.7, 6.9]	--	7.8 [5.8, 10.2]	9.8 [7.4, 12.1]
2017	0.2 [0, 0.3]	0.1 [0, 0.2]	0 [0, 0]	0.9 [0.3, 1.5]	--	--	52.2 [47.9, 56.4]
2018	0.6 [0.3, 0.9]	--	--	--	3.1 [1.9, 4.7]	--	21.9 [18.5, 25.7]
Across yrs	0.3 [0.2, 0.4]	2.8 [2.0, 3.6]	0.8 [0.6, 1.1]	6.9 [5.6, 8.3]	10.1 [8.9, 11.4]	13.5 [11.5, 15.7]	26.1 [24.3, 27.8]
Total	9.1 [8.6, 9.6]						

Calling Activity Thresholds

Medium CA (≥ 50%) was present in all years in the BSCH and at all SEBS sites in 2015 (Fig. 11). In addition, medium CA was present at SEBS site PM04 in 2013, 2014, and 2018, as well as SEBS site BS02 in 2016 and NBS site BS01 in 2016 (Fig. 11). High CA (≥ 80%) was present for at least one day at PM02 in all years except 2013 (Fig. 12). In addition, high CA was present for PM04 in 2014, PM04 and PM05 in 2015, and BS01 in 2016 (Fig. 12).

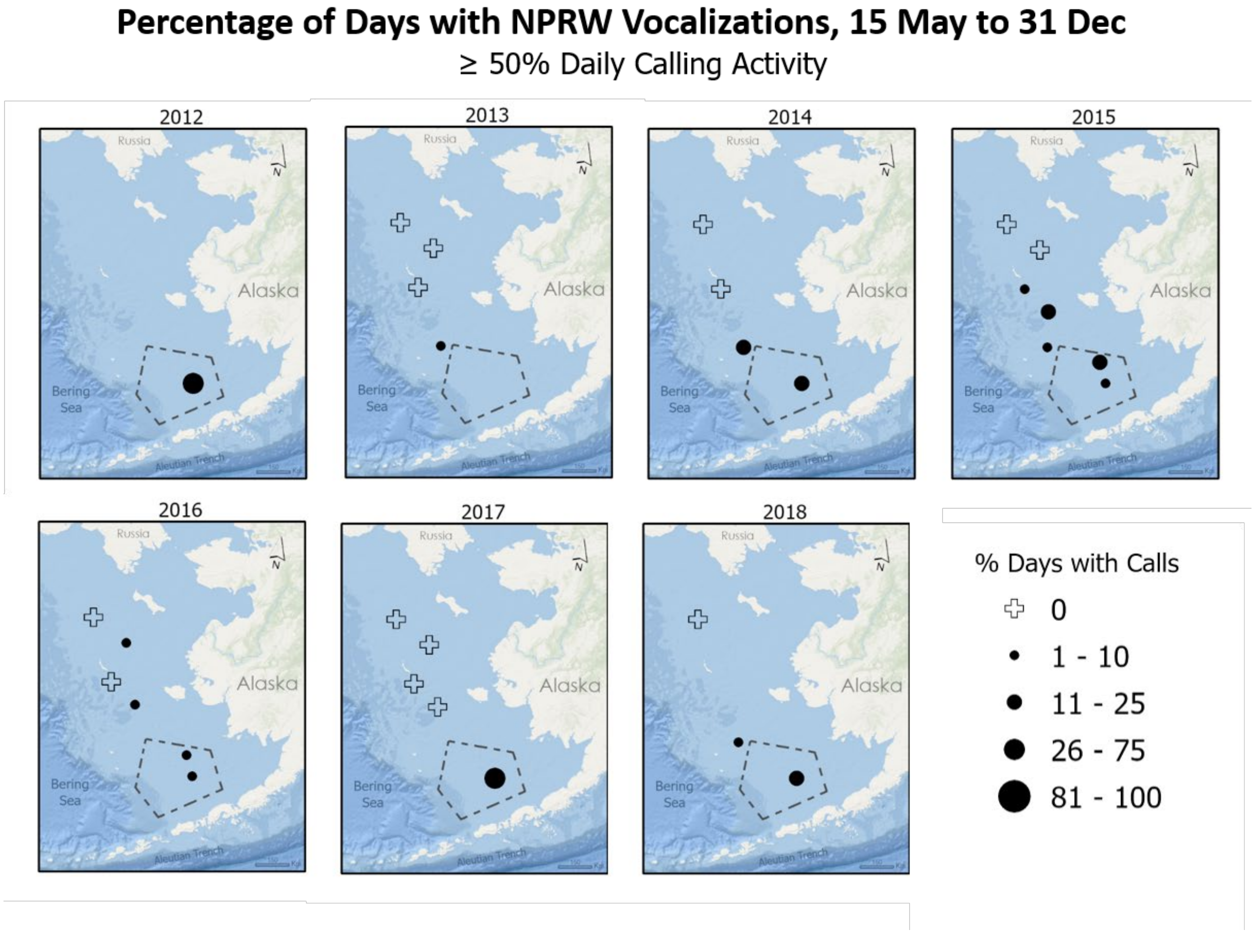


Figure 11. -- Percentage of days with daily calling activity (CA, %) ≥ 50 for NPRW vocalizations for 15 May to 31 Dec. by site and year, 2012 to 2018; refer to Figure 1 for all site locations. Moorings with zero days of calling denoted with cross; moorings with no symbol had > 5 days of missing data and were excluded (see Appendix Table A-1). CA label thresholds defined using natural breaks.

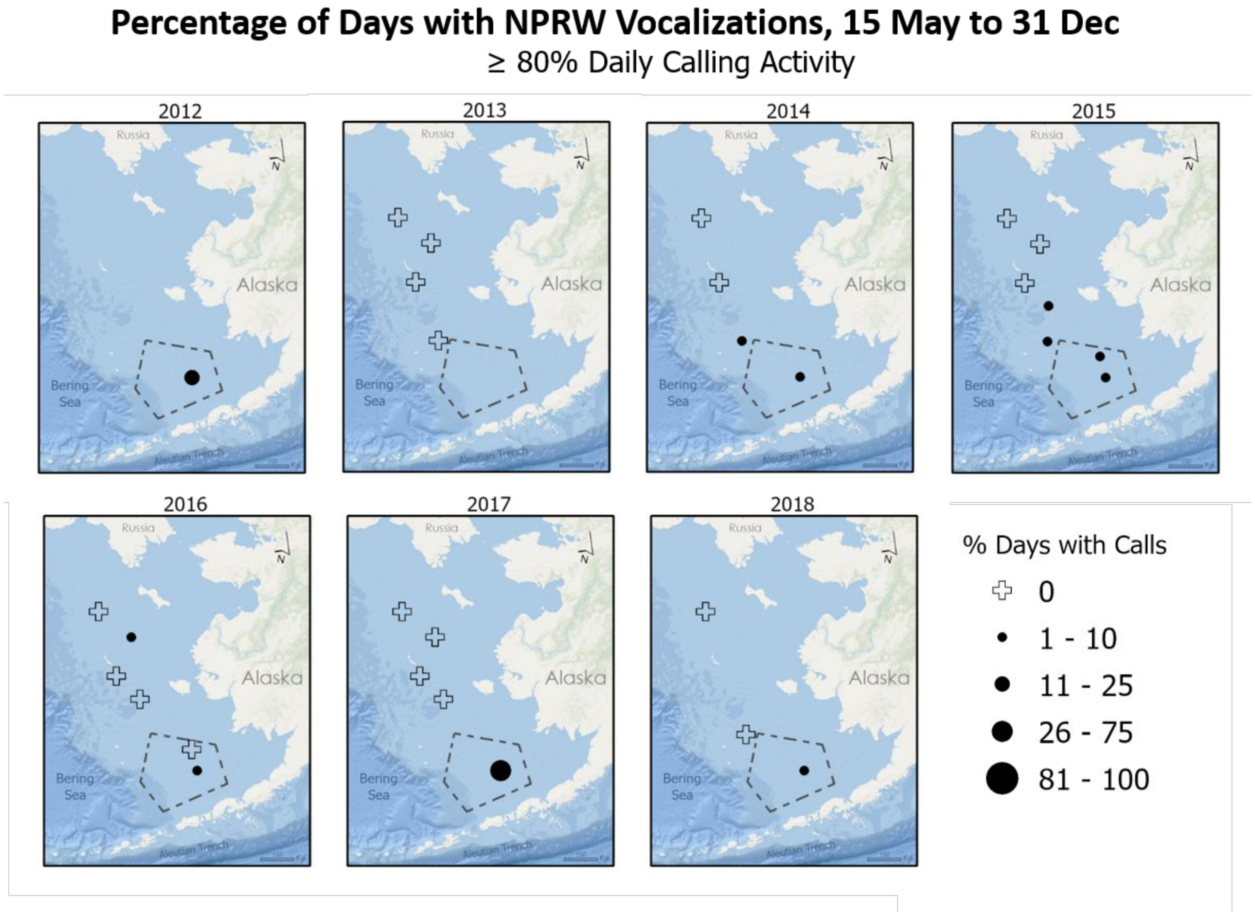


Figure 12. -- Percentage of days with daily calling activity (CA, %) ≥ 80 for NPRW vocalizations for 15 May to 31 Dec. by site and year, 2012 to 2018; refer to Figure 1 for all site locations. Moorings with zero days of calling denoted with cross; moorings with no symbol had > 5 days of missing data during the period for a given year (see Appendix Table A-1). CA label thresholds defined using natural breaks.

Table 3. -- Kruskal-Wallis rank sum tests comparing daily CA (%) for NPRW vocalizations by year and site for 15 May to 31 Dec. period. Significance defined as α < 0.05; denoted with bold. Post-hoc results in Appendix D.

Data	Model	Test Statistic (X^2)	Degrees of Freedom	p-value
PM02	~ year[a]	286.4	5	**< 0.0001**
BS03	~ year[b]	32.3	1	**< 0.0001**
PM04	~ year[c]	113.0	3	**< 0.0001**
BS02	~ year[d]	84.9	2	**<0.0001**
PM05	~ year[e]	90.6	4	**< 0.0001**
BS01	~ year[f]	96.1	3	**< 0.0001**
PM08	~ year[g]	17.6	5	**0.001 – 0.01**
2013	~Site[h]	206.6	2	**< 0.0001**
2014	~ Site[i]	252.3	3	**< 0.0001**
2015	~ Site[j]	384.3	6	**< 0.0001**
2016	~ Site[k]	143.4	5	**< 0.0001**
2017	~ Site[l]	810.4	4	**< 0.0001**
2018	~Site[m]	206.6	2	**< 0.0001**

[a]2012, 2014, 2015, 2016, 2017, 2018
[b]2015, 2016
[c]2013, 2014, 2015, 2018
[d]2015, 2016, 2017
[e]2013, 2014, 2015, 2016, 2017
[f]2013, 2015, 2016, 2017
[g]2013, 2014, 2015, 2016, 2017, 2018
[h]PM04, PM05, PM08
[i]PM02, PM04, PM05, and PM08
[j]PM02, BS03, PM04, BS02, PM05, BS01, PM08
[k]PM02, BS03, BS02, PM05, BS01, PM08
[l]PM02, PM05, BS01, PM08
[m]PM02, PM04, PM08

Kruskal-Wallis Tests

K-W tests revealed that annual mean CA varied by year for each site and among sites for each sampled year (Table 3; post hoc tables in APPENDIX D). Post-hoc analysis comparing annual means of daily CA (%) varied by site (Appendix Tables D-1-D-7). For PM02, annual pairings were different for all pairwise comparisons except 2014/2015 ($p = 0.38$), 2014/2016 ($p = 0.38$), and 2015/2018 ($p = 0.11$; Appendix Table D-1). For BS03, years 2015 and 2016 were different ($p < 0.0001$; Appendix Table D-2). For PM04, annual pairs were different for all pairs except

2013/2018 (p = 0.50) and 2014/2015 (p = 0.50; Appendix Table D-3). For BS02, all year pairings of 2015, 2016, and 2017 differed ($p < 0.0001$; Appendix Table D-4). For PM05, annual pairs differed for all pairs except 2013/2014 (p = 1.0), 2013-2017 (p = 1.0), and 2014/2017 (p = 1.0; Appendix Table D-5). For BS01, 2016 differed from all other years (2013, 2015, 2017; $p <$ 0.0001; Appendix Table D-6). For PM08, 2018 differed from 2016 ($0.001 \leq p \leq 0.01$) and 2017 (p = 0.01; Appendix Table D-7).

Post hoc analysis comparing site means by year for CA (%) also varied (Appendix Tables D-8-D-14). In 2013, PM04 differed from all other sites (PM05, BS01, PM08; $p < 0.0001$; Appendix Table D-8). In 2014, PM05 and PM08 differed from PM02 and PM04 ($p \leq 0.0001$; Appendix Table D-9). Similarly, in 2015, the NBS and BS05 sites did not differ (p = 1.0), and the BSCH and PM04 sites did not differ (Appendix Table D-10). Also in 2015, BS02 differed from all sites except PM04 (p = 1.0). In contrast, in 2016, NBS site PM08 differed from all other sites (Appendix Table D-11). Also in 2016, BSCH site PM02 differed from all sites except BS03 (p = 0.21). Moreover, in 2016, BS01 did not differ from BS02 (p = 0.21) and BS03 (p = 0.20), while PM05 did not differ from BS02 (p = 0.12; Appendix Table D-12). In 2017, PM02 differed from all other sites (Appendix Table D-13). In 2018, PM02 differed from all other sites (PM04 and PM08; $p \leq 0.0001$; Appendix Table D-14).

DISCUSSION

Distribution and Seasonality

PAM data revealed NPRW presence on the eastern Bering shelf over the 2012 to 2018 study period. Our results support prior work from the early 2000s that found NPRW calling is greatest within the BSCH (Munger et al. 2008). Additionally, NPRW vocalizations were heard outside of the BSCH in all years, most consistently at SEBS sites PM04 and BS02. Moreover, low and infrequent levels of calling occurred in the NBS for most years, dominated by individual, non-patterned gunshot calls (discussed below). An exception to this trend in the NBS is the occurrence of patterned gunshots during fall 2016 at site BS01. These BS01 gunshots occurred among NPRW upcalls at this site and lined up temporally with a pulse in NPRW detections at all southward sites, suggesting the NPRW distribution spanned nearly the entire study region in fall 2016.

The year 2016 was the third consecutive year of low sea ice extent (Stabeno et al. 2019). Sea ice is a primary driver of NPRW prey dynamics in the study region, influencing the quantity and quality of NPRW prey (Hunt et al. 2008, 2011; Stabeno et al. 2012b; Eisner et al. 2014; Kimmel et al. 2018; Nielson et al. 2024). NPRW tagging efforts uncovered a wider distribution of individual animals on the Bering shelf during years with reduced ice extent, which the authors attributed to possible distribution shifts in prey resources (Zerbini et al. 2015). Recent modeling efforts also hypothesize a northward shift in NPRW prey with reducing sea ice extent (Wright et al. 2023). Thus, it is possible that our 2016 acoustic data reflect shifts in NPRW distribution on the eastern Bering shelf driven by lower trophic level dynamics. In addition, the highest CA and PoD at all SEBS sites occurred in years following winters with low ice extent (2014-2016) while detections in the BSCH decreased during that period. Moreover, trends in the CA and PoD were nearly identical for BSCH site PM02 in years with larger ice extent (2012 and 2017). Seasonal calling also extended into winter months during low ice-extent years at BSCH sites and SEBS site PM04. Together, these data suggest variability in NPRW distribution and seasonal occurrence over the study period that is linked to sea ice dynamics.

Further, we found lower CA and intermittent calling across sites in fall 2018, which included an absence of calls across mooring sites from late November to mid-December that was not seen in prior years. The unprecedented low sea ice extent in the previous winter of 2017-18 in the Bering Sea (Stabeno and Bell 2019) had cascading effects on trophic dynamics in the region (Duffy-Anderson et al. 2019, Kimmel et al. 2023, Nielson et al. 2024), and it is believed to represent a window into a future new normal as the Arctic continues to warm (Wang and Overland 2009, Sigmond et al. 2018). As aforementioned, some NPRW tagged on the southeastern Bering Sea shelf in low ice extent years moved west to deeper waters on the shelf during fall months, which was hypothesized to be the result of changes in prey distribution on the shelf (Zerbini et al. 2015). Thus, it is possible that NPRW in 2018 used waters outside of our recording range from late November to mid-December. The return of NPRW calling at southern sites from mid-December to the end of sampling in 2018 could be explained by animals returning to the recording area. While specific migratory routes and patterns remain unknown, the timing of these late December detections could coincide with a southbound migration to lower latitudes.

Together, our findings strongly support continued PAM on the Bering shelf as well as increasing the recorder network on the Bering shelf to identify habitat for NPRW as climate continues to change in this region. We are currently processing PAM data from sites in the Aleutian Passes that overlap with our study period.

Calls in the Northern Bering Sea

The calls detected on the NBS BS01 site in the fall of 2016 likely came from NPRW as they included patterned gunshots (Crance et al. 2019), aligned temporally with southward sites, and were relatively large in CA (> 80%), consistent with southward sites. Presence of NPRW in the

NBS could become a conservation concern, as the Bering Strait is the only way to access the Pacific Arctic. This busy choke-point (Silber and Adams 2019) is expected to see an increase in vessel traffic as sea ice continues to decline, putting NPRWs in this region at increased risk of ship-strike. NPRW are especially vulnerable, as their foraging behavior is believed to heavily increase the likelihood of ship strike or entanglement, as shown in the congeneric North Atlantic right whales (*Eubalaena glacialis*; Baumgartner et al. 2017).

Outside of 2016, the majority of NBS 'yes' NPRW vocalizations were flagged as ambiguous, as they fit the call characteristics of NPRW but had minimal contextual information. The similar call repertoires of other baleen whales, namely humpback whales and bowhead whales in this region, preclude us from definitively concluding that all of the ambiguous NBS detections belong to NPRW. Bowhead whales have historically ranged in the northern Bering Sea outside of the winter (Bockstoce et al. 2005), but contemporary tagging efforts of eastern Bering-Chukchi-Beaufort bowhead whales have not shown animals in the Bering Sea outside of winter months (Citta et al. 2012, 2013, 2015). The absence of patterned gunshots calls outside of 2016 and overall low number of upcalls in the NBS could be explained by the low population size of NPRW combined with their tendency to call in bouts that might be missed as a result of duty cycling (Wright et al. 2018) and multiple possible functions of gunshot calls. Thus, it is possible that NPRW are vocalizing in the NBS across warm and cold years (Stabeno et al. 2012b), with more calling observed during low ice extent years such as 2016. Together, our NBS results warrant further investigation into call repertoires and distribution of NPRW, humpback, and bowhead whales in the NBS. Advancements in depth and range estimation of baleen whale species from single hydrophones (e.g., Bonnel et al. 2014, Thode et al. 2017) could be implemented in our study region to discern species with overlapping call repertoires for cases of individual vocalizations (e.g., bowhead and right whales).

Conclusions

NPRW vocalizations were detected on the eastern Bering shelf over a period of climate variability between 2012 and 2018, supporting the utility of PAM in monitoring this rare population in the Bering Sea. Calls were heard most frequently in the Bering Sea critical habitat, but NPRW vocalizations were also regularly detected north of the BSCH across the study period at stations PM04 and BS02. Similar to prior studies from the early 2000s, calling peaked in fall months across sites, suggesting seasonal occurrence in this area. Furthermore, trends in calling activity (CA) and occurrence (# days, PoD) suggest changes in distribution relative to ice extent, with an increase in both CA and occurrence north of the critical habitat in low ice years. A low and intermittent calling in 2018 following an unprecedented warm winter suggest seasonal distribution shifts that may be attributed to lower trophic level dynamics that are ultimately influenced by ice extent. Notably, patterned gunshot calls attributed to NPRW in the northern Bering Sea across 3 months in 2016 advocate for continued monitoring to ascertain drivers of habitat use in this region. Together, our results continue to support that the eastern Bering shelf is important habitat for NPRW and reveal variability in acoustic occurrence over the study that could be correlated to sea ice extent, which will continue to impact this Arctic environment under a changing climate.

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APPENDIX A: MOORING METADATA

Appendix Table A-1. -- Mooring deployments and sampling.

Mooring	Site	Record Start Date	Record End Date	# Days Record	Region	Lat (°N)	Long (°W)	Water Depth (m)	Sensor Depth (m)	Recorder Type	Sampling Rate	Duty Cycle: On [Total Cycle] (mins)
BS11_AU_PM08	PM08	8/16/2011	4/25/2012	254	NBS	62.196	174.66	71	65	AURAL	8192	6 [20]
BS12_AU_PM08	PM08	8/14/2012	8/20/2013	372	NBS	62.195	174.66	71	66	AURAL	16384	85 [300]
BS13_AU_PM08	PM08	8/20/2013	10/15/2014	422	NBS	62.193	174.676	72	65	AURAL	16384	80 [300]
BS14_AU_PM08	PM08	10/17/2014	9/24/2015	343	NBS	62.19	174.69	70	69	AURAL	16384	80 [300]
BS15_AU_PM08	PM08	9/25/2015	9/25/2016	367	NBS	62.194	174.684	72	68	AURAL	16384	80 [300]
BS16_AU_PM08	PM08	9/27/2016	9/29/2017	368	NBS	62.198	174.687	73	65	AURAL	16384	80 [300]
BS17_AU_PM08	PM08	10/1/2017	10/11/2018	376	NBS	62.199	174.678	74	70	AURAL	16384	80 [300]
BS18_AU_PM08	PM08	10/13/2018	9/23/2019	346	NBS	62.195	174.684	73	68	AURAL	16384	80 [300]
RW11_EA_BS01	BS01	9/4/2011	5/25/2012	265	NBS	61.587	171.324	54	50	EAR	4000	4 [60]
AW12_AU_BS01	BS01	8/13/2012	8/19/2013	372	NBS	61.588	171.324	52	49	AURAL	16384	85 [300]
AW13_AU_BS01	BS01	8/21/2013	9/29/2014	405	NBS	61.587	171.328	51	48	AURAL	16384	80 [300]
AW14_AU_BS01	BS01	10/16/2014	9/23/2015	343	NBS	61.586	171.328	63	47	AURAL	16384	80 [300]
AW15_AU_BS01	BS01	9/25/2015	9/25/2016	367	NBS	61.586	171.332	52	48	AURAL	16384	80 [300]
AL16_AU_BS01	BS01	9/26/2016	9/28/2017	368	NBS	61.585	171.319	52	50	AURAL	16384	80 [300]
AL17_AU_BS01	BS01	9/29/2017	10/16/2018	383	NBS	61.588	171.31	54	47	AURAL	16384	80 [300]
BS11_AU_PM05	PM05	9/28/2011	7/11/2012	288	SEBS	59.909	171.704	70	60	AURAL	8192	6 [20]
BS12_AU_PM05	PM05	8/12/2012	8/18/2013	374	SEBS	59.912	171.709	71	63	AURAL	16384	85 [300]
BS13_AU_PM05	PM05	8/20/2013	10/16/2014	423	SEBS	59.91	171.705	72	62	AURAL	16384	80 [300]
BS14_AU_PM05	PM05	10/18/2014	9/25/2015	343	SEBS	59.913	171.709	70	61	AURAL	16384	80 [300]
BS15_AU_PM05	PM05	9/26/2015	9/26/2016	367	SEBS	59.907	171.733	68	62	AURAL	16384	80 [300]
BS16_AU_PM05	PM05	9/28/2016	9/27/2017	365	SEBS	59.911	171.732	68	60	AURAL	16384	80 [300]
BS17_AU_PM05	PM05	9/29/2017	10/9/2018	376	SEBS	59.915	171.718	70	62	AURAL	16384	80 [300]

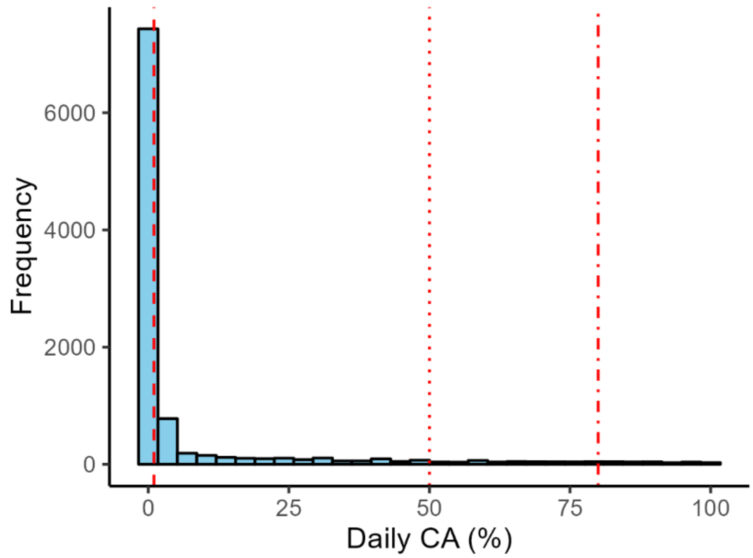
Appendix Table A-1. -- Cont.

Mooring	Site	Record Start Date	Record End Date	# Days Record	Region	Lat (°N)	Long (°W)	Water Depth (m)	Sensor Depth (m)	Recorder Type	Sampling Rate	Duty Cycle: On [Total Cycle] (mins)
AW12_AU_BS02	BS02	8/12/2012	8/17/2013	371	SEBS	59.244	169.413	53	49	AURAL	16384	85 [300]
AW14_AU_BS02	BS02	10/18/2014	9/26/2015	344	SEBS	59.243	169.414	65	50	AURAL	16384	80 [300]
AW15_AU_BS02	BS02	9/27/2015	9/27/2016	367	SEBS	59.243	169.413	53	49	AURAL	16384	80 [300]
AL16_AU_BS02	BS02	9/28/2016	9/30/2017	368	SEBS	59.241	169.417	52	49	AURAL	16384	80 [300]
AL17_AU_BS02	BS02	10/2/2017	11/17/2018	412	SEBS	59.234	169.408	55	48	AURAL	16384	80 [300]
BS11_AU_PM04	PM04	9/28/2011	7/20/2012	297	SEBS	57.858	168.881	72	66	AURAL	8192	6 [20]
BS12_AU_PM04	PM04	9/5/2012	9/12/2013	373	SEBS	57.867	168.872	72	64	AURAL	16384	85 [300]
BS13_AU_PM04	PM04	9/18/2013	10/17/2014	395	SEBS	57.867	168.873	75	65	AURAL	16384	80 [300]
BS14_AU_PM04	PM04	10/19/2014	9/26/2015	343	SEBS	57.882	168.879	70	65	AURAL	16384	80 [300]
BS15_AU_PM04	PM04	9/27/2015	9/27/2016	367	SEBS	57.895	168.878	70	66	AURAL	16384	80 [300]
BS16_AU_PM04	PM04	9/29/2016	10/2/2016	4	SEBS	57.895	168.878	70	64	AURAL	16384	80 [300]
BS17_AU_PM04	PM04	9/27/2017	10/7/2018	376	SEBS	57.872	168.892	72	64	AURAL	16384	80 [300]
BS18_AU_PM04	PM04	10/9/2018	9/28/2019	355	SEBS	57.866	168.884	72	65	AURAL	16384	80 [300]
RW11_EA_BS03	BS03	9/6/2011	6/7/2012	275	BSCH	57.67	164.725	54	51	EAR	4000	4 [60]
AW12_AU_BS03	BS03	8/11/2012	9/13/2013	399	BSCH	57.67	164.725	52	49	AURAL	16384	85 [300]
AW13_AU_BS03	BS03	9/18/2013	10/4/2013	18	BSCH	57.67	164.716	51	44	AURAL	16384	80 [300]
AW14_AU_BS03	BS03	10/20/2014	9/27/2015	343	BSCH	57.671	164.719	64	57	AURAL	16384	80 [300]
AW15_AU_BS03	BS03	9/28/2015	9/28/2016	367	BSCH	57.675	164.718	53	52	AURAL	16384	80 [300]
AL16_AU_BS03	BS03	9/29/2016	10/1/2017	368	BSCH	57.676	164.716	52	48	AURAL	16384	80 [300]

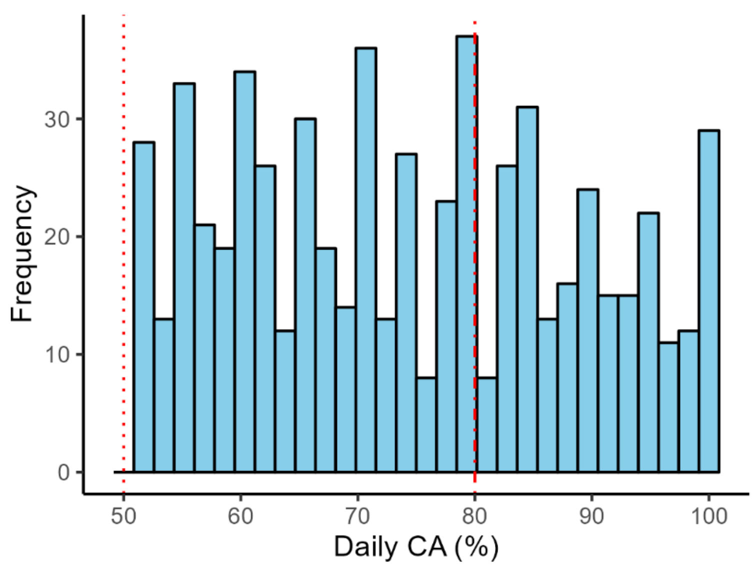
Appendix Table A-1. -- Cont.

Mooring	Site	Record Start Date	Record End Date	# Days Record	Region	Lat (°N)	Long (°W)	Water Depth (m)	Sensor Depth (m)	Recorder Type	Sampling Rate	Duty Cycle: On [Total Cycle] (mins)
BS12_AU_PM02-a	PM02	5/10/2012	9/7/2012	166	BSCH	56.865	164.059	73	67	AURAL	8192	40 [60]
BS13_AU_PM02-a	PM02	5/11/2013	7/19/2013	69	BSCH	56.866	164.057	72	65	AURAL	16384	210 [300]
BS14_AU_PM02-a	PM02	5/18/2014	10/19/2014	155	BSCH	56.872	164.05	72	68	AURAL	16384	255 [300]
BS15_AU_PM02-a	PM02	5/10/2015	9/27/2015	149	BSCH	56.867	164.067	73	61	AURAL	16384	180 [300]
BS16_AU_PM02-a	PM02	5/14/2016	9/29/2016	139	BSCH	56.873	164.053	72	65	AURAL	16384	180 [300]
BS17_AU_PM02-a	PM02	5/8/2017	10/2/2017	147	BSCH	56.871	164.05	70	64	AURAL	16384	180 [300]
BS18_AU_PM02-a	PM02	5/4/2018	10/1/2018	151	BSCH	56.933	164.06	71	62	AURAL	16384	180 [300]
BS12_AU_PM02-b	PM02	9/7/2012	5/5/2013	242	BSCH	56.866	164.057	73	64	AURAL	16384	135 [300]
BS13_AU_PM02-b	PM02	9/18/2013	11/23/2013	69	BSCH	56.863	164.059	71	63	AURAL	16384	165 [300]
BS14_AU_PM02-b	PM02	10/21/2014	4/30/2015	192	BSCH	56.871	164.055	71	65	AURAL	16384	165 [300]
BS15_AU_PM02-b	PM02	9/29/2015	5/5/2016	219	BSCH	56.878	164.065	70	65	AURAL	16384	165 [300]
BS16_AU_PM02-b	PM02	9/30/2016	2/27/2017	151	BSCH	56.87	164.066	71	65	AURAL	16384	80 [300]
BS17_AU_PM02-b	PM02	10/3/2017	5/1/2018	211	BSCH	56.873	164.054	73	64	AURAL	16384	80 [300]
BS18_AU_PM02-b	PM02	10/3/2018	4/24/2019	205	BSCH	56.869	164.06	70	65	AURAL	16384	130 [300]

APPENDIX B: HISTOGRAMS OF DAILY CA FOR NPRW VOCALIZATIONS



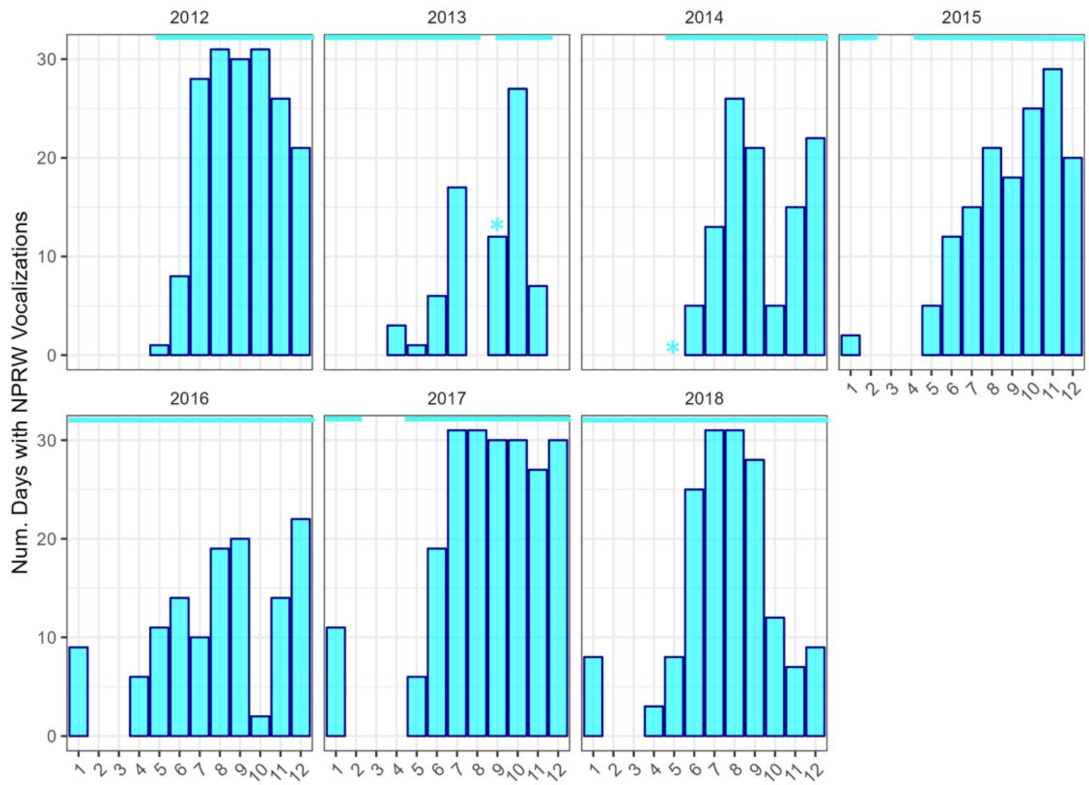
Appendix Figure B-1. --Histogram of Daily CA (%) for NPRW vocalizations. Red lines denote CA = 0% (dashed), 50% (dotted), and 80% (dot-dash).



Appendix Figure B-2. --Histogram of Daily CA (%) > 50% for NPRW vocalizations. Red lines denote CA = 50% (dotted), and 80% (dot-dash).

APPENDIX C: NUMBER OF DAYS WITH NPRW CALLS BY SITES, 2012 TO 2018

Site PM02



Appendix Figure C-1. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site PM02 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

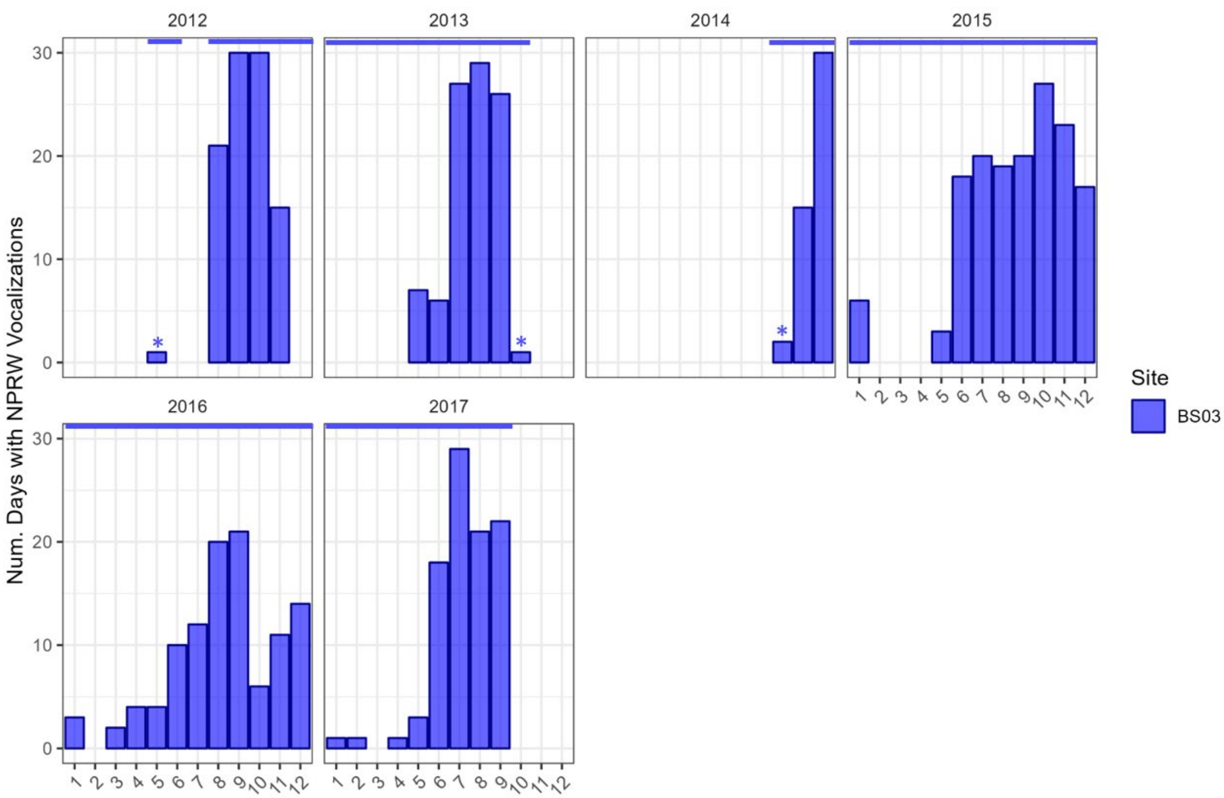
Appendix Table C-1. -- Effort Table. Number of days sampled by month at site PM02. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	--	3 (28)	31	31	31
Feb	--	28	--	28	29	27	28
Mar	--	31	--	10 (21)	31	--	31
Apr	--	13 (17)	--	30	30	--	30
May	17	26	13	22	23	24	29
Jun	30	30	30	30	30	30	30
Jul	31	19	31	31	31	31	31
Aug	31	--	31	31	31	31	31
Sep	31	13	30	29	30	30	30
Oct	31	31	30	31	31	30	30
Nov	30	23	30	30	30	30	30
Dec	22 (9)	--	31	31	31	31	31

Appendix Table C-2. -- Number of days with NPRW vocalizations by month at site PM02. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	11	--	2 (3)	9	11	8
Feb	--	0	--	1	0	0	0
Mar	--	0	--	0	0	--	0
Apr	--	3 (1)	--	0	6	--	3
May	1	1	0	5	11	6	8
Jun	8	6	5	12	14	19	25
Jul	28	17	13	15	10	31	31
Aug	31	--	26	21	19	31	31
Sep	30	12	21	18	20	30	28
Oct	31	27	5	25	2	30	12
Nov	26	7	15	29	14	27	7
Dec	21 (7)	--	22	20	22	30	9

Site BS03



Appendix Figure C-2. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site BS03 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

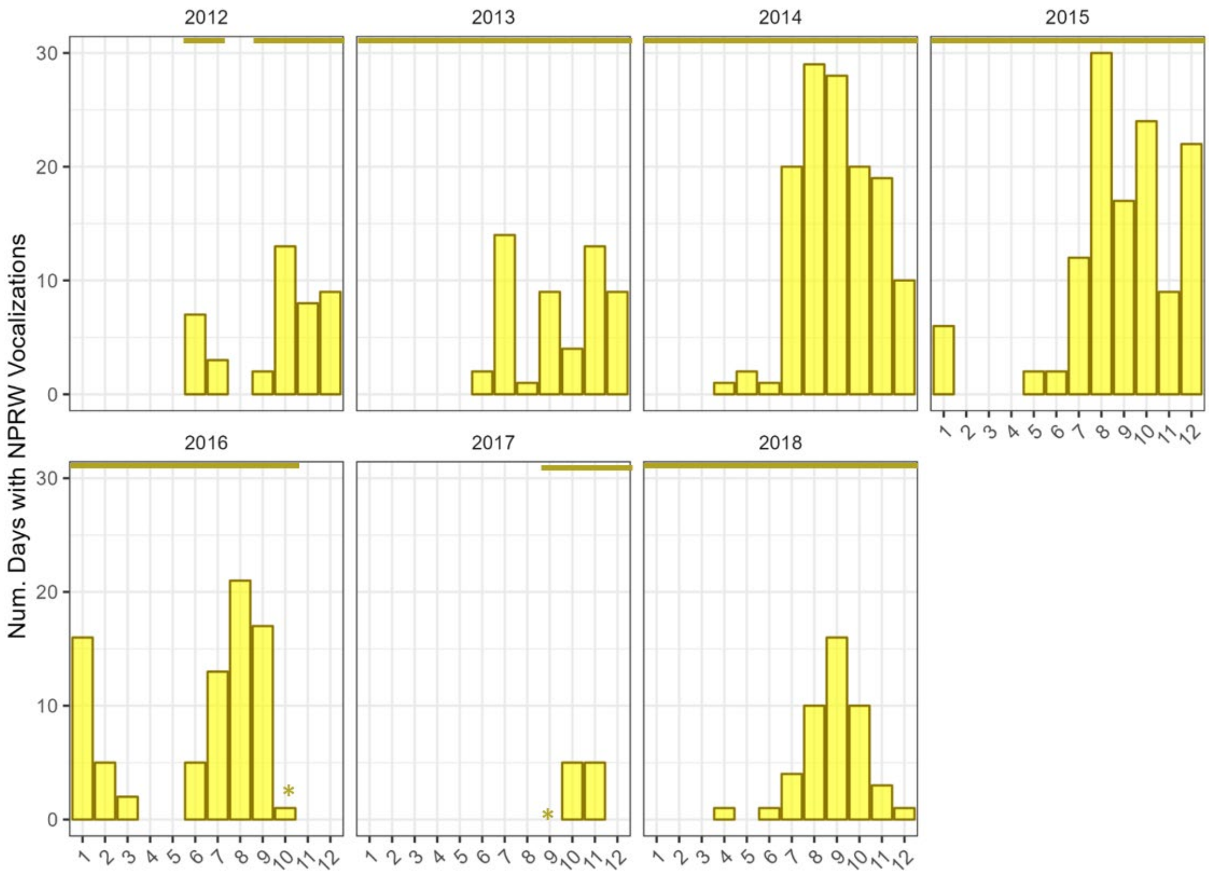
Appendix Table C-3. -- Effort Table. Number of days sampled by month at site BS03. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	--	31	31	31	--
Feb	--	28	--	4 (24)	29	14 (14)	--
Mar	--	31	--	31	31	31	--
Apr	--	30	--	24 (6)	30	19 (11)	--
May	17	15 (16)	--	31	31	31	--
Jun	6	30	--	30	30	30	--
Jul	--	31	--	31	31	31	--
Aug	21	31	--	31	31	31	--
Sep	30	26	--	30	30	30	--
Oct	31	4	12	31	31	1	--
Nov	30	--	30	30	30	--	--
Dec	4 (7)	--	31	31	31	--	--

Appendix Table C-4. -- Number of days with NPRW vocalizations by month at site BS03. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	0 (4)	--	6	3	1	--
Feb	--	0	--	0 (1)	0	1	--
Mar	--	0 (1)	--	2	2	0	--
Apr	--	0 (4)	--	0 (1)	4	1	--
May	1	7 (7)	--	3	4	3	--
Jun	0	6	--	18	10	18	--
Jul	--	27	--	20	12	29	--
Aug	21	29	--	19	20	21	--
Sep	30	26	--	20	21	22	--
Oct	30	1	2	27	6	0	--
Nov	15	--	15	23	11	--	--
Dec	0 (15)	--	30	17	14	--	--

Site PM04



Appendix Figure C-3. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site PM04 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

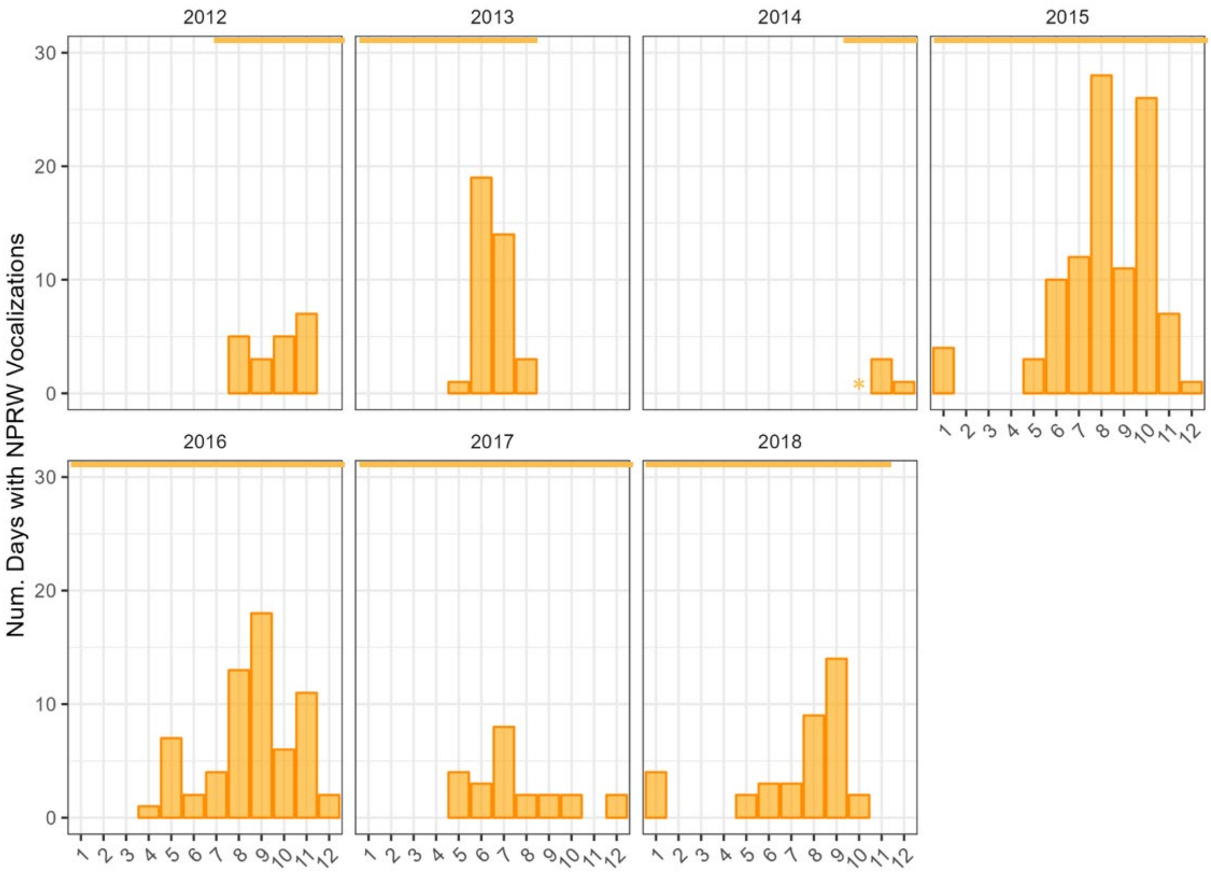
Appendix Table C-5. -- Effort Table. Number of days sampled by month at site PM04. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Jan	--	31	31	12 (19)	31	--	31
Feb	--	28	28	28	29	--	28
Mar	--	31	31	31	31	--	1 (30)
Apr	--	30	27 (3)	8 (23)	30	--	30
May	17	30 (1)	31	31	31	--	31
Jun	30	30	30	30	30	--	30
Jul	20	31	31	31	31	--	31
Aug	--	31	31	31	31	--	31
Sep	26	25	30	30	29	4	30
Oct	31	31	30	31	2	31	30
Nov	30	30	30	30	--	10 (20)	30
Dec	23 (8)	15 (16)	31	31	--	31	31

Appendix Table C-6. -- Number of days with NPRW vocalizations by month at site PM04. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Jan	--	15	9	6 (2)	16	--	7
Feb	--	8	5	0	5	--	2
Mar	--	16	4	2	2	--	2
Apr	--	1	2	1	0	--	1
May	--	0	2	2	0	--	0
Jun	7	2	1	2	5	--	1
Jul	3	14	20	12	13	--	4
Aug	--	1	29	30	21	--	10
Sep	2	9	28	17	17	0	16
Oct	13	4	20	24	1	5	10
Nov	8	13	19	9	--	5 (5)	3
Dec	9 (7)	9 (7)	10	22	--	18	1

Site BS02



Appendix Figure C-4. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site BS02 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

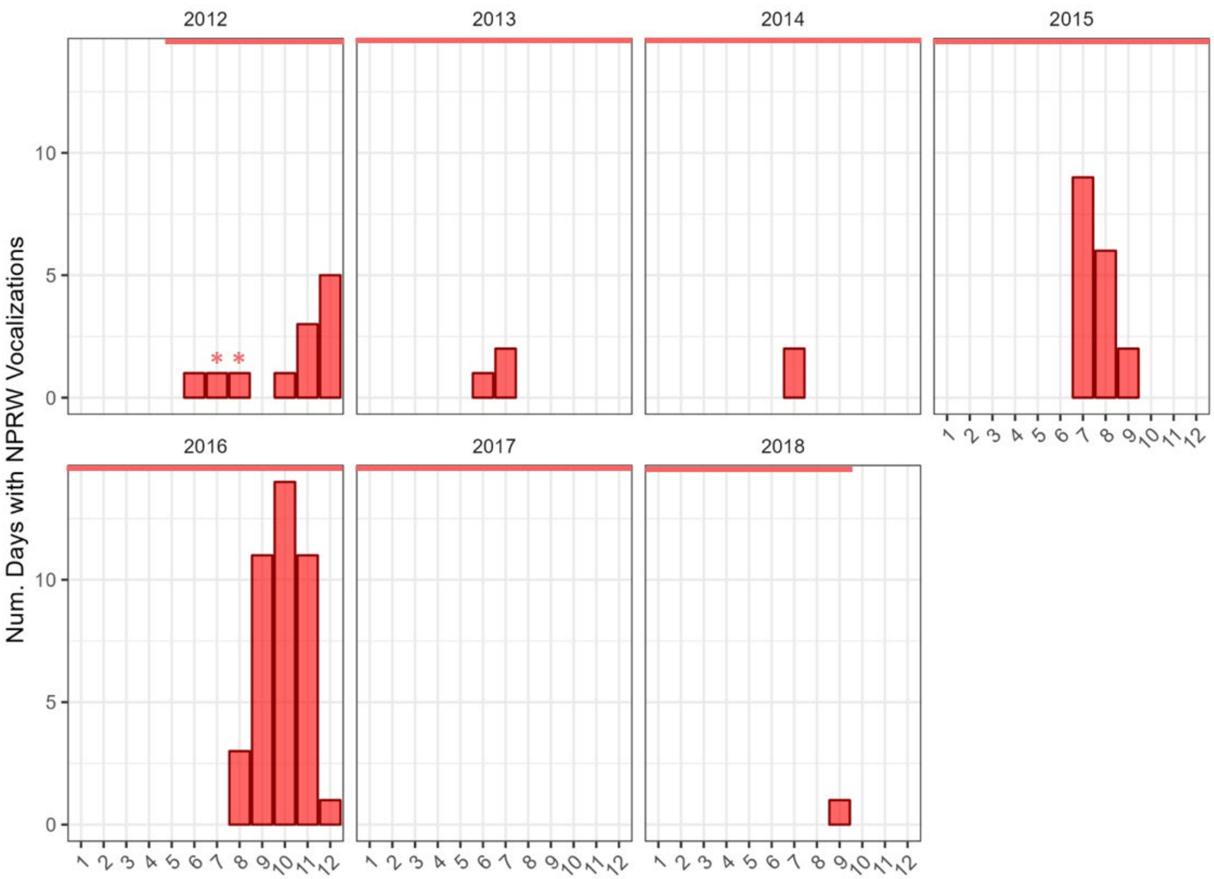
Appendix Table C-7. -- Effort Table. Number of days sampled by month at site BS02. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	--	17 (14)	31	31	29 (2)
Feb	--	28	--	28	29	28	28
Mar	--	31	--	31	31	31	31
Apr	--	30	--	30	13 (17)	2 (28)	30
May	--	6 (25)	--	23 (8)	31	31	31
Jun	--	30	--	30	30	30	30
Jul	--	31	--	31	31	31	31
Aug	20	17	--	31	31	31	31
Sep	30	--	--	30	30	30	30
Oct	31	--	14	31	31	30	31
Nov	29 (1)	--	30	30	30	30	17
Dec	31	--	31	15 (16)	18 (13)	31	--

Appendix Table C-8. -- Number of days with NPRW vocalizations by month at site BS02. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	2	--	4	1	8	4
Feb	--	3	--	4	0	1	0
Mar	--	2	--	4	1	13	0
Apr	--	2	--	0	1 (1)	0 (2)	1
May	--	1 (1)	--	3	7	4	2
Jun	--	19	--	10	2	3	3
Jul	--	14	--	12	4	8	3
Aug	5	3	--	28	13	2	9
Sep	3	--	--	11	18	2	14
Oct	5	--	0	26	6	2	2
Nov	7	--	3	7	11	0	0
Dec	12	--	1	1	2	2	--

Site PM05



Appendix Figure C-5. --Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site PM05 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

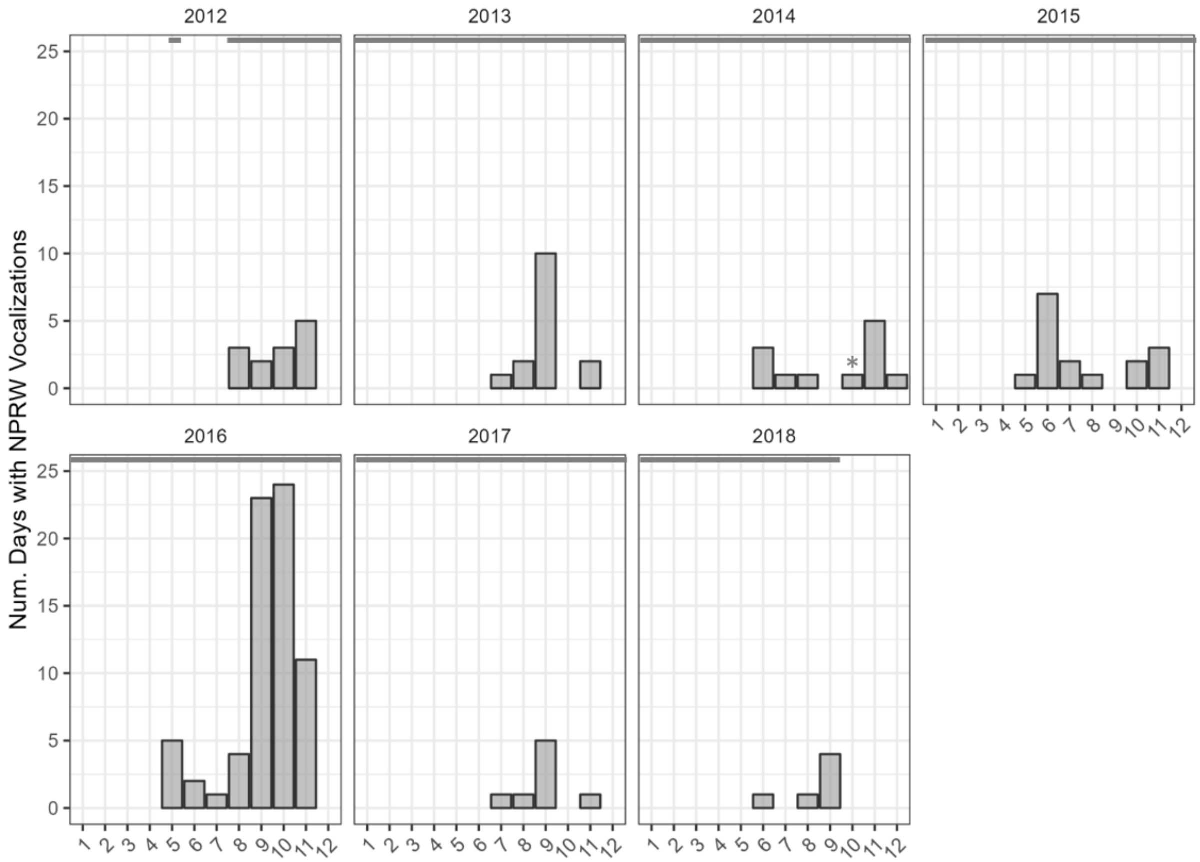
Appendix Table C-9. -- Effort Table. Number of days sampled by month at site PM05. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	31	31	31	31	31
Feb	--	28	28	28	29	28	28
Mar	--	31	31	31	31	31	31
Apr	--	30	30	30	30	30	30
May	17	4 (27)	21 (11)	11 (20)	16 (15)	27 (4)	31
Jun	30	30	30	30	30	30	30
Jul	11	31	31	31	31	31	31
Aug	20	30	31	31	31	31	31
Sep	30	30	30	30	29	29	30
Oct	31	31	30	31	31	31	--
Nov	30	26 (4)	30	26 (4)	30	30	--
Dec	18 (13)	31	9 (22)	31	22 (9)	31	--

Appendix Table C-10. -- Number of days with NPRW vocalizations by month at site PM05. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	1	0	0	0	0	0
Feb	--	1	0	2	0	0	0
Mar	--	6	0	8	1	10	0
Apr	--	1	0	0	2	1	0
May	0 (6)	0	0	0	0	0	0
Jun	1	1	0	0	0	0	0
Jul	1	2	2	9	0	0	0
Aug	1	0	0	6	3	0	0
Sep	0	0	0	2	11	0	1
Oct	1	0	0	0	14	0	--
Nov	3	0	0	0	11	0	--
Dec	5 (1)	0	0	0	1	0	--

Site BS01



Appendix Figure C-6. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site BS01 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

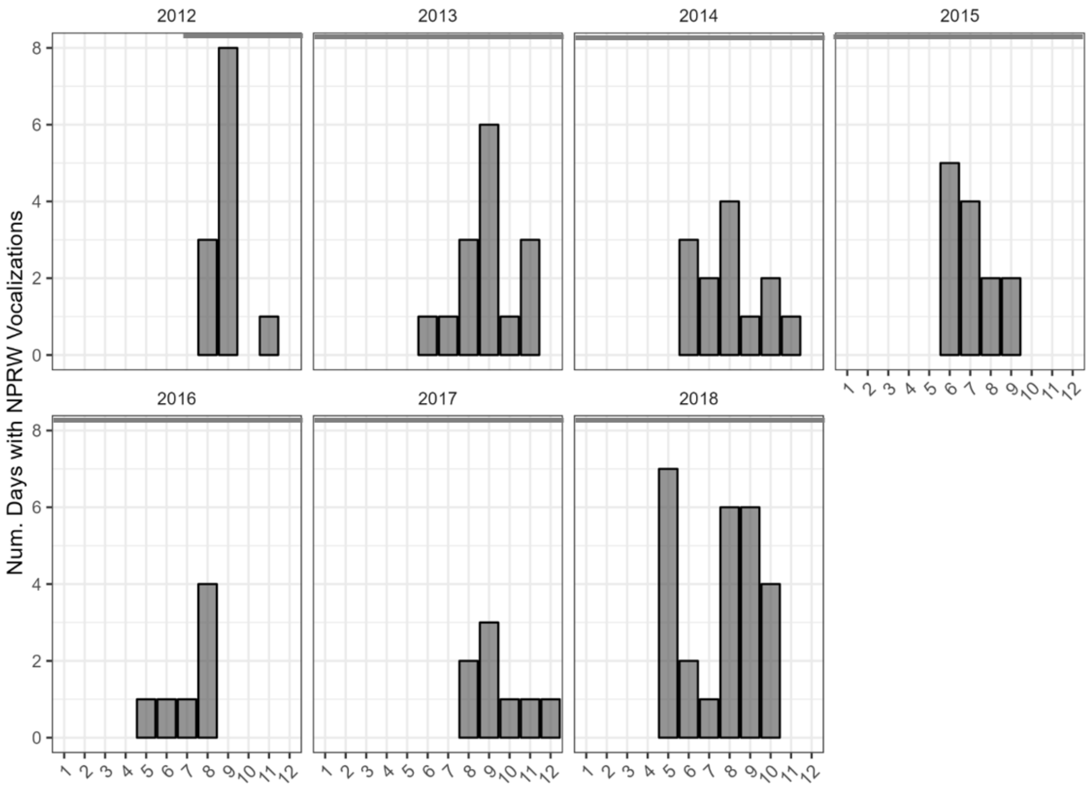
Appendix Table C-11. -- Effort Table. Number of days sampled by month at site BS01. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	31	31	31	9 (31)	31
Feb	--	28	28	28	29	28	28
Mar	--	31	31	31	31	31	31
Apr	--	30	30	30	30	30	30
May	10	31	17 (14)	18 (13)	13 (18)	20 (11)	21 (10)
Jun	--	30	30	30	30	30	30
Jul	--	31	31	31	31	31	31
Aug	19	30	31	31	31	31	31
Sep	30	30	29	29	30	30	30
Oct	31	31	16	31	31	31	16
Nov	24 (6)	27 (30)	30	30	24 (6)	30	--
Dec	31	31	9 (22)	13 (18)	31	5 (26)	--

Appendix Table C-12. -- Number of days with NPRW vocalizations by month at site BS01. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	2	1	3	0	4	0
Feb	--	9	0	13	2	2	1
Mar	--	5	5	2	7	4	0
Apr	--	1	3	1	3	1	0
May	0	1	0	1	5 (1)	0	0
Jun	--	0	3	7	2	0	1
Jul	--	1	1	2	1	1	0
Aug	3	2	1	1	4	1	1
Sep	2	10	0	0	23	5	4
Oct	3	0	1	2	24	0	--
Nov	5 (1)	2 (1)	5	3	11	1	--
Dec	7	3	1 (2)	0	0	0 (2)	--

Site PM08



Appendix Figure C-7. -- Number of days with NPRW vocalizations by month (1 = January, 12 = Dec.) for site PM08 by year, 2012 to 2018. Horizontal bar indicates the months the recorder was in the water. Asterisk indicates month(s) with less than 50% of data sampled.

Appendix Table C-13. -- Effort Table. Number of days sampled by month at site PM08. Gray text denotes the days that spanned the seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	31	31	31	31	31	31
Feb	--	28	28	28	29	28	28
Mar	--	31	31	31	31	31	31
Apr	--	30	30	30	30	5 (25)	30
May	--	4 (27)	21 (10)	11 (20)	26 (5)	31	16 (15)
Jun	--	30	30	30	30	30	30
Jul	--	31	31	31	31	31	31
Aug	18	31	31	31	31	31	31
Sep	30	30	30	30	29	29	30
Oct	31	31	30	31	31	31	30
Nov	19 (11)	26 (4)	30	26 (4)	30	30	30
Dec	31	31	9 (22)	31	27 (4)	22 (9)	31

Appendix Table C-14. -- Number of days with NPRW vocalizations by month at site PM08. Gray text denotes days with calls detected during seasonal window of ice and/or bowhead presence (excluded from analysis).

	2012	2013	2014	2015	2016	2017	2018
Jan	--	0	1	9	15	4	5
Feb	--	0	4	8	3	2	3
Mar	--	7	4	3	3	1	0
Apr	--	9	17	1	18	0	0
May	--	0 (1)	0	0	1	0	7 (2)
Jun	--	1	3	5	1	0	2
Jul	--	1	2	4	1	0	1
Aug	3	3	4	2	4	2	6
Sep	8	6	1	2	0	3	6
Oct	0	1	2	0	0	1	4
Nov	1 (1)	3	1	0 (1)	0	1	0
Dec	0	0	0	2	0	1 (3)	0

APPENDIX D: POST HOC TABLES OF KRUSKAL-WALLIS TESTS

Appendix Table D-1. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site PM02. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2012	2014	2015	2016	2017
2014	**< 0.0001**	--	--	--	--
2015	**< 0.0001**	0.38	--	--	--
2016	**< 0.0001**	0.38	**0.05**	--	--
2017	**0.02**	**< 0.0001**	**< 0.0001**	**< 0.0001**	--
2018	**< 0.0001**	**0.01 – 0.001**	0.11	**< 0.0001**	**< 0.0001**

Appendix Table D-2. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site BS03. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2015
2016	**< 0.0001**

Appendix Table D-3. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site PM04. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2013	2014	2015
2014	**< 0.0001**	--	--
2015	**< 0.0001**	0.50	--
2018	0.50	**< 0.0001**	**< 0.0001**

Appendix Table D-4. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site BS02. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2015	2016
2016	**< 0.0001**	--
2017	**< 0.0001**	**< 0.0001**

Appendix Table D-5. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site PM05. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2013	2014	2015	2016
2014	1.00	**--**	--	**--**
2015	**0.01**	**0.01 – 0.001**	**--**	**--**
2016	**< 0.0001**	**< 0.0001**	**< 0.001**	**--**
2017	1.00	1.00	**< 0.001**	**< 0.0001**

Appendix Table D-6. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across years for site BS01. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2013	2015	2016
2015	0.81	**--**	**--**
2016	**< 0.0001**	**< 0.0001**	**--**
2017	0.66	0.66	**<0.0001**

Appendix Table D-7. -- Post hoc analysis of K-W test comparing CA (%) of NPRW from the 15 May to 31 Dec. period across years for site PM08. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	2013	2014	2015	2016	2017
2014	1.00	**--**	**--**	**--**	--
2015	1.00	1.00	--	--	--
2016	0.32	1.00	1.00	--	--
2017	0.48	1.00	1.00	1.00	--
2018	1.00	0.36	0.56	**0.001 – 0.01**	**0.01**

Appendix Table D-8. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2013. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	PM08	BS01	PM05
BS01	0.93	--	--
PM05	0.13	0.13	--
PM04	**< 0.0001**	**< 0.0001**	**< 0.0001**

Appendix Table D-9. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2014. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	PM08	PM05	PM04
PM05	0.36	--	--
PM04	**< 0.0001**	**< 0.0001**	--
PM02	**< 0.0001**	**< 0.0001**	0.09

Appendix Table D-10. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2015. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons;; bold denotes significantly different pairings (α < 0.05).

	PM08	BS01	PM05	BS02	PM04	BS03
BS01	1.00	--	--	--	--	--
PM05	1.00	1.00	--	--	--	--
BS02	**< 0.0001**	**< 0.0001**	**< 0.0001**	--	--	--
PM04	**< 0.0001**	**< 0.0001**	**< 0.0001**	1.00	--	--
BS03	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.001 – 0.01**	0.06	--
PM02	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.04**	0.51	1.00

Appendix Table D-11. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2016. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	PM08	BS01	PM05	BS02	BS03
BS01	**< 0.0001**	--	--	--	--
PM05	**0.001 – 0.01**	**0.001 – 0.01**	--	--	--
BS02	**< 0.0001**	0.21	0.12	--	--
BS03	**< 0.0001**	0.20	**< 0.0001**	**0.001 – 0.01**	--
PM02	**< 0.0001**	**0.001 – 0.01**	**< 0.0001**	**< 0.0001**	0.21

Appendix Table D-12. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2017. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	PM08	BS01	PM05	BS02
BS01	1.00	--	--	--
PM05	1.00	1.00	--	--
BS02	1.00	1.00	0.33	--
PM02	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**

Appendix Table D-13. -- Post hoc analysis of K-W test comparing CA (%) of NPRW vocalizations from the 15 May to 31 Dec. period across sites, 2018. Values shown are p-values with Holm's correction, where the original p-value is multiplied by the number of comparisons; bold denotes significantly different pairings (α < 0.05).

	PM08	PM04
PM04	0.05	--
PM02	**< 0.0001**	**< 0.0001**

APPENDIX E: NUMBER OF DAYS WITH NPRW CALLS FOR 15 MAY TO 31 DEC.

Appendix Table E-1. -- Effort. Number of days included in the 15 May to 31 Dec. analysis, 15 May to 31 December 2012 to 2018. We excluded days that spanned the period of seasonal ice and/or bowhead whale presence and years with > 5 days of missing day, 2012 – 2018.

Year	PM08	BS01	PM05	BS02	PM04	BS03	PM02
2012	--	--	--	--	--	--	222
2013	173	180	182	--	209	--	**--**
2014	207	--	207	--	229	--	227
2015	190	213	190	214	230	230	229
2016	226	226	220	218	--	230	229
2017	220	204	229	229	--	--	229
2018	229	--	--	--	229	--	229

Appendix Table E-2. -- Number of days with daily calling activity (CA) > 0% for NPRW vocalizations detected during the 15 May to 31 Dec. period by site, 2012 – 2018.

Year	PM08	BS01	PM05	BS02	PM04	BS03	PM02
2012	--	--	--	--	--	--	176
2013	15	15	3	--	52	--	**--**
2014	13	--	2	--	128	--	107
2015	13	16	17	97	117	146	144
2016	7	70	40	59	--	95	109
2017	8	8	0	20	--	--	202
2018	26	--	--	--	45	--	151
Across yrs	82	109	62	176	342	241	889
Total	1,901						

Appendix Table E-3. -- Number of days with daily calling activity (CA) ≥ 50% for NPRW vocalizations detected during the 15 May to 31 Dec. period by site, 2012 – 2018.

Year	PM08	BS01	PM05	BS02	PM04	BS03	PM02
2012	--	--	--	--	--	--	97
2013	0	0	0	--	6	--	--
2014	0	--	0	--	28	--	34
2015	0	0	1	25	20	33	20
2016	0	21	1	5	--	10	15
2017	0	0	0	1	--	--	133
2018	0	--	--	--	3	--	40
Across yrs	0	21	2	31	57	43	339
Total				493			

Appendix Table E-4. -- Number of days with daily calling activity (CA) ≥ 80% for NPRW vocalizations during the 15 May to 31 Dec. period by site, 2012 – 2018.

Year	PM08	BS01	PM05	BS02	PM04	BS03	PM02
2012	--	--	--	0	--	--	55
2013	0	0	0	--	0	--	--
2014	0	--	0	--	12	--	16
2015	0	0	0	10	6	10	8
2016	0	2	0	0	--	0	3
2017	0	0	0	0	--	--	65
2018	0	--	--	--	1	--	17
Across yrs	0	2	0	10	19	10	164
Total				205			

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