Year-2
Annual Survey Report for New York Bight Whale Monitoring Passive Acoustic Surveys: October 2018 – October 2019

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Acronyms and Abbreviations

AMAR	Autonomous Multichannel Acoustic Recorder, JASCO Applied Sciences
BRP	Bioacoustics Research Program, Cornell University
CV	Coefficient of Variation
dB	Decibel (referenced to 1 μPa)
EEZ	Exclusive Economic Zone
FLAC	Free Lossless Audio Codec
FNR	False Negative Rate
FPR	False Positive Rate
L_{eq}	Sound Level Equivalent
L_{50}	Median Sound Level Equivalent (dB re: 1 μPa)
L_{05}	5^{th} Percentile Sound Level Equivalent (dB re: 1 μPa)
L_{95}	95^{th} Percentile Sound Level Equivalent (dB re: 1 μPa)
LF	Low Frequency (<100 Hz)
LTSA	Long Term Spectral Average
MARU	Marine Autonomous Recording Unit
NY Bight	New York Bight
NYSDEC	New York State Department of Environmental Conservation
PAM	Passive Acoustic Monitoring
RMS	Root-Mean-Square
SL	Source Level (dB re: 1 μPa @ 1m)
TB	Terabyte
TPR	True Positive Rate
TSS	Traffic Separation Scheme
UTC	Universal Time Coordinated
WNA	Western North Atlantic

Executive Summary

The Center for Conservation Bioacoustics (CCB; formerly the Bioacoustics Research Program) at Cornell University's Lab of Ornithology was contracted by the NYSDEC, Division of Marine Resources to conduct a three-year passive acoustic monitoring survey within New York Bight (NY Bight) to assess marine mammal occurrence and patterns of ambient noise in this region. Six large whale species known to occur within NY Bight are the focus of this passive acoustic monitoring effort: North Atlantic right whales (*Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), sei whales (*B. borealis*), blue whales (*B. musculus*), and sperm whales (*Physeter macrocephalus*). This report describes the results from Year-2 of this passive acoustic survey.

The objectives for this project are to:

1) Quantify the daily, monthly, and seasonal presence of the six large whale species found in NY Bight at all recording units.

2) Identify the spatial distribution of calling occurrence of focal whale species across NY Bight.

3) Characterize spatial and temporal patterns of ambient noise across NY Bight.

4) Describe acoustic masking potential that the different whale species encounter as they move through NY Bight.

Fifteen archival recording devices were deployed along two transect lines spanning the NY Bight to record whale sounds and noise levels in the study area. These transects parallel the two major shipping lanes entering and leaving NY Harbor (Nantucket-Ambrose and Ambrose-Hudson Canyon Lanes). Of these 15 recording devices, 10 were Cornell University's Marine Autonomous Recording Units (MARUs), and 5 were JASCO's third generation Autonomous Multichannel Acoustic Recorders (AMARs). Each deployment of MARUs recorded continuously for approximately 3 months at a 5 kHz sampling frequency, while AMARs recorded continuously for approximately 6 months at an 8 kHz sampling frequency. Whale sounds were identified using a combination of human visual analysis and species-specific automated detection algorithms with human review.

All of the focal species were detected in the New York Bight in Year-2. North Atlantic right whales, fin whales, and humpback whales were detected during every month of the recording period. Right whales showed peak presence between November and January, and were detected at all survey sites. Humpback whales had the lowest daily presence per month in October and highest in May and June, and were acoustically observed throughout the survey area. Sei whales were present during all months except January and July. Sei whales were not detected at site 8A, and were detected only a few times on sites 7M (n = 1) and 9A (n = 2). Fin whales were the most commonly detected large whale species, with nearly 100% acoustic presence throughout the year on all sites. Peak fin whale presence was bimodal, occurring in winter and again during the summer. Blue whales rarely detected (2% of the total recording days), and were only detected at sites in the northern transect and Site 14M, between December and February, with peak daily acoustic presence in February. Sperm whales were detected at low levels (<10% of days per month) in all months analyzed on the AMARs except November, December, February, and October 2019, and were not detected at the most inshore site (8A).

Ambient noise levels in the NY Bight were consistently high. The median sound level was estimated to reduce the typical whale detection range distances by more than 50-75%, significantly reducing the effective communication range of these whale species as well as their detectability on passive acoustic survey instruments.

Introduction

The Center for Conservation Bioacoustics (CCB; formerly the Bioacoustics Research Program) at Cornell University's Lab of Ornithology was contracted by the New York State Department of Environmental Conservation (NYSDEC), Division of Marine Resources to conduct a three-year passive acoustic monitoring survey to understand the occurrence of large whale species in NY Bight. For this project, BRP collaborated with JASCO Applied Sciences, Inc. (JASCO), and Bioacoustics and Behavioral Ecology Laboratory of Dr. Susan Parks at Syracuse University. This report presents species' acoustic occurrence data for the Year-2 survey, collected from October 2018-October 2019.

Background

New York Bight is an ecologically important marine region within the U.S. Atlantic Coast, and despite its economic and environmental value to New York State (NYS) and the United States, it has not been ecologically surveyed at the same level of intensity as other marine regions within the Mid-Atlantic. The Bight is approximately 17,000 mi^2, and the size of this immense marine area imposes significant logistical challenges for conducting surveys and assessing the diversity and abundance of its natural resources. Consequently, while scientists and state and federal natural resource managers know that marine mammals regularly traverse NY Bight waters, and these species are identified in the New York State Comprehensive Wildlife Conservation Strategy (NYSDEC 2005) and Ocean Action Plan (NYSDEC and NYSDOS 2015), the temporal and spatial extent of when marine mammals inhabit NY waters, and how they are using this habitat are unclear. In light of NYS conservation efforts, increasing human use of NY Bight, and possible impacts of climate change on NYS marine natural resources, the current state of scientific knowledge on marine mammals is not sufficient for management needs.

To address the current needs for more detailed information on the spatial and temporal occurrence of whale species in New York Bight, the New York State DEC has funded two baseline monitoring programs – aerial surveys and passive acoustic monitoring – to systematically document the presence of large whales within NY Bight and the NY Offshore Planning Area. The ongoing aerial surveys in the region, funded by both NYSDEC and NYSERDA (Normandeau and APEM 2018, Tetra Tech and Smultea Sciences 2018) have demonstrated extensive occurrence of marine mammals and other protected species in the area.

The six large whale species that are the focus of this passive acoustic monitoring survey include: North Atlantic right whales (*Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), sei whales (*B. borealis*), blue whales (*B. musculus*), and sperm whales (*Physeter macrocephalus*). All of these species are protected under the U.S. Marine Mammal Protection Act, and five of these species, with the exception of the Gulf of Maine stock of humpback whales, are listed under the U.S. Endangered Species Act. With the recent mortalities and risk of injury or mortality from ship strikes, North Atlantic right whales are a particular concern.

North Atlantic right whales occur along nearly the entire expanse of the U.S. Western North Atlantic (WNA) coastline (Hayes et al. 2019, Kraus and Rolland 2007). The Gulf of Maine serves as the primary feeding grounds in warmer months, and females migrate to southern waters in the fall and winter to give birth (Hayes et al. 2019). To protect animals in these regions, the feeding and calving grounds have been established and spatially expanded as federally protected right whale critical habitats as conservation measures (NOAA 2016). As right whales move between these areas, they have been acoustically detected for large portions of the year in the Gulf of Maine (Bort et al. 2015, Christian and Hendrick 2007, Morano et al. 2012a), the Mid-Atlantic Bight (Hodge et al. 2015, Leiter et al. 2017, Muirhead et al. 2018, Salisbury et al. 2016, Whitt et al. 2013), and South Atlantic Bight (Hodge et al. 2015, Soldevilla et al. 2014). However, right whale movement between these regions remains uncertain (Hayes et al. 2019). A meta-analysis of right whale occurrence revealed that right whale phenology has changed in recent years (Davis et al. 2017), possibly as a function of changes in ocean temperatures or prey availability (Meyer-Gutbrod et al. 2015, Pendleton et al. 2012, Record et al. 2019). As right whales move across their range, they cross the NY Bight (Muirhead et al. 2018), though it is unclear how long they spend in this region or how they are using this habitat. Previously, it was thought that right whales primarily fed in the Gulf of Maine, though recent aerial surveys observed right whales feeding near Nantucket and Block Island Sound (Leiter et al. 2017).

Because right whale habitat overlaps with significant human activity along the U.S., Atlantic coast (Kraus and Rolland 2007), right whales face a combination of anthropogenic threats (Knowlton and Kraus 2001, Kraus 1990), including noise (Cholewiak et al. 2018, Hatch et al. 2008, Parks et al. 2011, Parks et al. 2009, Rice et al. 2014, Rolland et al. 2012), entanglement with fishing gear (Clapham and Pace 2001, Johnson et al. 2005), and vessel strikes (Campbell-Malone et al. 2008, Conn and Silber 2013, Knowlton and Brown 2007, Parks et al. 2012, Ward-Geiger et al. 2005). With a small population size of less than 500 individuals (Hayes et al. 2019, Pace et al. 2017), and recent increases in mortality (Davies and Brillant 2019), the long-term recovery or survivorship of this species is perilous (Corkeron and Kraus 2018, Kraus et al. 2005, Meyer-Gutbrod and Greene 2018). Consequently, addressing data gaps in right whale ecology to improve effectiveness of management efforts is paramount. The median best population estimate of right whales is 451 individuals (Hayes et al. 2019), with the species likely now experience a population decline after years of growth (Hayes et al. 2019, Pace et al. 2017).

Humpback whales are widely distributed across the WNA Ocean, primarily using the Mid-Atlantic and Gulf of Maine as feeding grounds (Hayes et al. 2019). Humpbacks have been acoustically detected in these higher latitude regions throughout the year (Murray et al. 2014, Vu et al. 2012), and it is possible that the Mid-Atlantic may represent an additional winter feeding ground for humpback whales (Barco et al. 2002). A portion of the population migrates down to lower latitudes for mating and calving (Hayes et al. 2019), however, humpback song – produced by males likely in an advertisement context – has been widely recorded in the Mid-Atlantic and Gulf of Maine throughout much of the year (Clark and Clapham 2004, Murray et al. 2014, Vu et al. 2012). Humpbacks have been readily observed within NY Bight (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018), with some individuals venturing well into the New York Lower Harbor Estuary (Brown et al. 2018). The current NOAA population estimate for the Gulf of Maine Stock is 896 (CV=0), with an increasing population trend (mean± SE) of 3.100±0.005% per year (Hayes et al. 2019).

Fin whales are regularly detected along most of the U.S. Atlantic Coast, north of Cape Hatteras (Hayes et al. 2019), and are present nearly year round north of 35°N latitude (Edwards et al. 2015). Acoustic and aerial surveys in NY Bight observed fin whales throughout the year in NY Bight and the NY Offshore Planning Area (Morano et al. 2012b, Muirhead et al. 2018, Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). Fin whales have a repertoire of low-frequency calls with high source levels, and consequently have a large acoustic detection range up to hundreds of kilometers (Širović et al. 2007); thus, fin whale acoustic detections at individual acoustic sensors do not necessarily indicate that the calling individual was calling from within or near the acoustic survey area. Fin whales occur across both shelf and pelagic habitats, but they have also been observed extremely close to shore in the Mid-Atlantic (Ambler 2011). Between the coastal waters of Virginia and the Bay of Fundy, the current fin whale abundance estimate is 1595 (CV=0.33), though the population trend of this WNA stock is currently unclear (Hayes et al. 2019).

Compared to other large whale species in the WNA, sei whales have not received extensive study, and consequently, many aspects of their biology and ecology are unclear. Around NY Bight, it is the Nova Scotia stock of sei whales that inhabit this area, with the highest abundance occurring in the spring (Hayes et al. 2017). NY Bight represents the southernmost observations of sei whales in the WNA (Hayes et al. 2017), with the majority of sightings occurring in deeper waters along the shelf edge, though they have been periodically observed in shallower waters (Hayes et al. 2017). In the WNA, it has been suggested that there is a migration to and from more northerly waters, as there are increased observations in the summer and fall (Mitchell 1975). Only recently have Atlantic sei whales been acoustically monitored (Baumgartner et al. 2008, Tremblay et al. 2019), and a more complete understanding of their seasonal distribution in the U.S. Exclusive Economic Zone (EEZ) has not yet emerged. The best population estimate of sei whales between Virginia to the Bay of Fundy is 357 (CV=0.52), though there are currently insufficient data to establish population trends (Hayes et al. 2017).

Blue whales have been infrequently documented within the U.S. Atlantic waters, and this region may represent the southern limit of the species' feeding range (Waring et al. 2010). Blue whales occur primarily offshore in deep waters, though Muirhead et al. (2018) acoustically tracked a blue whale in the NY Bight on the shelf edge. Previous surveys have observed blue whales within the U.S. Atlantic EEZ in August (CETAP 1982, Wenzel et al. 1988), and recent aerial surveys observed blue whales in January and February within the NY Offshore Planning Area (Tetra Tech and Smultea Sciences 2018). Due to their high source level and low frequency calls, blue whale songs propagate over very large distances, and are thus detectable at ranges of hundreds of kilometers (Payne and Webb 1971, Širović et al. 2007). Consequently, acoustic detections of blue whales at single acoustic sensors does not necessarily indicate that the blue whale was in immediate proximity of that particular acoustic survey area. It is currently unclear how many blue whales are found within the WNA, and while they are federally listed as an endangered species, their population trend is uncertain (Waring et al. 2010).

Sperm whales in NY Bight have been primarily documented along the continental shelf edge (NEFSC and SEFSC 2016, Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018), consistent with their observed (Stanistreet et al. 2018) and modeled (Roberts et al. 2016) occurrence elsewhere across the WNA. Few sightings have been documented in depths less than 180 m (Scott and Sadove 1997). The geographical distribution of sperm whales in the Atlantic appears to be socially structured, with males primarily occurring at higher latitudes and juveniles and females at lower latitudes; females have rarely been observed north of New England (Waring et al. 2015). The current NOAA stock assessment is that it is unclear how connected the US Atlantic EEZ and other Atlantic habitat areas are for sperm whales (Waring et al. 2015). Sperm whale occurrence in the WNA appears to be south of New England in the fall, with the center of distribution in the Mid-Atlantic (between VA and NE of DE) highest in the spring (Waring et al. 2015). In the New York Offshore Planning area, there has been a location with persistent sperm whale observations in shallower waters (depths ranging from 41-67 m), centered around the 50 m isobath, 27 km SSE off of Montauk (Scott and Sadove 1997). With the last population estimate from 2011, the best estimate of the number of sperm whales occurring between Virginia and the Bay of Fundy is 1593 (CV=0.36) (Waring et al. 2015), though it is unclear what proportion of this population occurs in the NY Bight.

The NY Bight represents a potentially ecologically important area for these large whale species, though these taxa are exposed to high anthropogenic noise levels (Rice et al. 2014). Whales in the NY Bight have faced a rapidly changing ocean soundscape in recent decades. In particular, vessel traffic and volume has been increasing over time. One consequence of this increased exposure to vessel traffic and associated shipping noise is that noise produced by ships overlaps in the frequency ranges that baleen whales utilize for communication (Erbe et al. 2016, Richardson et al. 1995), therefore, acoustic "masking" (Clark et al. 2009) is a concern for heavily trafficked areas, such as the Ambrose Traffic Separation Schemes. Acoustic masking is a term that refers to a situation in which ambient noise levels exceed the received level of a signal emitted by a whale that was intended for a conspecific receiver. Consequently, the transmission of the signal to the receiver is impeded and the range over which the signal can be detected is decreased (Erbe et al. 2016).

We conducted a passive acoustic survey to provide a more detailed understanding of the temporal and spatial dynamics of large whales in the NY Offshore Planning Area, and address ongoing data gaps. Specifically, the passive acoustic survey objectives for this project are to:

1) Describe the daily, monthly, and seasonal presence of the six species of large whales found in NY Bight at all recording units.

2) Describe the spatial distribution of calling occurrence of six large whale species across NY Bight.

3) Describe spatial and temporal patterns of ambient noise across NY Bight.

4) Describe acoustic masking potential that the different whale species encounter as they move through NY Bight.

In Year-1 and Year-2 of their aerial surveys, the Tetra Tech team observed North Atlantic right whales, humpback whales, fin whales blue whales, and sperm whales, but had only one definitive identifications of sei whales (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). These large whales species were observed in relatively limited numbers of individuals or observations (Tetra Tech and Smultea Sciences 2018). The difference in spatial and temporal presence data of the target species between aerial surveys and passive acoustic monitoring underscore the differences in species detectability through the two methods and demonstrate the complimentary value that both methods contribute to understanding habitat use and large-scale spatiotemporal occurrence of the target whale species in NY Bight.

Methods

DATA COLLECTION: INSTRUMENTATION AND SURVEY DESIGN

Passive acoustic monitoring (PAM) methods were utilized to describe spatiotemporal acoustic occurrence patterns of six large whale species and to characterize ambient noise levels across two transect lines along the Nantucket-Ambrose and the Ambrose-Hudson Traffic Separation Schemes (TSS). PAM has several advantages over other survey methods, such as visual surveys, since passive acoustic recording provides stationary, continuous coverage across multiple locations, and is independent of inclement weather events (e.g., poor visibility or high sea states) which make visual detection of marine mammals challenging. The acoustic detection of these focal species, however, is dependent on their acoustic behavior, source levels and frequency band of their acoustic signals, as well as ambient noise conditions in the survey area. In high noise environments, acoustic masking can reduce detectability of target species' signals whose received levels are below the ambient noise floor (Cholewiak et al. 2018, Clark et al. 2009, Erbe 2015, Hatch et al. 2008, Hatch et al. 2012). In addition, as a form of acoustic interference, acoustic masking drastically reduces whales' ability to hear the sounds of conspecifics, and may have profound behavioral or social consequences (Clark et al. 2009).

Acoustic data were collected using two different archival digital acoustic recording devices: Cornell's Marine Autonomous Recording Units (MARUs) and JASCO Applied Sciences' Autonomous Multichannel Acoustic Recorders (AMARs, http://www.jasco.com/amar) (Figure 1 and Figure 2). Two different sensor types were used in the survey to balance recording schedule and coverage, cost, and species coverage (i.e., baleen whale species versus sperm whales). MARUs are contained in a positively buoyant 43 cm glass sphere that is deployed on the bottom of the ocean for periods of weeks to months (Calupca et al. 2000). A hydrophone (HTI-94-SSQ, High Tech, Inc.) mounted outside the sphere is the mechanism for acquiring sounds that are recorded and stored in a binary digital audio format on internal electronic storage media. The MARU can be programmed to record on a daily schedule and deployed in a remote environment, where it is held in place by an anchor, suspended approximately 2 m above the seafloor. Upon retrieval, the MARU is sent an acoustic command to release itself from its anchor and float to the surface for recovery. After the recovery, the MARU data are extracted, converted into lossless audio files and stored on a server for analysis. The unit is then refurbished (batteries and hard drive replaced, etc.) in preparation for a subsequent deployment. Data recorded by a MARU are thus accessible only after the device is retrieved, cleaned of biofouling (e.g., microorganisms, animals, algae) and saltwater, and unsealed and depressurized in the BRP fabrication facility in Ithaca, NY. The MARUs recorded continuously at a 5 kHz sample rate, with a high-pass filter set at 10 Hz to reduce electrical interference produced by the MARU, and a low-pass filter set at

2000 Hz to reduce aliasing. Aliasing is the distortion of sound signals that occur in frequencies above the Nyquist frequency (half the sampling rate) which appear as artifacts in the sound file. Audio data were recorded at a bit depth (number of recorded bits per sample) of 12 bits. The effective recording bandwidth of 10 Hz to 2000 Hz had a sensitivity of -168 dB ± 3.0 dB re 1 µPa (re: 1V/µPa) with a flat frequency response between 15-585 Hz. Sound files were down-sampled (or decimated) to a 400 Hz sample-rate for the fin whale, sei whale, and blue whale analyses, increasing computational efficiency for the analysis of these lower-frequency calling species.

AMARs function similarly to MARUs, but have increased capacity for battery storage, which allows for collecting data over longer periods of time, or at higher sampling rates. AMARs are contained in a PVC, anodized aluminum and stainless-steel tube measuring 16.5 cm in diameter and 57.2 cm in length. AMARs are attached to a weighted sled to anchor at the bottom of the ocean and are retrieved by catching an attached tow line via a dragged grapple hook and winch. An external mounted hydrophone sits approximately 1 m above the seafloor and records wav sound files to storage media. AMARs recorded continuously at 8 kHz with a bit depth of 24 bits. The AMAR hydrophones were calibrated with a sensitivity of -164 dB re 1V/µPa at 1 kHz. The combination of hydrophone calibration and high bit-depth allows for collection of high-resolution ambient noise data. While the MARUs and AMARs recorded at different sample rates, they both covered the low frequency range needed for baleen whales and ambient noise analysis.

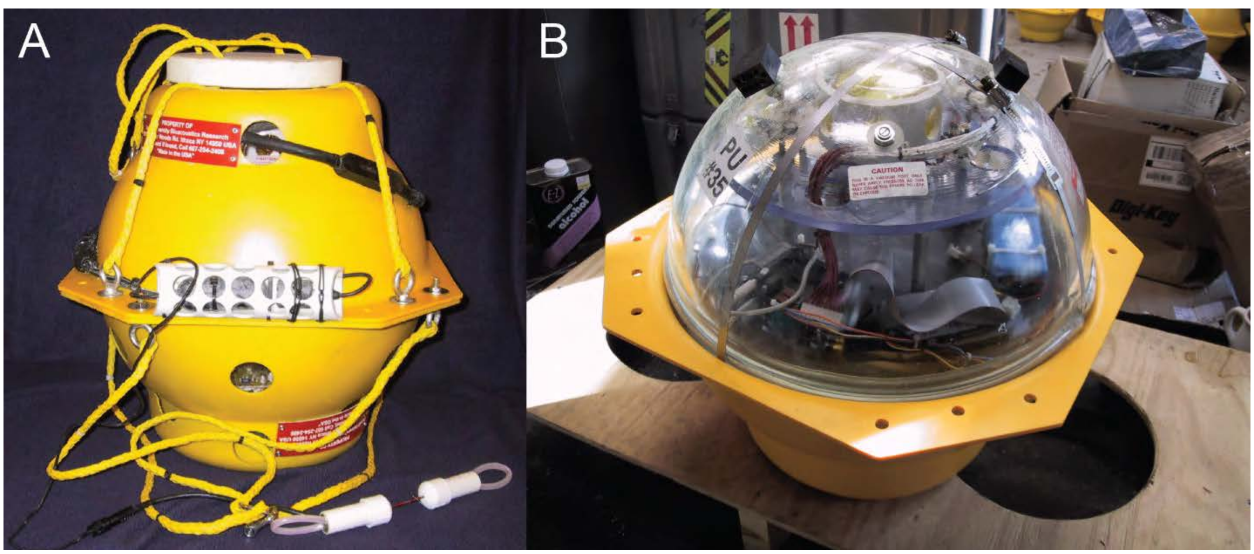

Figure 1. Instrumentation used for passive acoustic recordings: Cornell's Marine Autonomous Recording Unit (MARU), showing A) External and B) Internal views.

Figure 2. Instrumentation used for passive acoustic recordings: JASCO's Autonomous Multichannel Acoustic Recorder Generation 3 (AMAR G3), showing an AMAR mounted to the mooring sled, with the hydrophone wrapped in an orange sleeve.

Fifteen sites were configured along two transects along the Nantucket-Ambrose and Ambrose-Hudson Traffic Separation Schemes (Figure 4). Data were collected and retrieved from October 2018 through October 2019 (Table 2, Table 3, Figure 3), totaling 3,896 full days of sound data across all sites. Data gaps in the recordings did occur and are described in detail below.

During the Year-2 survey, there were several equipment issues that resulted in data loss at a number of sites in the different deployments. Data loss was due to three primary causes: 1) units were trawled, lost or surfaced prematurely, 2) units were damaged when trawled/dragged, which led to unit malfunction, and 3) system malfunction on the MARUs. The system malfunctions were primarily caused by a corruption of the recording media due to power loss from the batteries running out, as a result of delayed recovery. The significant delays in recovery were caused by turbulent weather and limited opportunities to safely conduct field operations. See Table 1 for deployment dates and names.

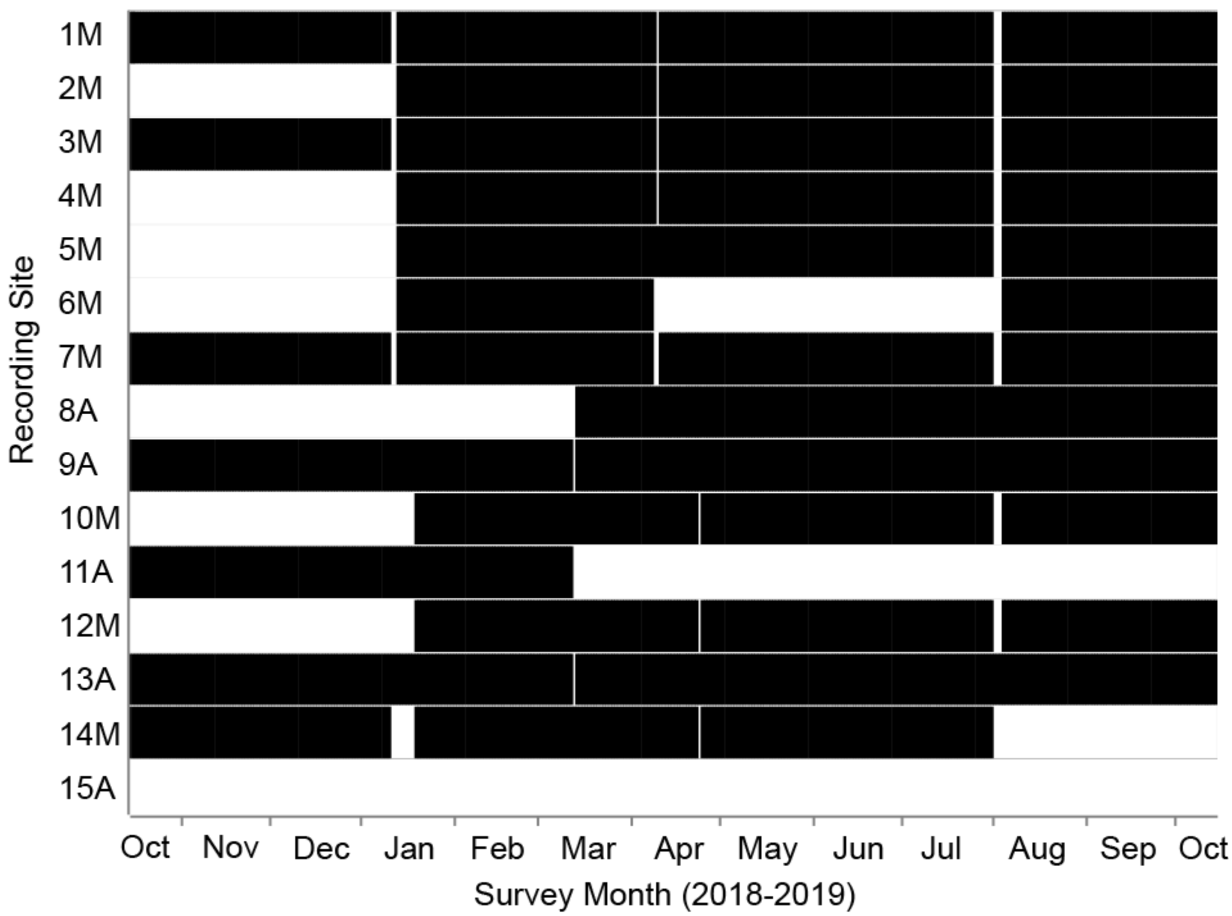

Figure 3. Recording effort for each MARU and AMAR site between 16 October 2018 and 15 October 2019. Black horizontal bars indicate the time periods in which the site was recording acoustic data. The white gaps indicate times in which there were no acoustic recordings.

The first swap of MARUs in Year-2 was delayed from the scheduled October 2018 field trip to mid-January 2019, due to persistent and sustained unsafe weather conditions throughout the winter. The power of the batteries for most MARUs from deployment 3 (hereafter, M-D3) were depleted by the end of December 2018, resulting in a data gap from the time the unit powered down to when MARUs were swapped in mid-January 2019. Site 6M was trawled on 3 October 2018, resulting in complete data loss for that site. MARU number 304 (PU304) at site 2M during M-D3 recorded a rapid, low-frequency (<40 Hz) pulse, which interfered with ambient noise measurements. After investigating the source of the malfunction, it was determined that saltwater intrusion corroded the hydrophone signal conductor, which damaged the signal path of the hydrophone. After repairing the affected components, PU304 was deployed during M-D5 at site 6M; however, the internal noise issue persisted, preventing reliable species' and noise analyses for that site during that deployment. The unit was quarantined and tested again during M-D6, and the issue resulted from a damaged pressure sensor, which is why the internal noise only presented itself while under pressure. The unit PU304 is now functioning normally.

During the first recovery effort of site 15A (A-D1), the AMAR did not surface and the mooring unit from site 15A was not recovered, therefore the next AMAR for that site was not able to be deployed during the second deployment of AMARs, since the deployment of that unit was dependent on the mooring device returning to the surface. An AMAR at site 15A was deployed during A-D4.

During survey years 2 and 3, the deployment duration of the MARUs and AMARs were decreased from the original schedule plan (4 and 8 months, respectively) to better align with annual survey deliverable timelines, as noted in the Year-1 Report. For the remainder of the project, MARUs will be recovered every 3 months, and AMARs will be recovered every 6 months. This will reduce the risk of data loss due to units reaching power limitations, as well as provide for an opportunity to capitalize on weather windows more frequently.

Table 1. Deployment and Retrieval dates for MARUS and AMARs of each deployment for Year-2 (MARUs=M, AMARs=A, Deployment=D).

Deployment Name	Device	Deployment Date	Retrieval Date
M-D3	MARU	15-Jul-18	11-Jan-19
M-D4	MARU	12-Jan-19	10-Apr-19
M-D5	MARU	10-Apr-19	02-Aug-19
M-D6	MARU	02-Aug-19	20-Oct-19
A-D2	AMAR	15-Jul-18	14-Mar-19
A-D3	AMAR	13-Mar-19	20-Oct-19

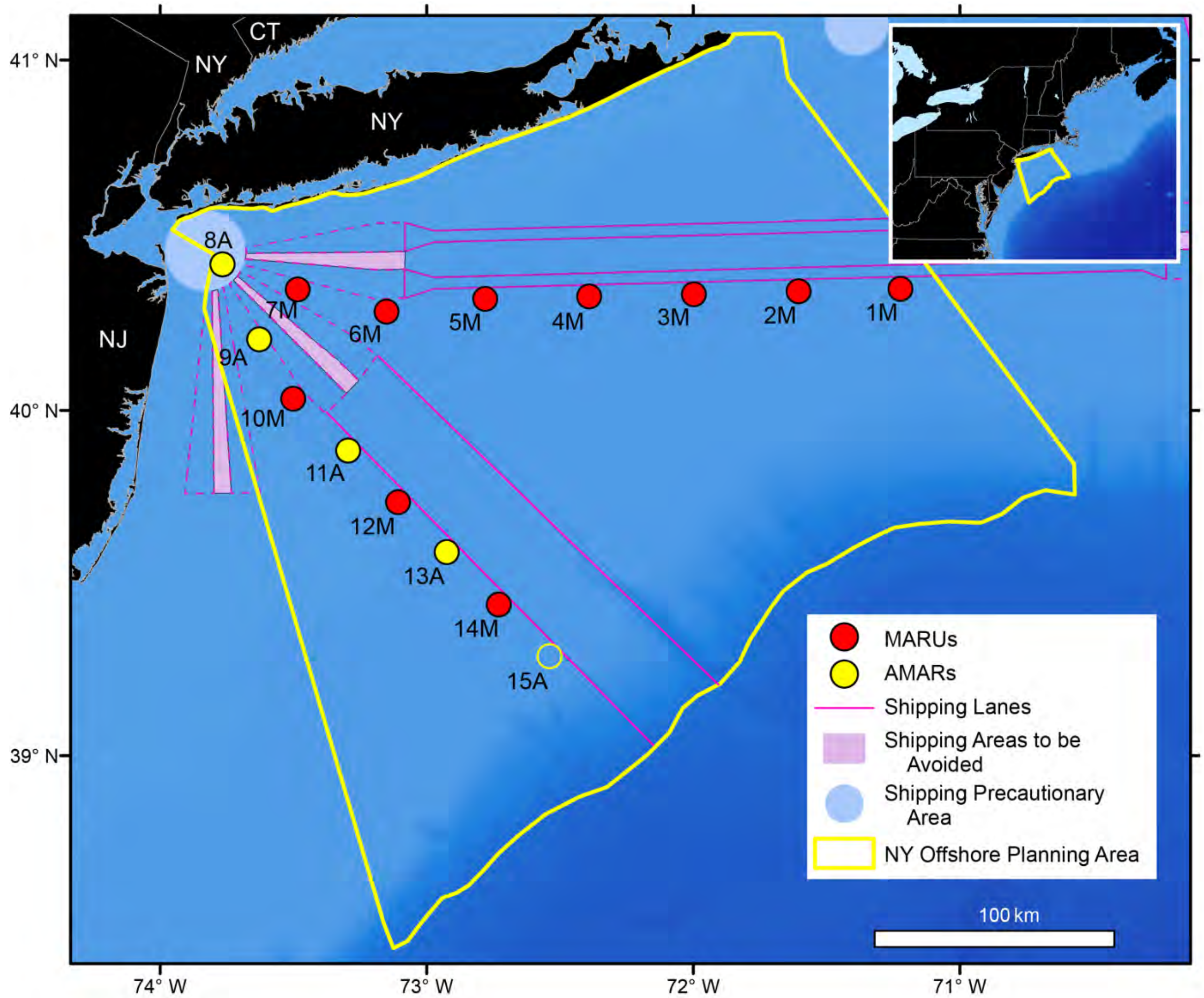

Figure 4. Map of the acoustic recording locations within New York Bight, with sensor location numbers. "M" denotes MARUs (red), and "A" denotes AMARs (yellow). The hollow circle indicates that data were not recovered during the entire Year-2 survey at that site. Inset shows the NY Bight at a larger spatial scale for geographical context.

Table 2. Deployment information for MARUs for Year-2.

Deployment	Site	Unit Number	Latitude (°N)	Longitude (°W)	Depth (m)	Deploy Date	Retrieval Date	Analysis Start Date	Analysis End Date	Recorded Days	% Coverage	Notes
M-D3	1M	310	40.34884	71.22556	88	19-Jul-18	12-Jan-19	16-Oct-18	23-Dec-18	69	79%	
M-D3	2M	304	40.34263	71.60848	84	19-Jul-18	13-Jan-19	No Data	No Data	0	0%	Internal noise
M-D3	3M	307	40.33393	72.00130	64	19-Jul-18	13-Jan-19	16-Oct-18	22-Dec-18	68	77%	
M-D3	4M	303	40.32781	72.40787	53	18-Jul-18	13-Jan-19	No Data	No Data	0	0%	Stopped recording on 9/16/2018
M-D3	5M	301	40.31991	72.78250	50	18-Jul-18	13-Jan-19	No Data	No Data	0	0%	CF card corrupt
M-D3	6M	311	40.28409	73.15230	40	18-Jul-18	1-Oct-18	No Data	No Data	0	0%	Trawled around 3 Oct 2018
M-D3	7M	308	40.34806	73.48566	30	18-Jul-18	13-Jan-19	16-Oct-18	23-Dec-18	69	78%	
M-D3	10M	300	40.03231	73.49923	49	15-Jul-18	18-Jan-19	No Data	No Data	0	0%	CF card corrupt
M-D3	12M	302	39.73353	73.10452	51	15-Jul-18	18-Jan-19	No Data	No Data	0	0%	CF card corrupt
M-D3	14M	309	39.43877	72.72832	80	15-Jul-18	17-Jan-19	16-Oct-18	19-Dec-18	65	71%	
M-D4	1M	314	40.34938	71.22603	88.0	12-Jan-19	11-Apr-19	13-Jan-19	10-Apr-19	88	100%	
M-D4	2M	306	40.34231	71.60760	83.0	13-Jan-19	11-Apr-19	14-Jan-19	10-Apr-19	87	100%	
M-D4	3M	321	40.33381	72.00063	65.0	13-Jan-19	11-Apr-19	14-Jan-19	10-Apr-19	87	100%	
M-D4	4M	316	40.32791	72.40718	54.0	13-Jan-19	11-Apr-19	14-Jan-19	10-Apr-19	87	100%	
M-D4	5M	313	40.31928	72.78249	50.4	13-Jan-19	21-Apr-19	14-Jan-19	10-Apr-19	87	100%	
M-D4	6M	318	40.28386	73.15194	40.0	13-Jan-19	10-Apr-19	14-Jan-19	9-Apr-19	86	100%	
M-D4	7M	319	40.34806	73.48566	36.0	13-Jan-19	10-Apr-19	14-Jan-19	9-Apr-19	86	100%	
M-D4	10M	305	40.03189	73.49901	48	18-Jan-19	25-Apr-19	19-Jan-19	24-Apr-19	96	100%	
M-D4	12M	317	39.73312	73.10454	50	18-Jan-19	25-Apr-19	19-Jan-19	24-Apr-19	96	100%	
M-D4	14M	320	39.43941	72.72879	81	17-Jan-19	25-Apr-19	18-Jan-19	24-Apr-19	97	100%	

Table 2, continued. Deployment information for MARUs for Year-2.

Deployment	Site	Unit Number	Latitude (°N)	Longitude (°W)	Depth (m)	Deploy Date	Retrieval Date	Analysis Start Date	Analysis End Date	Recorded Days	% Coverage	Notes
M-D5	1M	301	40.34756	71.22794	88.9	11-Apr-19	4-Aug-19	12-Apr-19	3-Aug-19	114	100%	
M-D5	2M	303	40.34307	71.60787	84.6	11-Apr-19	4-Aug-19	12-Apr-19	3-Aug-19	114	100%	
M-D5	3M	300	40.33433	72.00121	65.3	11-Apr-19	4-Aug-19	12-Apr-19	3-Aug-19	114	100%	
M-D5	4M	307	40.32778	72.40862	54.1	10-Apr-19	4-Aug-19	11-Apr-19	3-Aug-19	115	100%	
M-D5	5M	311	40.31922	72.78351	50.7	10-Apr-19	3-Aug-19	11-Apr-19	2-Aug-19	114	100%	
M-D5	6M	304	40.28400	73.15348	39.8	10-Apr-19	3-Aug-19	No Data	No Data	0	0%	Internal noise
M-D5	7M	312	40.34836	73.48706	30.2	10-Apr-19	3-Aug-19	11-Apr-19	2-Aug-19	114	100%	
M-D5	10M	309	40.03275	73.50000	48	25-Apr-19	2-Aug-19	26-Apr-19	1-Aug-19	98	100%	
M-D5	12M	310	39.73422	73.10571	51	25-Apr-19	2-Aug-19	26-Apr-19	1-Aug-19	98	100%	
M-D5	14M	302	39.44002	72.72978	81	25-Apr-19	2-Aug-19	26-Apr-19	1-Aug-19	98	100%	
M-D6	1M	319	40.34755	71.22902	86.5	4-Aug-19	25-Oct-19	5-Aug-19	15-Oct-19	72	100%	
M-D6	2M	314	40.34304	71.60850	82.6	4-Aug-19	25-Oct-19	5-Aug-19	15-Oct-19	72	100%	
M-D6	3M	321	40.33471	72.00192	65.3	4-Aug-19	24-Oct-19	5-Aug-19	15-Oct-19	72	100%	
M-D6	4M	320	40.32823	72.40906	54.1	4-Aug-19	24-Oct-19	5-Aug-19	15-Oct-19	72	100%	
M-D6	5M	318	40.31896	72.78440	50.5	3-Aug-19	24-Oct-19	4-Aug-19	15-Oct-19	73	100%	
M-D6	6M	317	40.28438	73.15464	39.0	3-Aug-19	24-Oct-19	4-Aug-19	15-Oct-19	73	100%	
M-D6	7M	316	40.34891	73.48807	27.6	3-Aug-19	24-Oct-19	4-Aug-19	15-Oct-19	73	100%	
M-D6	10M	305	40.03372	73.49926	47.4	2-Aug-19	20-Oct-19	3-Aug-19	15-Oct-19	74	100%	
M-D6	12M	306	39.73487	73.10667	48.9	2-Aug-19	20-Oct-19	3-Aug-19	15-Oct-19	74	100%	
M-D6	14M	313	39.44064	72.73072	79.6	2-Aug-19	Not Recovered	3-Aug-19	No Data	0	0%	Did not surface

Table 3. Deployment information for AMARs for Year-2.

Deployment	Site	Unit Number	Latitude (°N)	Longitude (°W)	Depth (m)	Deploy Date	Retrieval Date	Analysis Start Date	Analysis End Date	Recorded Days	% Percent Coverage during Survey	Notes
A-D2	8A	395	40.41739	73.76308	28	16-Jul-18	Not Recovered	No Data	No Data	0	0%	Not recovered
A-D2	9A	399	40.20318	73.62847	38	15-Jul-18	14-Mar-19	16-Oct-18	13-Mar-19	149	100%	
A-D2	13A	397	39.59182	72.92208	63	15-Jul-18	14-Mar-19	16-Oct-18	13-Mar-19	149	100%	
A-D2	15A	NA				Not Deployed	NA	No Data	No Data	0	0%	Not Deployed due to lack of available mooring
A-D3	8A	447	40.41367	73.76214	32	13-Mar-19	20-Oct-19	14-Mar-19	15-Oct-19	216	100%	
A-D3	9A	427	40.19968	73.62833	37	13-Mar-19	20-Oct-19	14-Mar-19	15-Oct-19	216	100%	
A-D3	11A	431	39.88142	73.28865	49	14-Mar-19	Not Recovered	15-Mar-19	No Data	0	0%	Did not surface
A-D3	13A	394	39.58882	72.92199	63	14-Mar-19	20-Oct-19	15-Mar-19	15-Oct-19	215	100%	
A-D3	15A	446	39.28598	72.53463	141	14-Mar-19	Not Recovered	15-Mar-19	No Data	0	0%	Did not surface

DATA ANALYSIS FOR FOCAL SPECIES DETECTION

To evaluate temporal patterns of whale acoustic presence, we used a combination of automated detection algorithms and human visual analysis to establish daily presence of North Atlantic right whales, fin whales, humpback whales, blue whales, and sei whales across all recording sites. Sperm whales were analyzed only on the AMARs, as the AMARs' higher sampling rate (and thus larger frequency range) were better suited to sperm whale detection than the MARUs' lower sampling rate. Sound files were browsed using Raven Pro 1.6 Sound Analysis Software (Bioacoustics Research Program 2017). All target signals that were used to determine presence were subject to a second verification process to ensure data accuracy.

North Atlantic Right Whales

Daily presence of right whales at each site was determined by identifying contact calls (referred to as upcalls, see Figure 5). Upcalls are the most common sound produced by migrating right whales (Parks and Clark 2007, Parks and Tyack 2005, Urazghildiiev et al. 2009), and are frequently used to determine acoustic presence of right whales (e.g., Hodge et al. 2015, Morano et al. 2012a, Muirhead et al. 2018, Salisbury et al. 2016). The following quantitative criteria help to distinguish upcalls from other biological and anthropogenic sounds: (i) starting frequency occurs between 65-170 Hz; (ii) minimum and maximum frequencies differ by 75-200 Hz; (iii) duration ranges from 0.3-1.3 s; (iv) energy is concentrated in the lower portion of the signal; and (v) signal contour slopes upward. In this analysis, a custom MATLAB-based automated detector algorithm was used to detect upcalls (Dugan et al. 2013) and was applied to all sound data. Spectrogram settings for reviewing detections included a 60 s page duration, a frequency range of 10 – 450 Hz, and a Fast Fourier Transform (FFT) window size of 512 points. Right whale detections were marked on a daily basis per site., Automated detection of right whale upcalls can falsely detect humpback whale signals with similar acoustic properties in geographic regions where the two species overlap (Mellinger et al. 2011, Mussoline et al. 2012). Detection events with concurrent bioacoustic activity suggestive of humpback whale song were not included in the right whale presence analysis (Mellinger et al. 2011, Mussoline et al. 2012).

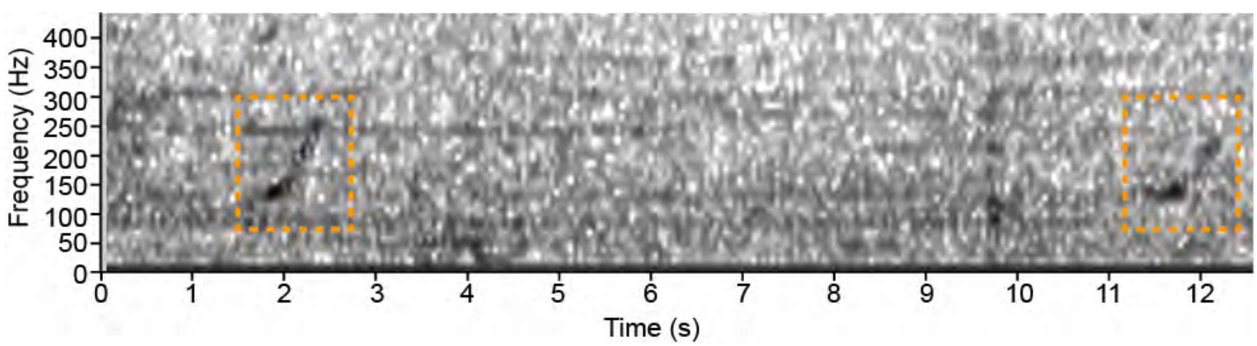

Figure 5. Representative spectrogram of North Atlantic right whale up-calls from site 12M on 14 April 2018. The two calls shown here are indicated by dashed orange boxes.

Humpback Whales

Two types of humpback whale signals were used to determine their presence in NY Bight: songs and social calls (Payne and McVay 1971, Silber 1986, Chabot 1988). Analysts used Raven Pro to visually review spectrograms in search of humpback whale sounds. For the Year-2 analysis, every-other sound file was manually reviewed for humpback whale presence, resulting in a 50% subsample of the data. When tested with a subset of 50 days, humpback whale daily presence per site yielded the same daily presence results as manually reviewing 100% of the sound files. MARU file durations are 15 min, and AMAR file durations are 30 min. Spectrogram settings included a 5 min page duration, frequency range of 10–600 Hz, and a FFT window size of 512 points. Humpback vocalizations (Figure 6) were marked on a daily basis per site.

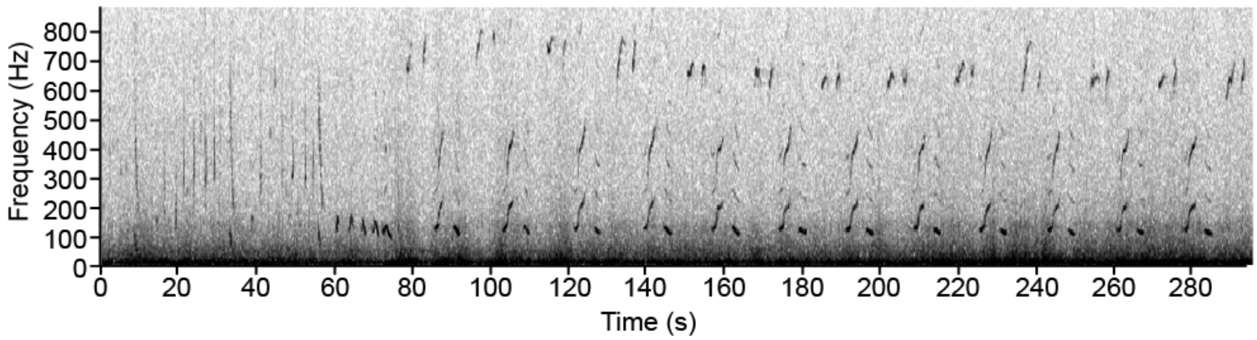

Figure 6. Spectrogram of representative humpback whale song, recorded from site 1M on 6 March 2018.

Fin Whales

Fin whale song is comprised of long sequences of individual 20-Hz notes (Figure 7) (Watkins et al. 1987, McDonald et al. 1995, Clark et al. 2002). We used a matched-filter data-template detection algorithm to automatically detect 20-Hz notes in the acoustic data. The detector is trained using multiple exemplars of 20-Hz fin whale notes and is able to cross-correlate sounds with similar characteristics, yielding detections with an associated correlation score. Exemplars comprised fin whale 20-Hz pulses with a high signal-to-noise ratio. Each detection was reviewed until a true positive (TP) detection was identified for each day and site. Down-sampled 400 Hz sound data were used for this analysis, with spectrogram settings that comprised a 90 s page duration, 10–60 Hz frequency band, and an FFT window size of 512 points.

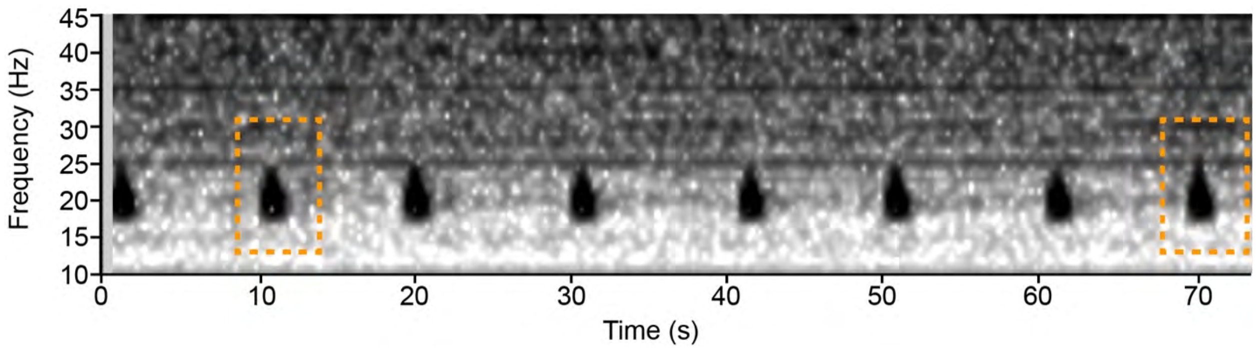

Figure 7. Spectrogram of representative fin whale 20-Hz pulse song, recorded at site 7M on 26 December 2017. Two of the pulses are indicated by dashed orange boxes.

Sei Whales

Sei whales produce low-frequency (34–82 Hz) downsweeps (Figure 8) that last approximately 1.4 s (Baumgartner et al. 2008). The downsweeps can occur singularly, or in doublets and triplets. To determine the daily presence of sei whales, we used the template detector in Raven Pro to detect sei whale downsweeps. To develop the detector, six examples of sei whale downsweeps with high signal-to-noise ratio from this dataset were used as templates. Those templates were then cross-correlated against the continuous sound data to find instances of sei whale downsweeps with an associated correlation value. The correlation value, or “threshold”, was subsequently used to determine the threshold cutoff based on the detector performance evaluation. Spectrogram settings comprised a 60 s page duration, 0–200 Hz frequency band, and an FFT window size of 512 points

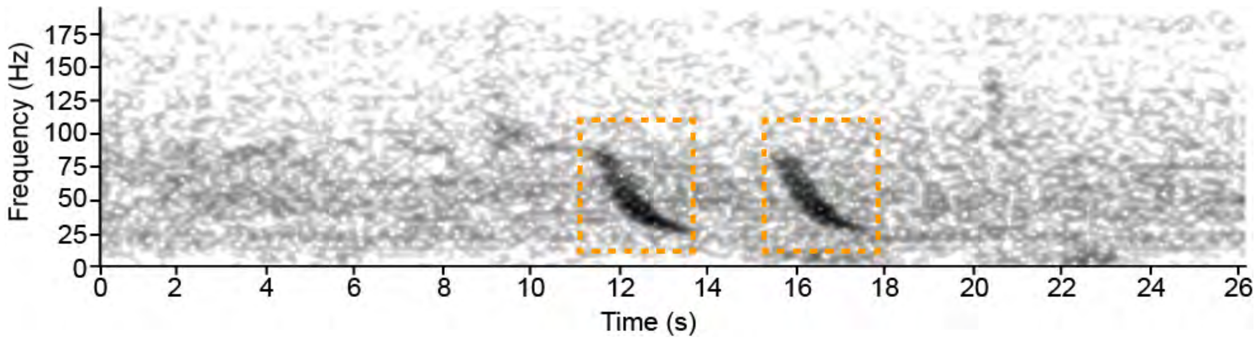

Figure 8. Spectrogram of representative sei whale downsweeps, recorded at site 1M on 26 April 2018. The two calls are indicated by a dashed orange box.

Blue Whales

Blue whales in the North Atlantic produce song that is characterized by a sequence of phrases, commonly comprising phrase part A and part B (referred to as the A-B phrase), between 15 and 20 Hz (Mellinger and Clark 2003). To determine daily acoustic presence of blue whale song at each site, analysts manually browsed through the down-sampled sound files with a bandwidth of 0-200 Hz (to improve computational efficiency) and marked blue whale song (Figure 9). Analysts then used the long-term spectrogram visualization in Raven Pro to search for characteristic patterns of 14–22 Hz blue whale sounds. In analyzing these data, a page length of 60 min and a frequency range of 10–25 Hz were used. The FFT window size was set to 512 points.

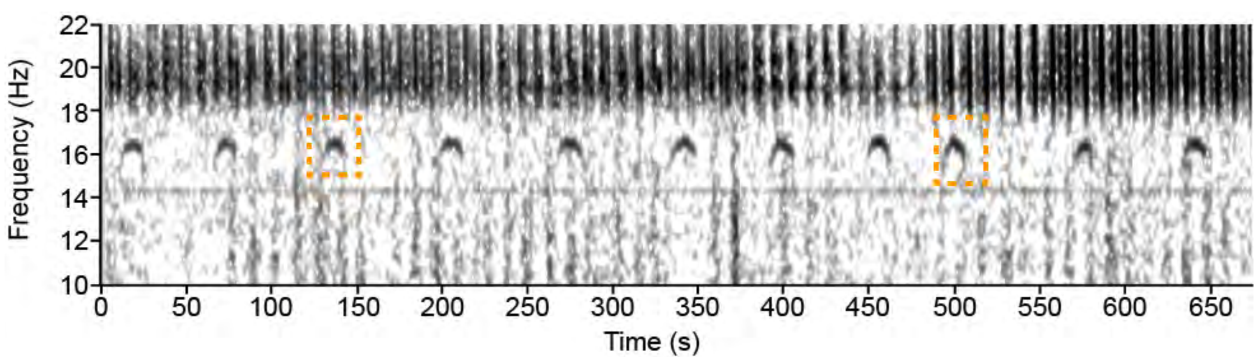

Figure 9. Spectrogram of a representative sequence of A-B phrases of a blue whale song, from site 1M on 1 November 2017. Two of the phrases are indicated by dashed orange boxes.

Sperm Whales

When foraging, sperm whales produce echolocation clicks, called “usual clicks” or “regular clicks” which are impulsive, broadband sounds, and are the most common click type produced by sperm whales, and thought to be associated with foraging (Goold and Jones 1995, Jaquet et al.

2001, Madsen et al. 2002). Sperm whales spend 72% of their time in dive cycles (Jochens et al. 2008, Watwood et al. 2006) and produce usual clicks in 80-91% of the dive (Teloni et al. 2008, Watwood et al. 2006). Previous research suggests that the number of hours per day that sperm whales are vocally active is relatively constant (Aoki et al. 2007, Whitehead and Weilgart 1991). Usual clicks are broadband (200 Hz – 13 kHz), with an omnidirectional component between 1-3 kHz (Diogou et al. 2019); clicks associated with feeding events ("buzzes"), are higher in frequency and highly directional (Madsen et al. 2002). While sperm whales also produce buzzes and "codas" used in social contexts (Oliveira et al. 2016, Schulz et al. 2011, Watkins and Schevill 1977), given the amount of time in a day that sperm whales produce usual clicks, and their omnidirectional nature, usual clicks are well suited as focal signals for passive acoustic monitoring of sperm whales in an area. To determine daily sperm whale acoustic presence per site, every 4th sound files (25% subsample) was reviewed. Sperm whale usual clicks were identified by analysts from manually reviewing spectrograms in Raven Pro. Sequences of five or more broadband pulses that had a regular inter-click-interval between 0.5 s and 1.5 s were annotated as sperm whale clicks (Figure 10). This conservative criterion was developed to exclude clicks that were produced by other sound sources, however, it remains difficult to distinguish between target and non-target signals due to the low sample-rate (8 kHz) of the acoustic recording.

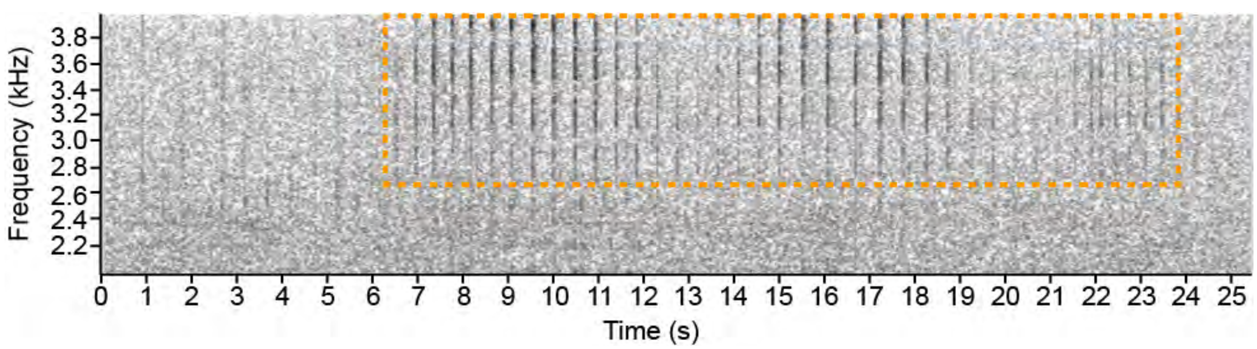

Figure 10. Spectrogram of representative sperm whale usual clicks, recorded at site 13A on 6 February 2018. A "usual click" sequence is indicated by a dashed orange box.

EVALUATION OF WHALE CALL AUTOMATED DETECTOR PERFORMANCE

For analysis of right whale, sei whale, and fin whale daily presence-absence, we relied on detection algorithms to find the target signals. To quantify how well the automated detectors performed at a daily resolution, we manually reviewed a subset of the sound data from M-D1 (Year-1) and marked every occurrence of the target signals for which an automatic detector was run (fin whale 20-Hz pulse, right whale upcalls, and sei whale downsweeps). These manually marked target signals are referred to as the 'ground-truth' dataset.

To quantify detection algorithm performance, every 20th day from the full M-D1 dataset was manually reviewed, resulting in 9 days that span the recording period. From those days, data from a selection of sites were reviewed (sites were rotated through the subset of days; see Table 4). This process resulted in a total of 33 full days of ground-truth data selected across different sites. For each of the three species', every instance of a target signal was annotated. Those annotated events were compared against the results of the automatic detectors to determine (1) true positive rates, (2) false positive rates, and (3) false negative rates. Days in which any automatic detection temporally overlapped with a manually annotated event were considered as “true positive days”. Days that contained automatic detections that did not temporally overlap with manually verified calls were defined as “false positive days”.

True positive rate (TPR) is defined as the number of true positive days divided by the total number of days with manually verified calls. False positive rate (FPR) is defined as the number of false positive days divided by the sum of true positive and false positive days. The False Negative Rate (FNR) is defined as the number of days in which true events from the ground-truth dataset were not detected, and is computed by subtracting the TPR from 1.The automatic detection results were subset using a variety of detection thresholds (based on correlation values), and TPR and FPR were calculated at each detection threshold. The detection threshold was then used to determine a threshold cut-off at which there was a reasonable balance of TPR and FPR, meaning that enough target signals were detected, while maintaining a low FPR to keep the number of detections that need to be reviewed manageable. Relying on a threshold cutoff significantly reduces the volume of detections (mostly false positives) that need to be reviewed.

Table 4. Subsampled dates and sites used for the Year-1 ground-truth dataset

Date	Site
16-Oct-17	1M
4-Nov-17	2M
23-Nov-17	3M
12-Dec-17	4M
31-Dec-17	5M
19-Jan-18	6M
7-Feb-18	7M
26-Feb-18	10M
16-Oct-17	4M
4-Nov-17	5M
23-Nov-17	6M
12-Dec-17	7M
31-Dec-17	10M
19-Jan-18	12M
7-Feb-18	1M
26-Feb-18	2M
17-Mar-18	3M

Date	Site
16-Oct-17	7M
4-Nov-17	10M
23-Nov-17	12M
12-Dec-17	1M
31-Dec-17	2M
19-Jan-18	3M
7-Feb-18	4M
26-Feb-18	5M
17-Mar-18	6M
16-Oct-17	12M
4-Nov-17	1M
23-Nov-17	2M
12-Dec-17	3M
19-Jan-18	5M
7-Feb-18	6M
26-Feb-18	7M

OCCURRENCE ANALYSIS OF FOCAL WHALE SPECIES

For each target species, daily presence was annotated for each recording site. From those daily occurrence data, we were able to compute the percentage of site-days per week, month, season, in which a target species was present. The resulting percentage is referred to as the *percent daily presence* in this report. Only days in which acoustic data were available were factored into the percentage in order to normalize the relative percentages across sites, months, and seasons. For seasonal occurrence, we defined seasons as Fall: October – December, Winter: January – March, Spring: April – June, and Summer: July-September.

NOISE ANALYSIS

Ambient Noise Levels

Acoustic data were processed using the Raven-X toolbox (Dugan et al. 2016) in MATLAB using a Hann window with zero overlap, a fast Fourier transform (FFT) size where Δ *time* = 1 s and Δ *frequency* = 1 Hz. We used the metric of equivalent continuous sound pressure level or L_{eq} (dB_{rms} re: 1 µPa) to represent the average unweighted sound level of a continuous time-varying signal of pressure (Morfey 2001) over specified time intervals. The resulting root-mean-square pressure is expressed by:

$$L_{eq} = 10log_{10}\frac{1}{T}\int_0^T\left(\frac{P_m^2(t)}{P_{ref}^2}\right)dt \tag{1}$$

where T is the time interval, P_m is the measured sound pressure, t refers to time, and P_{ref} is the reference pressure of 1 µPa. Percentiles of the resulting L_{eq} values were used to quantify ambient noise levels. To reflect noise levels that could represent a period of time in which ships would pass by the sensors, we used a time average of 10-minutes, allowing for direct comparison of noise metrics measured on nearby Stellwagen Bank in Massachusetts waters (Hatch et al. 2012).

Table 5. Referenced signal type, frequency band, and source levels of the target species used for detection range estimation and masking potential.

Species	**Target Signal**	**Frequency Band**	**1/3rd Octave Band (lower - upper)**	**Source Level (dB re: 1µPa @ 1m RMS)**
North Atlantic Right Whale	Upcall	71-224 Hz (Hatch et al. 2012)	70.8 – 224 Hz	137-172 (Hatch et al. 2012, Parks and Tyack 2005)
Humpback Whale	Song	29-2480 Hz (Dunlop et al. 2007)	28.2 – 708 Hz	169 (Au et al. 2006)
Fin Whale	20-Hz pulse	15-25 Hz (Weirathmueller et al. 2013)	17.8 – 28.2 Hz	189 (Weirathmueller et al. 2013)
Sei Whale	Downsweep	34 – 82 Hz (Baumgartner et al. 2008)	44.7 – 112 Hz	177 (Romagosa et al. 2015)
Blue Whale	Song	15 – 19 Hz (Mellinger and Clark 2003)	14.1 – 22.4 Hz	194 (McDonald et al. 2009)
Sperm Whale	Usual clicks	1000-4000 Hz (Diogou et al. 2019)	891 – 3550 Hz	155 (Diogou et al. 2019)

To illustrate the overall variation in ambient noise levels between sites, we calculated the cumulative percent distribution of L_{eq} values at each recording site and frequency band, which illustrates the percentage of time that sound pressure levels reached a particular L_{eq} value. The cumulative percent distribution allows for a comparison of noise values across sites within a particular frequency band. Species-specific frequency bands (Table 5) were used to represent the range in which each whale species' hearing is likely most sensitive, and the bandwidth in which each whale species target vocalizations occur (Dunlop et al. 2007; Hatch et al. 2012; Weirathmueller et al. 2013; Risch et al. 2014). For additional ambient noise measurements, see Appendix A.

Whale Acoustic Masking
Because ship noise in this area is so extensive (Rice et al. 2014), this pervasive noise source poses limitations for both our ability to detect whales, as well as for whales to communicate. The influence of ship noise is a major issue for species whose sounds have significant overlap with low-frequency ship noise in the time and frequency domain, such as right whales or humpback whales. The signals of fin whales and blue whales typically occur in frequencies below the majority ship noise, and sperm whale clicks occur in higher frequencies than ship noise.

Since ambient noise levels can dramatically affect the range in which a target signal from a sender can be received by a "listener", we estimated the detection range of each target species signal given their respective source level estimates (see Table 5) as a function of measured ambient noise level percentiles at the sites with the highest and lowest median noise levels during the survey period. Detection range was estimated to be the distance from the receiver at which the receive level (RL) is exceeded by the ambient noise level. Detection range estimates were derived from the intermediate spreading loss model below:

$$TL = 20log_{10}(H) + 17log_{10}\left(\frac{R}{H}\right) \qquad (2)$$

where *RL* is the received level, *SL* is the source level, and *R*represents the direct distance of the signal from the source to the receiver. These calculations account for source level and measured local ambient noise levels at each location. Source levels for each whale were estimated using values documented in the peer-reviewed scientific literature (see Table 5). Ambient noise measurements from species-specific bandwidths (Table 5) were calculated within each deployment. The intermediate $17log_{10}R$ spreading loss model, was used in a custom Matlab package to estimate sound propagation and transmission loss (Dugan et al. 2011). The algorithm incorporates bathymetry and sediment type. We estimated the detection range of the six whale species for eight different bearings (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) from each site location to account for varying bathymetry around each sensor, during high (95th percentile), median (50th percentile), and low (5th percentile) noise conditions.

Results

EVALUATION OF WHALE CALL AUTOMATED DETECTOR PERFORMANCE

True positive (TPR), false positive (FPR), and false negative (FNR) rates were calculated for right whale, sei whale and fin whale detections. Of the 33-day subsample, detections were manually found in 9, 27, and 5 days for right, fin, and sei whales, respectively.

The North Atlantic right whale upcall detector had a TPR ranging from 0.1 (threshold = 0.95) to 0.65 (threshold = 0.1). At a threshold of 0.55, the TPR was low (0.40), but the number of false positives per hour (0.14) resulted in a manageable number of detections to review within the constraints of the survey, therefore we decided to use a cutoff threshold of 0.55 (Table 6). On a daily basis, the right whale upcall detector found presence on all 9 days with a threshold of 0.1, however, the false positive rate (FPR) was high (0.73), creating a prohibitively high number of detections to manually review. The right whale detector began to miss days with presence if the threshold was set above 0.1 (Table 6, Table 7; Figure 11A, Figure 12A). In Table 7, the increase in FPR as a function of increasing threshold is a statistical artifact of converting the number of total positive detections to the number of days with presence.

Table 6. Performance of the right whale upcall detector. Threshold is the sensitivity level of the algorithm, TPR is the true positive rate, Precision is the total true positive detections (TP Truth) divided by the total number of detections (Total Test), FP/hr (the false positive rate) represents the rate of false positives (FP) per hour, TP represents the number of true upcalls the detector found, FN represents the number of true upcalls the detector missed, Total Truth represents the true number of upcalls in the ground-truth data validated through human review, TP Test represents the number of detector events that found a true upcall (which may contain more than one detection event per true call), FP Test represents the number of false positive (TP) detections, and Total Test represents the total number of detection events.

Threshold	TPR	Precision	FP/hr	TP Truth	FN Truth	Total Truth	TP Test	FP Test	Total Test
0.1	0.647	0.006	39.24	185	101	286	186	31076	31262
0.15	0.594	0.011	20.13	170	116	286	171	15941	16112
0.2	0.58	0.018	11.69	166	120	286	167	9256	9423
0.25	0.549	0.026	7.42	157	129	286	158	5873	6031
0.3	0.524	0.037	4.89	150	136	286	150	3871	4021
0.35	0.49	0.049	3.41	140	146	286	140	2698	2838
0.4	0.458	0.064	2.41	131	155	286	131	1911	2042
0.45	0.455	0.087	1.71	130	156	286	130	1358	1488
0.5	0.416	0.11	1.21	119	167	286	119	960	1079
0.55	0.399	0.143	0.86	114	172	286	114	683	797
0.6	0.378	0.18	0.62	108	178	286	108	493	601
0.65	0.36	0.228	0.44	103	183	286	103	349	452
0.7	0.336	0.28	0.31	96	190	286	96	247	343
0.75	0.322	0.347	0.22	92	194	286	92	173	265
0.8	0.294	0.412	0.15	84	202	286	84	120	204
0.85	0.252	0.462	0.11	72	214	286	72	84	156
0.9	0.21	0.504	0.07	60	226	286	60	59	119
0.95	0.115	0.493	0.04	33	253	286	33	34	67

Table 7. Summary of human-verified days used for right whale automated detector algorithm evaluation (“total true days”), with days with detection, and resulting true positive (“TPR”), false positive rates (“FPR”), and false negative rates (“FNR”) for right whale upcalls using the algorithm at differing thresholds.

Threshold	Total true days	Total days with detections	Total TP days	Total FP days	TPR	FPR	FNR
0.1	9	33	9	24	1.0	0.73	0
0.2	9	33	8	25	0.89	0.76	0.11
0.3	9	33	7	26	0.78	0.79	0.22
0.4	9	33	6	27	0.67	0.82	0.33
0.5	9	33	5	28	0.56	0.85	0.44
0.6	9	32	4	28	0.44	0.88	0.56
0.7	9	31	4	27	0.44	0.87	0.56
0.8	9	21	4	17	0.44	0.81	0.56
0.9	9	9	3	6	0.33	0.67	0.67

On an event-to-event basis (e.g., when a detection aligns temporally with all possible target signals), the fin whale detector had a TPR that ranged from 0.11 (threshold = 0.95) to 0.98 (threshold = 0.25). At a threshold of 0.75, the TPR was 0.48 and the FPR was 0.44 per hour. Given the high number of false positives, it was reasonable to use a threshold cutoff of 0.75 (Table 8). To better understand detector performance one a scale that is more comparable to appropriate monitoring scales and acoustic presence results that we report for each species, we also looked at the detector performance on a daily basis. Here, if the detector correctly identified at least one true target signal within the 24-hour calendar day, the day was classified as TP. On a daily basis, the fin whale detector did not miss any of the manually verified days (daily TPR = 100%) up to a sensitivity threshold of 0.5 (Table 8, Table 9; Figure 11B, Figure 12B). At thresholds greater than 0.5, the daily TPR gradually decreased. The daily FPR for the fin whale 20-Hz pulse detector with a threshold of 0.5 was 0.16, meaning that of the 33 days, 6 days had detections in which there were no true 20-Hz pulses. The daily FPR drastically decreased with higher thresholds. We used a threshold of 0.75 for the fin whale daily presence-absence analysis since the daily TPR remained high (0.96), and the daily FPR was low (0.07). At the 0.75 threshold, the detector missed one out of 27 days with presence.

Table 8. Performance of the fin whale 20-Hz pulse template detector. Threshold is the correlation score, TPR is the true positive rate, Precision is the total true positive detections (TP Truth) divided by the total number of detections (Total Test), FP/hr represents the rate of false positives (FP) per hour, TP Truth represents the number of 20-Hz pulses the detector found, FN Truth represents the number of pulses the detector missed, Total Truth represents the number of pulses in the ground-truth data, TP Test represents the number of detector events that found a true pulse (which may contain more than one detection event per true call), FP Test represents the number of false positive (TP) detections, and Total Test represents the total number of detection events.

Threshold	TPR	Precision	FP/hr	TP Truth	FN Truth	Total Truth	TP Test	FP Test	Total Test
0.25	0.98	0.603	186.13	1695	35	1730	119182	78456	197638
0.3	0.969	0.637	156.56	1677	53	1730	115829	65994	181823
0.35	0.953	0.677	126.96	1648	82	1730	112000	53517	165517
0.4	0.923	0.84	46.6	1596	134	1730	103143	19642	122785
0.45	0.81	0.926	18.21	1401	329	1730	96225	7678	103903
0.5	0.748	0.961	8.82	1294	436	1730	90909	3719	94628
0.55	0.699	0.978	4.52	1210	520	1730	85699	1907	87606
0.6	0.645	0.988	2.37	1115	615	1730	80195	1000	81195
0.65	0.599	0.993	1.29	1036	694	1730	74099	543	74642
0.7	0.542	0.996	0.69	937	793	1730	67238	290	67528
0.75	0.483	0.997	0.44	836	894	1730	59277	184	59461
0.8	0.433	0.997	0.33	749	981	1730	49090	141	49231
0.85	0.362	0.997	0.22	627	1103	1730	35877	91	35968
0.9	0.247	0.997	0.13	427	1303	1730	19137	54	19191
0.95	0.113	0.998	0.03	195	1535	1730	5699	11	5710

Table 9. Summary of human-verified days used for fin whale automated detection algorithm evaluation, ("total true days"), with days with detection, and resulting true positive ("TPR"), false positive rates ("FPR"), and false negative rates ("FNR") for fin whale 20-Hz pulses using a data template detector at differing thresholds.

Threshold	Total true days	Total detection days	Total TP days	Total FP days	TPR	FPR	FNR
0.4	27	33	27	6	1	0.18	0
0.5	27	32	27	5	1	0.16	0
0.6	27	30	26	4	0.96	0.13	0.04
0.7	27	28	26	2	0.96	0.07	0.04
0.8	27	24	24	0	0.89	0	0.11
0.9	27	20	20	0	0.74	0	0.26

An evaluation of the sei whale template detector performance on an event-by-event basis (Table 10) revealed a drastic drop on TPR from a threshold of 0.6 (TPR = 0.8) to a threshold of 0.65 (TPR = 0.52), in which there was also a drastic drop in the total number of false positive detections (FP = 47,102 and 5,465, respectively). We, therefore, selected a cutoff threshold of 0.68, in which there was a balance between false positives and TPR. On a daily basis, the sei whale detector, correctly identified four of the five days with sei whale downsweeps, resulting in a maximum daily TPR of 0.8 (Table 10, Table 11; Figure 11C, Figure 12C). With a threshold of 0.68, the detector had a TPR of 0.7.

Table 10. Performance of the sei whale downseep template detector. Threshold is the score, TPR is the true positive rate, Precision is the total true positive detections (TP Truth) divided by the total number of detections (Total Test), FP/hr represents the rate of false positives (FP) per hour, TP Truth represents the number of downsweeps the detector found, FN Truth represents the number of downsweeps the detector missed, Total Truth represents the number of downsweeps in the ground-truth data, TP Test represents the number of detector events that found a true downsweep (which may contain more than one detection event per true call), FP Test represents the number of false positive (TP) detections, and Total Test represents the total number of detection events.

Threshold	TPR	Precision	FP/hr	TP Truth	FN Truth	Total Truth	TP Test	FP Test	Total Test
0.6	0.804	0.005	59.58	78	19	97	244	47102	47346
0.65	0.515	0.029	6.91	50	47	97	163	5465	5628
0.7	0.258	0.206	0.58	25	72	97	118	456	574
0.75	0.124	0.63	0.06	12	85	97	75	44	119
0.8	0.052	1	0	5	92	97	25	0	25
0.85	0.031	1	0	3	94	97	5	0	5
0.9	0	NaN	0	0	97	97	0	0	0
0.95	0	NaN	0	0	97	97	0	0	0

Table 11. Summary of human-verified days used for sei whale automated detection algorithm evaluation, (“total true days”), with days with detection, and resulting true positive (“TPR”), false positive rates (“FPR”), and false negative rates (“FNR”) for sei whale calls using the Raven data template detector at differing thresholds.

Threshold	Total true days	Total detection days	Total TP days	Total FP days	TPR	FPR	FNR
0.6	5	33	4	29	0.8	0.88	0.2
0.7	5	22	3	19	0.6	0.86	0.4
0.8	5	1	1	0	0.2	0	0.8
0.9	5	0	0	0	0	N/A	1

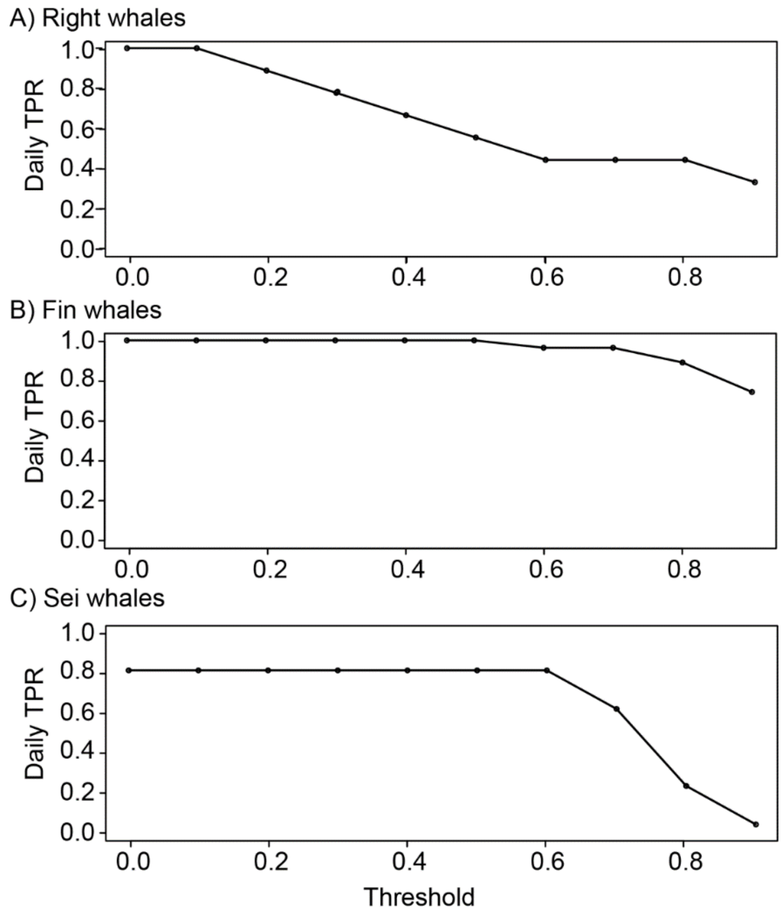

Figure 11. Daily true positive rates of detection algorithms for three target species at varying sensitivity thresholds: A) Right whales, B) Fin whales, C) Sei Whales.

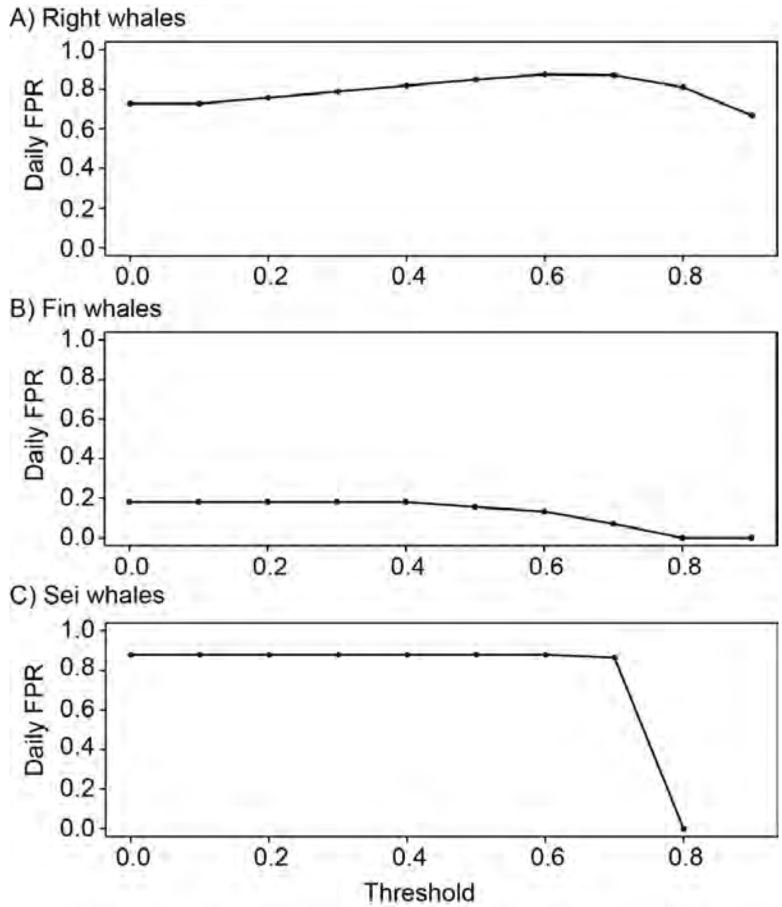

Figure 12. Daily false positive rates of detection algorithms for three target species at varying sensitivity thresholds: A) Right whales, B) Fin whales, C) Sei Whales.

OCCURRENCE OF FOCAL WHALE SPECIES

Deployment-wide Whale Acoustic Occurrence

During the Year-2 portion of M-D3 (October 2018 – January 2019), a total of 271 days of sound were recorded across all MARUs, comprising 69 calendar days, during which right, sei, fin, blue, and humpback whales were detected (sperm whale presence was not annotated on MARUs due to the low sample-rate) (Table 12).). During deployment A-D2 for Year-2 (16 Oct 2018 – 13 Mar 2019), 149 days were recorded, during which the six focal species were detected. The M-D4 data comprised 101 calendar days of sound (Jan – Apr 2019), during which the five baleen whale species were detected. Units for M-D5 (Apr – Aug 2019) recorded 112 calendar days and all baleen whale species, but blue whales, were recorded during that time. MARUs from deployment M-D6 recorded for 73 calendar days to the end of the survey year, again recording all the baleen whale species except blue whales. Deployment A-D3 (Mar – Oct 2019) spanned 215 calendar days and recorded all six target species (Figure 13). While “deployment” time periods are not biologically meaningful here, it is useful to report the presence for each species in relation to survey effort by deployment to convey the relationship between presence and sampling effort (Table 12, Table 13).

Table 12. Summary of the total calendar-days in which the focal baleen whale species were detected per deployment for Year-2 (October 2018 – 2019), and the corresponding percentage of calendar-days in which the species was detected.

		Right		Humpback		Fin		Sei		Blue	
Deployment	**Surveyed Calendar-Days**	**# Days with presence**	**% Days**	**# Days with presence**	**% Days**	**# Days with presence**	**% Days**	**# Days with presence**	**% Days**	**# Days with presence**	**% Days**
M-D3 & A-D2	149	102	68	113	76	148	99	13	9	1	1
M-D4	101	81	80	37	37	100	99	49	49	7	7
M-D5	112	64	57	105	94	112	100	59	53	0	0
M-D6 & A-D3	215	98	46	159	74	199	93	82	38	0	0
Total	577	345	60	414	72	556	96	203	35	8	1

Table 13. Summary of total days and percent of time in which sperm whales were detected during Year-2 (October 2018 – 2019).

Deployment	Calendar Days	Presence Days	% Days
A-D2	149	4	3
A-D3	215	33	15
Total	364	37	6

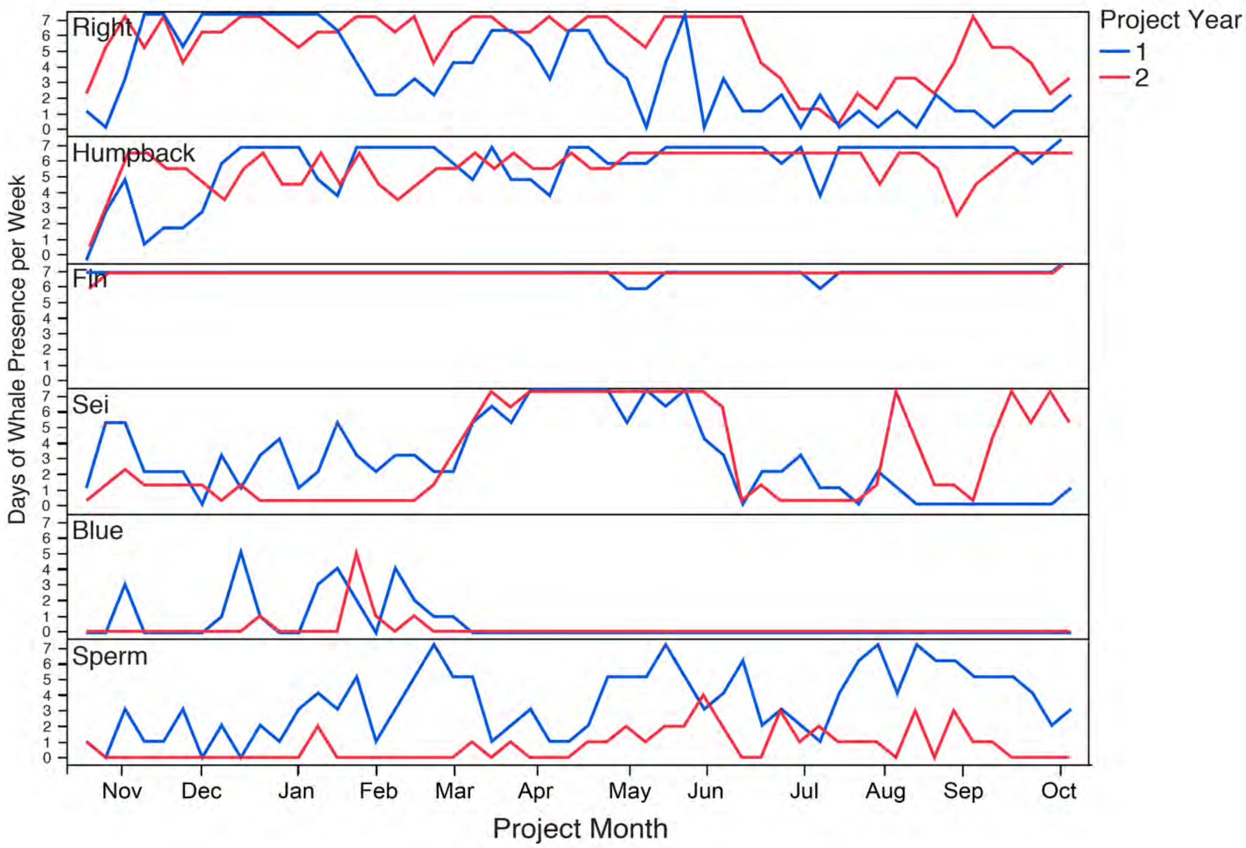

Figure 13. Weekly acoustic presence of focal whale species detected within New York Bight across survey years 1 and 2, shown as number of days per week with confirmed acoustic detections integrated across all sensors. Survey Year-1 (October 2017-October 2018) is in blue, and Survey Year-2 (October 2018-October 2019) is in red.

North Atlantic Right Whale Occurrence

North Atlantic right whales were detected during every month of the Year-2 survey period, with daily presence per month ranging from 13% in July 2019, to 97% in March 2019 (Table 14), with peak presence between December and May (Figure 14, Figure 15). Looking at a finer resolution of weekly presence better illustrates right whale movement trends at each recording site and between sites throughout the survey, where right whales gradually begin to enter the survey area in November and leave around June. There is another peak in presence during September, which may represent right whale migration through this survey area. At both weekly and monthly scales, right whale presence was dynamic, reflecting a relationship between a neighboring time period, while varying greatly over longer periods of time (Figure 14, Figure 15).

Monthly spatial presence data (Figure 16) illustrates that right whales occurred at sites closest to New York Harbor (5M, 6M, 7M, 8A, 9A, 10M, 11A, and 12M) during their peak months between November and February. Between March and June, right whales were detected more on sites closer to the shelf break (1M, 2M, and 3M).

North Atlantic right whale seasonal presence was highest during the winter and spring seasons (80% days), and gradually declined by the summer (38%) (Table 15, Figure 18), and these were primarily in the middle of the planning area (Figure 19). During the winter, right whales were detected at all sites, while during the fall they were detected closer to New York Harbor, and during the spring they were detected closer to the shelf edge (Figure 19).

Year-2 had an increased number of overall right whale daily detections from Year-1 (Year-2=585, Year-1= 437). Specifically, sites 1M, 2M, 3M, 4M, 9A, 11A, 13A, and 14A all had increases in detections in Year-2. On the eastern and southern parts of the array (sites 1M, 2M, 13A, 14M), right whale detections increased later (March-June) compared to the northern and central sites (4M-11A) where most detections there occurred between December and February, and there were few detections in both years at these locations after May. Figure 20 shows an increase in seasonal occurrence in Winter, Spring and Summer for nearly all sites, in Year-2 versus Year-1.

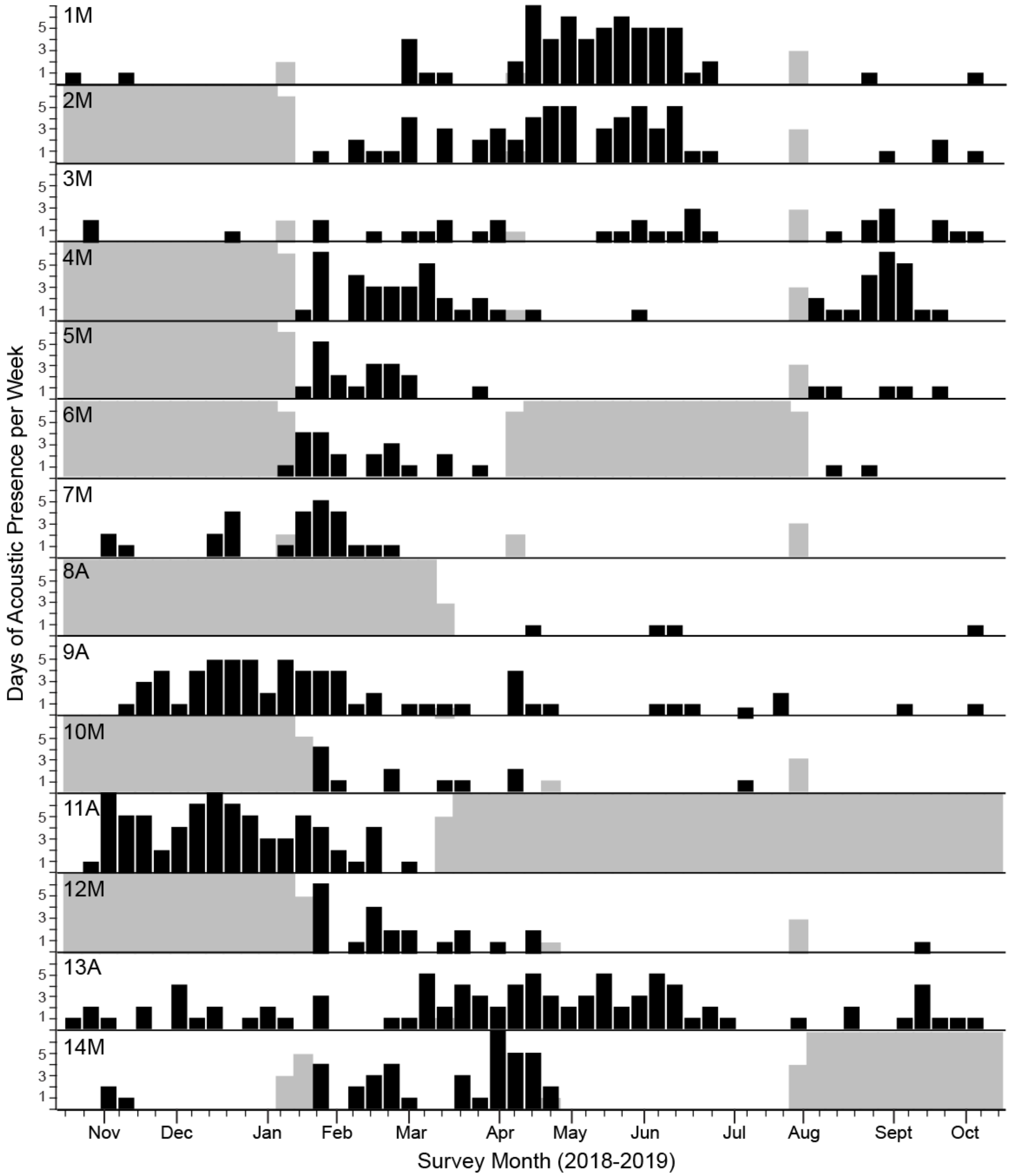

Figure 14. Weekly acoustic presence of North Atlantic right whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed right whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

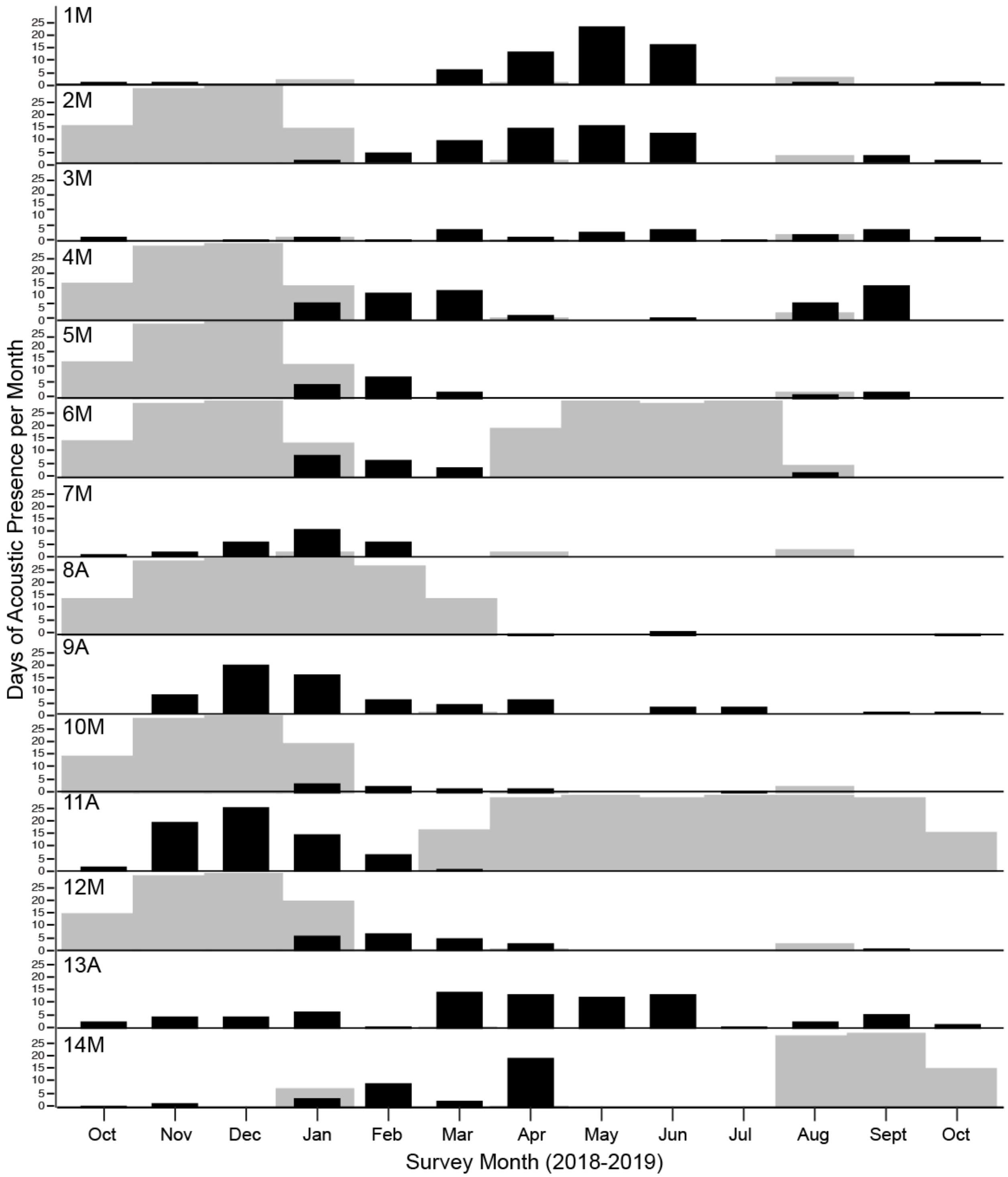

Figure 15. Monthly acoustic presence of North Atlantic right whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed right whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

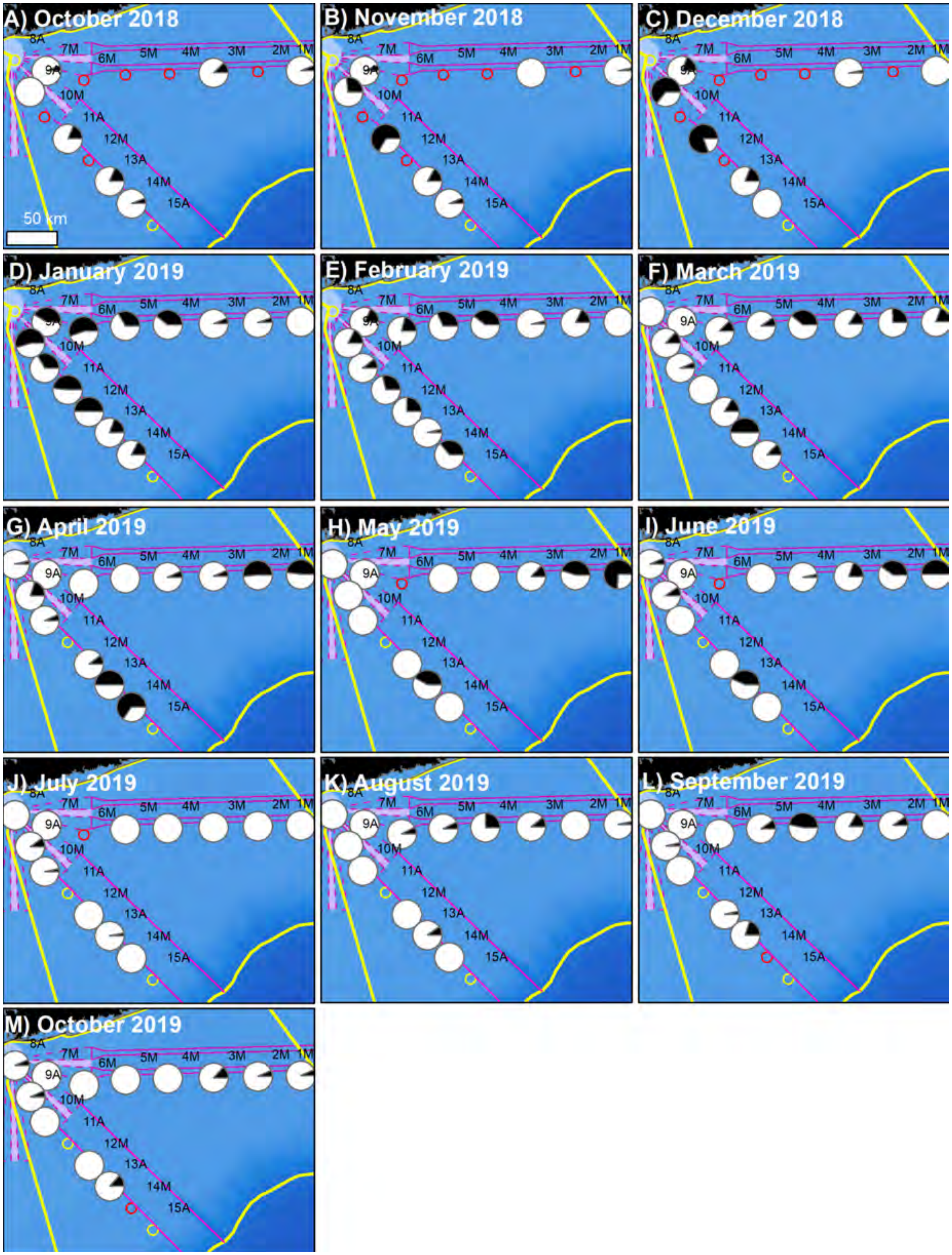

Figure 16. Spatial patterns of monthly presence of North Atlantic right whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

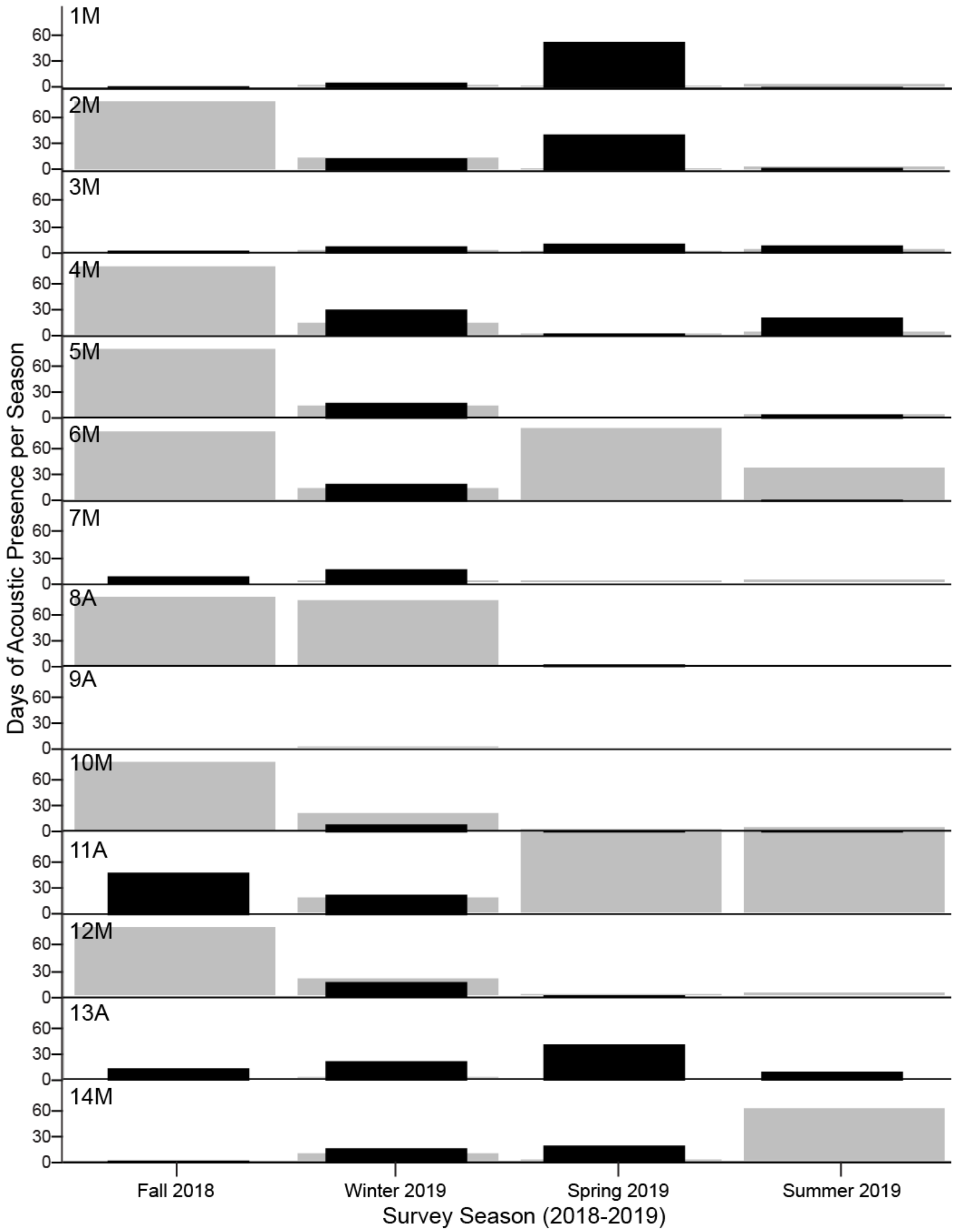

Figure 17. Seasonal acoustic presence of North Atlantic right whales detected within New York Bight from Fall 2018 through Summer 2019, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

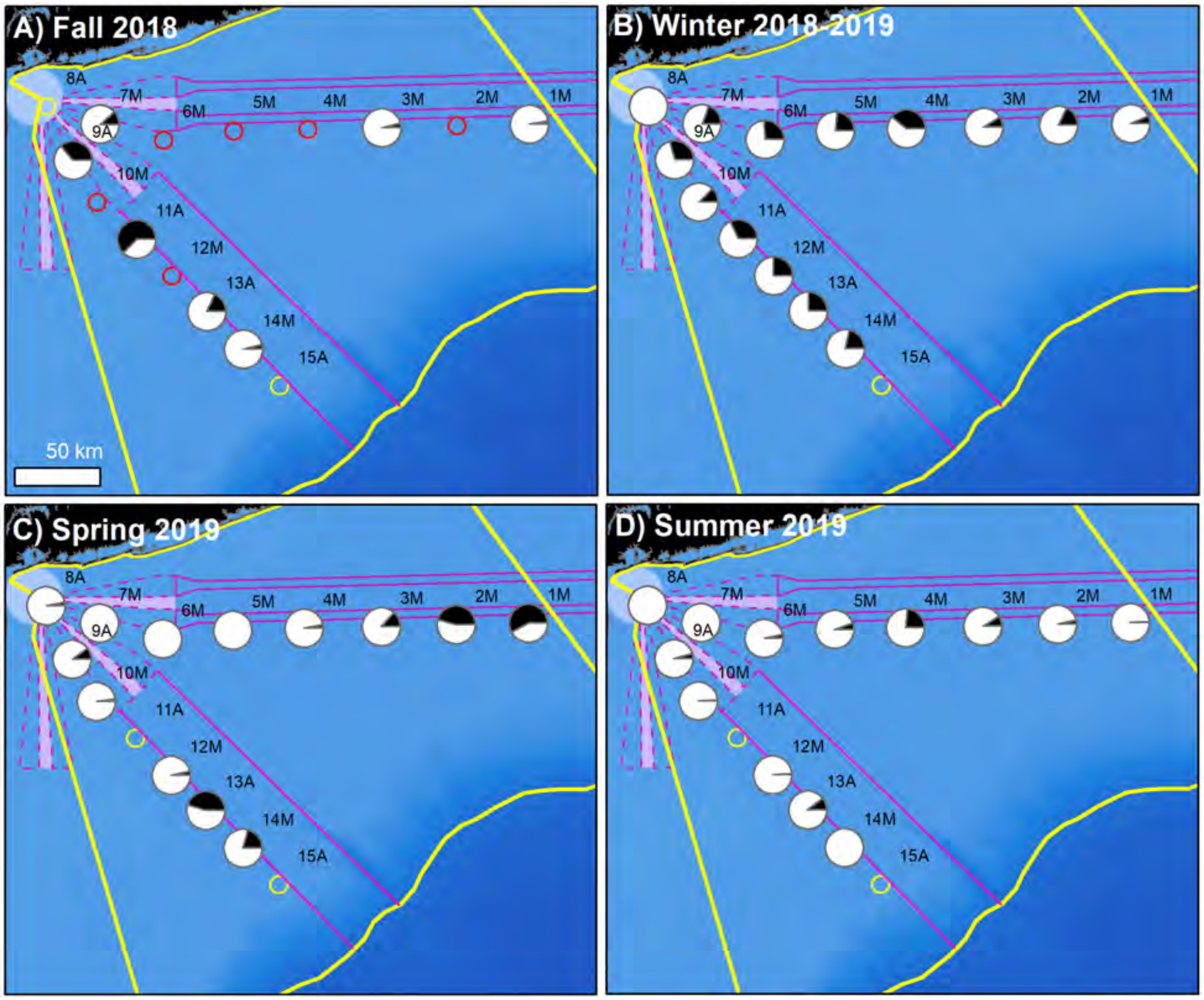

Figure 18. Spatial patterns of seasonal acoustic presence of North Atlantic right whale upcalls in New York Bight, shown as percentage of days per season on each recording unit,. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

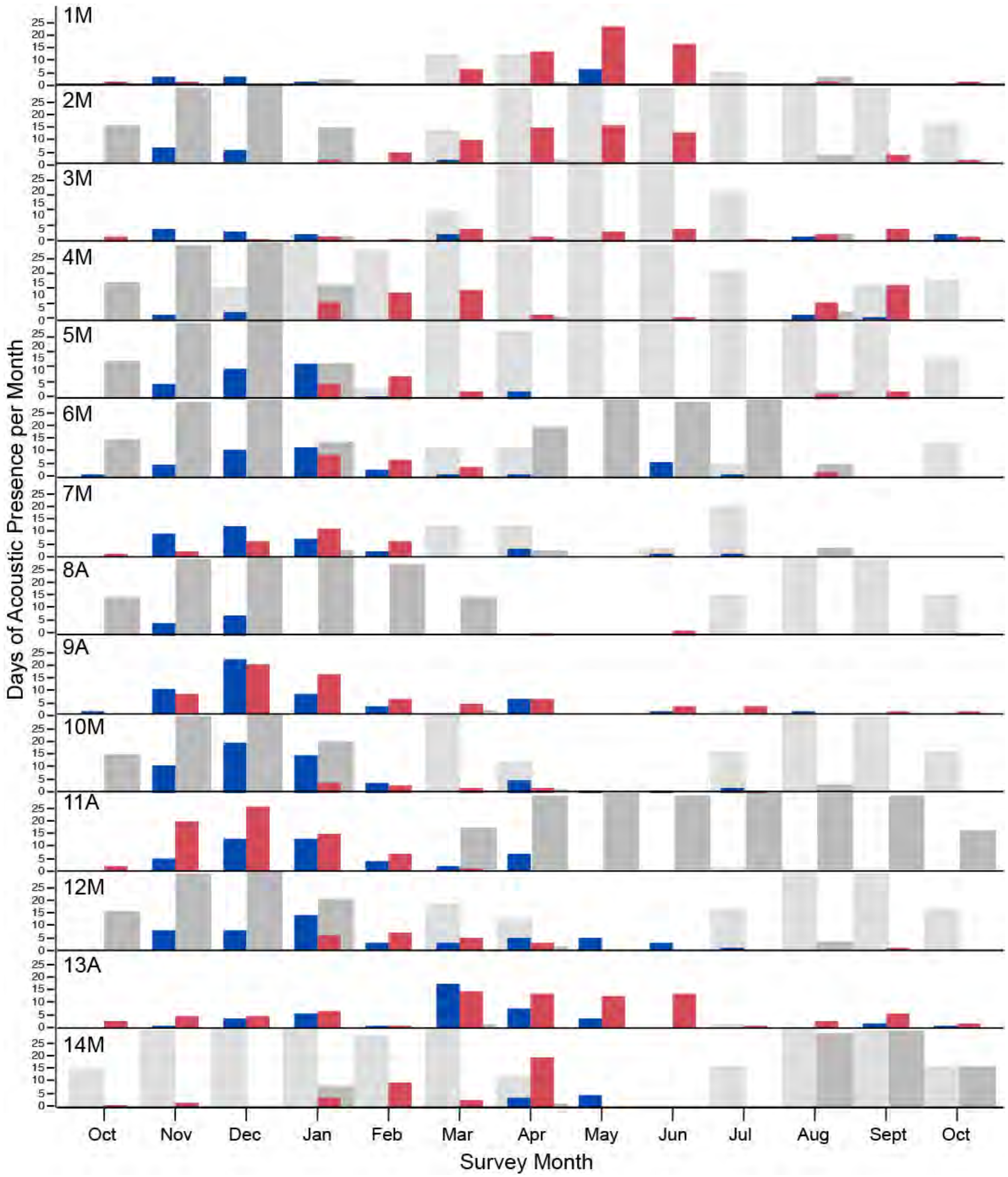

Figure 19. Internannual North Atlantic right whale monthly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month.

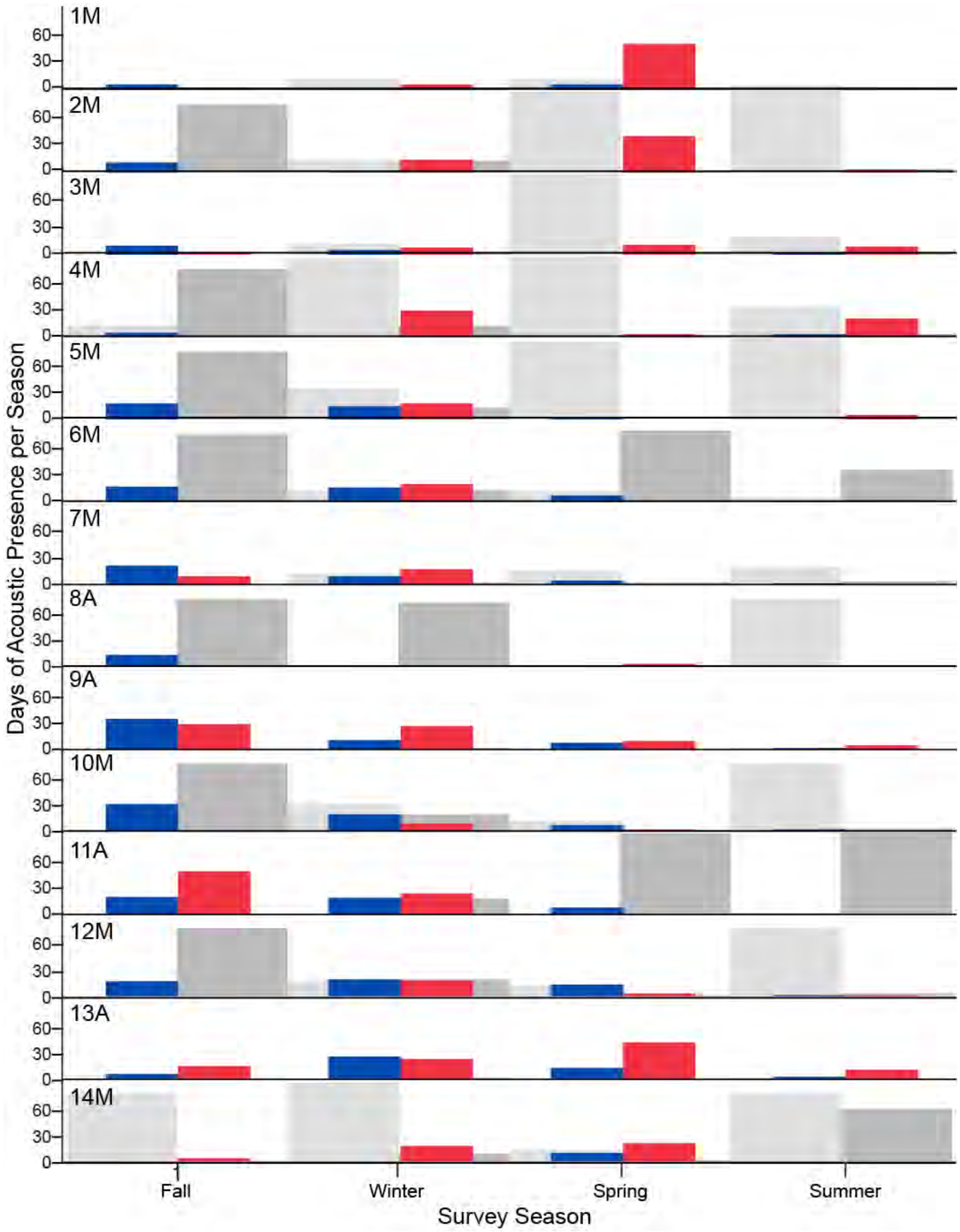

Figure 20. Internannual North Atlantic right whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

Humpback Whale Occurrence

Humpback whales were detected during most weeks (Figure 21) and during every month (Figure 22) of the Year-2 survey period. Humpback whale acoustic presence peaked between December and September (Table 14, Figure 21, Figure 22), while the lowest presence occurred during October 2018 (44%) and 2019 (14%). During May, June, and July, humpback whales were detected on 100% of the recorded days of those months. Acoustic presence for humpback whales was generally lowest during the fall months for 2018 and 2019 (58% and 14% of recorded days, respectively), and highest during the spring months, with 88% of the days in spring with humpback presence (Table 15).

Humpback whales were detected at all sensors throughout the Year-2 survey (Table 16, Figure 22, Figure 23). Humpback whales were detected across both transects, though more presence was found in the southern transect during the winter months (Figure 23). The least humpback whale presence was at site 8A (7%) and 6M (8%), and the highest presence was among sites 11A, 12M, and 13A, along the southern transect (53%, 35%, and 49% daily presence, respectively; Table 16).

There were fewer overall humpback whale daily detections in Year-2 compared to Year-1 (Year-2=1000, *Year-1*= 1267). Sites 1M, 6M, 8A, 10M, 11A, 12M, 13A all exhibited decreased acoustic presence during Year-2. While the decrease in acoustic presence at sites 1M, 12M, and 13A represent a change in temporal occurrence patterns of humpback whales, the decreases in daily detections at sites 6M, 8A and 11A are due to data losses in Year-2, and not necessarily a change in temporal occurrence of humpback whales. Site 13A exhibited an earlier increase in humpback presence in the area during Year-2 than Year-1. Humpback whale spatial distribution appears similar between years.

Given the data gaps between October 2018 and January 2019 at many of the sites, it is difficult to discern if the apparent increasing presence of humpback whales in November 2018 occurred in both transects, or just the southern transect, which is where the AMAR devices were recording during that time. The Year-3 surveys will provide more data to help us better understand the humpback whale monthly trends in this survey area. It is interesting to note that there is presence at site 13A during every month of Year-2.

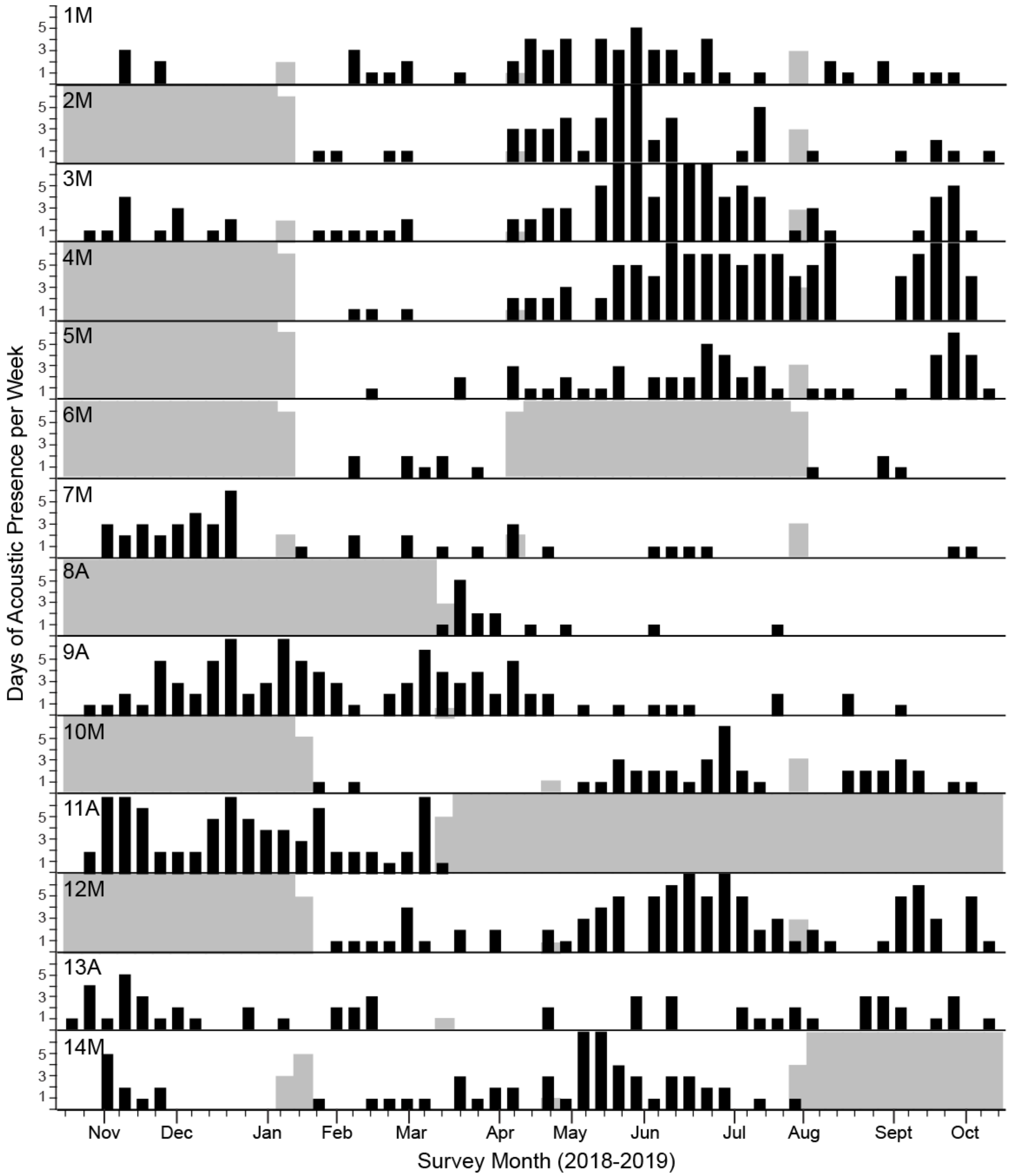

Figure 21. Weekly acoustic presence of humpback whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed humpback whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

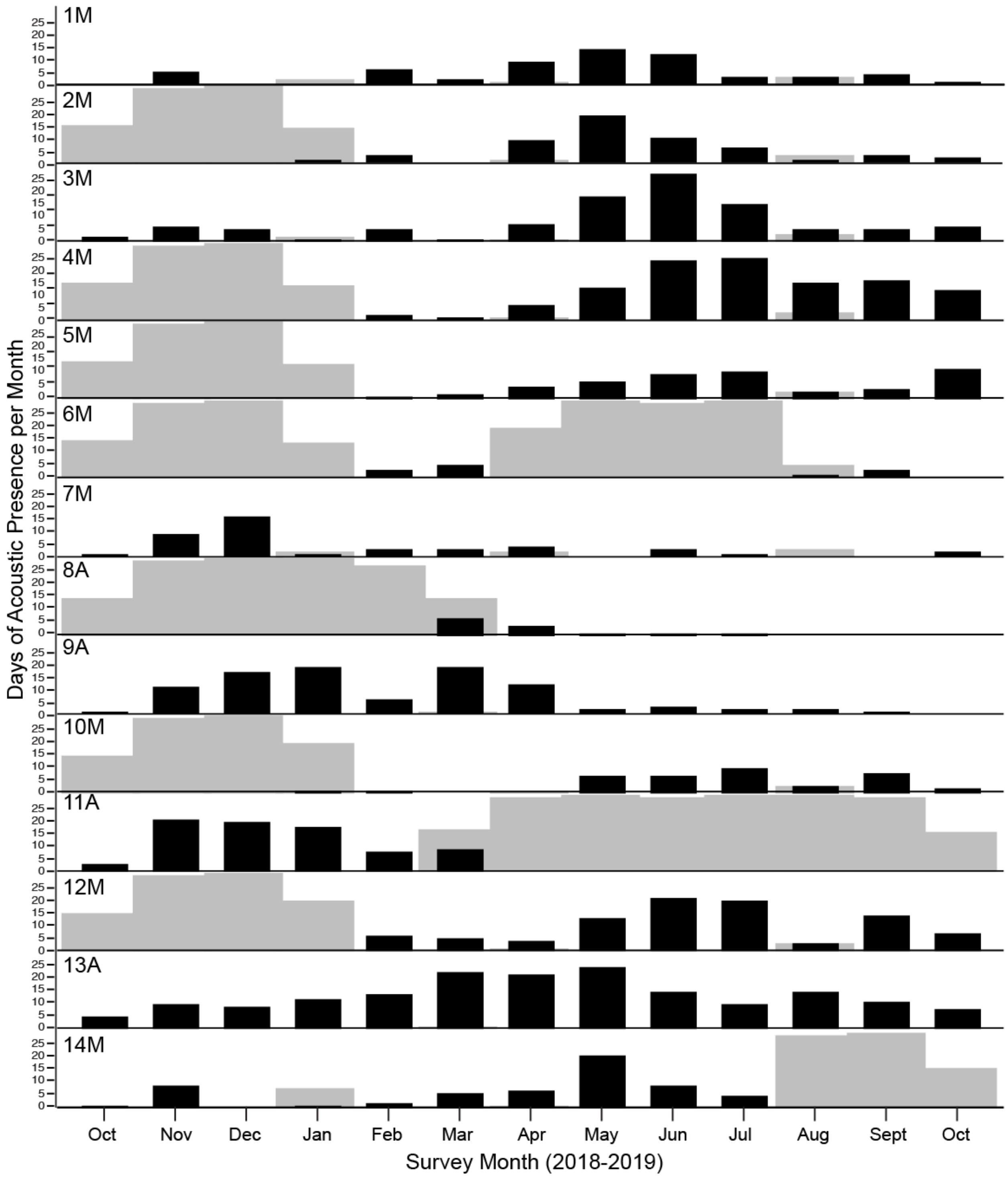

Figure 22. Monthly acoustic presence of humpback whales detected within New York Bight between October 2018-October 2019, shown as number of days per month with confirmed humpback whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

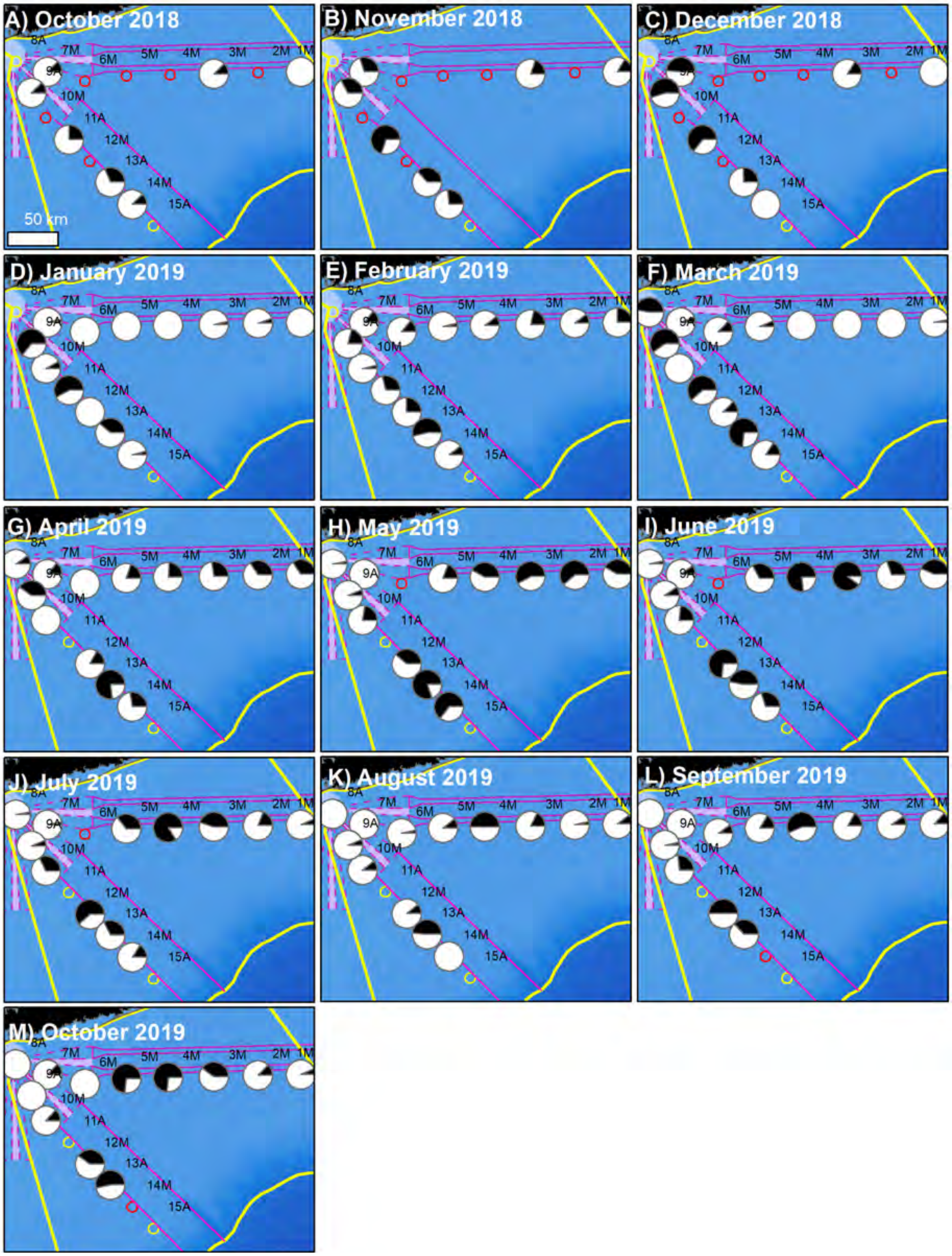

Figure 23. Spatial patterns of monthly presence of humpback whales in New York Bight, shown as percentage of days per month on each recording unit, . Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

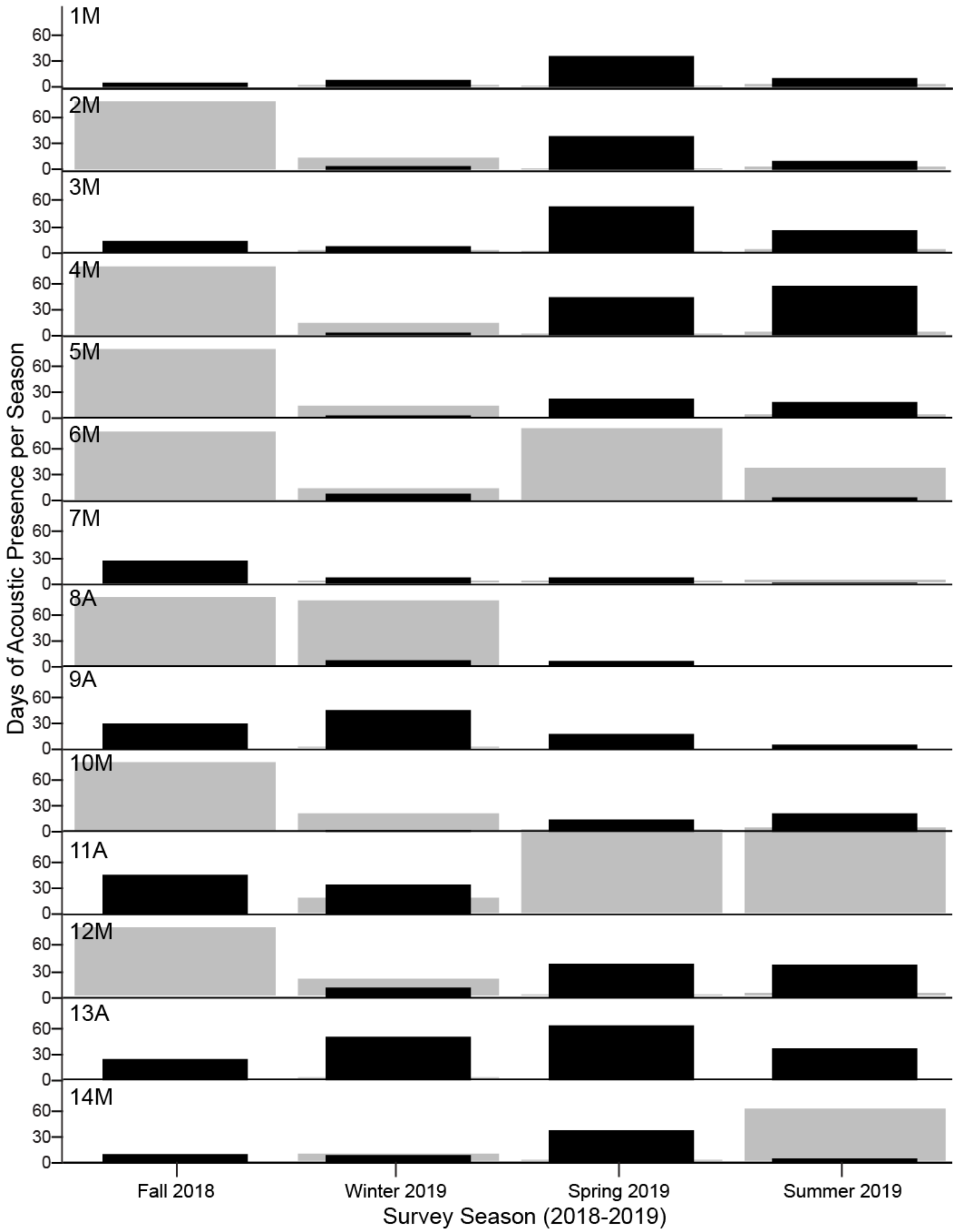

Figure 24. Seasonal acoustic presence of humpback whales detected within New York Bight from Fall 2018 through Summer 2019, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

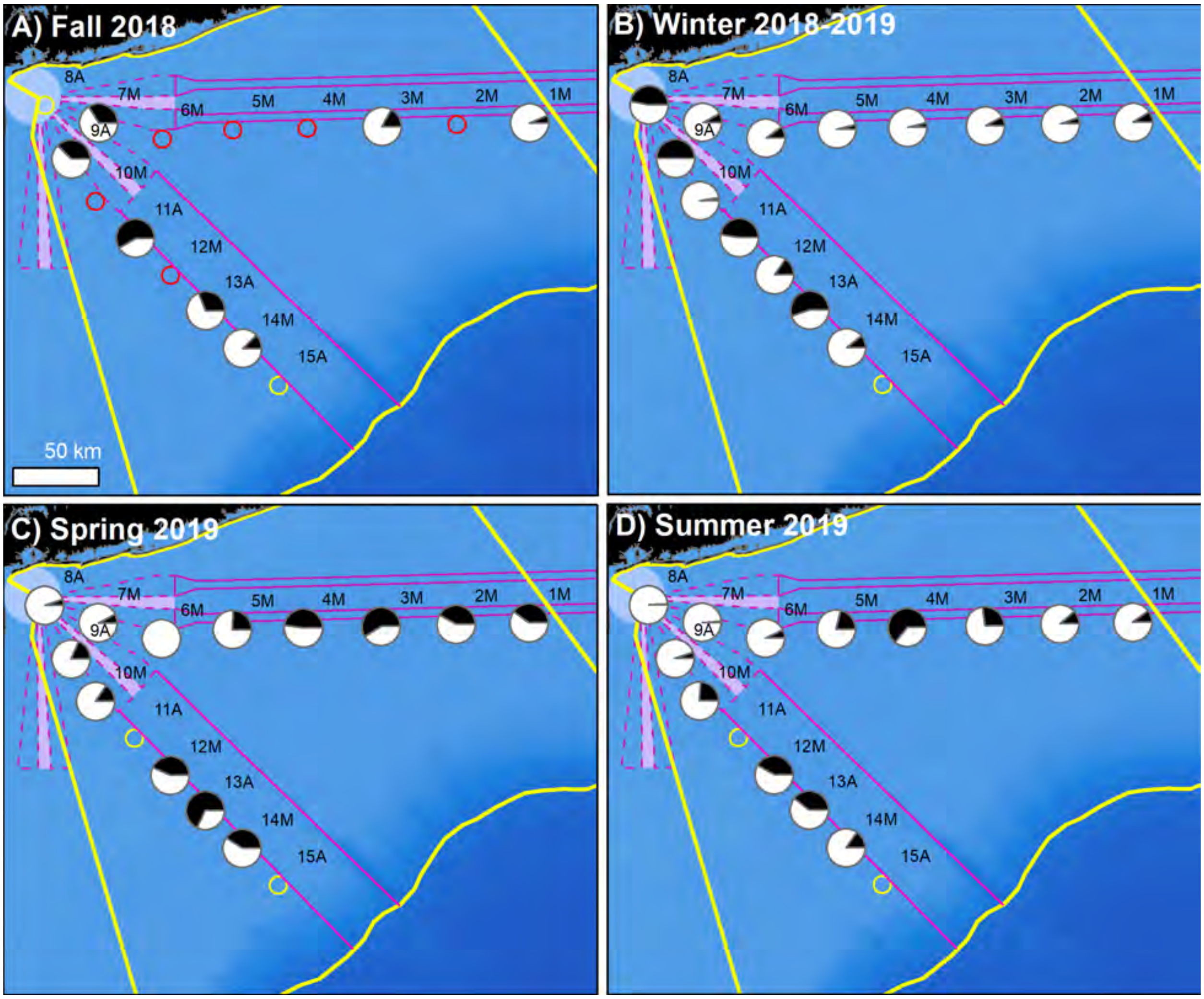

Figure 25. Spatial patterns of seasonal acoustic presence of humpback whales in New York Bight, shown as percentage of days per season on each recording unit, . Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

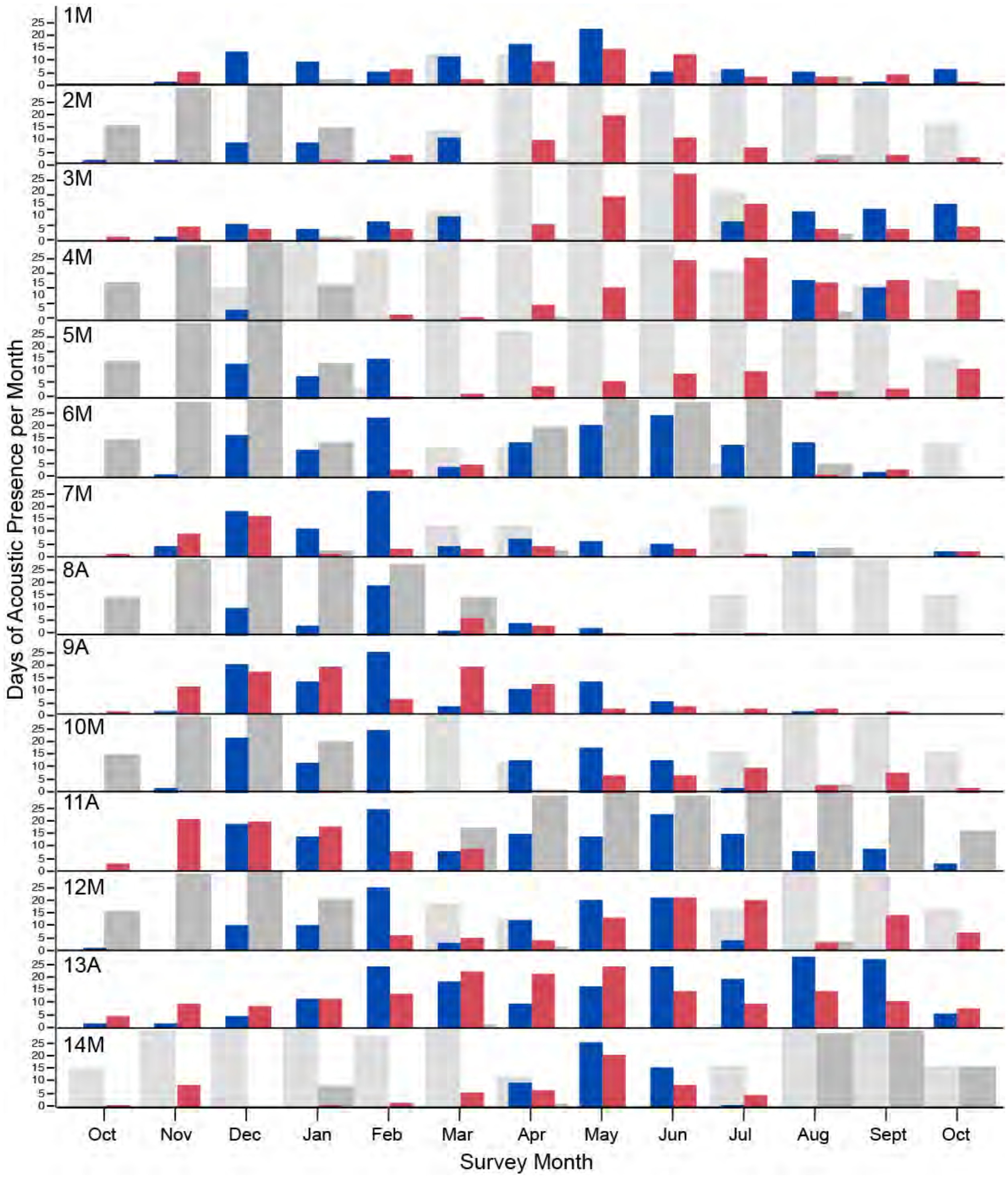

Figure 26. Internannual humpback whale monthly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

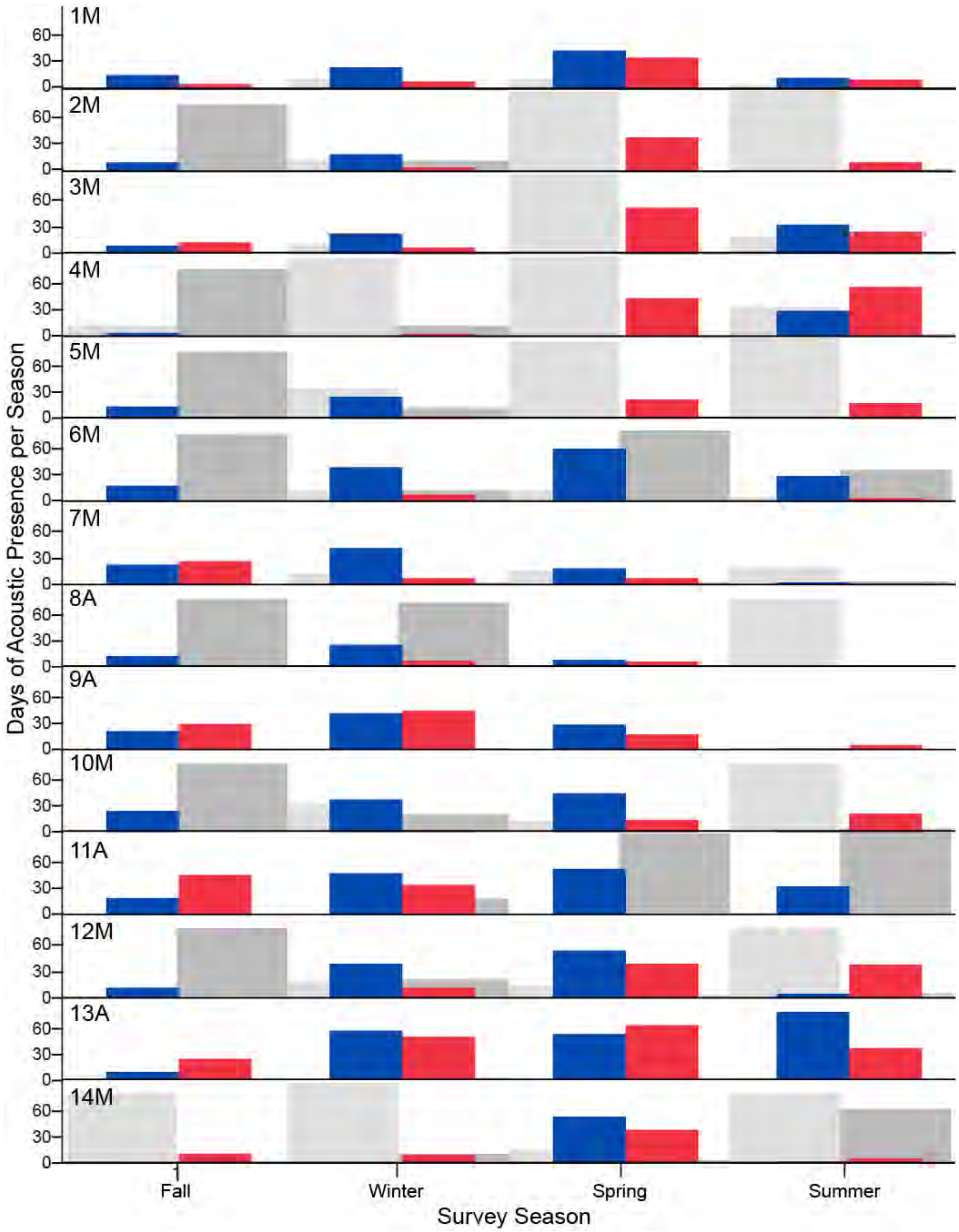

Figure 27. Internannual humpback whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month.

Fin Whale Occurrence

Fin whales were the most regularly detected whale species in NY Bight. Across all of the NY Bight sensors, fin whales were detected during every week (Figure 28), and in every month of the Year-2 survey (Table 14, Figure 29, Figure 30). Site 3M had the highest number of daily detections through the Year-2 recording period (n = 308), and site 8A had the fewest (n = 54). Many of the outer recording sites in the array (1M-6M, 10M-13A) had 100% daily presence per week between August and October 2019 (Figure 28).

At a monthly scale, peak occurrence occurred in November 2018 – January 2019, and then a secondary peak in August/September for Sites (Figure 29). Spatial examination of monthly trends of fin whale presence across the array suggests some small-scale spatial variability, but for the most part, spatial detection patterns appear similar across sites (Figure 30). The sites farther from NY Harbor have higher number of days with detections (Table 16, Figure 30), and 8A had the lowest monthly presence throughout the survey period (15%), suggesting the fin whales tend to occur farther from the area of convergence between the two shipping lanes.

Seasonally, fin whale presence is lowest in the spring (67%; Table 15, Figure 31), with detections concentrated towards the southwestern and western units in the survey array (Figure 32). However, the seasonal pattern of detections further demonstrate that fin whales are broadly detected across the project area for much of the year (Figure 31, Figure 32).

There were more overall fin whale daily detections in Year-2 compared to Year-1 (Year-2=2687, Year-1=2316). All sites except for 6M, 8A, and 11A showed increases in fin detections in year 2. In both years, fin whale occurrence was highest at sites 1M-5M and 10M-14M. Both years also showed lowest occurrence of fin whales in the summer, particularly at sites 7M, 8A and 9A.

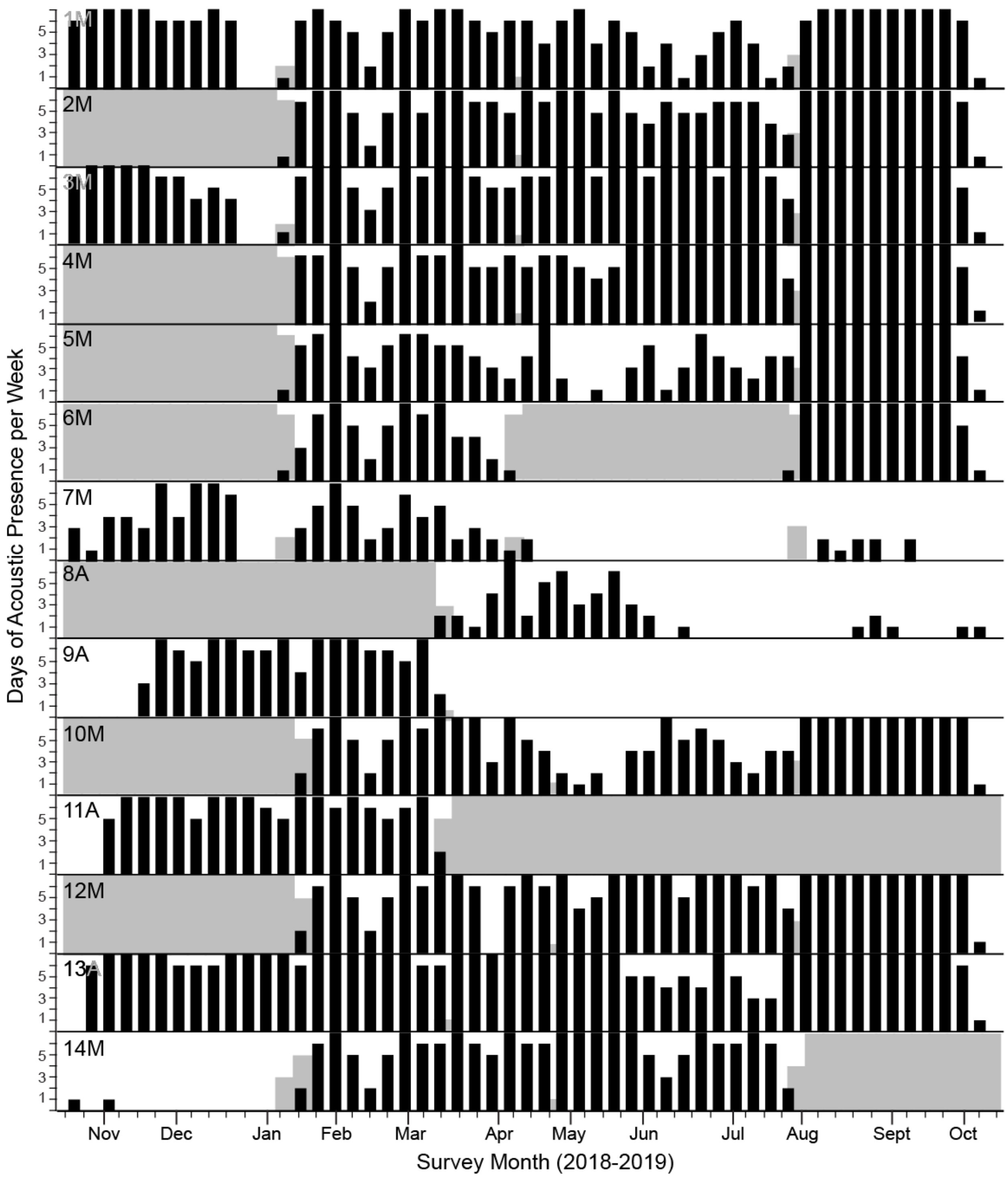

Figure 28. Weekly acoustic presence of fin whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed fin whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

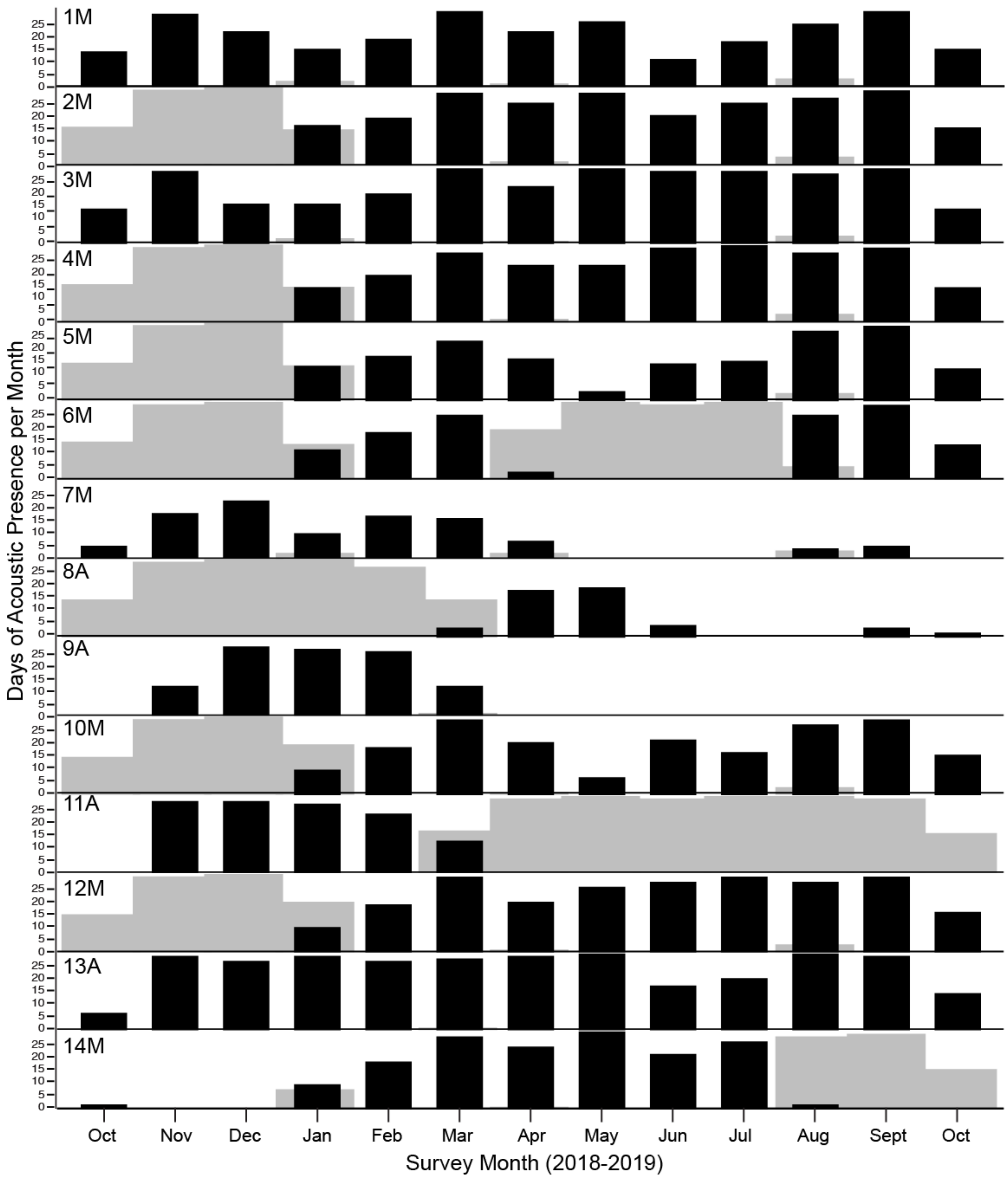

Figure 29. Monthly acoustic presence of fin whales detected within New York Bight between October 2018-October 2019, shown as number of days per month with confirmed fin whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

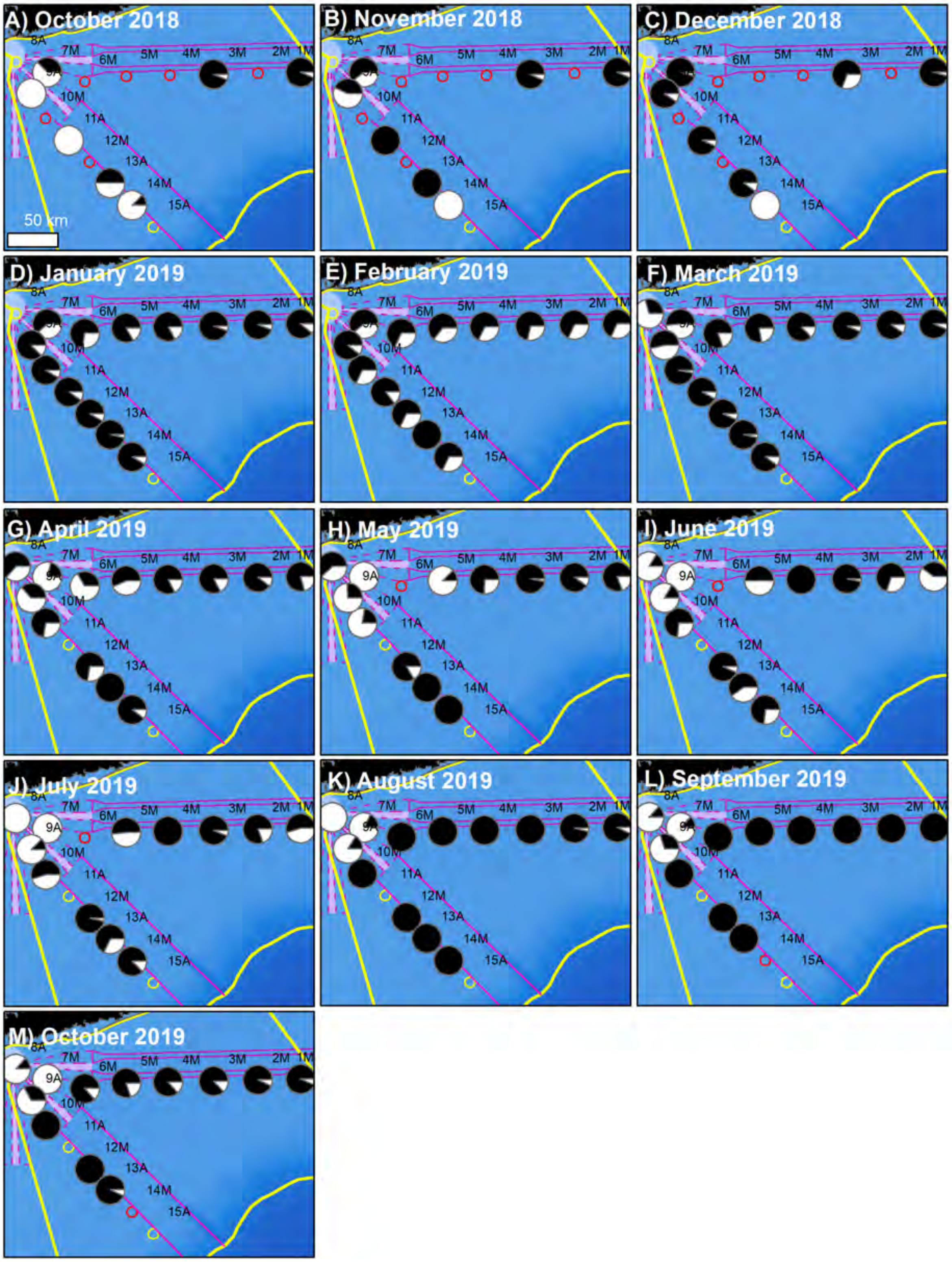

Figure 30. Spatial patterns of monthly presence of fin whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

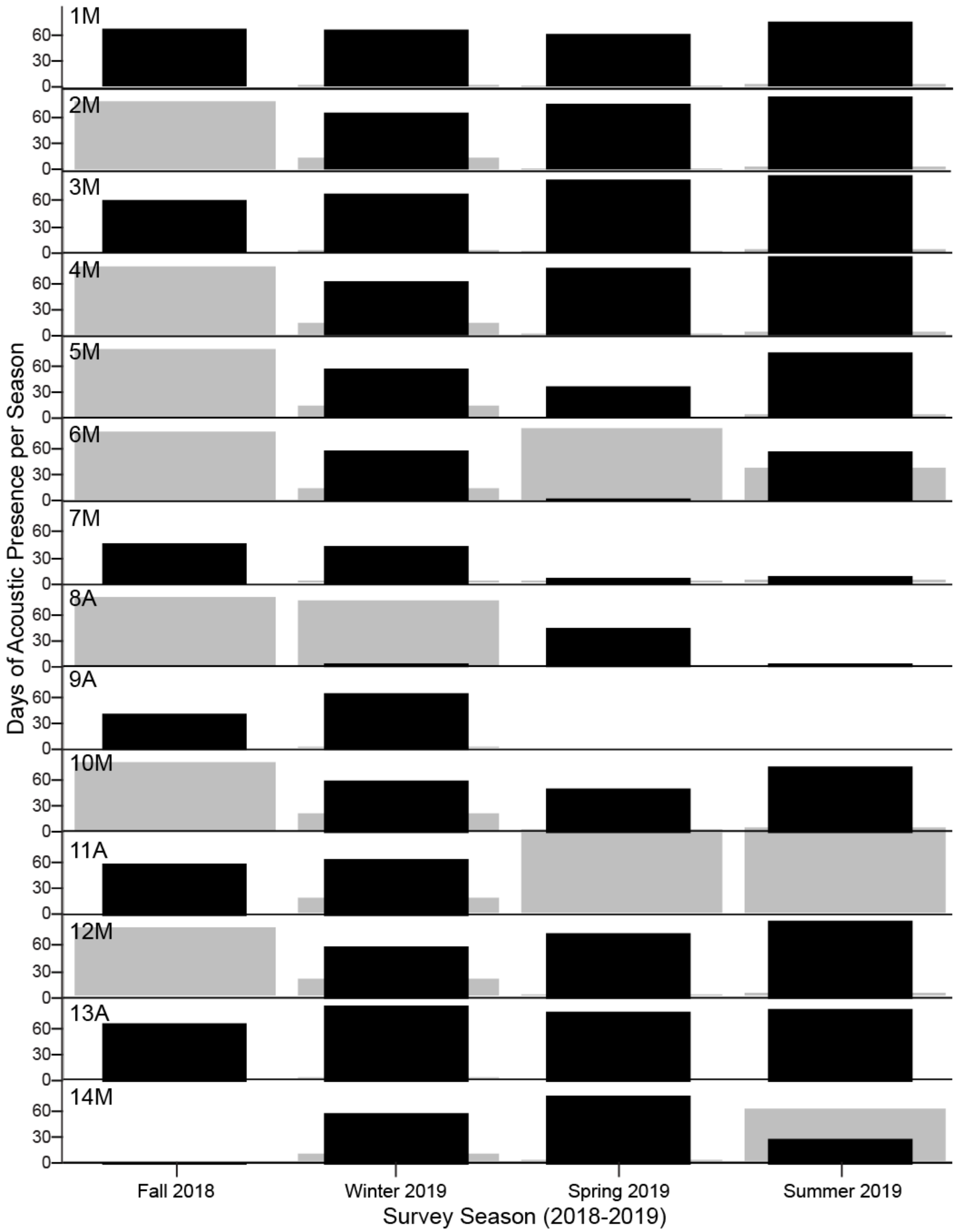

Figure 31. Seasonal acoustic presence of fin whales detected within New York Bight from Fall 2018 through Summer 2019, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

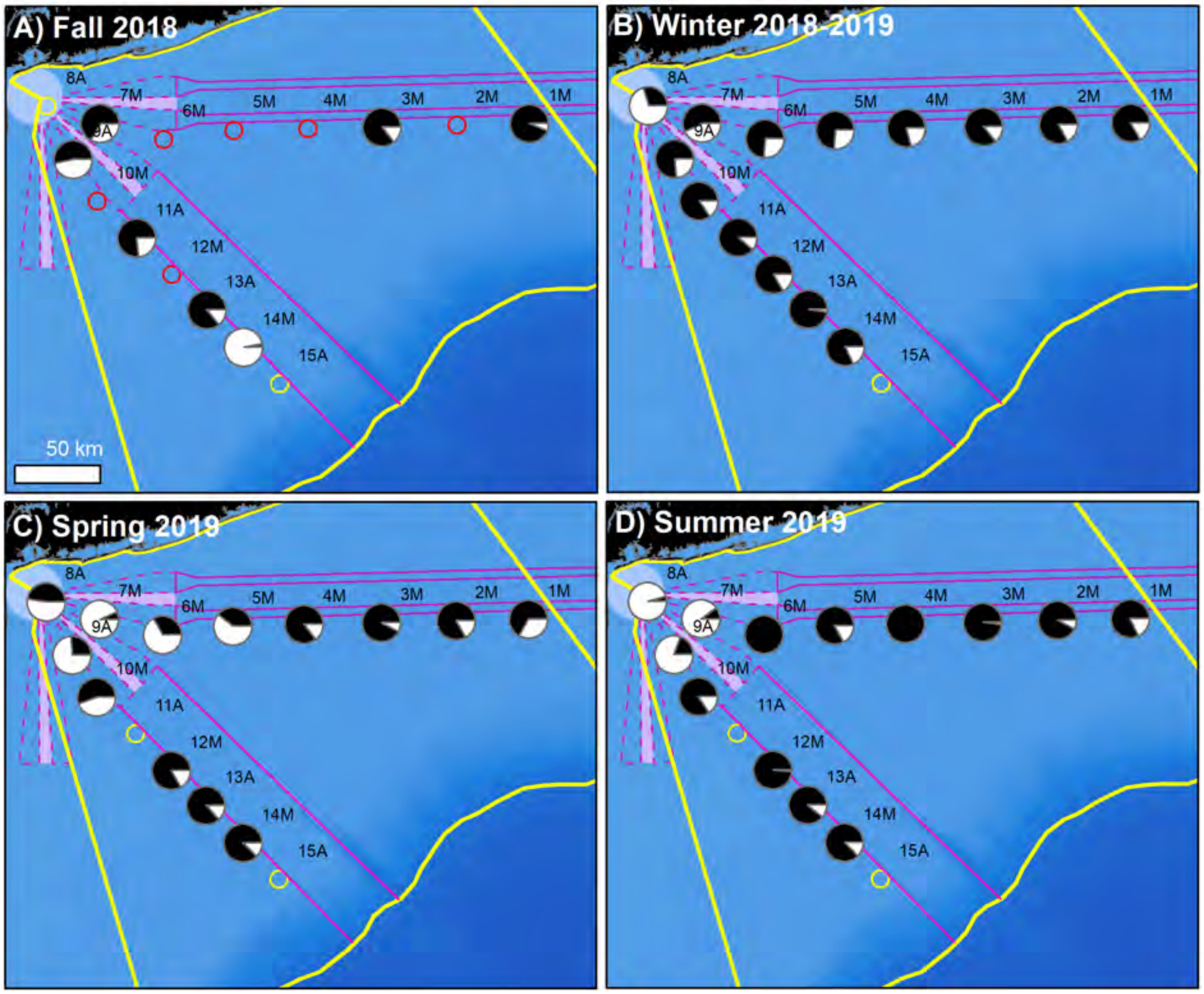

Figure 32. Spatial patterns of seasonal acoustic presence of fin whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

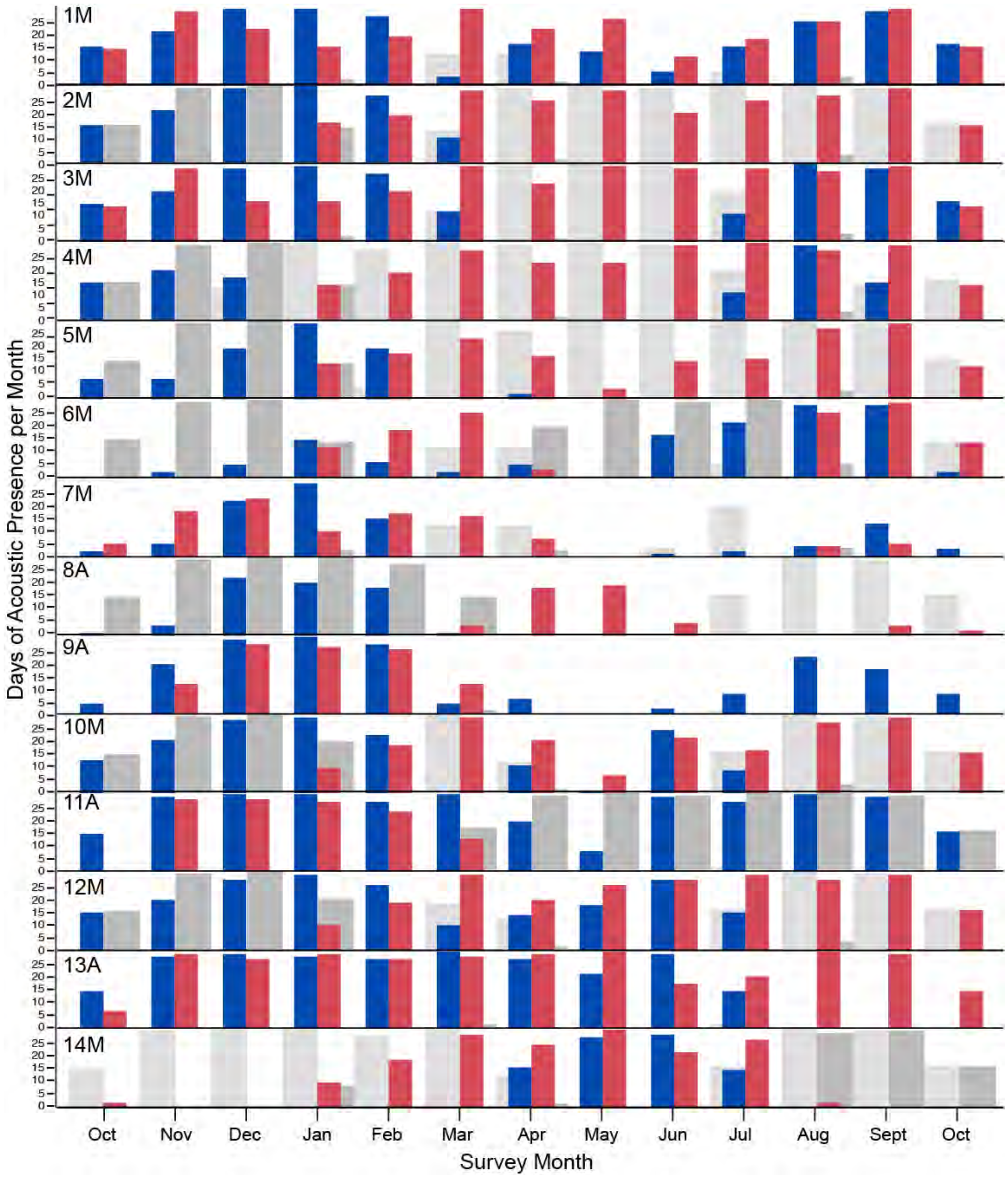

Figure 33. Internannual fin whale monthly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

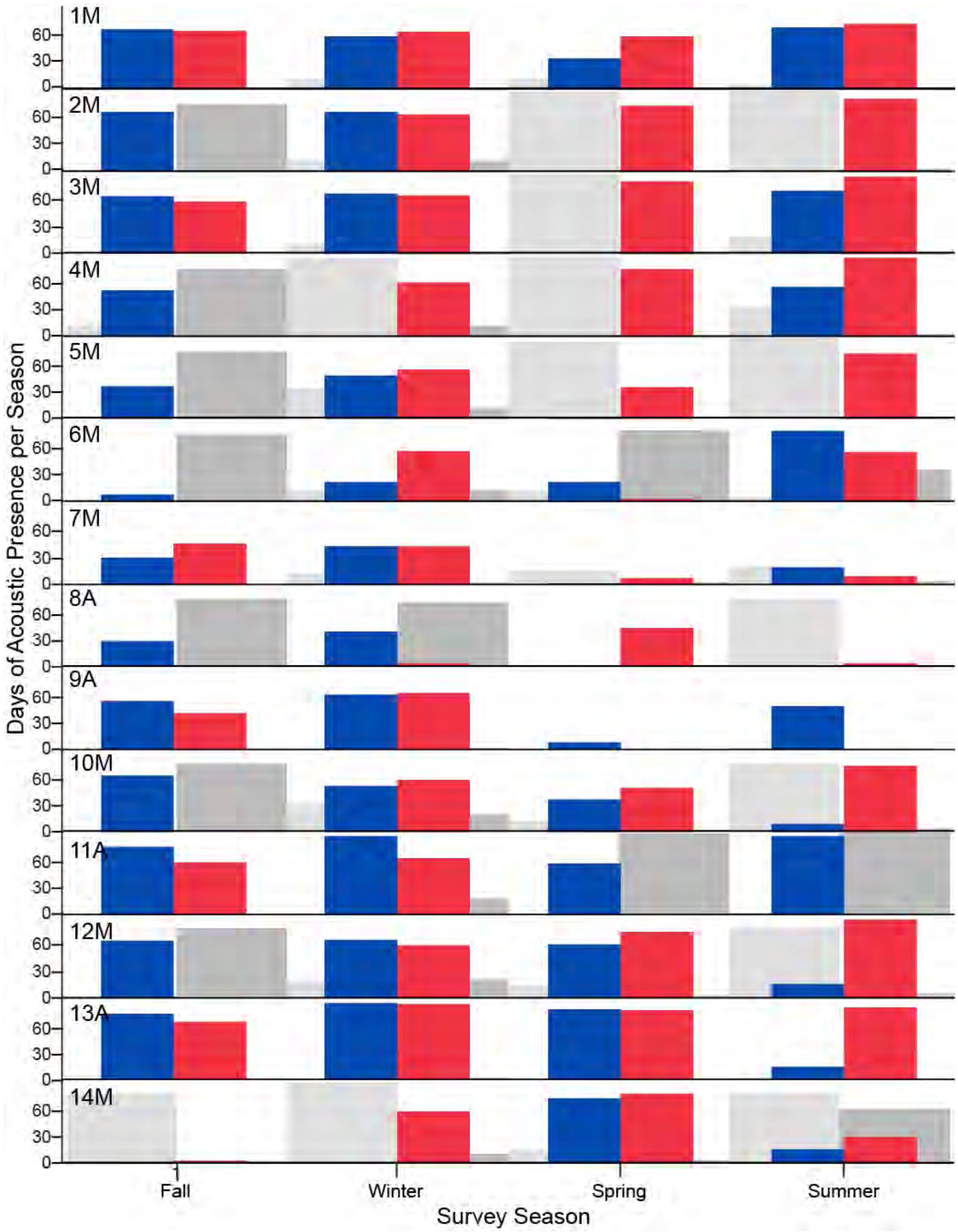

Figure 34. Internannual fin whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

Sei Whale Occurrence

Compared with the other baleen whale species (except for blue whales), sei whales had a lower overall number of daily detections in NY Bight. October 2018 through early March 2019 had low weekly sei whale presence, with 13 total days of presence between October and February across all sites (Figure 35). Sei whale acoustic presence dramatically increased in March 2019, with 27 days of presence, and tapered off in May. Between March and May, there were 88 days of sei whale presence (Table 14). Sites 1M-4M each had two or more consecutive weeks of acoustic presence every day of the week (Figure 35). Sites 2M-5M, 6M, 10M, 12M, 13A had any sei whale detections in mid-July through October (Figure 35).

Across the entire survey area, sei whales were detected in all months except January and July 2019 (Table 14). There appears to be a bimodal trend in occurrence, where presence was relatively low from October 2018 through February 2019, with a mean of 1.2 days pf presence per month across all sites, followed by an increase in presence during March through May (mean daily presence across sites = 32.9). After May, presence dropped, then began to increase again in August through the end of the survey period (Figure 36).

During March and April, sei whales were acoustically detected at all sites except 7M and 8A. Throughout the survey year, sites 7M recorded one day with sei whale presence (in November 2018), while site 8A did not record sei whale presence at all during the survey year. The highest number of sei whale detections occurred on the northeastern and southwestern recording units (Figure 37), suggesting a preference for deeper waters near the shelf break. Interestingly, during August, September, and October 2019, sei whales were recorded mostly at sites in the middle of the two transects, indicating that there may be seasonal movement within the survey area (Figure 39).

Sei whale percent daily presence was highest during the spring (n = 71) and lowest fall (n = 8; Table 15, Figure 38). Low-level acoustic daily presence occurred across the entire survey area in Winter (n = 28) and Summer (n = 30; Table 15, Figure 39).

There were more sei whale daily detections in Year-2 compared to Year-1 (Year-2=476, Year-1=298). In both years, the highest number of detections occurred March-April at sites 1M-4M, and 12M-14M, though there were a few detections throughout the years on most sites. The fewest detections occurred across all sites in Fall.

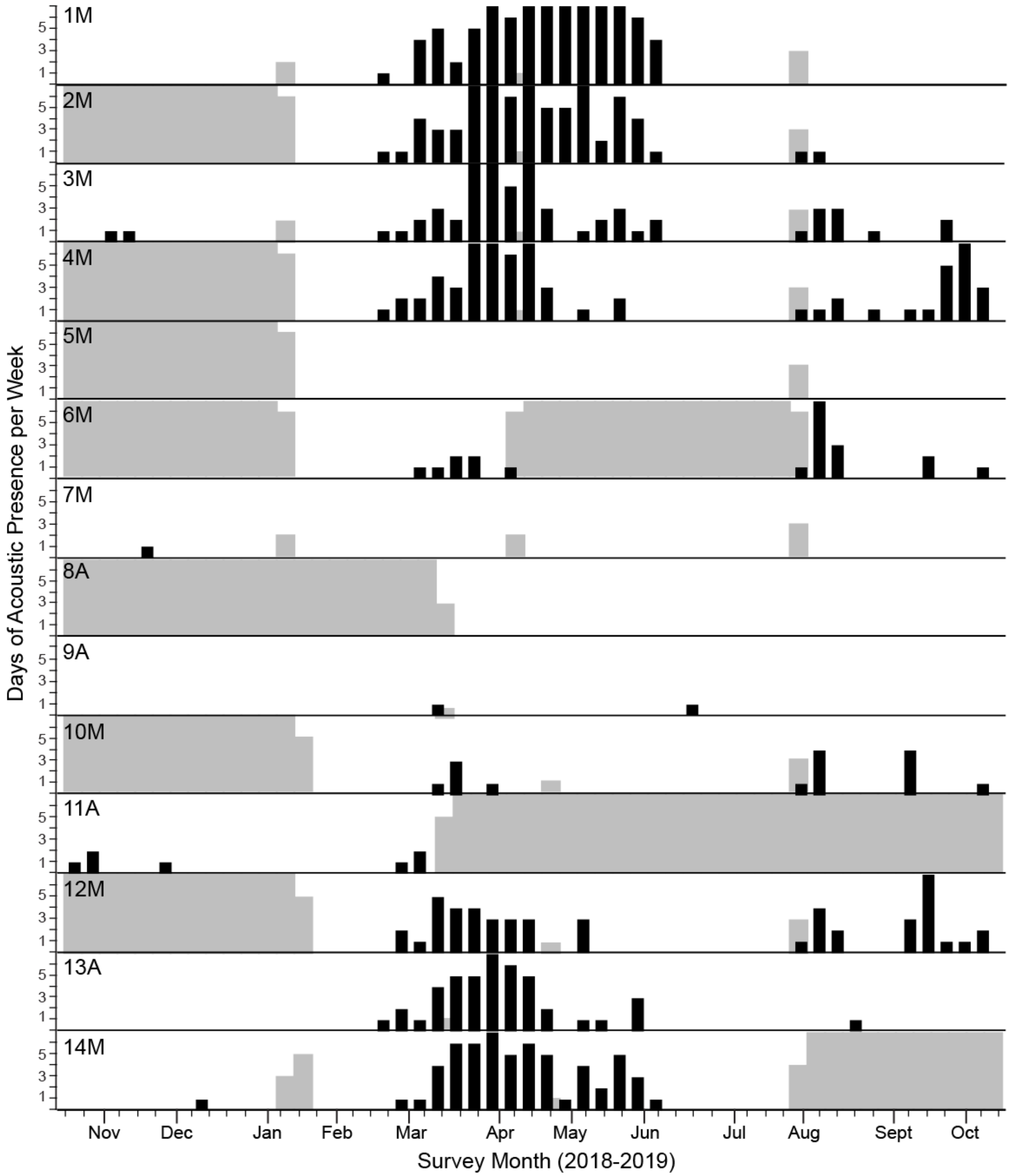

Figure 35. Weekly acoustic presence of sei whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed sei whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

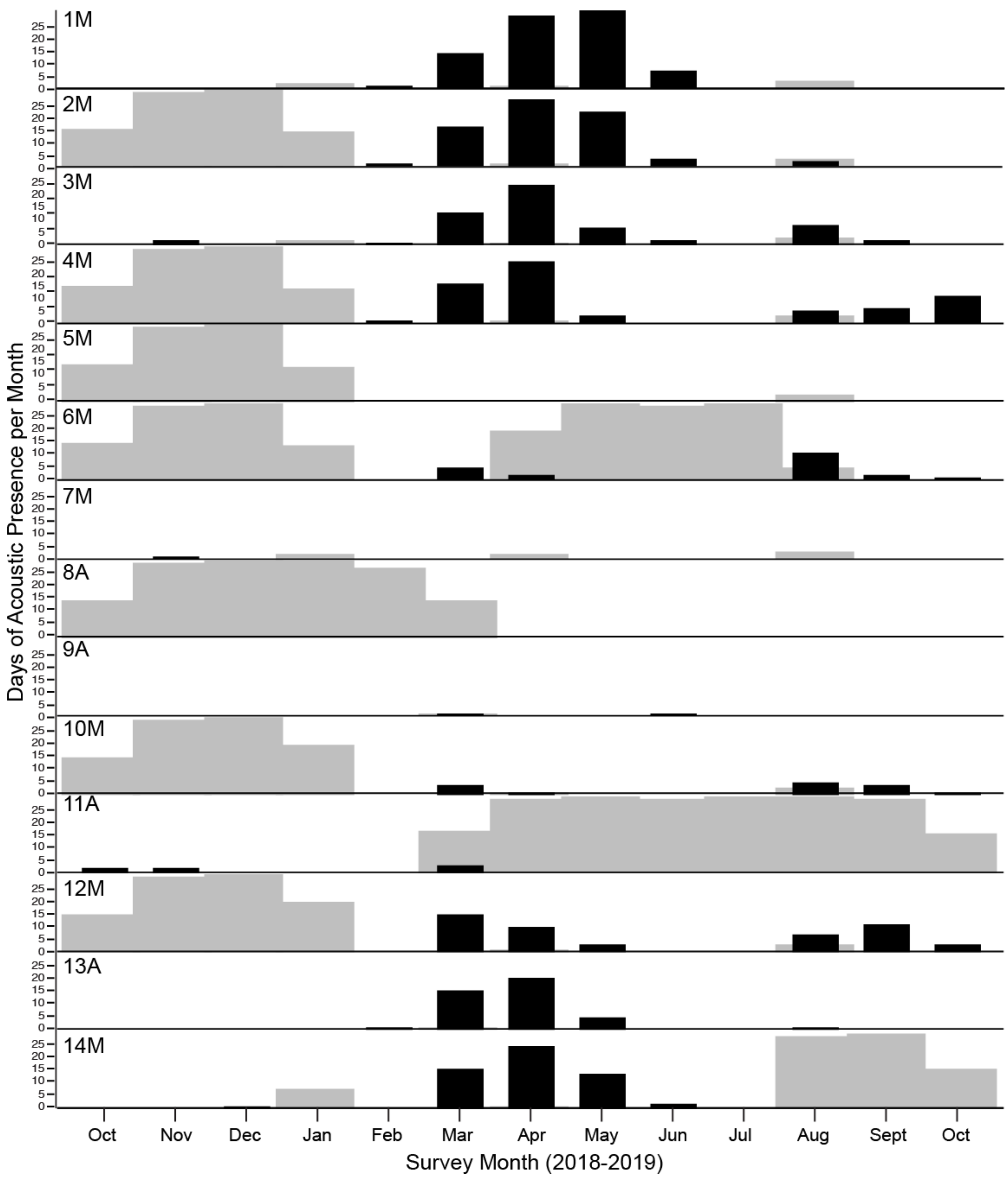

Figure 36. Monthly acoustic presence of sei whales detected within New York Bight between October 2018-October 2019, shown as number of days per month with confirmed sei whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

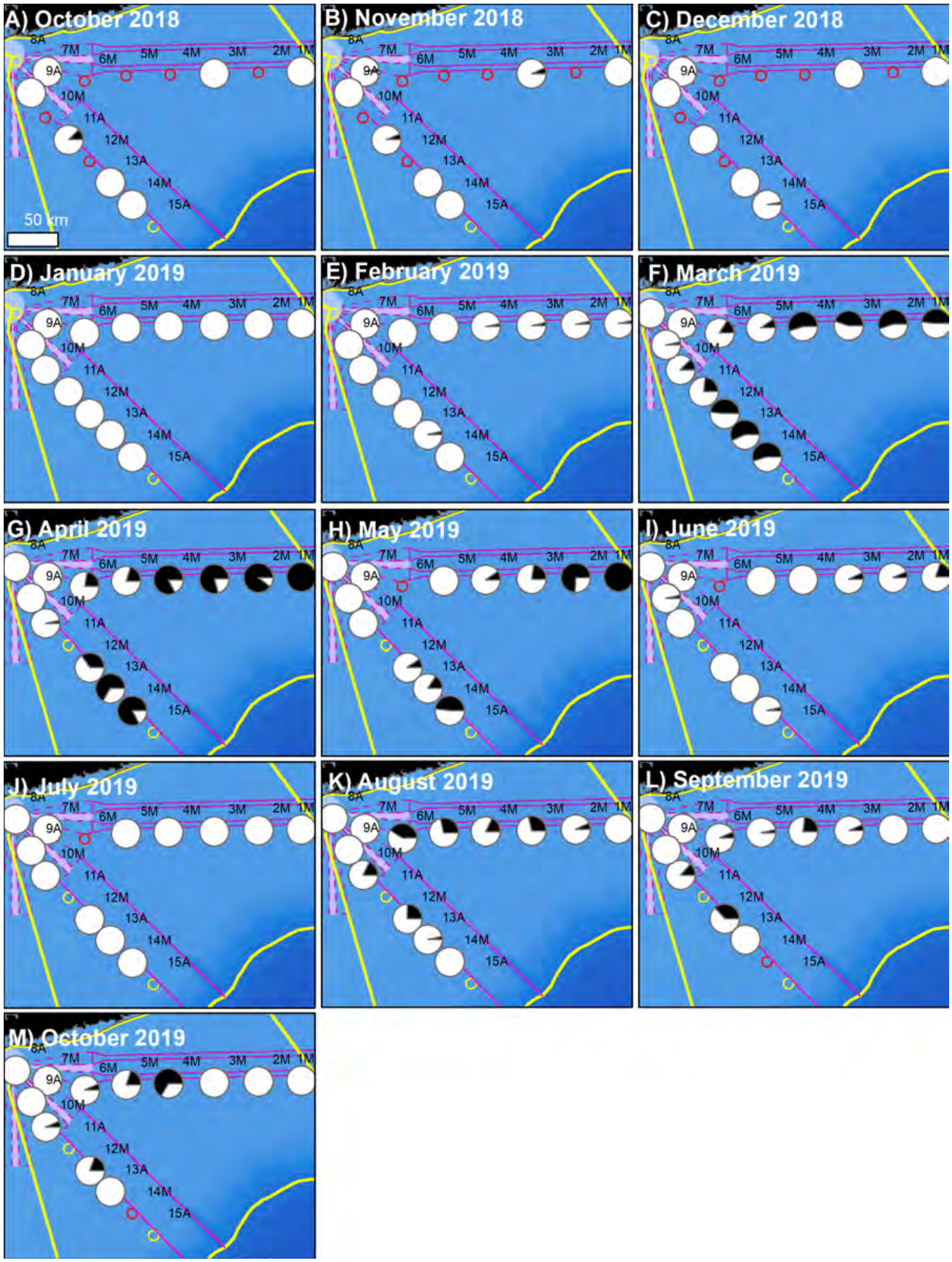

Figure 37. Spatial patterns of monthly presence of sei whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

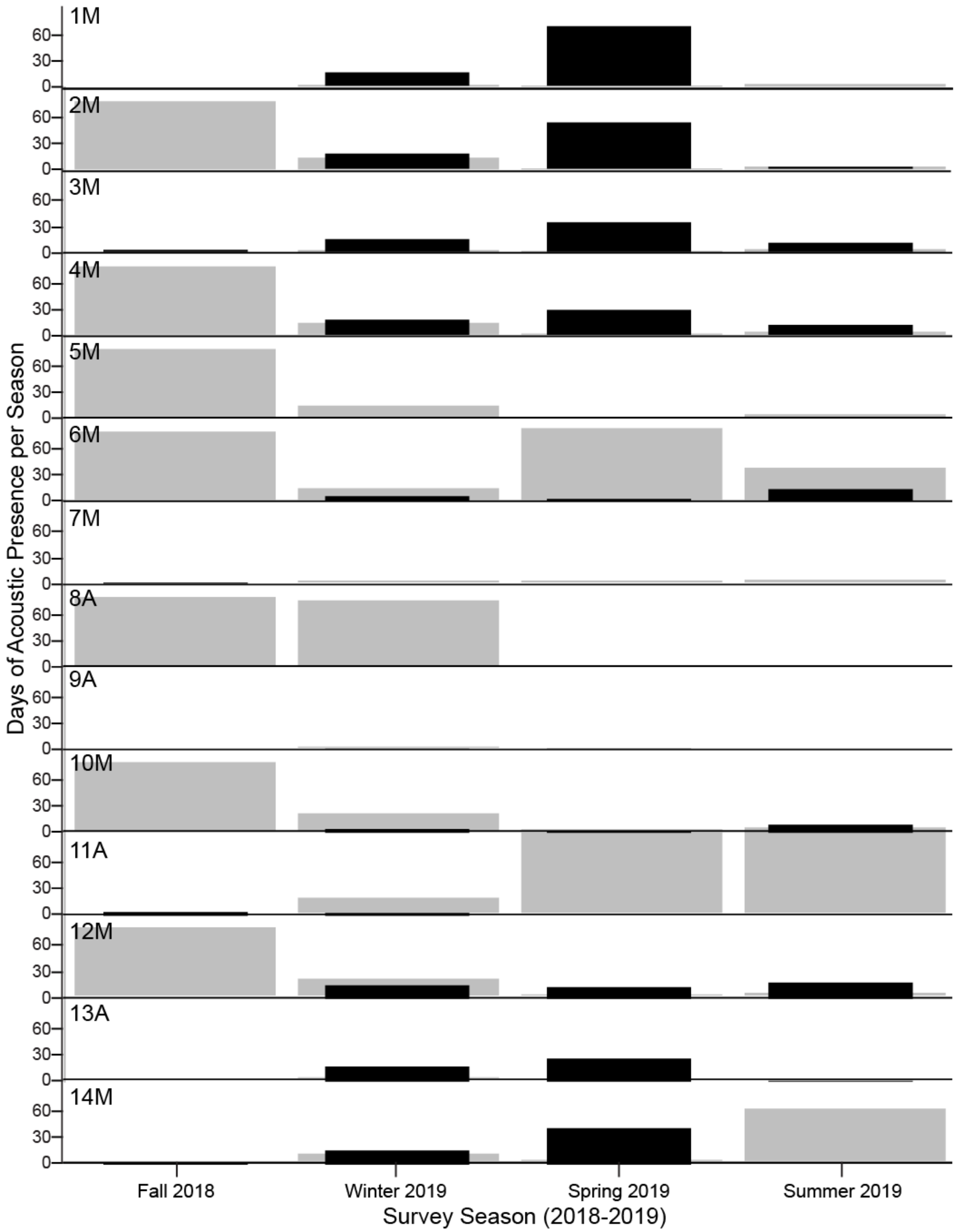

Figure 38. Seasonal acoustic presence of sei whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

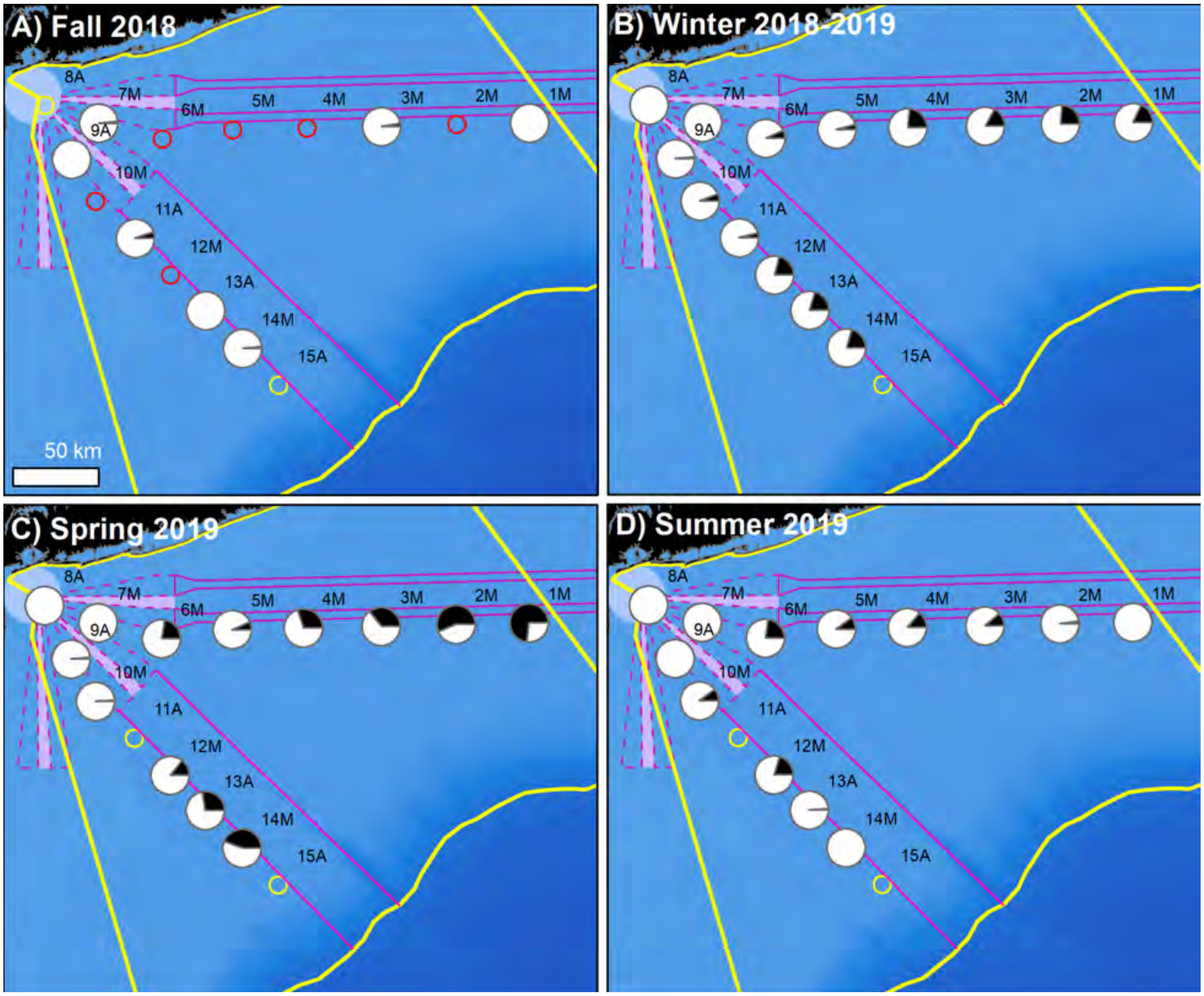

Figure 39. Spatial patterns of seasonal acoustic presence of sei whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

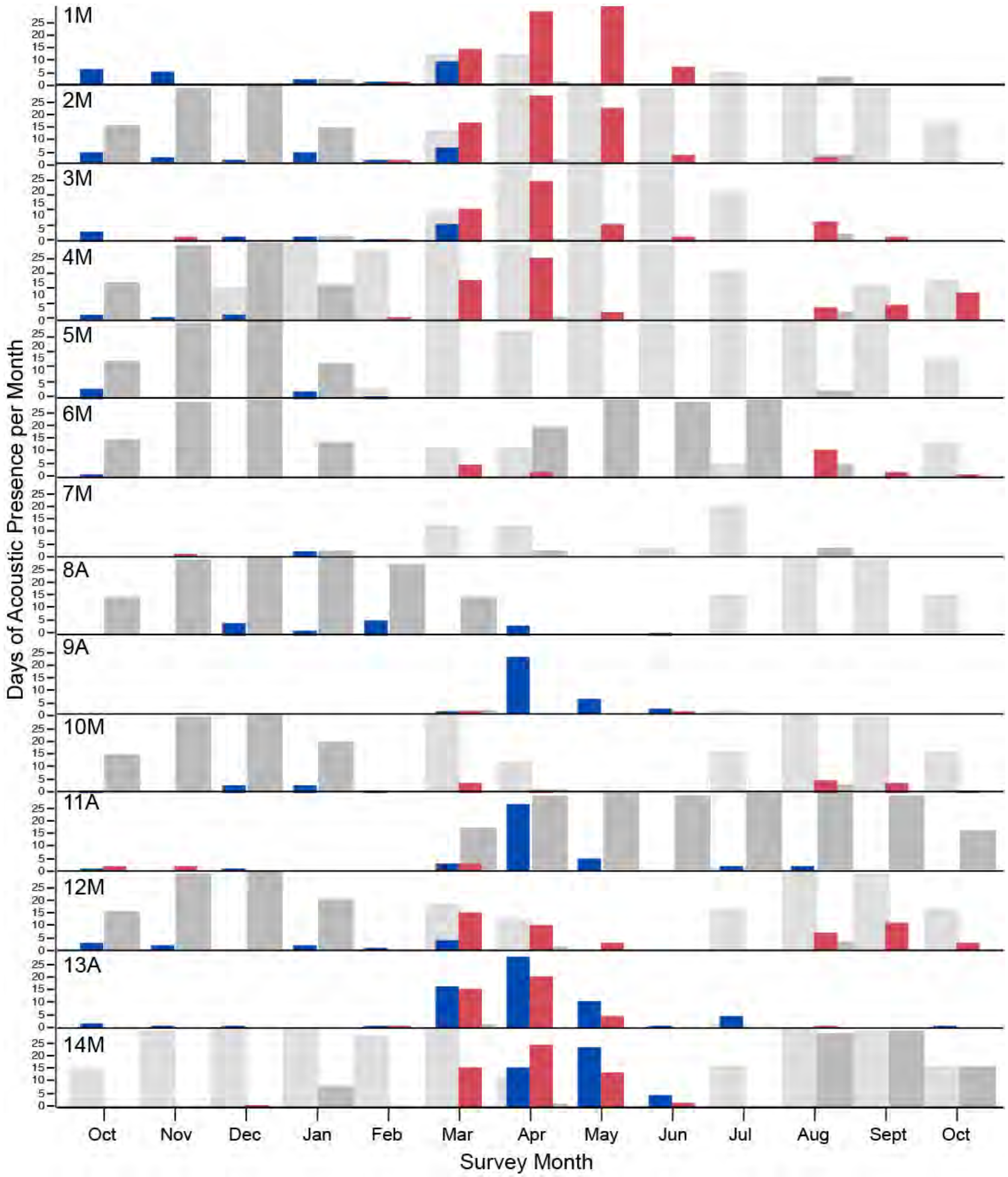

Figure 40. Internannual sei whale monthly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

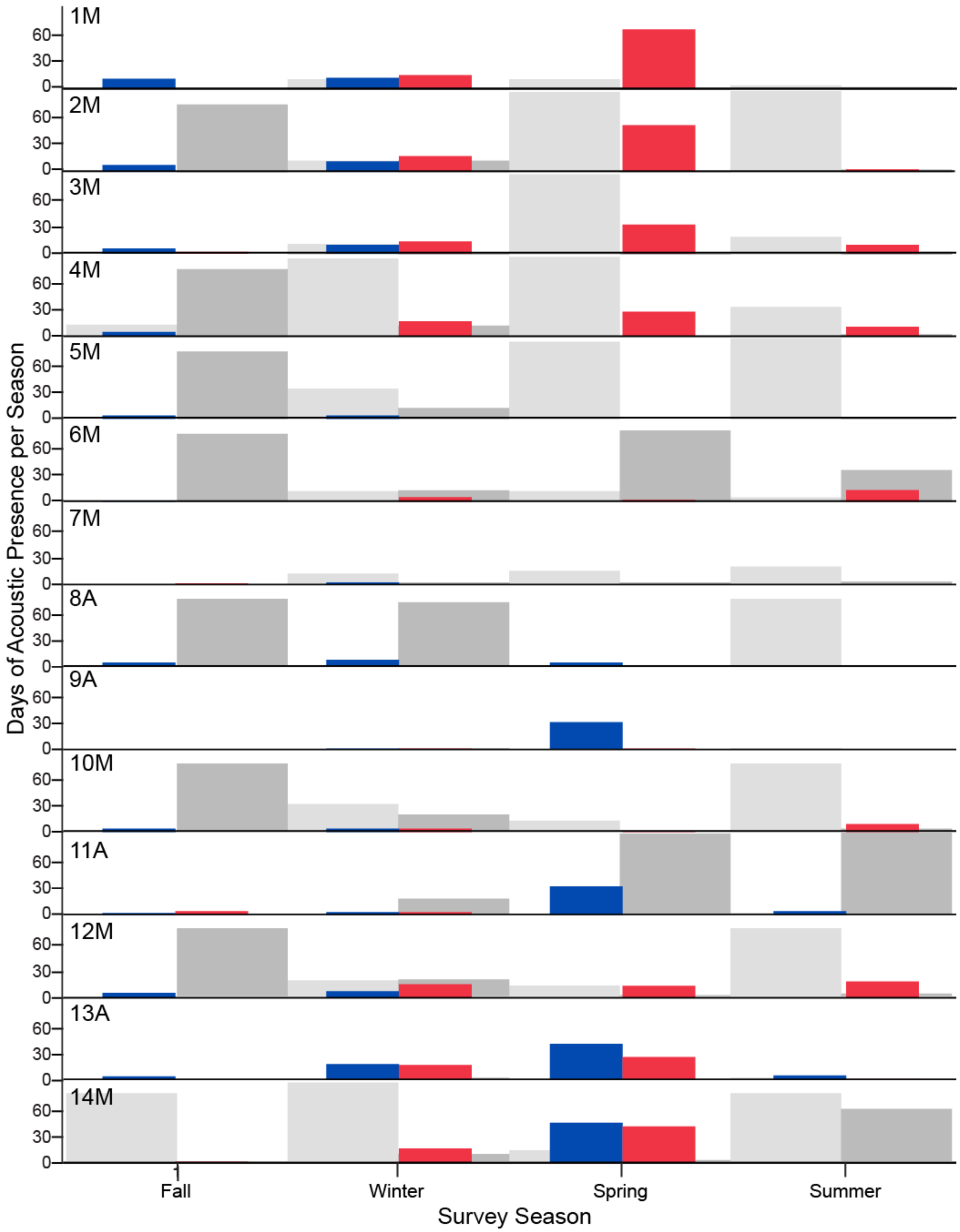

Figure 41. Internannual sei whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

Blue Whale Occurrence

Blue whales were the least frequently detected species within NY Bight, with a total of 8 days of acoustic presence. Blue whales were only detected during the winter, from December 2018 - February 2019 (Table 14, Figure 42, Figure 43), comprising four short weekly periods of daily occurrence in the area on sites 1M (n = 5), 2M (n = 5) 3M (n = 2), and 14M (n = 4; Table 14, Figure 42, Figure 44). It is unclear whether the blue whale signals that were detected during those 4 weeks were produced by the same animal, or whether they are a different individual or individuals.

There were fewer daily detections of blue whales in Year-2 compared to Year-1 (Year-2=16, Year-1=53; Figure 47). In both years, calls were detected on sites 1M-3M, though in higher numbers in year 1. During Year-1, blue whale calls were detected on more sites (4M, 11A, and 13A) than Year-2, and for a wider range of time, with presence from November through February (Figure 47, Figure 48). With rare occurrence of blue detections combined with the large number of data gaps in the survey, it is difficult to establish any changing patterns in blue whale acoustic presence between years 1 and 2.

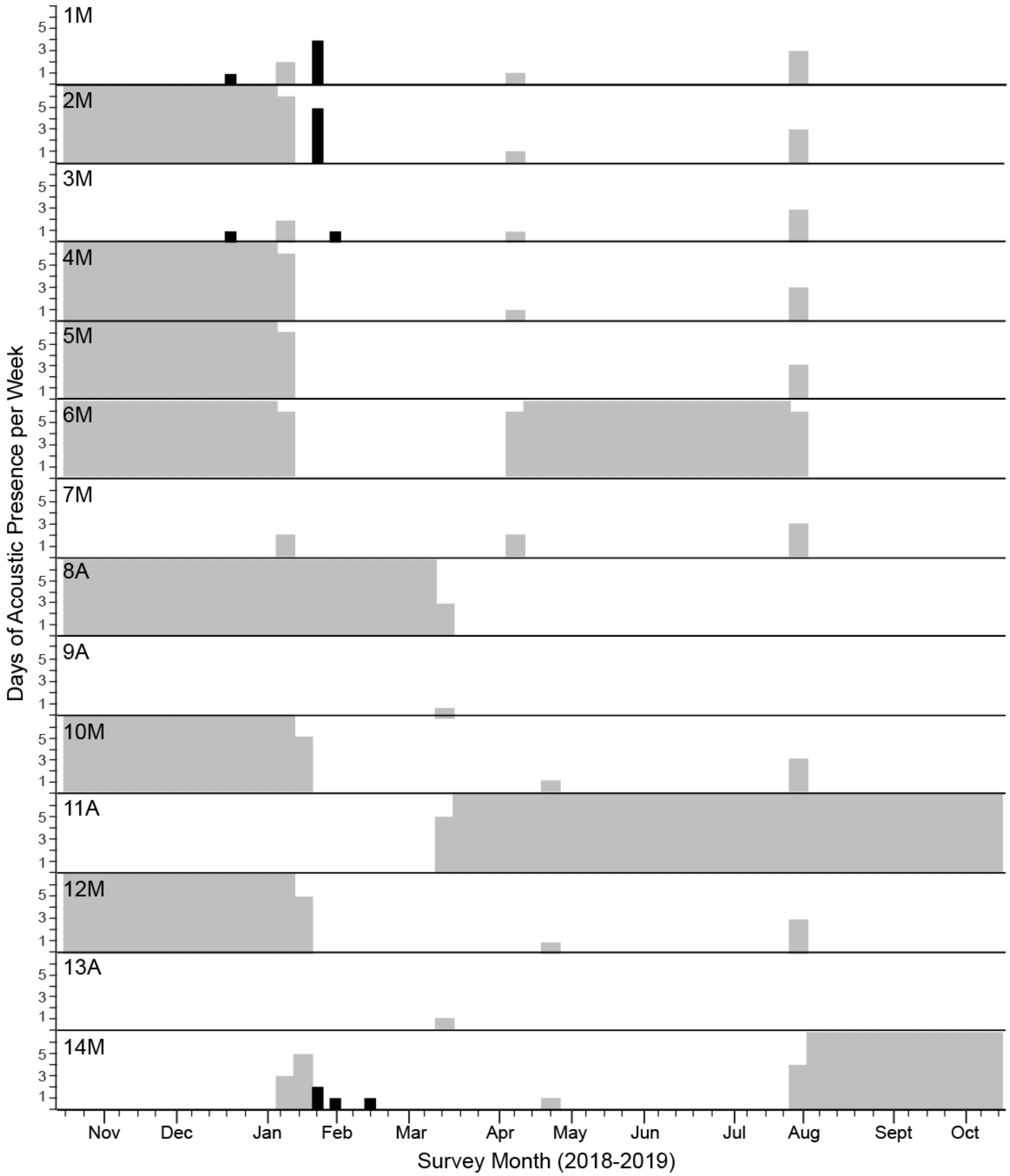

Figure 42. Weekly acoustic presence of blue whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed blue whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

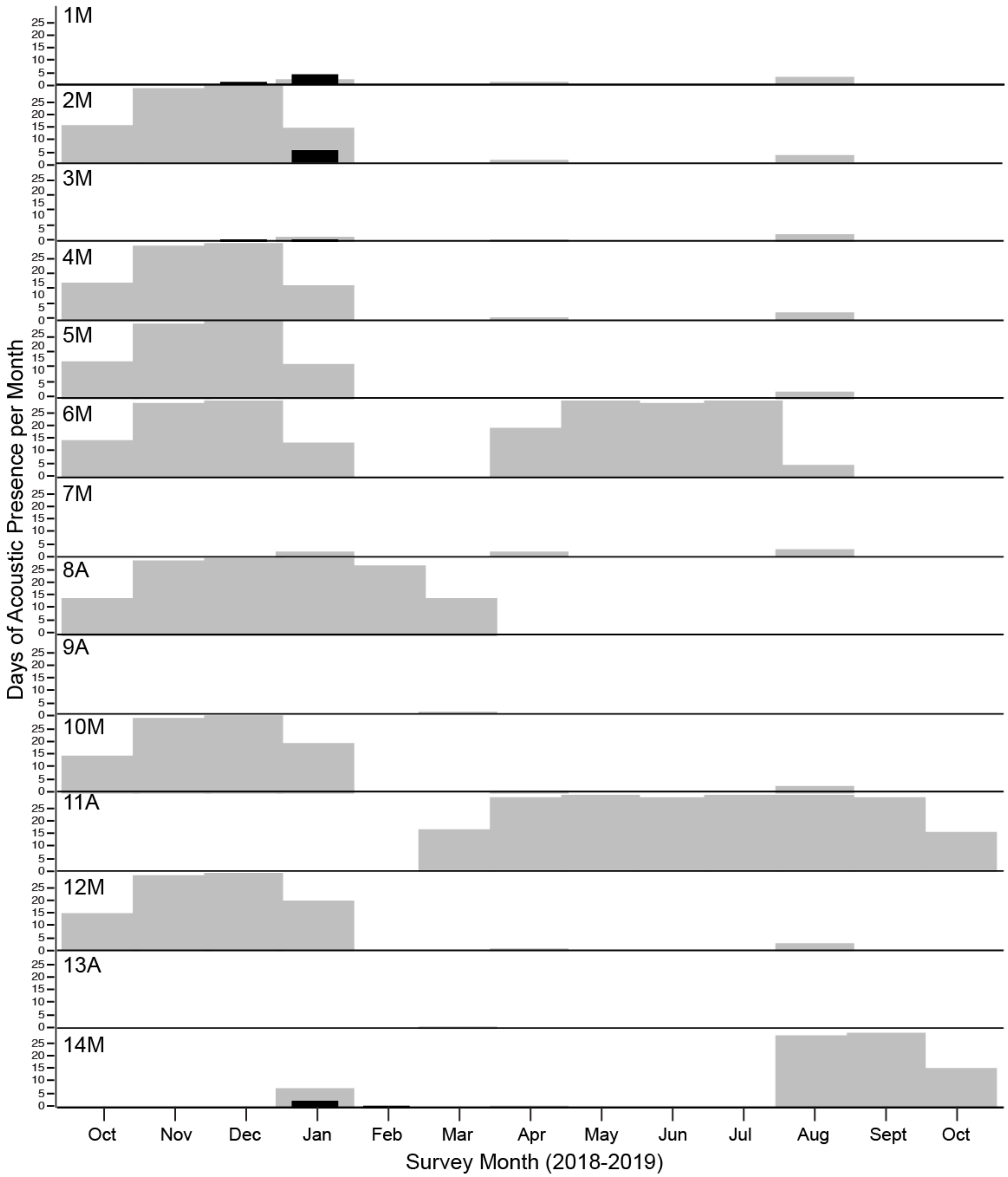

Figure 43. Monthly acoustic presence of blue whales detected within New York Bight between October 2018-October 2019, shown as number of days per month with confirmed blue whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there is no sound data.

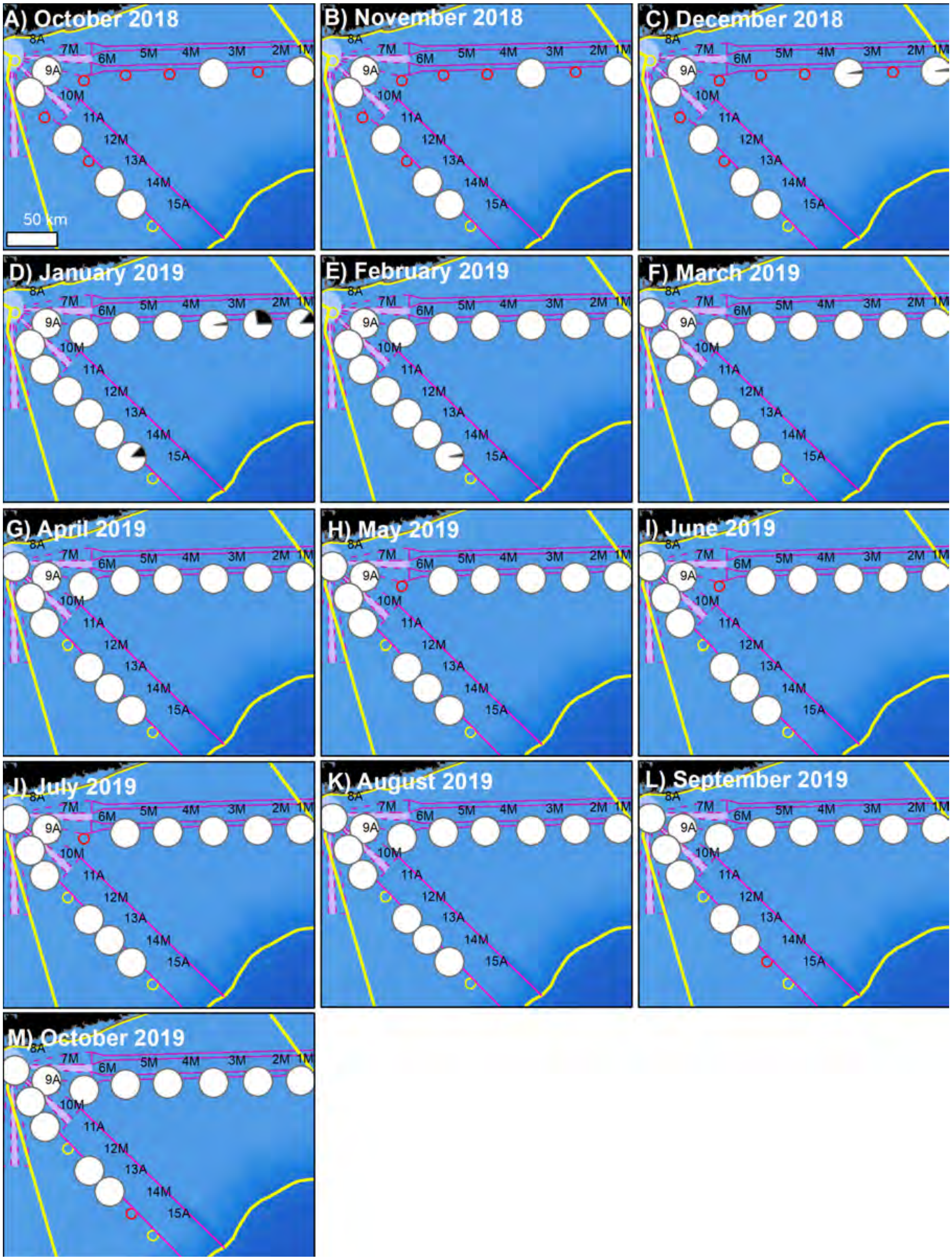

Figure 44. Spatial patterns of monthly presence of blue whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

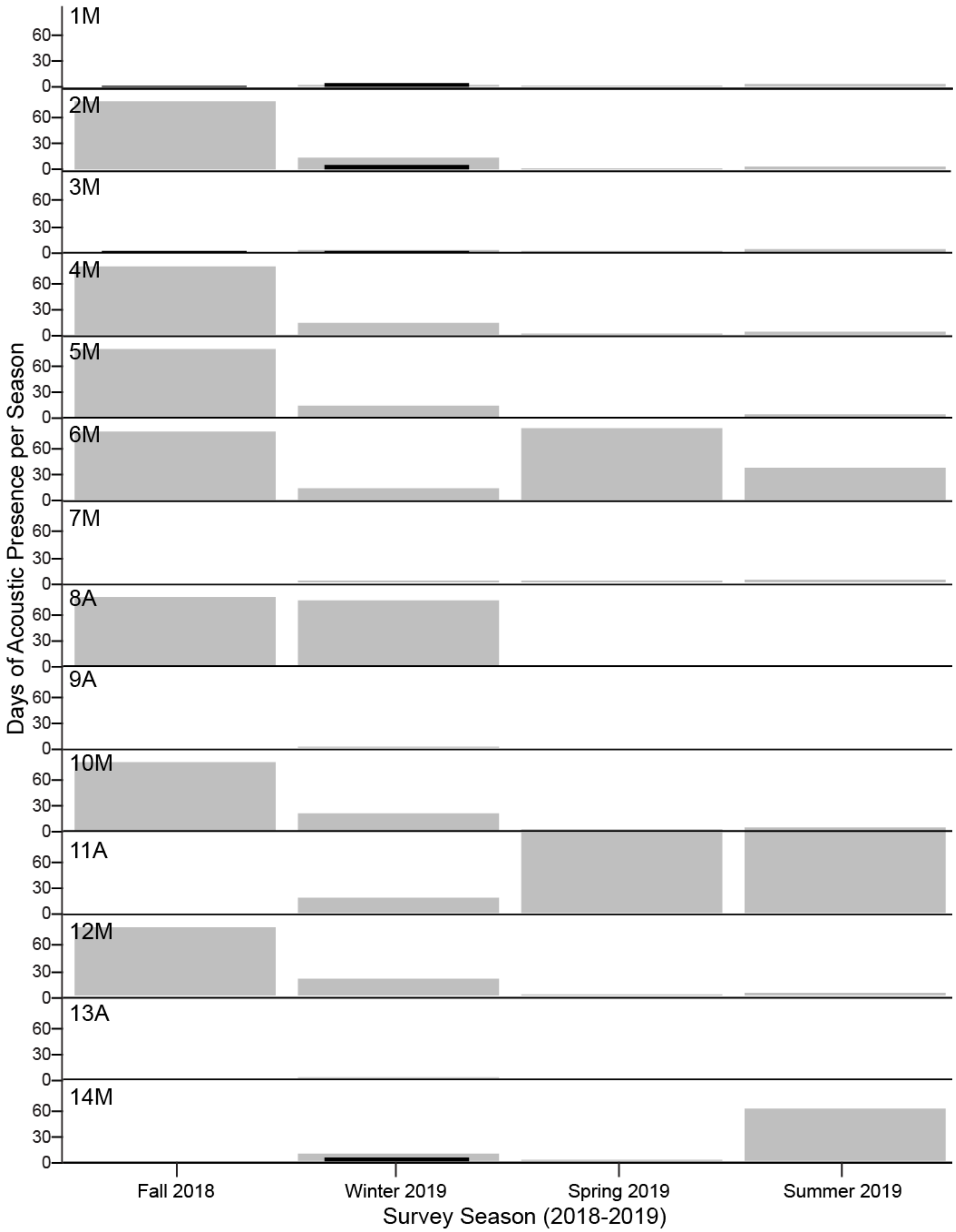

Figure 45. Seasonal acoustic presence of blue whales detected within New York Bight from Fall 2018 through Summer 2019, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

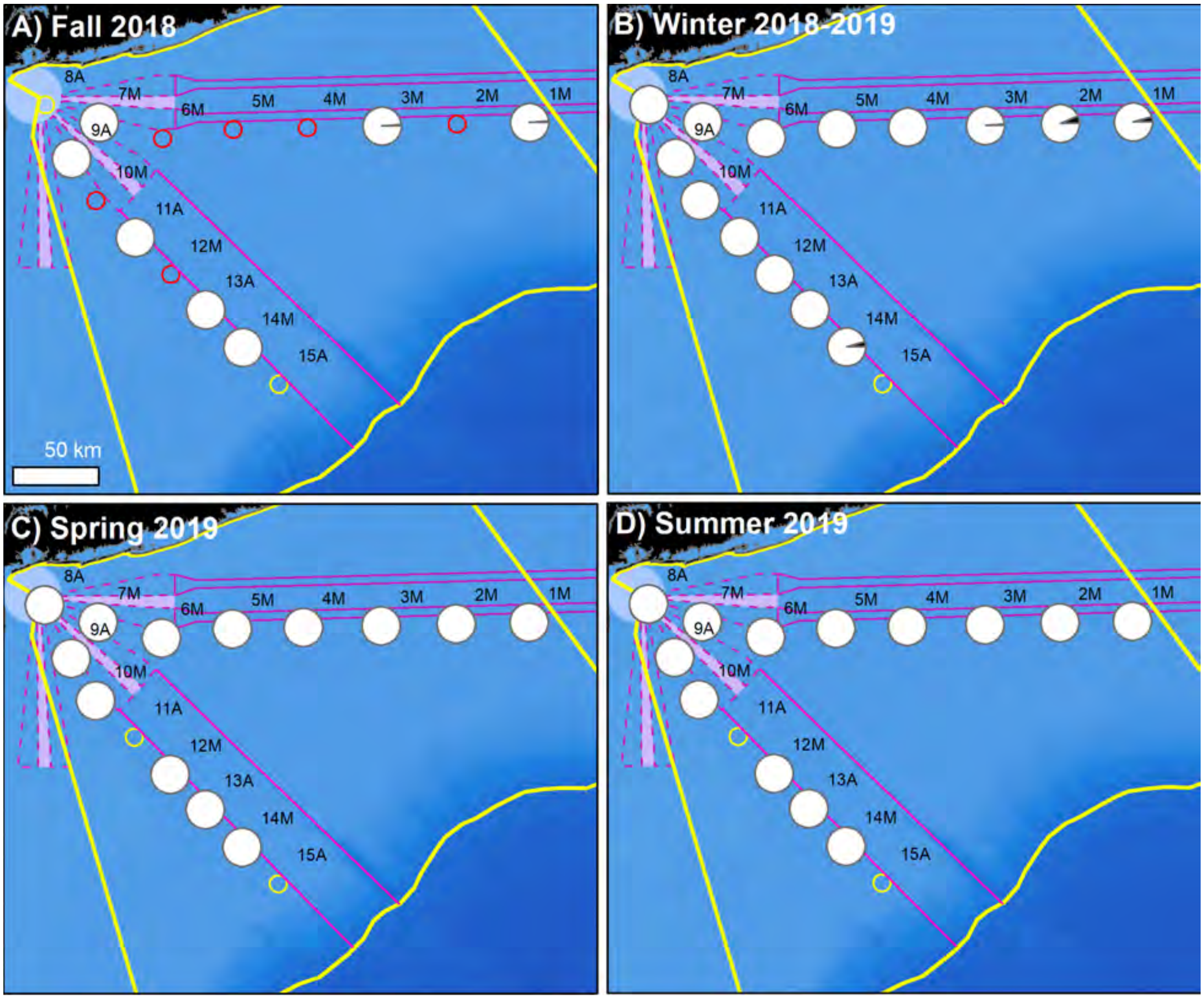

Figure 46. Spatial patterns of seasonal acoustic presence of blue whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

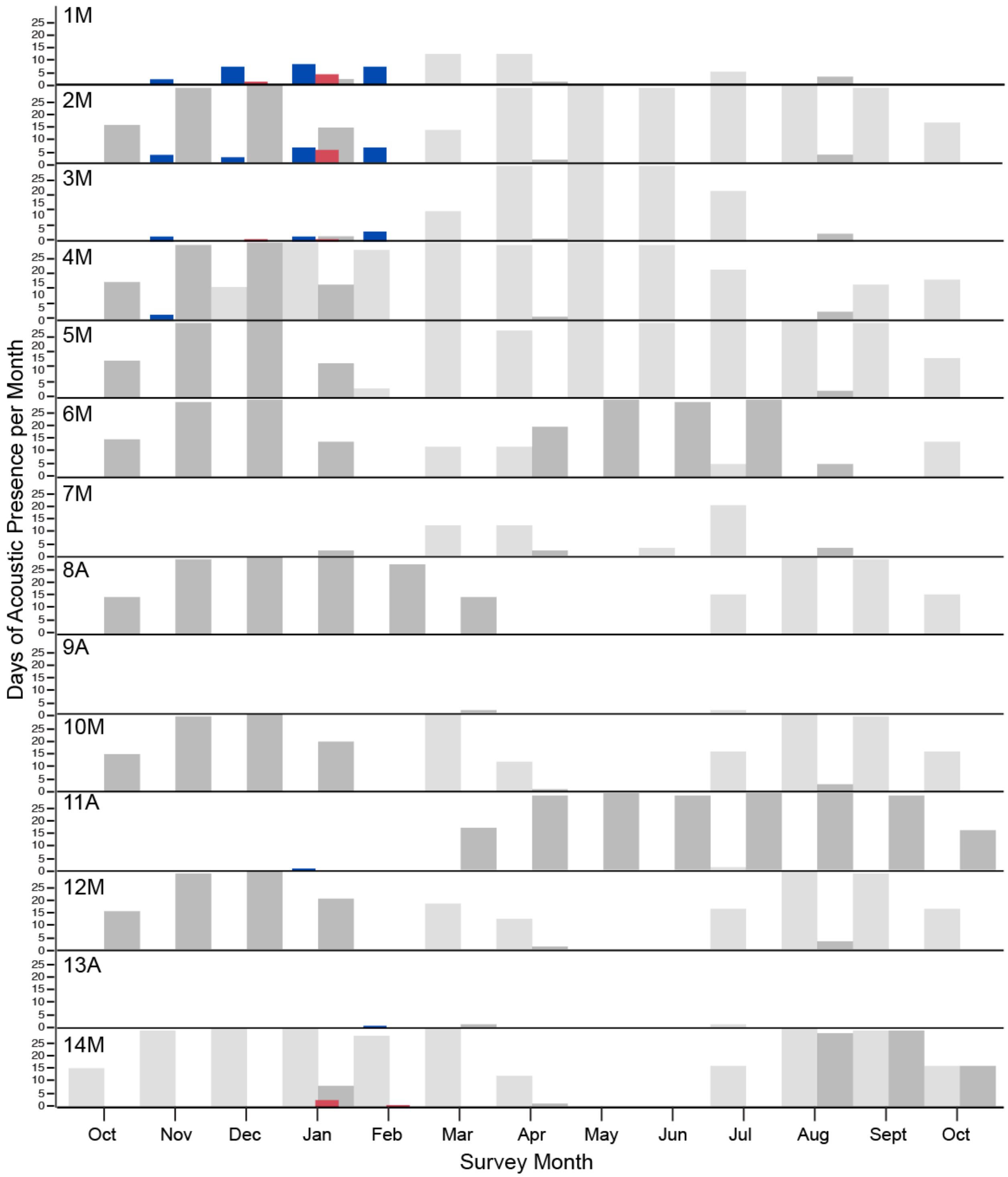

Figure 47. Internannual blue whale monthly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

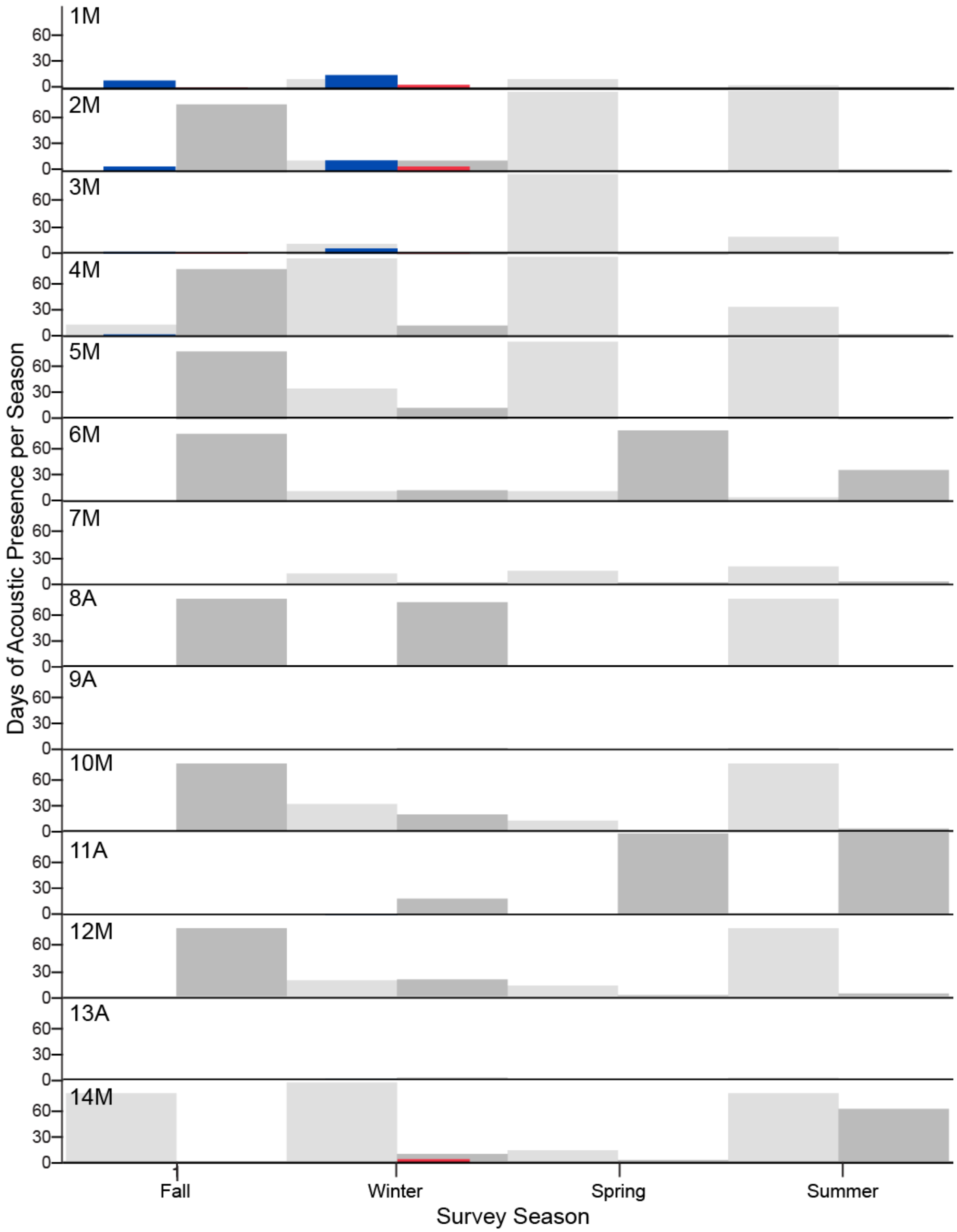

Figure 48. Internannual blue whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

Sperm Whale Occurrence

Sperm whales were detected throughout the year on the four AMAR sites, with many weeks exhibiting multiple days of detections (Figure 49). Daily detections were the highest at Sites 9A and 13A (Table 16, Figure 49). Detections were lowest in October 2018-April 2019 (Figure 49, Figure 50) across all sites (Figure 51). From January-August, sperm whales were detected at all four AMAR sites, while between October 2018-March 2019 sperm whale clicks were only detected at site 11A (Table 14, Figure 50, Figure 51). Seasonally, sperm whales were detected more during spring and summer, and least during the fall (Table 15, Figure 52).

There were fewer days with sperm whale detections in Year-2 compared to Year-1 (Year-1=229, Year-2=38). There was a significant reduction on the number of sperm whales detected at Site 8A during Year-2, however, that may be due to the data loss at site 8A during the fall and winter months, when sperm whales were detected at site 8A during Year-1. Site 9A recorded continuously without data loss for both Year-1 and Year-2 surveys, offering a more representative temporal comparison in sperm whale occurrence between years. Sperm whale occurrence at site 9A was higher during Year-1 than it was during Year-2.

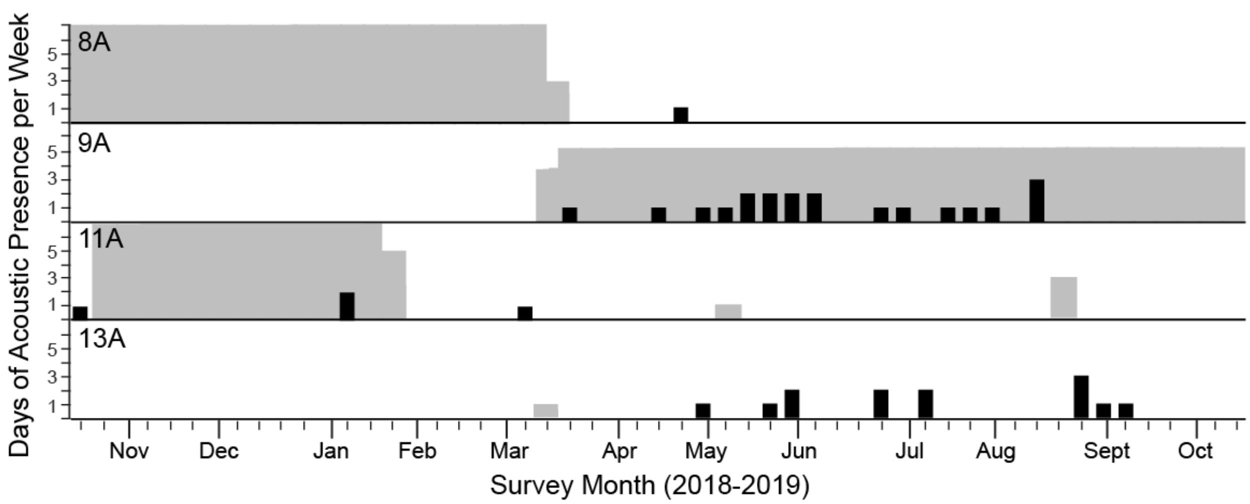

Figure 49. Weekly acoustic presence of sperm whales detected within New York Bight between October 2018-October 2019, shown as number of days per week with confirmed sperm whale acoustic detections across all AMARs. Gray bars indicate the number of days for each week during which there are no sound data.

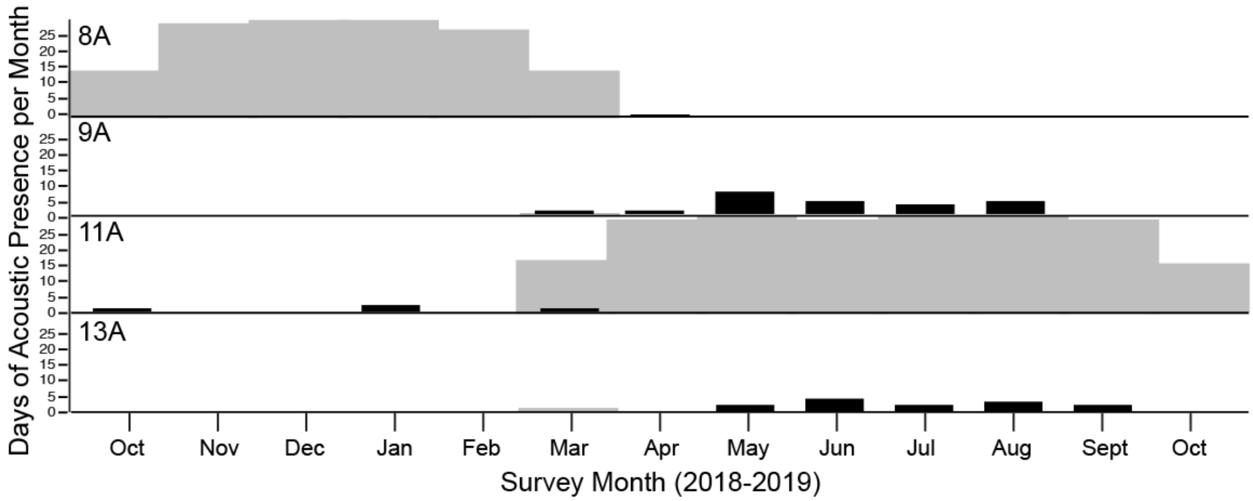

Figure 50. Monthly acoustic presence of sperm whales detected within New York Bight between October 2018-October 2019, shown as number of days per month with confirmed sperm whale acoustic detections across all AMARs (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

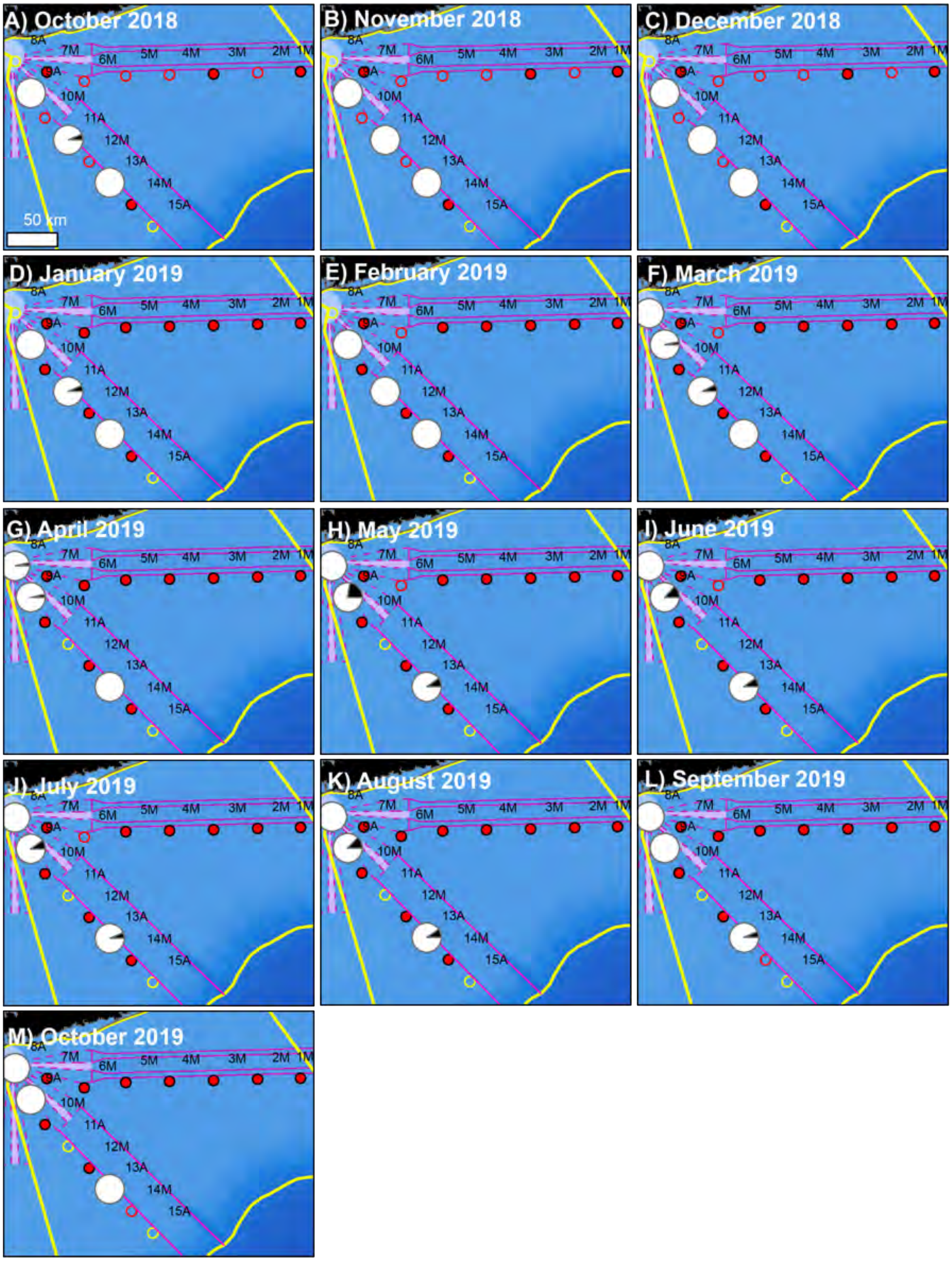

Figure 51. Spatial patterns of monthly presence of sperm whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Only AMARs were analyzed for sperm whale presence; MARUs were not included in the analysis. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

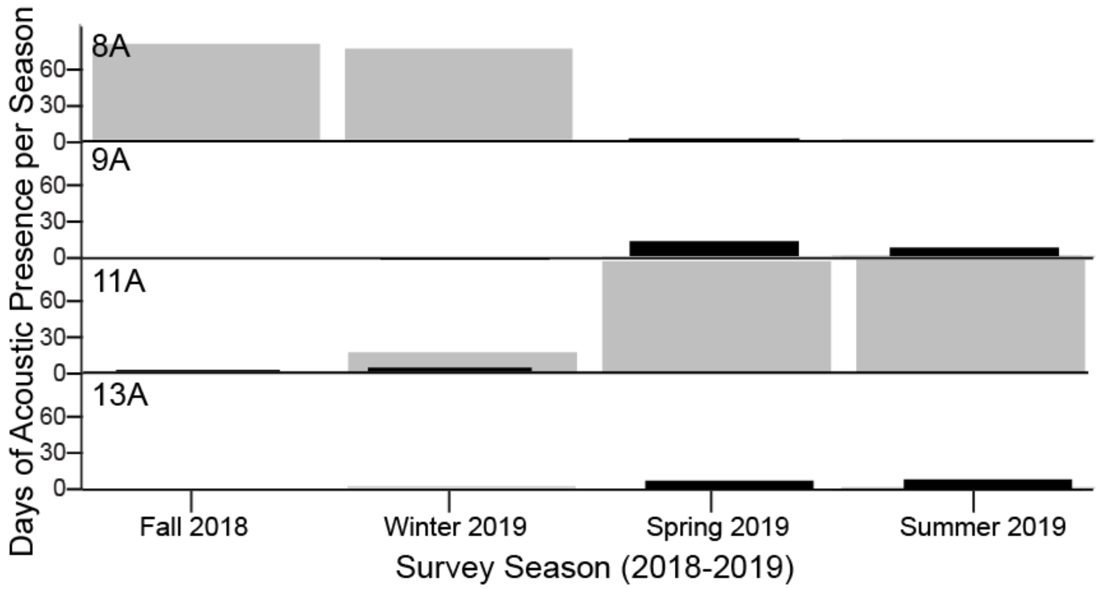

Figure 52. Seasonal acoustic presence of sperm whales detected within New York Bight from Fall 2018 through Summer 2019, shown as number of days per month with confirmed right whale acoustic detections across all AMARs for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

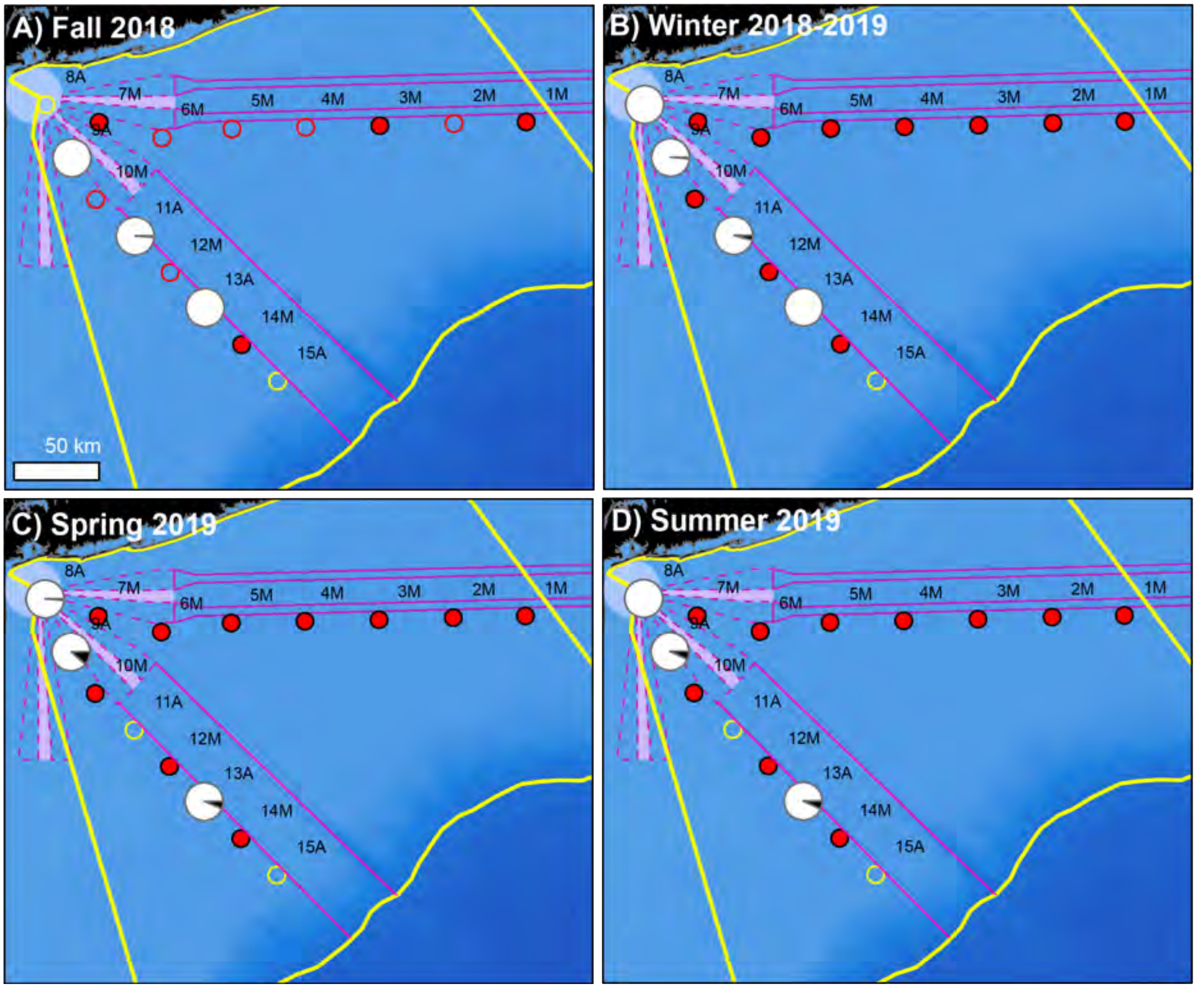

Figure 53. Spatial patterns of seasonal acoustic presence of sperm whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Only AMARs were analyzed for sperm whale presence; MARUs were not included in the analysis. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season

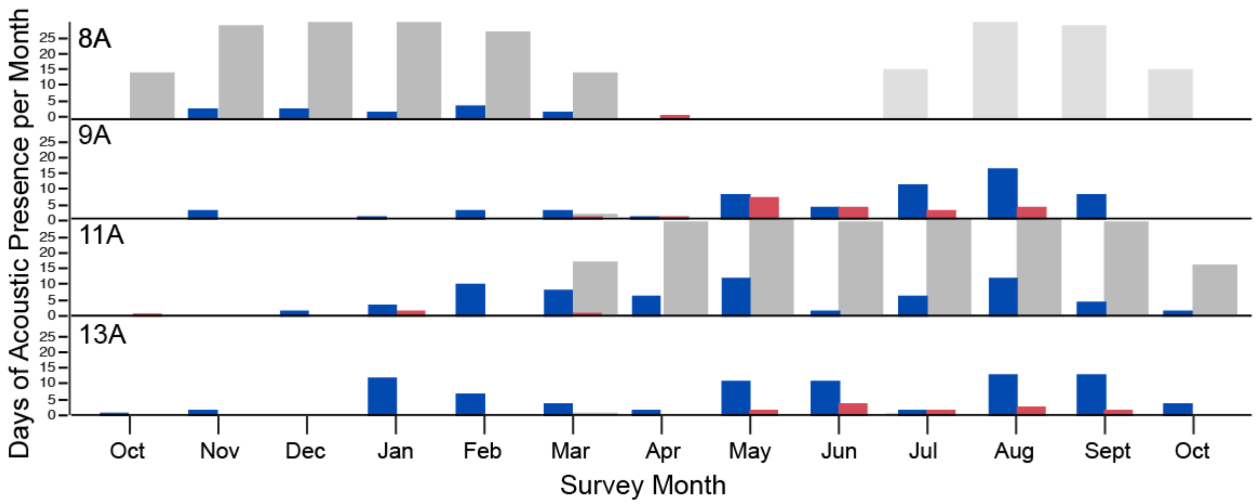

Figure 54. Internannual sperm whale montly acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

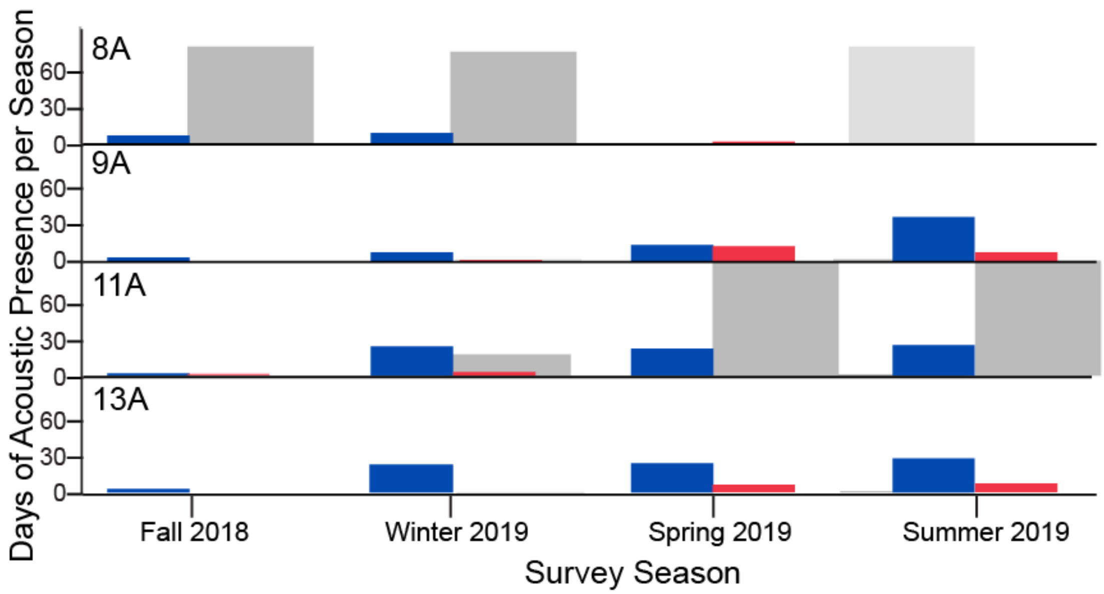

Figure 55. Internannual sperm whale seasonal acoustic presence for survey Year-1 (blue) and Year-2 (red) as a function of days with acoustic presence per month. Data gaps for years 1 and 2 are shown in grey (light grey and dark grey, respectively), as the number of missing days per month

Table 14. Monthly daily presence for each focal whale species across all sites (MARUs and AMARs), and the corresponding percentage of total calendar-days in which the species was detected. The sperm whale data are for AMAR sites only.

Month-Year	Total Days Recorded	Right		Humpback		Fin		Sei		Blue		Sperm	
		# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected
Oct-18	16	9	56	7	44	15	94	2	13	0	0	1	6
Nov-18	30	25	83	27	90	30	100	5	17	0	0	0	0
Dec-18	31	28	90	24	77	31	100	1	3	1	3	0	0
Jan-19	31	27	87	26	84	31	100	0	0	6	19	2	6
Feb-19	28	23	82	21	75	28	100	1	4	1	4	0	0
Mar-19	31	30	97	28	90	31	100	27	87	0	0	2	6
Apr-19	30	28	93	27	90	30	100	30	100	0	0	2	7
May-19	31	28	90	31	100	31	100	31	100	0	0	9	29
Jun-19	30	24	80	30	100	30	100	10	33	0	0	7	23
Jul-19	31	4	13	31	100	31	100	0	0	0	0	5	16
Aug-19	31	12	39	25	81	31	100	14	45	0	0	7	23
Sep-19	30	22	73	26	87	30	100	16	53	0	0	2	7
Oct-19	15	5	33	14	93	15	100	12	80	0	0	0	0
Total	365	265	73	317	87	364	100	149	41	8	2	37	10

Table 15. Seasonal daily presence for each focal whale species across all recording sites: Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Sperm whale acoustic presence was evaluated with AMAR data only.

Season	Total Days Recorded	Right	Humpback	Sei	Fin	Blue	Sperm
Fall 2018	77	62	58	8	76	1	1
Winter 2019	90	80	75	28	90	7	4
Spring 2019	91	80	88	71	91	0	18
Summer 2019	92	38	82	30	92	0	14

Table 16. Summary of site-wise percent daily occurrence for each focal species. “Days” represents the total days in which the target species was detected, and percent days represents the percentage of days in which there were detections of that species at each site.

Site	Total Days Recorded	Right		Humpback		Fin		Sei		Blue		Sperm	
		# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected	# Days Detected	% Days Detected
1M	359	62	17	59	16	276	77	82	23	5	1	*NA*	*NA*
2M	271	59	22	54	20	235	87	71	26	5	2	*NA*	*NA*
3M	359	33	9	103	29	308	86	59	16	2	1	*NA*	*NA*
4M	271	54	20	114	42	240	89	67	25	0	0	*NA*	*NA*
5M	272	23	8	55	20	179	66	21	8	0	0	*NA*	*NA*
6M	158	22	14	12	8	130	82	21	13	0	0	*NA*	*NA*
7M	358	26	7	43	12	105	29	1	0	0	0	*NA*	*NA*
8A	215	4	2	14	7	54	25	0	0	0	0	1	0
9A	364	68	19	95	26	156	43	2	1	0	0	20	5
10M	265	12	5	39	15	200	75	15	6	0	0	*NA*	*NA*
11A	149	71	48	79	53	123	83	7	5	0	0	4	3
12M	265	22	8	93	35	237	89	49	18	0	0	*NA*	*NA*
13A	364	89	24	179	49	328	90	44	12	0	0	13	4
14M	281	40	14	61	22	167	59	58	21	4	1	*NA*	*NA*

AMBIENT NOISE ANALYSIS

Average Ambient Noise Levels

Median values of the 10-minute average ambient noise levels across all whale bands ranged between 92 dB (blue whale frequency band) and 107 dB (humpback whale band). Sites 5M, 6M, and 7M tended to record the lowest noise levels for the baleen whale species bands, while sites 8A and 11A tended to record the highest median noise levels (Table 17). Median noise levels within the right whale frequency band (70 – 244 Hz) across MARU and AMAR sites ranged from 99 dB (6M and 10M) to 105 dB (8A), with the highest 95th percentile noise level of 120 dB at 8A. Within the humpback whale frequency band (28 – 708 Hz), the highest 95th percentile noise levels were recorded at site 8A (125 dB). Median noise levels within the humpback whale band ranged between 104 (5M, 6M, and 7M) to 110 dB (8A). Median noise levels within the sei whale frequency band (28 – 89 Hz) ranged from 99 dB (sites 5M and 7M) to 107 dB (site 8A). The highest median noise levels in the fin whale (17 – 28 Hz) and blue whale (14 – 22 Hz) bands occurred at site 11A (116 dB). The lowest median noise levels for the fin whale band was at site 5M(86 dB), and at site 7M (85 dB) for the blue whale band. Median noise levels in the sperm whale frequency band (1 – 4 kHz) at the AMAR sites had little variation, ranging from 101 dB (9A) to 104 dB (11A), however the highest 1-hour averaged period of noise in the 95th percentile occurred at site 8A (117 dB; Table 17).

Within all species frequency bands, median noise levels were overall higher during Year-1 at sites in the northern transect (1M - 5M; Table 18) than during Year-2. At site 6M, however, median noise levels were higher during Year-2, with a median increase of 2 dB. Within the fin and blue whale frequency bands, median noise levels were higher by 4 dB and 5 dB, respectively, during Year-2. The sperm whale frequency band was the only species frequency band in which noise levels were higher during Year-2 (102 dB) than Year-1 (93 dB), where median noise levels were approximately 9 dB higher.

The cumulative percent distribution shows the noise level percentiles per species frequency band (Figure 56), and illustrates that noise levels were variable among sites in the low-frequency blue whale and fin whale frequency bands, differing by approximately 15 dB between sites. For the humpback whale, right whale, and sei whale frequency bands, noise levels remained within approximately 10 dB between sites. Throughout Year-2, sites 5M and 6M the lowest noise levels across all species' frequency bands.

For additional detail on ambient noise analysis results, see Appendix A.

Table 17. Average 10-minute ambient noise levels within each target species frequency bands from October 2018 – October 2019. Ambient noise levels are represented as Sound Level Equivalent (L_{eq}, in dB re: 1μPa).

	Right (70 – 224 Hz)			**Humpback (28 – 708 Hz)**			**Sei (28 – 89 Hz)**		
Site	**95th**	**50th**	**5th**	**95th**	**50th**	**5th**	**95th**	**50th**	**5th**
1M	116	103	94	121	108	99	120	106	95
2M	114	102	92	120	107	98	118	104	93
3M	115	102	92	120	108	99	118	104	94
4M	114	100	93	119	106	99	117	103	95
5M	114	100	89	118	104	93	115	99	87
6M	111	99	89	116	104	95	113	100	90
7M	114	100	90	118	104	95	116	99	88
8A	120	105	91	125	110	96	123	107	90
9A	115	102	91	120	107	96	118	102	90
10M	111	99	89	117	105	95	114	101	90
11A	113	101	94	120	108	100	115	101	92
12M	112	101	91	119	107	97	116	102	93
13A	114	102	93	119	107	98	116	102	94
14M	114	102	92	119	107	98	118	103	94
15A	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Median	114	101	92	119	107	98	116	102	93

Table 17, continued. Average 10-minute ambient noise levels within each target species frequency bands from October 2018 – October 2019. Ambient noise levels are represented as Sound Level Equivalent (L_{eq}, in dB re: 1μPa).

	Fin (17 – 28 Hz)			Blue (14 – 22 Hz)			Sperm (1- 4 kHz)		
Site	**95th**	**50th**	**5th**	**95th**	**50th**	**5th**	**95th**	**50th**	**5th**
1M	109	96	86	106	95	85	*NA*	*NA*	*NA*
2M	107	94	85	105	93	83	*NA*	*NA*	*NA*
3M	110	97	86	109	95	85	*NA*	*NA*	*NA*
4M	110	93	84	109	90	82	*NA*	*NA*	*NA*
5M	106	86	80	104	84	80	*NA*	*NA*	*NA*
6M	106	89	81	103	86	81	*NA*	*NA*	*NA*
7M	102	87	75	100	85	73	*NA*	*NA*	*NA*
8A	113	95	81	112	95	84	117	102	91
9A	111	91	76	110	87	76	111	101	90
10M	106	90	80	104	87	78	*NA*	*NA*	*NA*
11A	116	98	86	116	98	85	114	104	98
12M	113	93	83	112	92	82	*NA*	*NA*	*NA*
13A	111	94	82	112	94	81	112	103	92
14M	110	95	87	109	94	86	*NA*	*NA*	*NA*
15A	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Median	110	94	83	109	92	82	113	103	91

Table 18. Median noise levels for Year-1 and Year-2 per species' frequency band. Ambient noise levels are represented as Sound Level Equivalent (L_{eq}, in dB re: 1μPa).

	NARW		Humpback		Sei		Fin		Blue		Sperm	
Site	**Year-1**	**Year-2**	**Year-1**	**Year-2**	**Year-1**	**Year-2**	**Year-1**	**Year-2**	**Year-1**	**Year-2**	**Year-1**	**Year-2**
1M	106	103	111	108	108	106	100	96	99	95	*NA*	*NA*
2M	107	102	112	107	109	104	102	94	101	93	*NA*	*NA*
3M	106	102	112	108	108	104	103	97	102	95	*NA*	*NA*
4M	103	100	110	106	105	103	99	93	97	90	*NA*	*NA*
5M	105	100	110	104	104	99	93	86	91	84	*NA*	*NA*
6M	96	99	102	104	98	100	87	89	84	86	*NA*	*NA*
7M	102	100	106	104	99	99	82	87	80	85	*NA*	*NA*
8A	104	105	110	110	104	107	97	95	95	95	94	102
9A	103	102	107	107	103	102	91	91	87	87	92	101
10M	104	99	109	105	103	101	95	90	94	87	*NA*	*NA*
11A	103	101	109	108	103	101	97	98	95	98	96	104
12M	104	101	109	107	103	102	95	93	94	92	*NA*	*NA*
13A	103	101	108	108	103	101	93	94	92	93	92	102
14M	99	102	105	107	102	103	93	95	91	94	*NA*	*NA*
15A	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Median	104	101	109	107	103	102	95	93	94	92	93	102

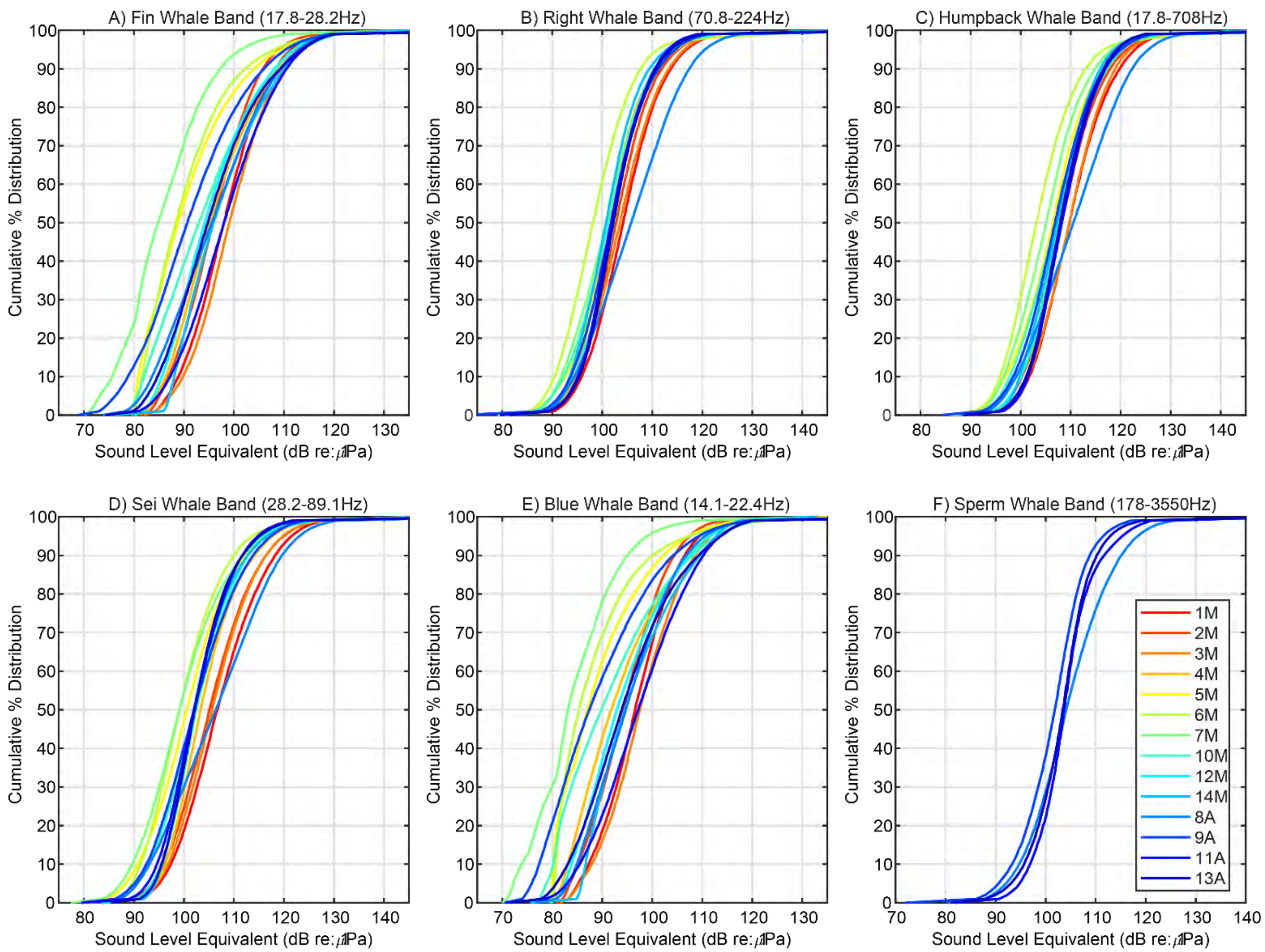

Figure 56. Cumulative percent distribution of ambient noise levels for each recording site in different whale frequency bands, measured in 10-minute averages. A) fin whale, B) right whale, C) humpback whale, D) sei whale, E) blue whale, and F) sperm whale frequency bands.

Masking Potential

Masking potential was evaluated using preliminary detection range models as a function of the ambient noise environment to estimate the spatial extent over which whale calls propagate. To illustrate the variability in range estimates, we plotted estimated detection range against received level for the recording sites with the highest and lowest median noise levels for each target species (see Table 19, Table 20). For North Atlantic right whales (Figure 57), the estimated detection range at the quietest site (6M) based on median (L_{50}) noise levels is approximately 10 km, while the range at the site with highest median noise levels (8A) is approximately 9 km. During the lowest 5th percentile noise conditions at site 6M, upcalls are estimated to be detectable up to 40 km. For humpback whales, the same two sites were compared (Figure 58), resulting in an estimated detection range at site 6M (L_{50} = 104 dB) of approximately 4 km, and 2 km at site 1M (L_{50} = 110 dB), given the median noise levels. At the 5th percentile noise conditions at site 6M, humpback signals are estimated to be detectable out to 13 km. In the sei whale frequency band (45 – 112 Hz), sites 7M and 1M (Figure 59) recorded the lowest and highest median noise levels, respectively. Estimated detection range for sei whale downsweeps during median noise levels is approximately 21 km for site 7M (L_{50} = 99 dB) and 10 km at site 1M (L_{50} = 106 dB). Fin whale 20-Hz pulses can be detected over potentially very large distances (Figure 60), where estimated detection range at site 5M (L_{50} = 86 dB) is 245 km. During the lowest 5th percentile ambient noise conditions, the pulses are estimated to be detectable at ranges to 573 km, however, these ranges are dependent on the bathymetry and noise conditions out to such distances. At site 3M, the site with the highest median noise levels (L_{50} = 97 dB), fin whale 20-Hz pulses are estimated to be detectable out to 91 km. Similarly, blue whale (Figure 61) song was estimated to be detectable over a range of 1,000 km during median noise levels (L_{50} = 84 dB) at site 5M, and approximately 155 km at site 11A (L_{50} = 98 dB). The calls of blue whales are primarily detected in deeper, offshore sites with much greater propagation distances, suggesting singing blue whales are potentially >100 km offshore, given the anticipated detection ranges. Fin whales also have large detection ranges, so the spatial patterns of detection of fin whale song may simply be the same call being detected on multiple sensors and not reveal much about the spatial distribution of the population in this habitat. We did, however, observe fin whale pulses where the arrival time of the call on recording device suggests that the sound originated within the survey area.

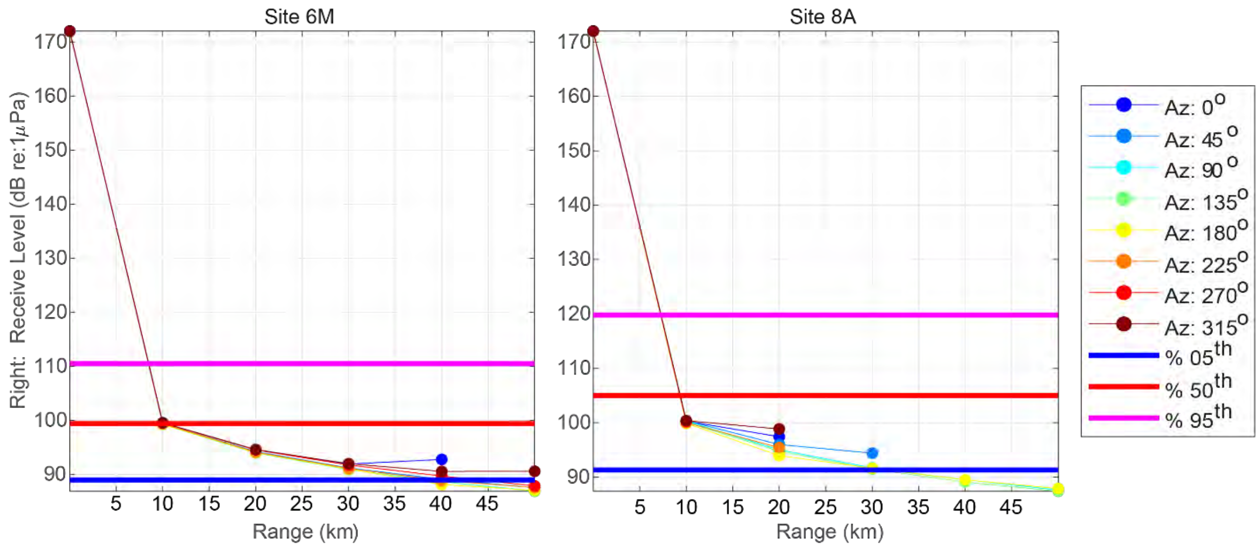

Figure 57. Estimated detection ranges (km) of North Atlantic right whale upcalls under varying noise conditions, given the estimated source level of 172 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (8A) in the right whale frequency band (71 – 224 Hz) between October 2018 and October 2019. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site.

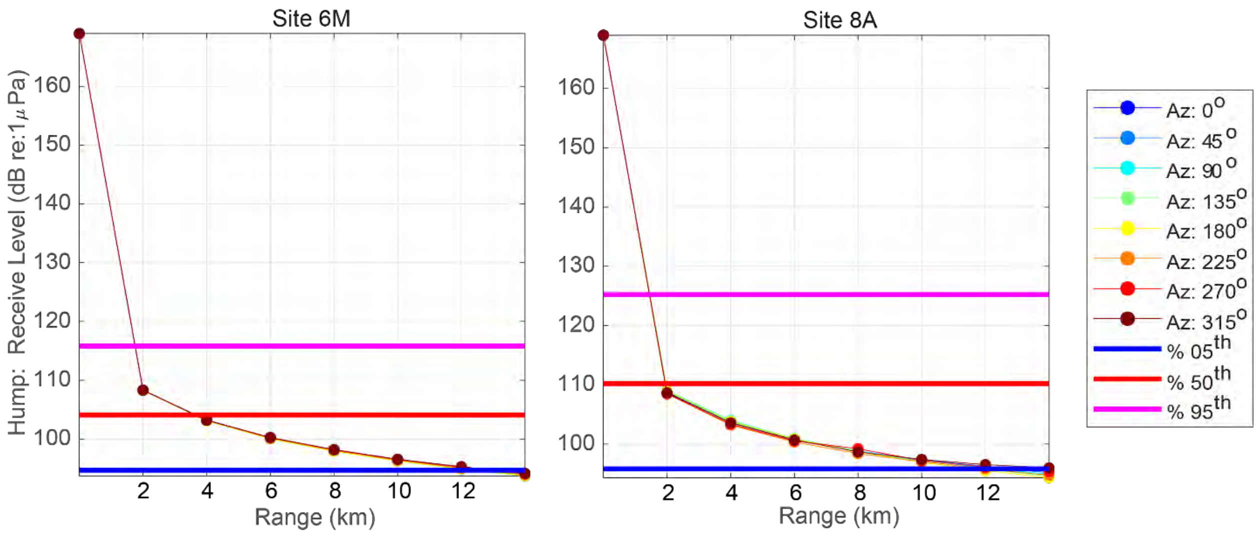

Figure 58. Estimated detection ranges (km) of humpback whale calls under varying noise conditions, given the estimated source level of 169 dB re: 1μPa @ 1m for the site with the lowest noise (6M) and highest noise (8A) in the humpback whale frequency band (28 – 708 Hz) between October 2018 and October 2019. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site.

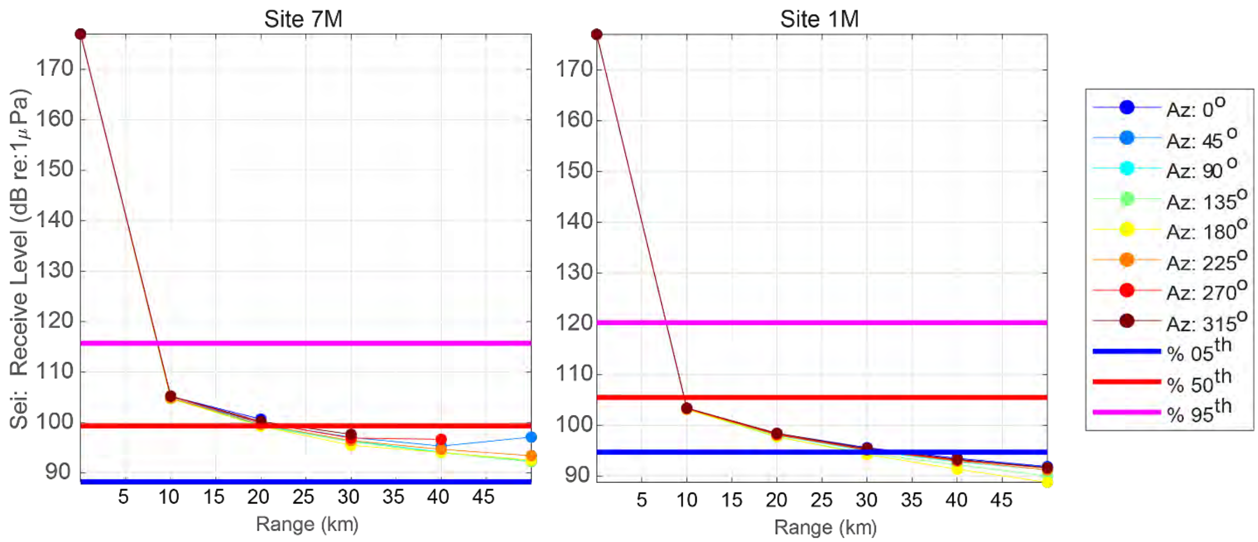

Figure 59. Estimated detection ranges (km) of sei whale downsweeps under varying noise conditions, given the estimated source level of 177 dB re: 1μPa @ 1m for the site with the lowest noise (7M) and highest noise (1M) in the sei whale frequency band (45 – 112 Hz) between October 2018 and October 2019. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site

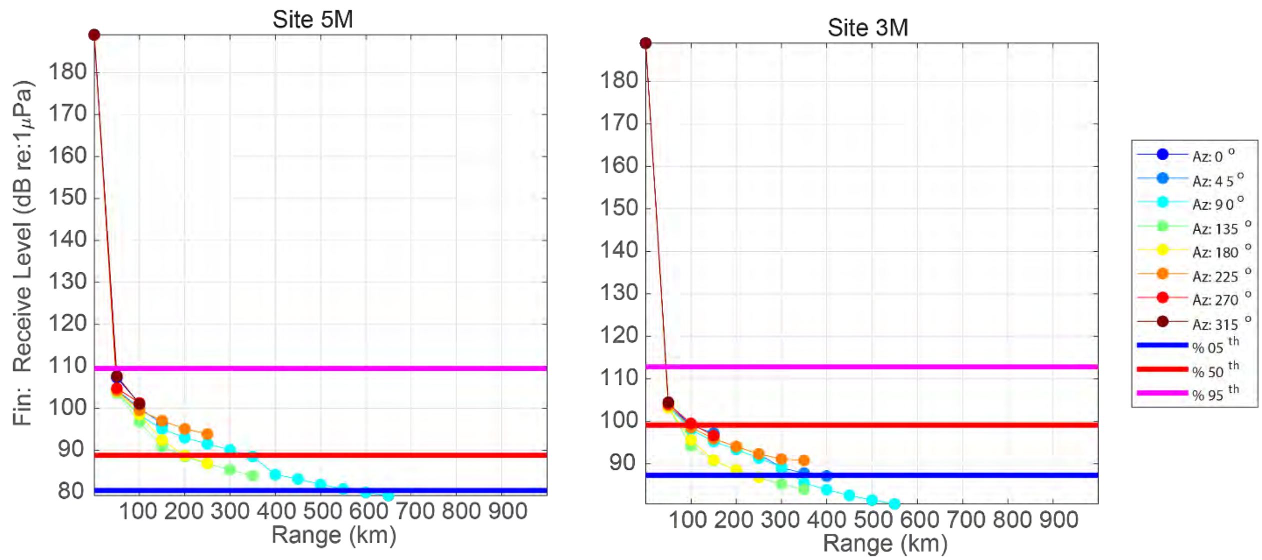

Figure 60. Estimated detection ranges (km) of fin whale 20-Hz pulses under varying noise conditions, given the estimated source level of 189 dB re: 1µPa @ 1m for the site with the lowest noise (5M) and highest noise (3M) in the fin whale frequency band (18 – 28 Hz) between October 2018 and October 2019. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site.

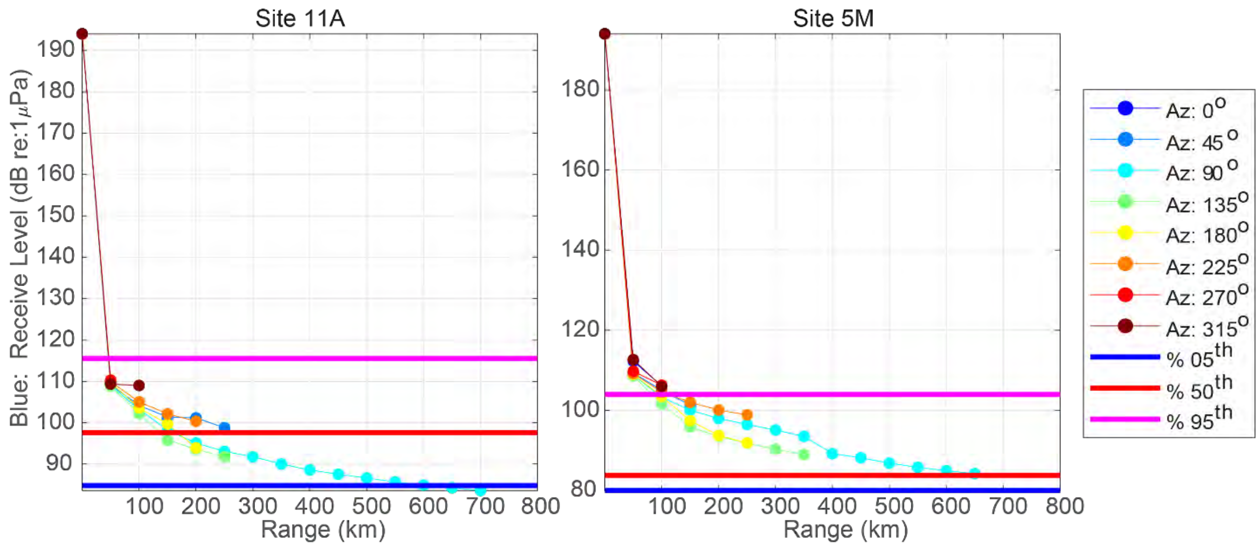

Figure 61. Estimated detection ranges (km) of blue whale calls under varying noise conditions, given the estimated source level of 194 dB re: 1μPa @ 1m for the lowest noise (11A) and highest (5M) sites within the blue whale frequency band (14 – 22 Hz) between October 2018 and October 2019. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site.

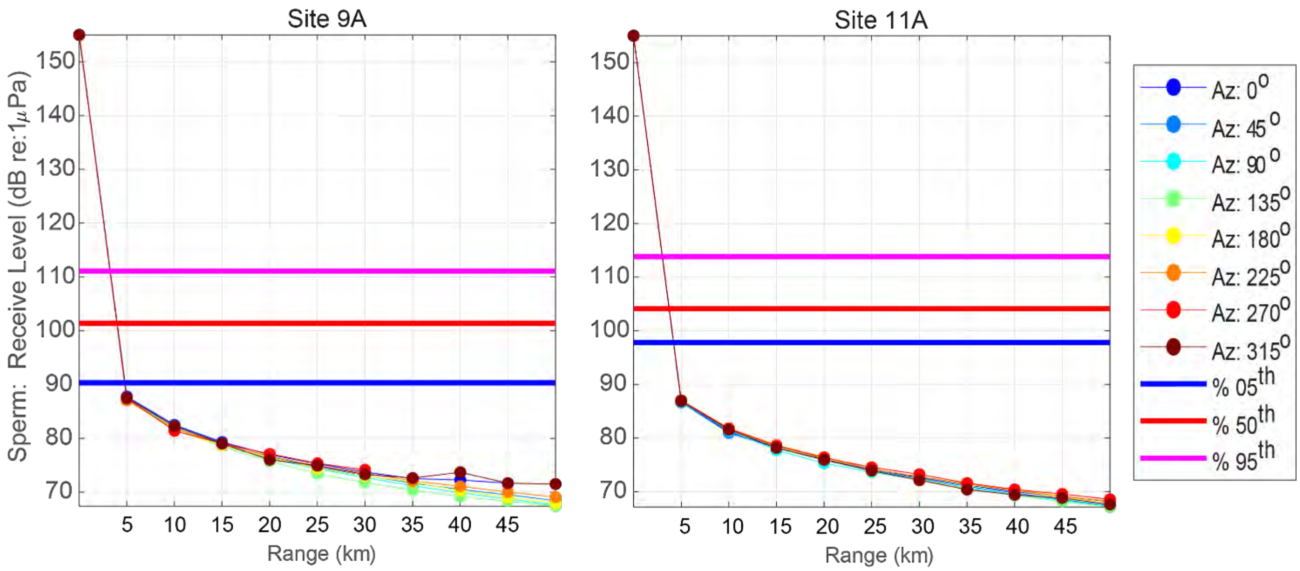

Figure 62. Estimated detection ranges (km) of sperm whale clicks under varying noise conditions, given the estimated source level of 155 dB re: 1µPa @ 1 m at sites 9A and 11A within the sperm whale frequency band (1 – 4 kHz) between October 2018 and October 2019. All AMARs had similar noise values. Each curved line represents the detection range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site.

Table 19. Detection range estimates (km) at representative sites for all target baleen whale species based on median noise levels.

Site	Right	Humpback	Sei	Fin	Blue
1M	9	2	10	104	232
2M	10	3	14	165	254
3M	10	2	10	91	215
4M	10	3	12	152	363
5M	10	4	20	245	*NA*
6M	10	4	19	260	542
7M	10	4	21	391	603
8A	9	2	10	153	247
9A	10	3	15	223	511
10M	10	3	17	164	513
11A	10	2	16	112	155
12M	10	3	15	163	257
13A	10	2	13	131	204
14M	10	2	12	109	252

Table 20. Detection range estimates at representative sites for sperm whales based on median noise levels.

Site	Sperm Whale Detection Range (km)
8A	4
9A	4
11A	4
13A	4

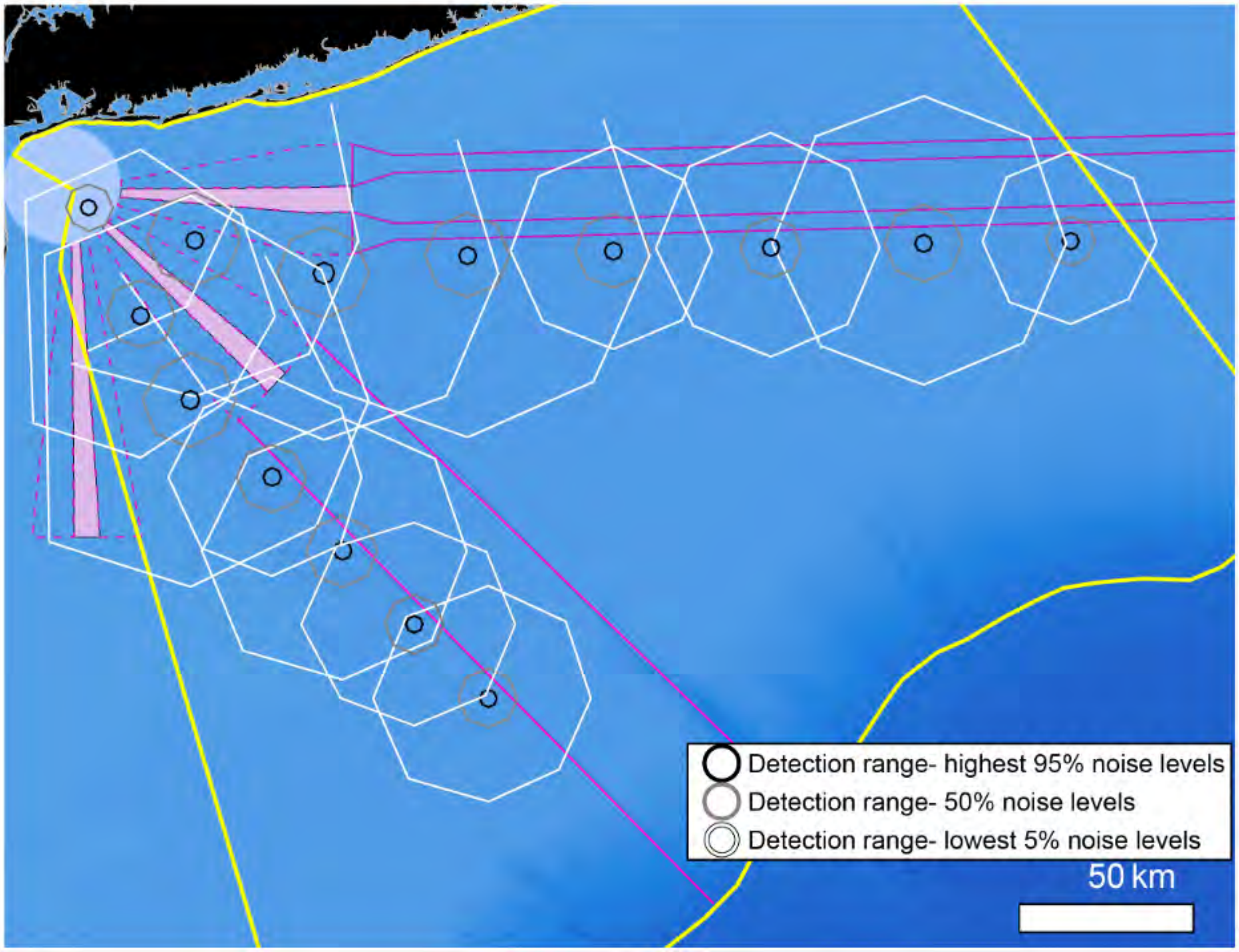

Figure 63. Map of estimated North Atlantic right whale acoustic detection ranges under different noise conditions for all sites with data collected in Year-2, and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

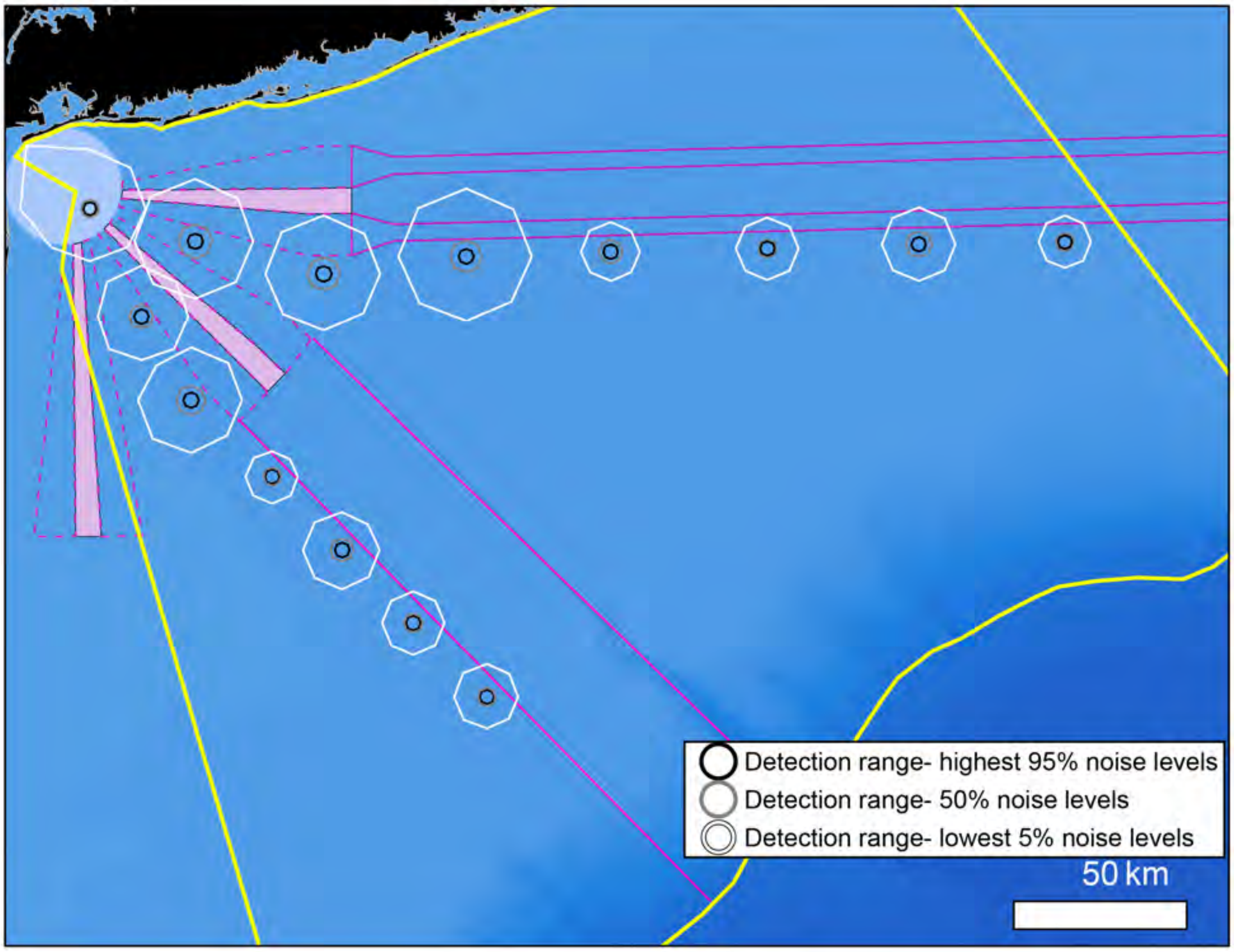

Figure 64. Map of estimated humpback whale detection ranges under different noise conditions for all sites with data collected in Year-2, and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

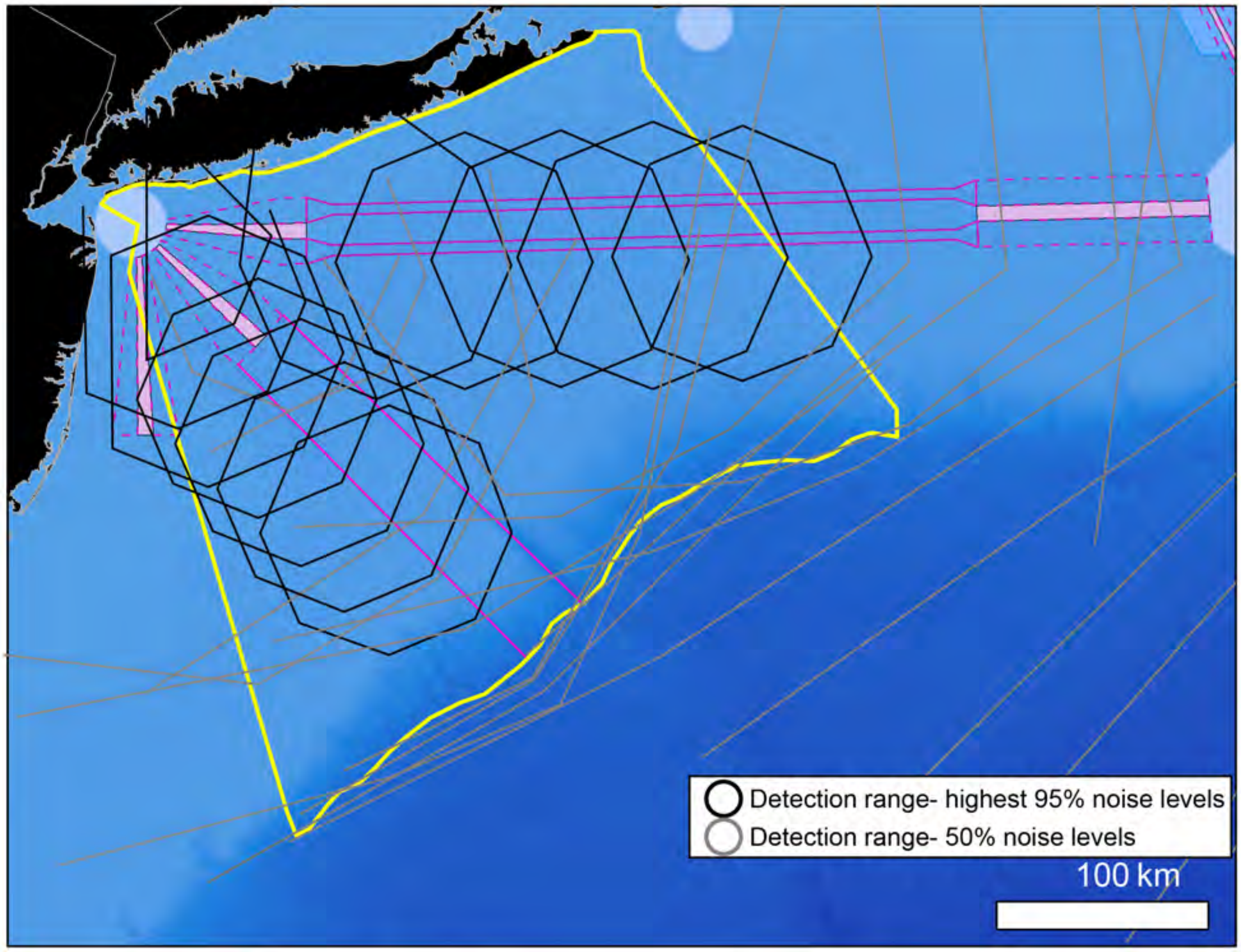

Figure 65. Map of estimated fin whale acoustic detection ranges under different noise conditions for all sites with data collected in Year-2, and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

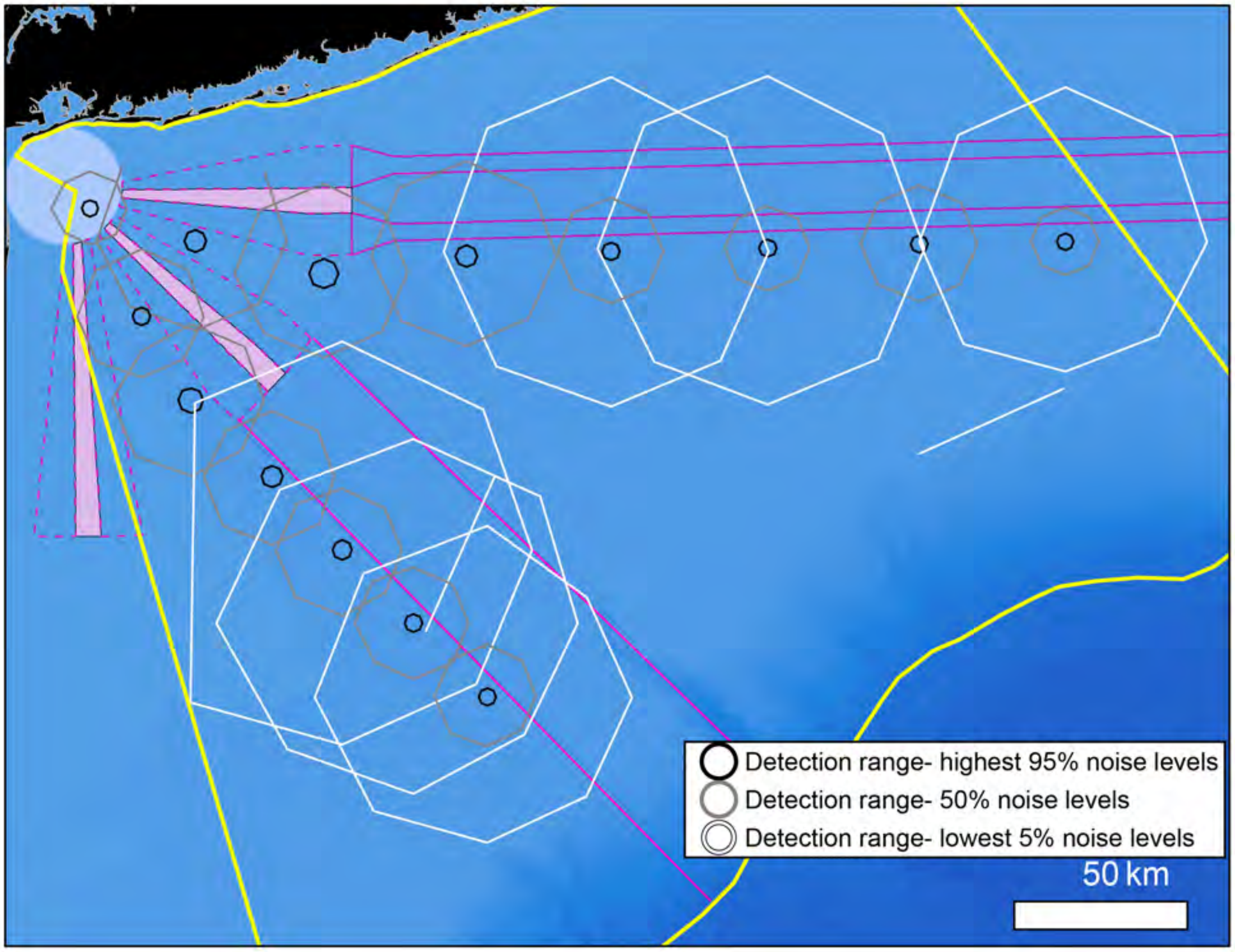

Figure 66. Map of estimated sei whale detection ranges under different noise conditions for all sites with data collected in Year-2, and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

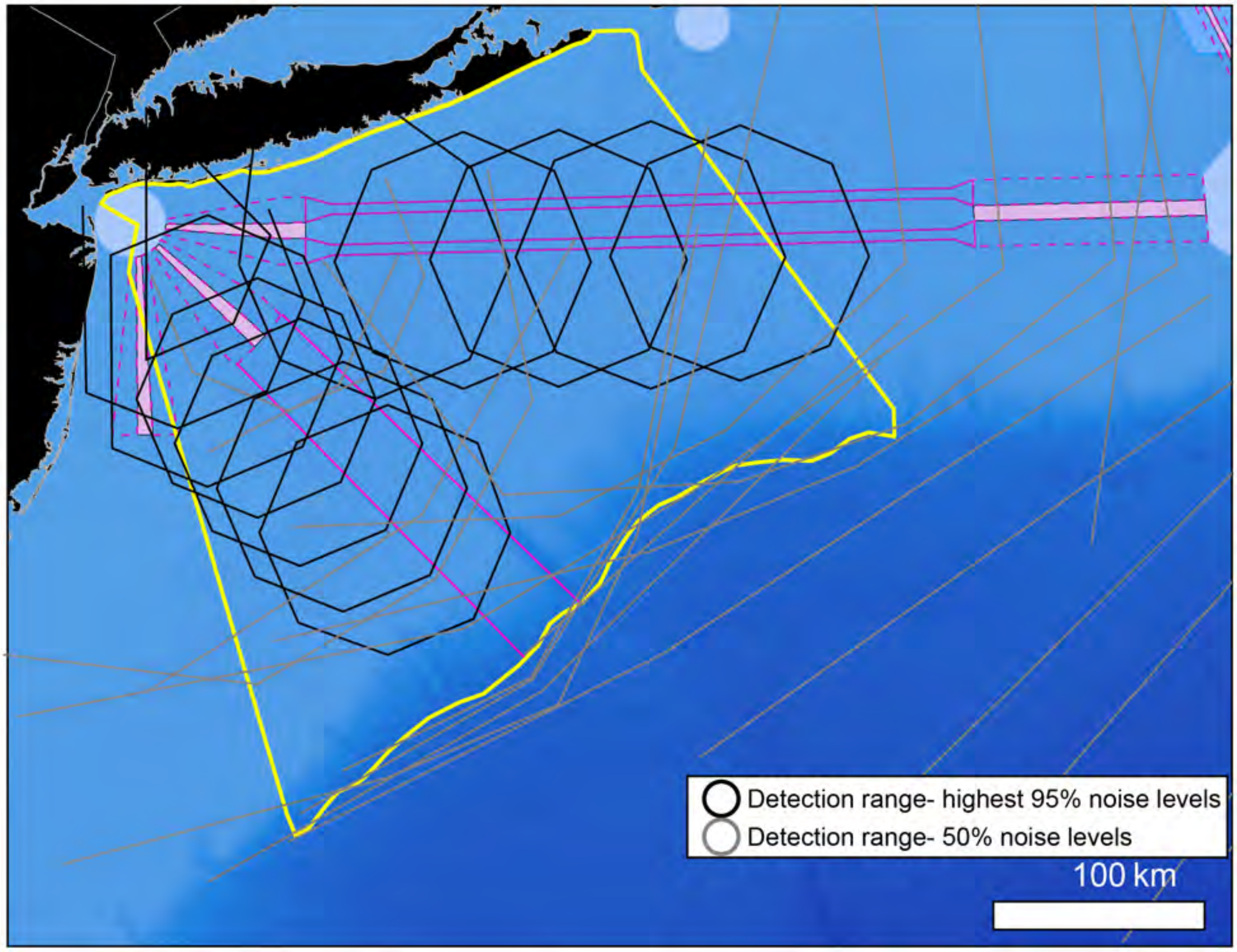

Figure 67. Map of estimated blue whale detection ranges under different noise conditions for all sites with data collected in Year-2, and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels. Note that at this spatial scale, detection ranges for the lowest 5th percentile noise conditions are >500 km and outside the bounds of the map (and not shown here).

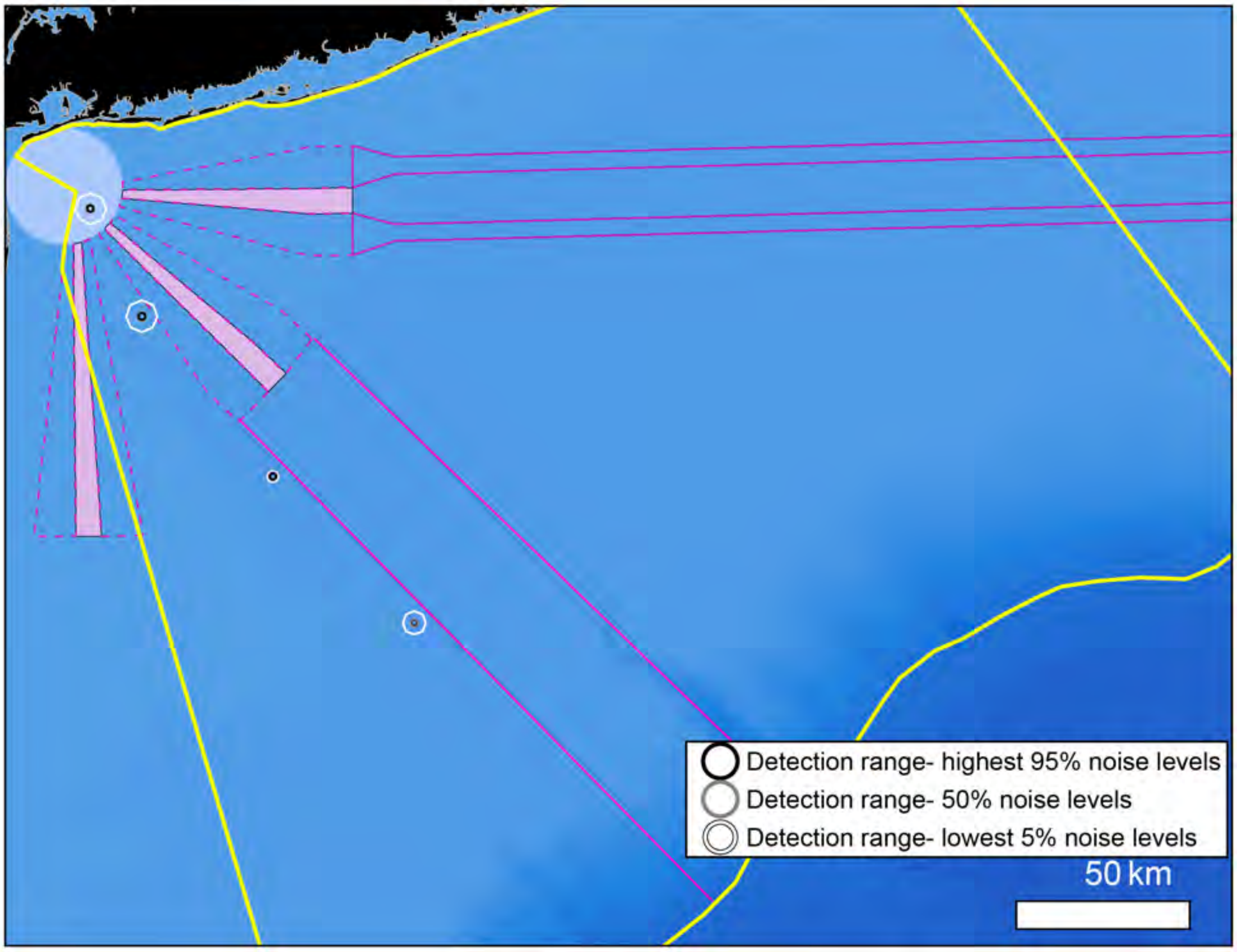

Figure 68. Map of estimated sperm whale acoustic detection ranges under different noise conditionsfor the AMAR sites with data collected in Year-2 (8A, 9A, 11A, 13A), and based on the Year-2 ambient noise levels. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

Discussion

Similar to the Year-1 passive acoustic survey effort, in Year-2, all focal whale species detected in NY Bight throughout most of the year in NY Bight. Fall, winter and spring were the time periods with the highest levels of presence within the Bight, and summer months exhibited the lowest level of cetacean occurrence. Two of the focal species, fin whales and humpback whales, were present in NY Bight throughout most of the year. There were no clear spatial trends in cetacean occurrence across NY Bight in Year 2, other than that species were detected on all units in the two transect lines. The detections across all sensors further highlights the broad spatial patterns in habitat usage across this area.

Despite passive acoustic data loss due to sensor failure or loss due to trawling (~30% of survey days), the Year-2 passive acoustic survey still had a high detection rate and detection probability of these focal species. Overall, the results from the Year-1 and Year-2 passive acoustic survey had a overall higher number of detections and detection probability than other survey methods (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018), particularly for elusive species. The aerial surveys recorded a large number of observations of fin and humpback whales, but had significantly fewer detections of North Atlantic right whales, sei whales, blue whales, and sperm whales, often with few, if any observations (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). The low number of observations of some of these cetacean species also likely underestimates their density and abundance in NY Bight.

In comparing results from survey Year-1 and Year-2, several notable changes in cetacean occurrence emerge in Year-2. There were more days of detections with right whales in Year-2 compared to Year-1 (e.g., Figure 13), with increased days of occurrence in the spring and fall of Year-2. In contrast, there were fewer days with detections in Year-2 compared to Year-1 for humpback whales, sei whales, blue whales, and sperm whales (Figure 13); these different detection patterns were not due to data loss or data gaps between years. At a broader temporal scale, the overall spatial and temporal seasonal patterns of whale occurrence are similar for both species across both survey years.

It is particularly interesting to compare trends in the Year-1 and Year-2 detections for these species and compare and occurrence patterns in NY Bight to recently published Atlantic meta-analyses (Davis et al. 2020, Davis et al. 2017). When compared to the 2008-2009 NY Bight passive acoustic survey, detections across Year-1 and Year-2 in the 2017-2019 NY Bight passive acoustic monitoring suggests that whale occurrence has been increasing in NY Bight over the last decade (Davis et al. 2020, Davis et al. 2017, Muirhead et al. 2018, Zeh et al. 2020). The underlying environmental drivers for this temporal shift in occurrence is unclear, but may be related to directional increases in ocean temperature (Molinos et al. 2016, Poloczanska et al. 2016) as has been predicted or observed for fishes in the Western North Atlantic (e.g., Morley et al. 2018, Pinsky et al. 2013). Whether this can be attributed to a combination of cetacean thermal preference, changes in ocean fronts, or is mediated through shifts is prey distribution is unclear.

As observed in Year-2, there were high ambient and anthropogenic noise levels on all of the sensors from NY Bight. Shipping noise was the dominant anthropogenic sound source. There were no consistent geographical trends in noise levels, likely because the instruments were consistently deployed relative to the shipping lanes for the entire transect. At the northeast convergence of the two shipping lanes, site 8A consistently experienced some of the higher sound levels compared to other locations (e.g., Figure 56), presumably because of the increased vessel traffic compared to other sites. These elevated ambient noise levels consequently limit both the acoustic detection range of whales (Figures 62-67) and restrict their conspecific communication space through increased acoustic masking (Figures 57-62) (Cholewiak et al. 2018, Clark et al. 2009, Hatch et al. 2012). From the lowest ambient sound level (5th percentile) to the median ambient sound levels in NY Bight, the communication space decreases by >60%. Additionally, the increased exposure of marine mammals to elevate noise levels upon entering NY Bight likely represents a source of chronic stress (Nowacek et al. 2007, Shannon et al. 2016, Weilgart 2007), which may have a variety of physiological, behavioral, or ecological consequences (e.g., Kight and Swaddle 2011); most of which have not been measured for these focal species (Shannon et al. 2016).

SPECIES SPECIFIC OCCURRENCE PATTERNS

North Atlantic Right Whales

Right whales were the most frequently detected in NY Bight from fall through spring, with presence >5 days/week for most of this period. Higher levels of right whale presence were documented in Year-2 compared to Year-1, with significantly higher presence in spring and fall (Figure 13). We also observed significantly higher number of right whale detections in spring, fall and winter in 2017-2019 compared to the 2008-2009 acoustic survey in both the mid-Bight and NY Harbor locations (Muirhead et al. 2018). In the 2008-2009 data, there were few detections close to the entrance of NY Harbor; and in the 2016-2018 data, while there were few detections on unit 8A (closest to the NY Harbor entrance), but relatively high presence at the nearby locations, 7M and 9A.

From previous passive acoustic surveys in the Mid-Atlantic and Gulf of Maine, we know that North Atlantic right whale occurrence can be highly variable across years (Bailey et al. 2018, Charif et al. 2020, Davis et al. 2017, Kraus et al. 2016, Salisbury et al. 2019).

For example, off the coast of Maryland, the month with the highest North Atlantic right whale occurrence varied between January through March (Bailey et al. 2018). This pronounced interannual variability in occurrence suggests major differences in right whale movement patterns through much of the Mid-Atlantic. It would be helpful to understand the coupling of spatial occurrence patterns for North Atlantic right whales in NY bight compared to other areas in the Mid-Atlantic or Gulf of Maine, and whether occurrence in areas outside of NY waters are predictive of eventual occurrence within NY Bight. The Mid-Atlantic and NY Bigth are thought to be part of the right whale migratory corridor (Kraus et al. 1986, Kraus and Rolland 2007). However, the extended presence in right whales in NY Bight outside of their migratory windows suggests right whales may not exclusively be migrating through this region. Similar patterns in extended seasonal occurrence of right whales outside of migration periods have been observed in other areas (Davis et al. 2017, Hodge et al. 2015, Morano et al. 2012a, Salisbury et al. 2016). Yet, it is unclear what role NY Bight plays in right whale ecology. Right whales have been observed feeding as far south as Nantucket Shoals (Leiter et al. 2017), but is unclear whether calanoid copepods (right whales' principal food source) are in sufficient density in NY Bight to support feeding behavior. However, if right whales are not feeding in NY Bight, and they are also not migrating, it is unclear how they are using this habitat and why this region may be important.

Humpback Whales
Both song and social sounds of humpback whales were detected in NY Bight throughout Year-2. Since humpback song is hypothesized to be produced only by males, and associated with courtship or advertisement behavior, this is suggestive of this region being associated with some aspect of HB reproductive-related behavior. There have been similar observations of humpback song detected in the Western North Atlantic (Clark and Clapham 2004, Davis et al. 2020, Murray et al. 2014, Vu et al. 2012). Comparison of the 2008-2009 NY Bight acoustic survey data (Davis et al. 2020, Zeh et al. 2020) with the Year-1 and Year-2 NYBight data show a higher level of detections in recent years, particularly during June-December. While there is not a direct overlap in sensor placement between these two survey efforts, there are likely overlapping detection ranges.

Similar to the seasonal trends for right whales, the year-round detections of humpback whales in NY Bight suggest this area is of year-round importance. While some portion of the Gulf of Maine population of humpbacks migrate between Gulf of Maine and the Tropical western Atlantic (Hayes et al. 2019, Heenehan et al. 2019), the Year-1 and Year-2 NY Bight passive acoustic survey data further demonstrate that not all of the humpback whale population is migrating. It is unclear what portions of the population may be using different regions of the Mid-Atlantic to overwinter, though the prevalence of song suggests a large number of males. With the nearly year-round presence of humpback whales in many Mid-Atlantic areas (Davis et al. 2020), it raises the question whether there is site fidelity for different cohorts within the humpback whale stock, or whether overwintering whales moving between these locations.

Fin Whales
As with other areas in Mid-Atlantic and Gulf of Maine, fin whales are detected all year (Davis et al. 2020, Morano et al. 2012b). While this may be influenced by fin whales' large detection range, the heterogeneous spatial detection patterns across NY Bight (Figures 30, 32) suggest that distant fin whales are the primary source of detections in NY Bight; this is corroborated by the large number of observations during aerial surveys (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). The 2008-2009 passive acoustic data show a decrease in fin whale activity during May-August (Davis et al. 2020, Morano et al. 2012b, Muirhead et al. 2018) compared to 2017-2019, however, some of these discrepancies are likely due to the limited number of sensors operating during summer months in 2008-2009. Despite their prevalence in NY Bight, it is unclear how fin whales are using this habitat.

Sei Whales

NY Bight likely represents the more southerly extent of the range for sei whales (Hayes et al. 2019), though a lower level of acoustic detections have been recorded as far south as the South Atlantic Bight (Davis et al. 2020). The Year-1 and Year-2 acoustic survey data collected in NY Bight are one of the most extensive time-series records of sei occurrence collected to date. Both years of survey data show that March- mid-June is the peak occurrence period for seis in NY Bight, though Year-1 had higher levels of detections in the fall and winter, while Year-2 exhibited higher levels of detections in late summer and early fall.

Sei whales have only been recently the focus of PAM surveys (Baumgartner et al. 2008, Davis et al. 2020, Nieukirk et al. 2020, Tremblay et al. 2019) and data on their occurrence in the Gulf of Maine and Mid-Altantic have only recently been analyzed (Davis et al. 2020). As a result, Davis et al. (2020) represents the first synthesis of sei whale occurrence in the Western North Atlantic from PAM data and provides the first large-scale analyses of their occurrence across this region. The "Region 7" in Davis et al. (2020) is the transect line from Cornell's 2008-2009 survey, and is similar to the present 2017-2019 acoustic survey data in identifying spring as the time period with peak occurrence in NY Bight. It is presently unclear what portion of the sei whale population stops at NY Bight, and how many individuals and what size classes or sex travel further south in the Mid-Atlantic. However, the fact that NY Bight is one of the southern-most regions with sustained sei whale occurrence highlights the likelihood that this area is important to their ecology.

Blue Whales

The Year-2 survey exhibited an extremely limited number of days of detection of blue whales in NY Bight, as seen both in 2008-2009 (Davis et al. 2020, Muirhead et al. 2018) and in the Year-1 acoustic survey. The small number of days with detections suggests blue whales do not spend much time in NY Bight, and instead are likely migrating through the area. An important question is how far into the NY Offshore Planning area they are getting, or whether they are off the shelf. A single blue whale was acoustically tracked by Muirhead et al. (2018), and shown to be on the shelf, suggesting that individuals may be transiting through the planning area.

Sperm Whales

Occurrence patterns for sperm whales from Year-1 and Year 2 within NY Bight continue to pose a number of question about their ecology. Whereas the aerial surveys observered sperm whales at the shelf break (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018), the acoustic recorders had regular detections of sperm whales (or sperm whale-like click trains) extending well onto the shelf. The fact that the transect line of units 8A-15M run parallel to the Hudson Canyon may indicate that sperm whales are foraging in the canyon into shallower shelf waters. There was no clear seasonal signal detected in sperm whale occurrence data, so unclear if these are a limited number of resident individuals in the area, or whether there are animals regularly moving through.

MANAGEMENT IMPLICATIONS FOR PASSIVE ACOUSTIC SURVEY RESULTS

The Year-1 and Year-2 passive acoustic data highlight how these data can inform adaptive or actionable management for protected species in NY Bight. The interannual variability of whale occurrence combined with extended periods of time of their occurrence may make implementation of seasonal management areas (done other high-traffic areas in Mid-Atlantic) difficult to impose or only partly effective.

The high number of detections of marine mammals in close proximity to the shipping lanes indicates that ship strikes remain a risk. Some of these focal whale species (e.g., right whales, blue whales), are transiting across NY Bight from southwest to northwest, and consequently, are having to cross both of the major shipping lanes. However, because international vessel traffic has to cross this shelf region, moving the shipping lanes to decrease the possibility of ship strikes (similar to Massachusetts Bay)(as done for Stellwagen Bank National Marine Sanctuary; Petruny et al. 2014) may be extremely difficult or ineffective. Consequently, other mitigation efforts (e.g., speed reductions, dynamic management areas) may need to be evaluated for their efficacy in reducing the probability of ship strikes.

With the spatial planning process for offshore wind energy across NY Bight (NYSDEC and NYSDOS 2015), wind lease areas will impose a large spatial footprint on NY Bight. For the eventual build-out of offshore wind, the year-round occurrence of marine protected species in NY Bight will create difficulties in implementing seasonal exclusions on pile-driving. Instead, if there are restrictions imposed, dynamic management areas may be a more viable and effective approach for balancing development needs with mitigating impacts to marine mammals. Understanding whale occurrence in offshore wind planning areas is an important and ongoing part of wind farm site assessment (Bailey et al. 2018, Hodge et al. 2015, Leiter et al. 2017, Salisbury et al. 2019, Stone et al. 2017). Whales occurring these wind energy areas may be exposed to a number of stressors associated with windfarm construction and operation (Bergstrom et al. 2014, Carstensen et al. 2006, King et al. 2015, Petersen and Malm 2006, Schuster et al. 2015, Thompson et al. 2010, Tougaard et al. 2007), but impulsive sounds from pile driving are of the most urgent concern (Amaral et al. 2020, Bailey et al. 2010, Kastelein et al. 2016, Madsen et al. 2006, Schuster et al. 2015, Thompson et al. 2010, Zampolli et al. 2013).

RECOMMENDATIONS FOR FUTURE STUDY OF CETACEANS IN NY BIGHT

While these two years of passive acoustic surveys have produced a wealth of data on data-deficient marine mammal species in NY Bight, there are still several data gaps that should be addressed for a more complete understanding of marine mammal habitat use of the Bight. For example, the existing surveys have collected data along two transect lines paralleling the shipping lanes, yet there have been few data collected in the center region of NY Bight. It is unclear how whales are using this center region, and how patterns of occurrence there compare with the norther or western edges. Additionally, it will become increasingly important to understand how and why marine mammals are using NY Bight as a habitat, and what role it plays in their life history. This critical ecological information may be needed to develop a more mechanistic perspective on what brings marine mammals to NY Bight, and what may be more effective mitigation strategies to minimize impacts on these protected species. Lastly, comparison of the Year-1 and Year-2 data with previously collected data suggests an increasing trend in marine mammal occurrence in NY Bight. If true, this may further highlight the potential for NY Bight as an important habitat for marine mammal species.

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Appendix A: Long Term Spectrograms and Noise Statistics per Site and Deployment

Long-term spectrograms were generated to visually represent ambient noise variation in the time and frequency domain, where L_{eq} values were averaged within discrete 10-minute time bins. Spectrograms were generated with both linear (Figure 69, Figure 82, first panel) and 1/3 octave (Figure 69, Figure 82, second panel) frequency scales. Since 1/3 octave bandwidths approximates the frequency sensitivity of the mammalian ear (Southall et al. 2007), frequency bandwidths based on 1/3rd octaves were selected to represent the frequency band in which each target species hearing is potentially most sensitive (Table 5).

Time series plots (Figure 69, Figure 82, third panel) are presented to illustrate the variation in average-10-minute noise levels throughout the survey period within each target species 1/3 octave frequency band. The time series plot also allows for a direct comparison in noise level over a given period of time between different species bands, and aligns with the spectrograms such that noise events are visible at a given time.

Power spectral density (PSD) plots (Figure 69, Figure 82, fourth panel) of L_{eq} values were used to compare the dominant frequencies of each recording site. The PSD plot captures variation of sound pressure levels across the frequency domain of long-term ambient noise data (Wenz 1972) by representing the sound pressure level (dB re: $1\mu Pa^2/Hz$) as a function of frequency in the signal (Merchant et al. 2013). Here, data from the specified time duration and site location are represented using the 1st, 25th, 50th, 75th, and 99th noise percentiles.

Discrete ship noise events are visible in all spectrograms, particularly at site 8A. Fin whale 20-Hz pulses are visible in the 1/3 octave spectrogram (second panel) for sites 3M – 5M (Figure 69, Figure 70, Figure 71, Figure 72, Figure 73), 9A (Figure 77), 10M (Figure 78), 11A (Figure 79), 12M (Figure 80), 13A (Figure 81), and 14M (Figure 82). Across all sites, the blue whale frequency band consistently recorded the lowest noise levels throughout the two deployments (third panel). In the power spectral density plots, fin whale pulses are reflected in the slight peak in noise levels around 20 Hz. The higher noise levels below 100 Hz at all sites are likely attributed to anthropogenic noise (e.g., shipping).

Site 1M

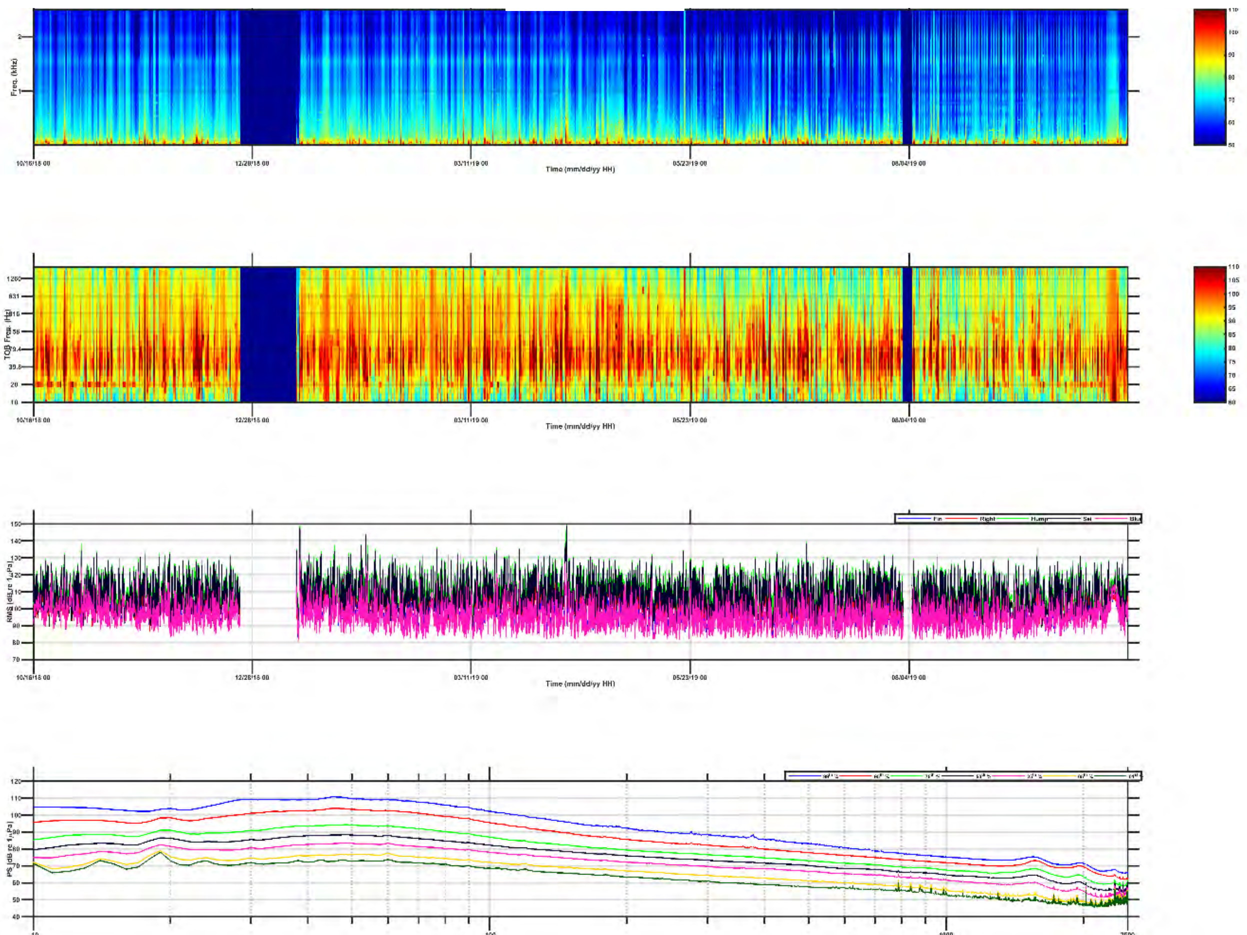

Figure 69. 10-minute averaged ambient noise metrics for site 1M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

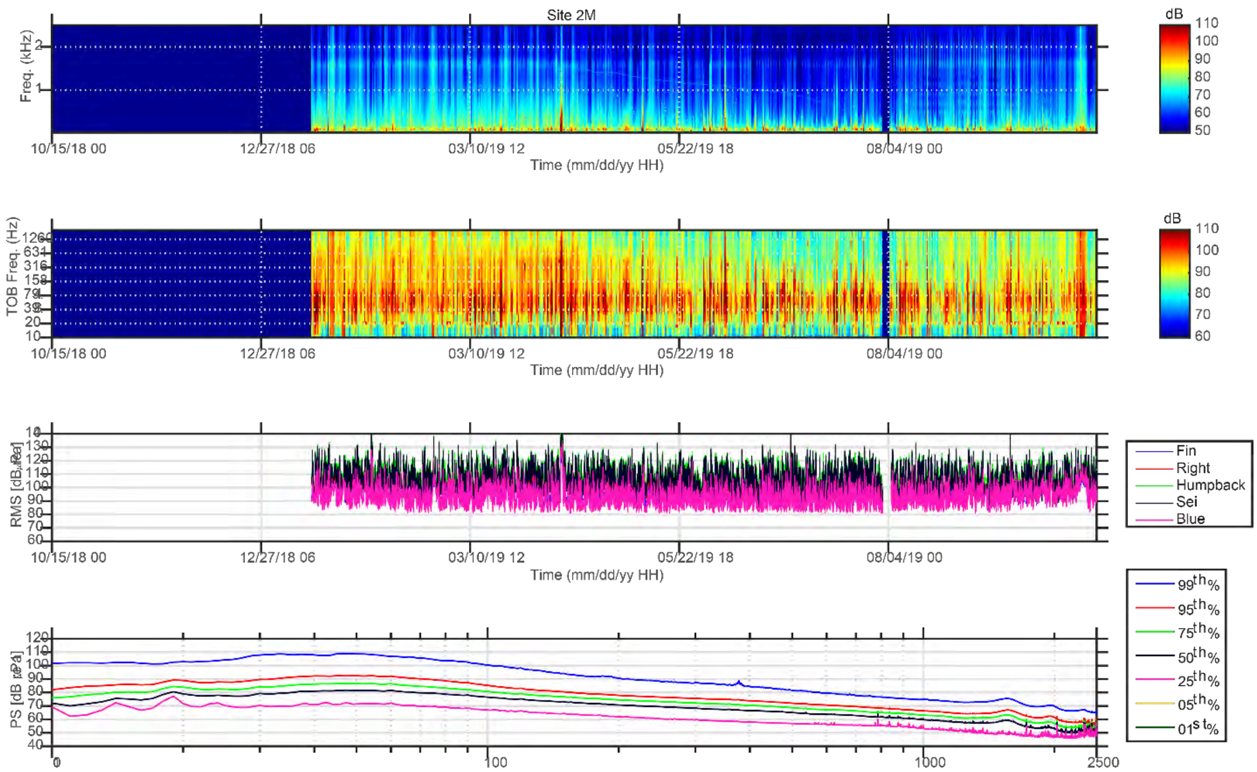

Figure 70. 10-minute averaged ambient noise metrics for site 2M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). The third panel is a time series of noise levels (dB re: 1µPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1µPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

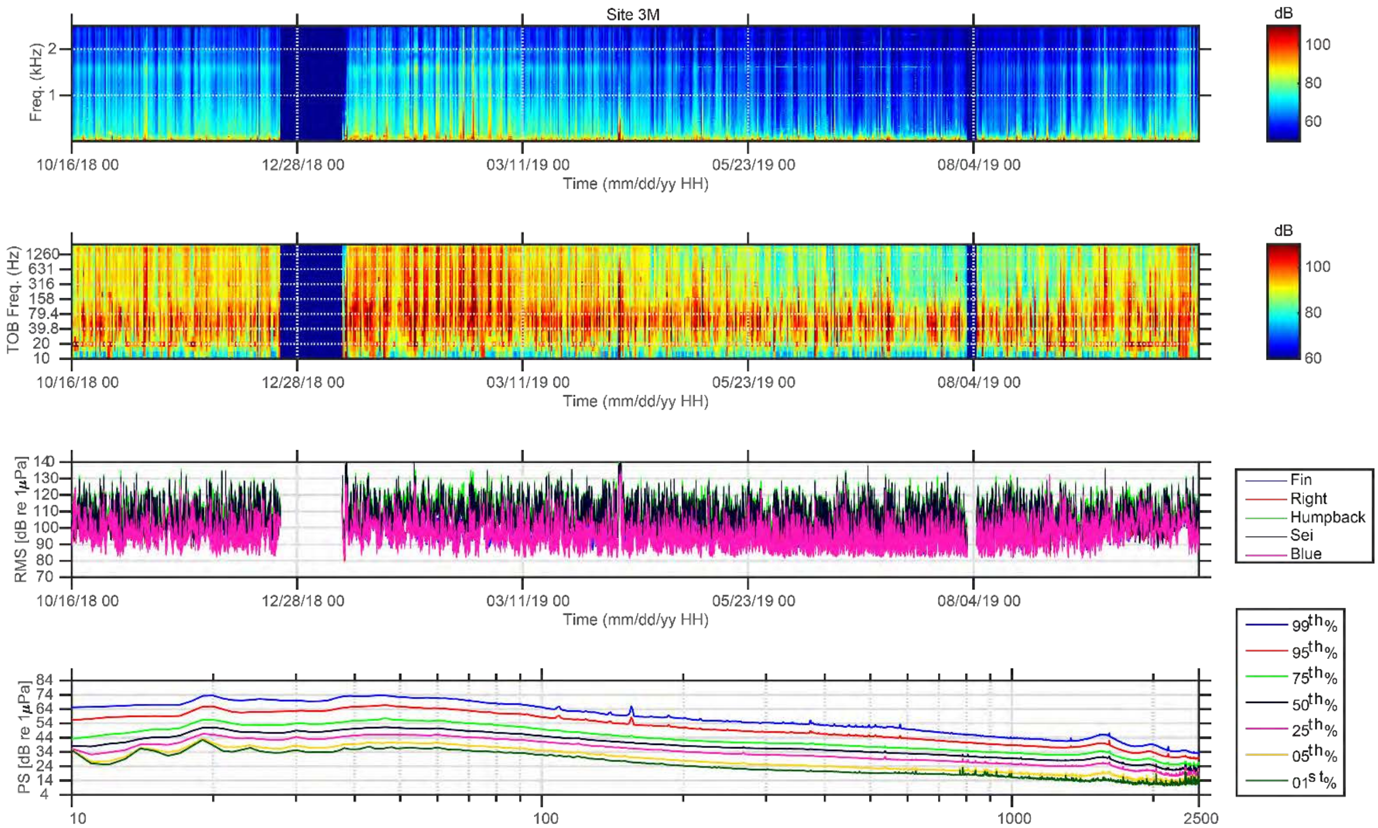

Figure 71. 10-minute averaged ambient noise metrics for site 3M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1^{st}, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, and 99^{th}) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

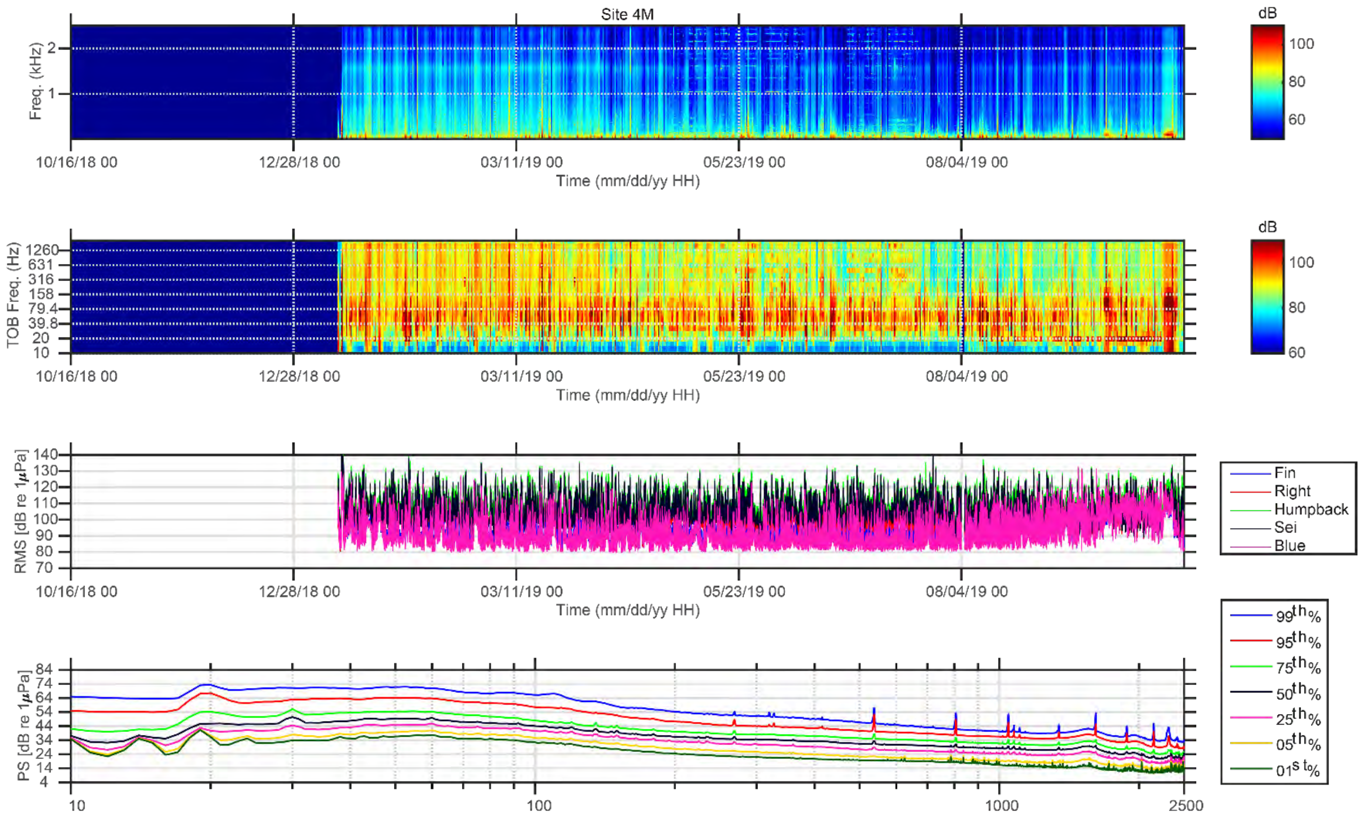

Figure 72. 10-minute averaged ambient noise metrics for site 4M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

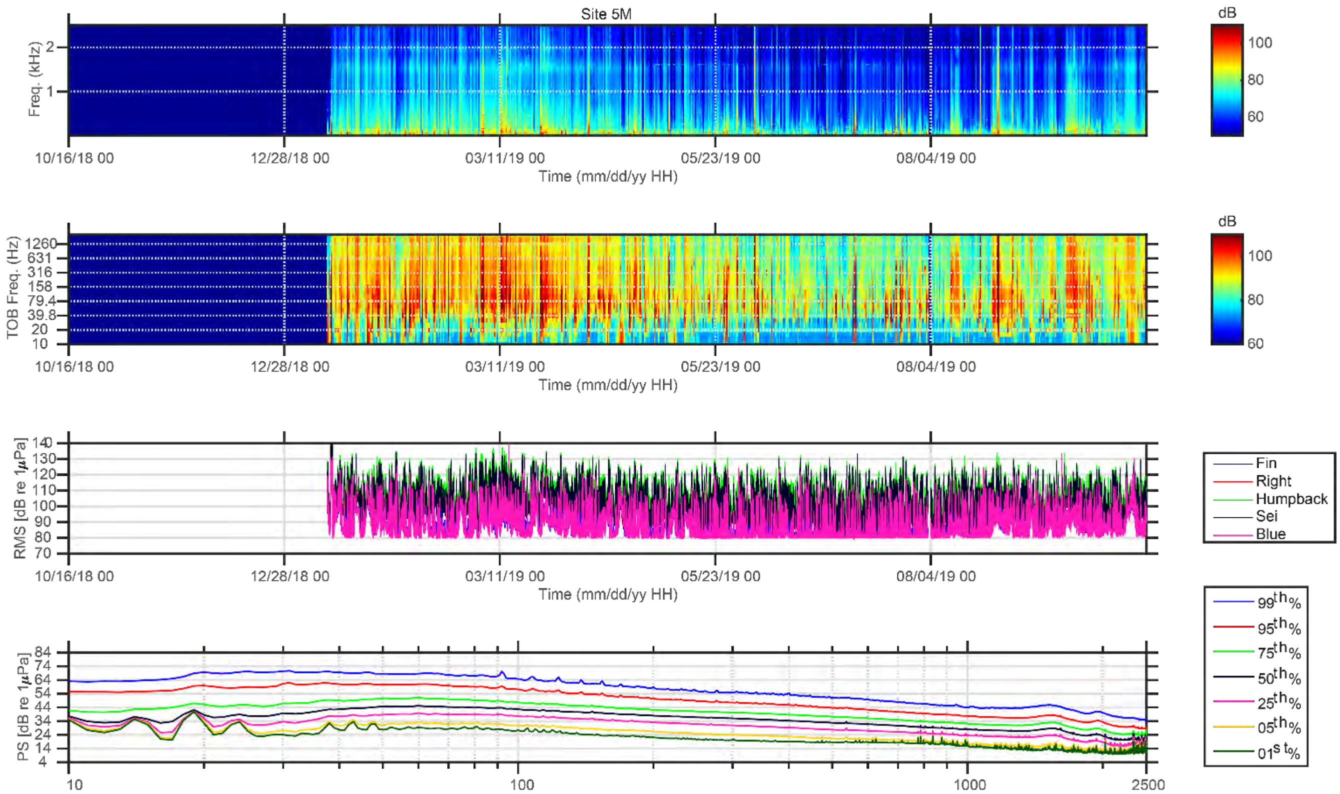

Figure 73. 10-minute averaged ambient noise metrics for site 5M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

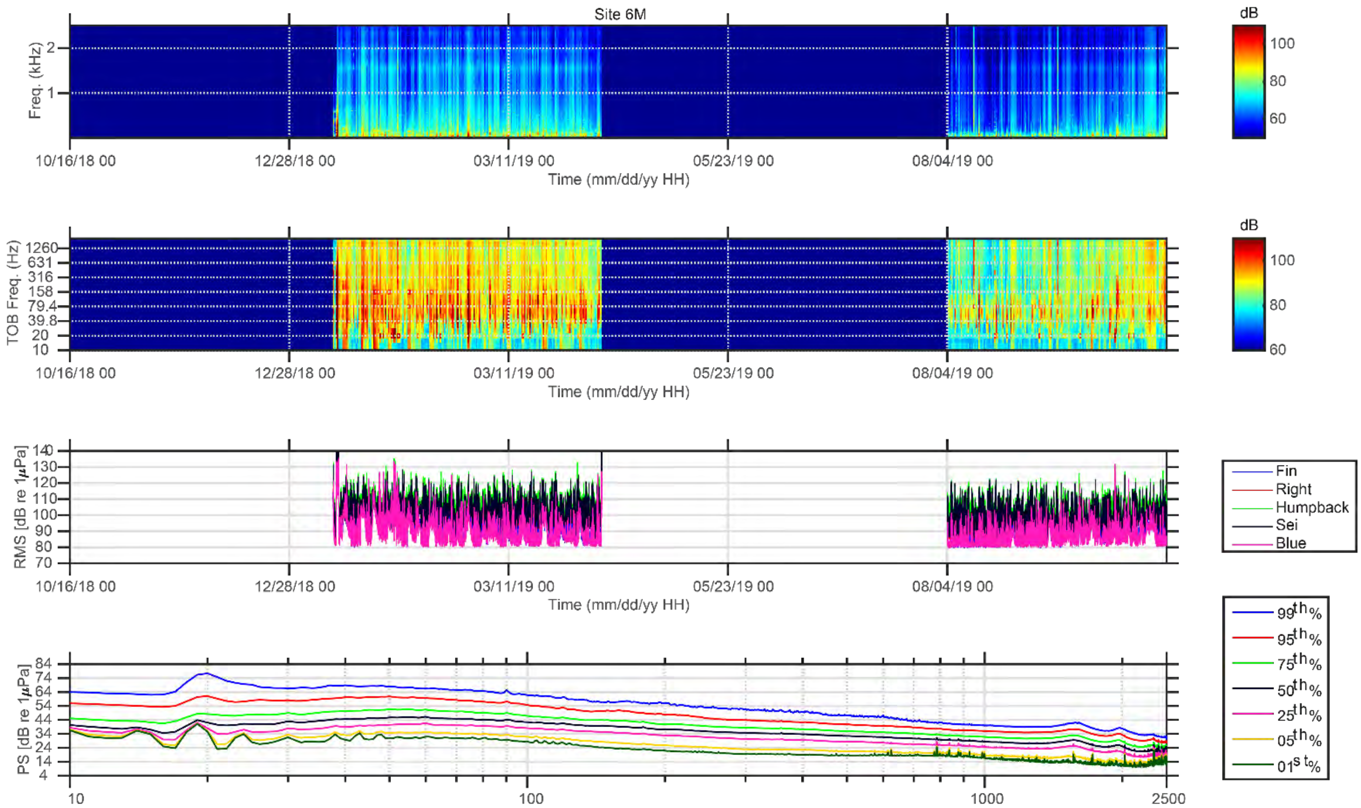

Figure 74. 10-minute averaged ambient noise metrics for site 6M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

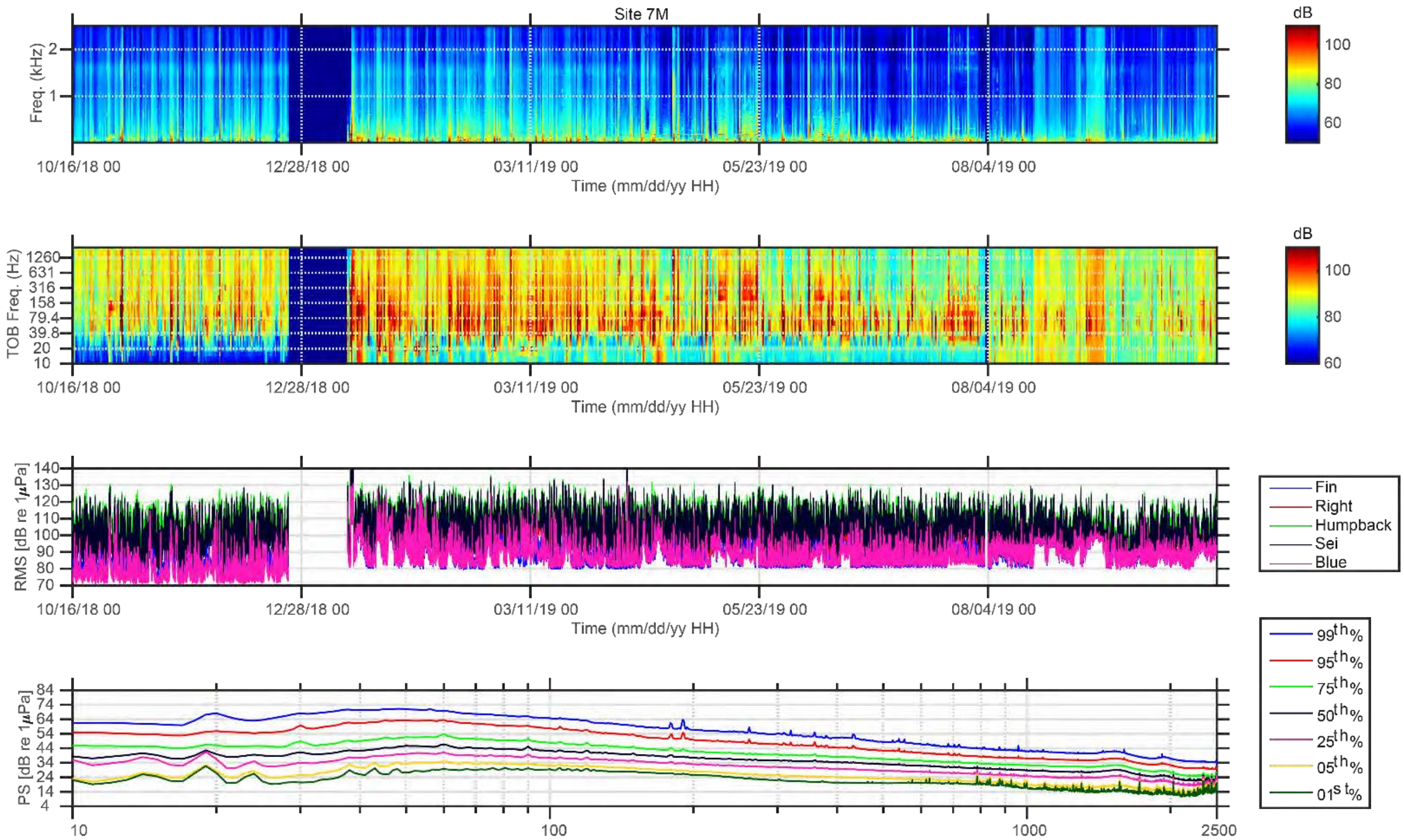

Figure 75. 10-minute averaged ambient noise metrics for site 7M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). The third panel is a time series of noise levels (dB re: 1µPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1µPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

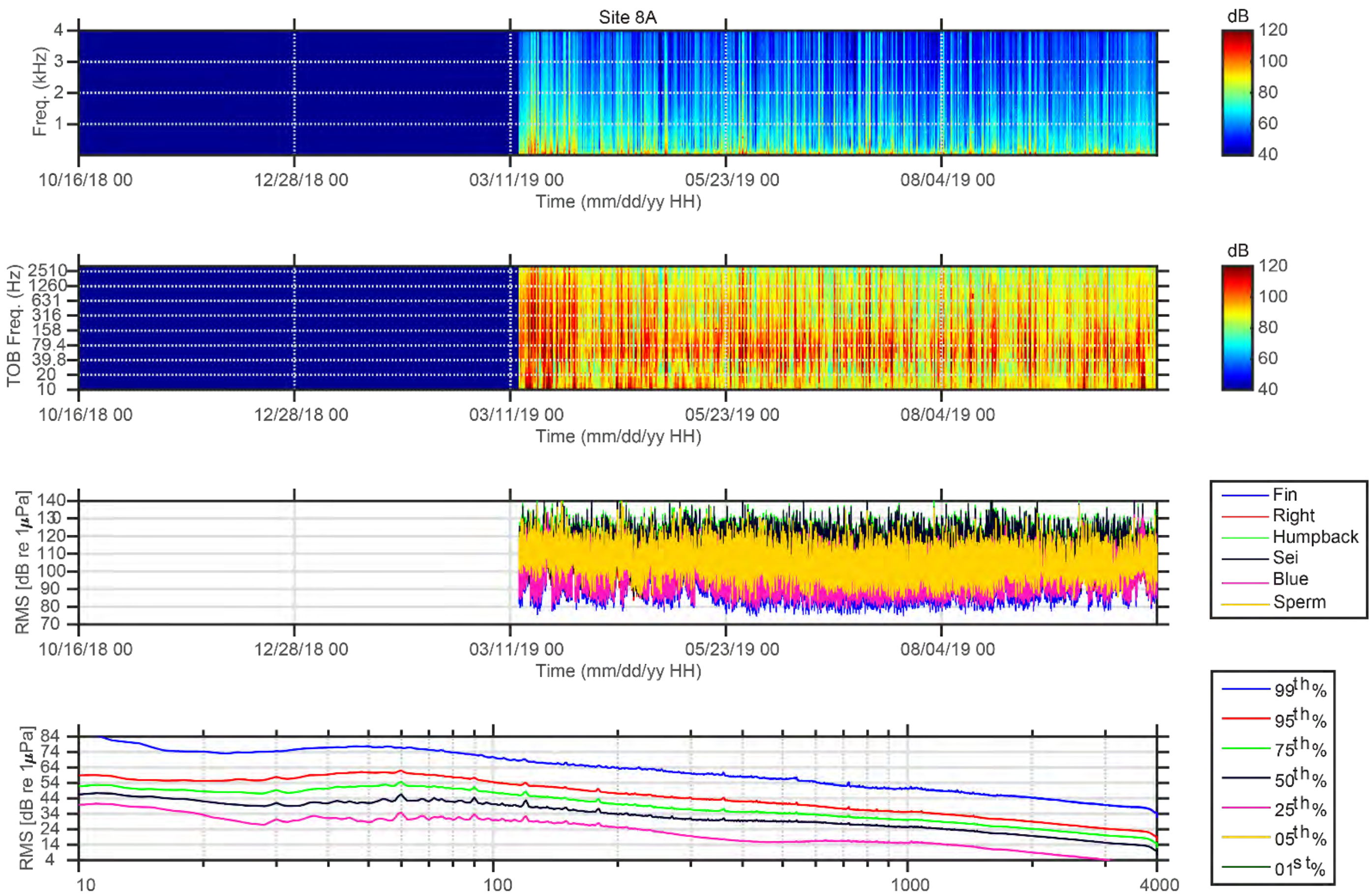

Figure 76. 10-minute averaged ambient noise metrics for site 8A between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band.

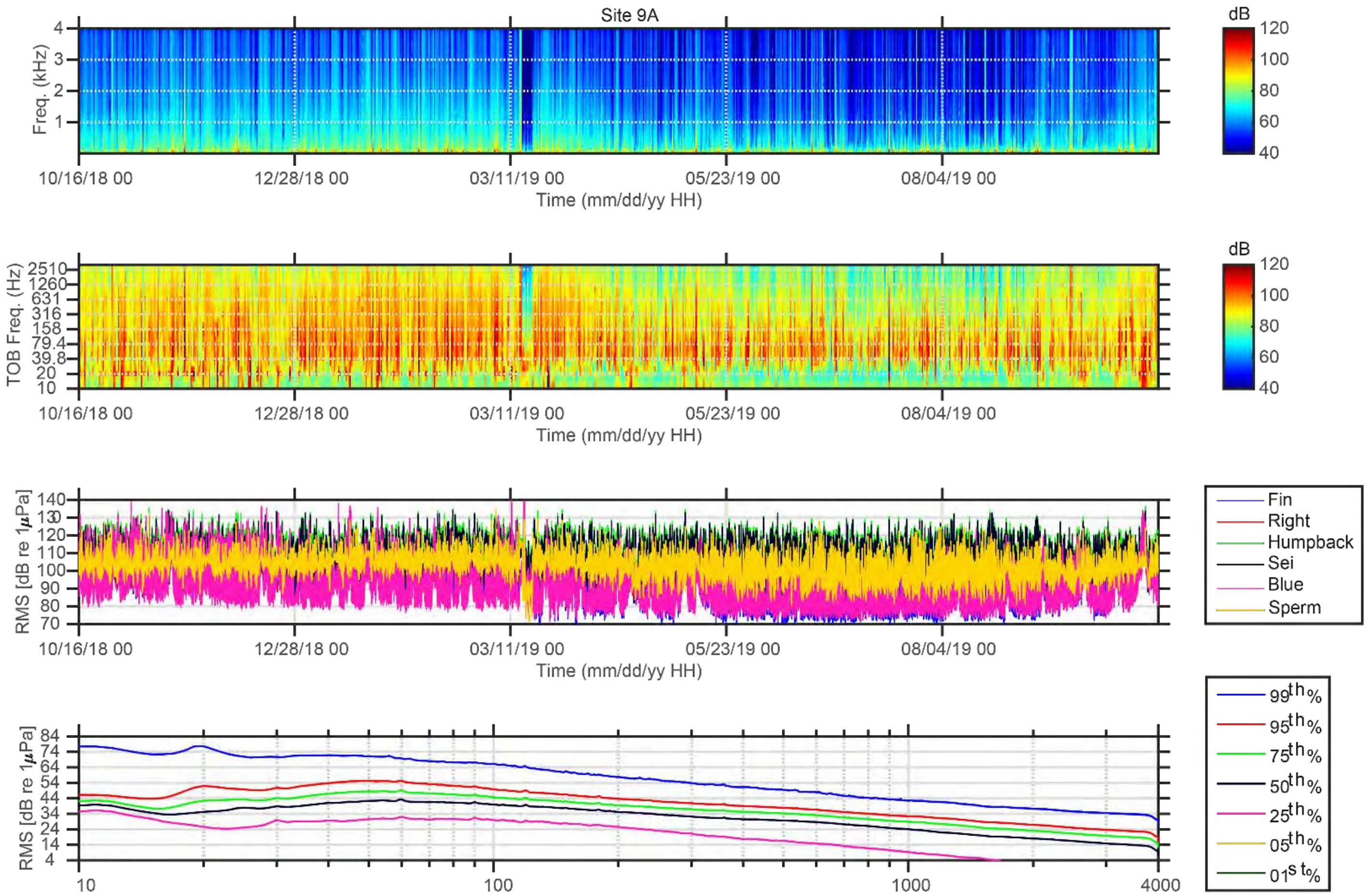

Figure 77. 10-minute averaged ambient noise metrics for site 9A between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). The third panel is a time series of noise levels (dB re: 1µPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1µPa) across a logarithmic frequency scale for the full frequency band.

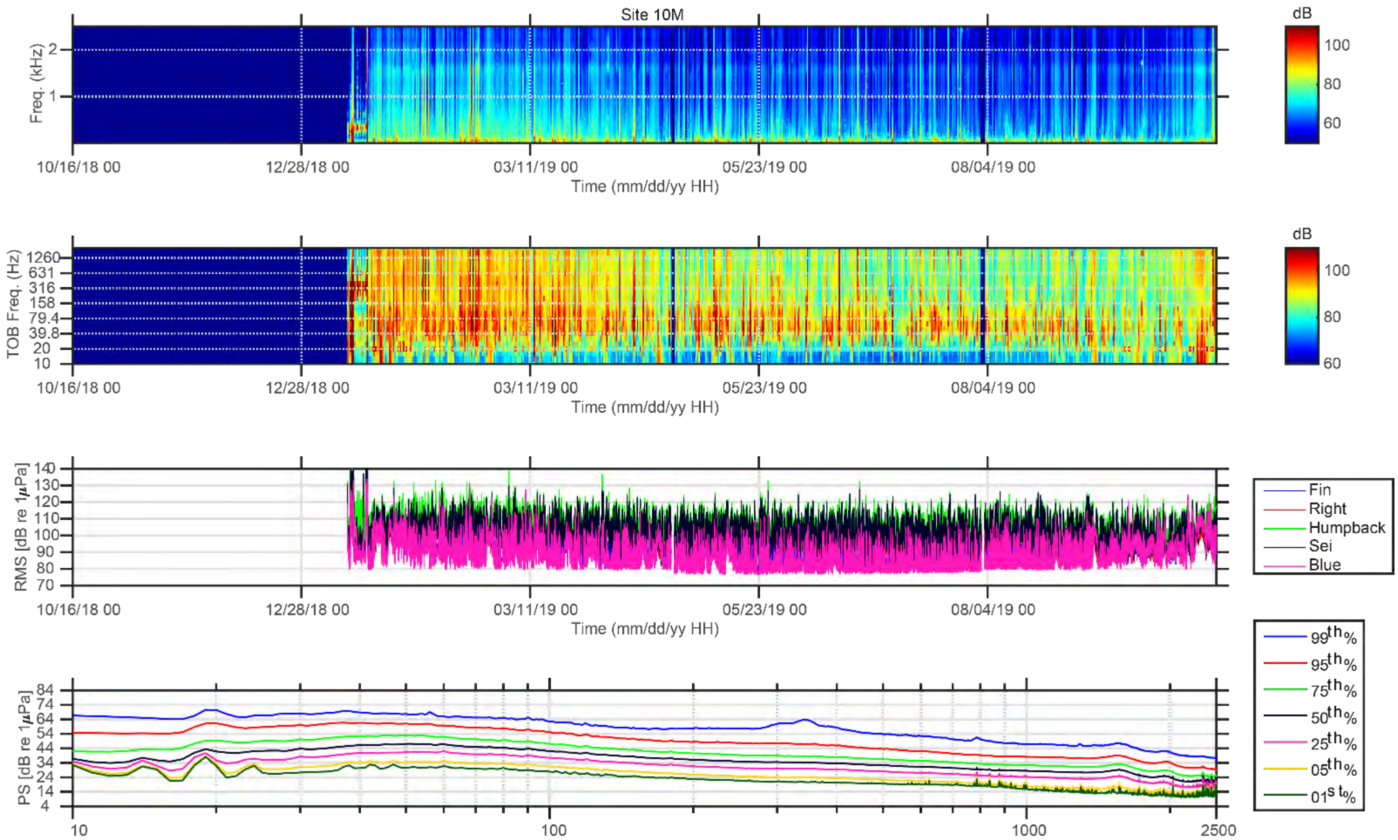

Figure 78. 10-minute averaged ambient noise metrics for site 10M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

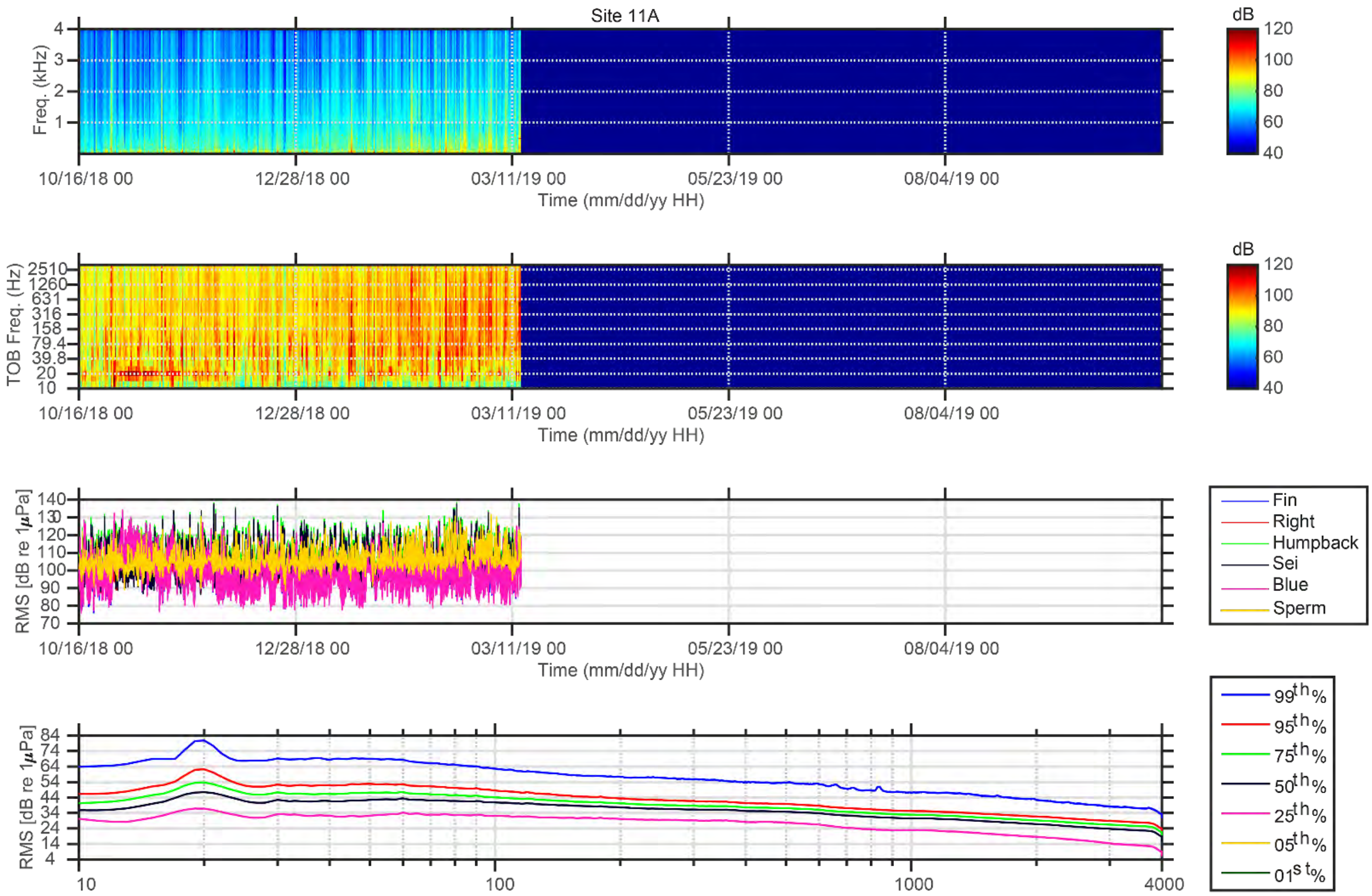

Figure 79. 10-minute averaged ambient noise metrics for site 11A between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band.

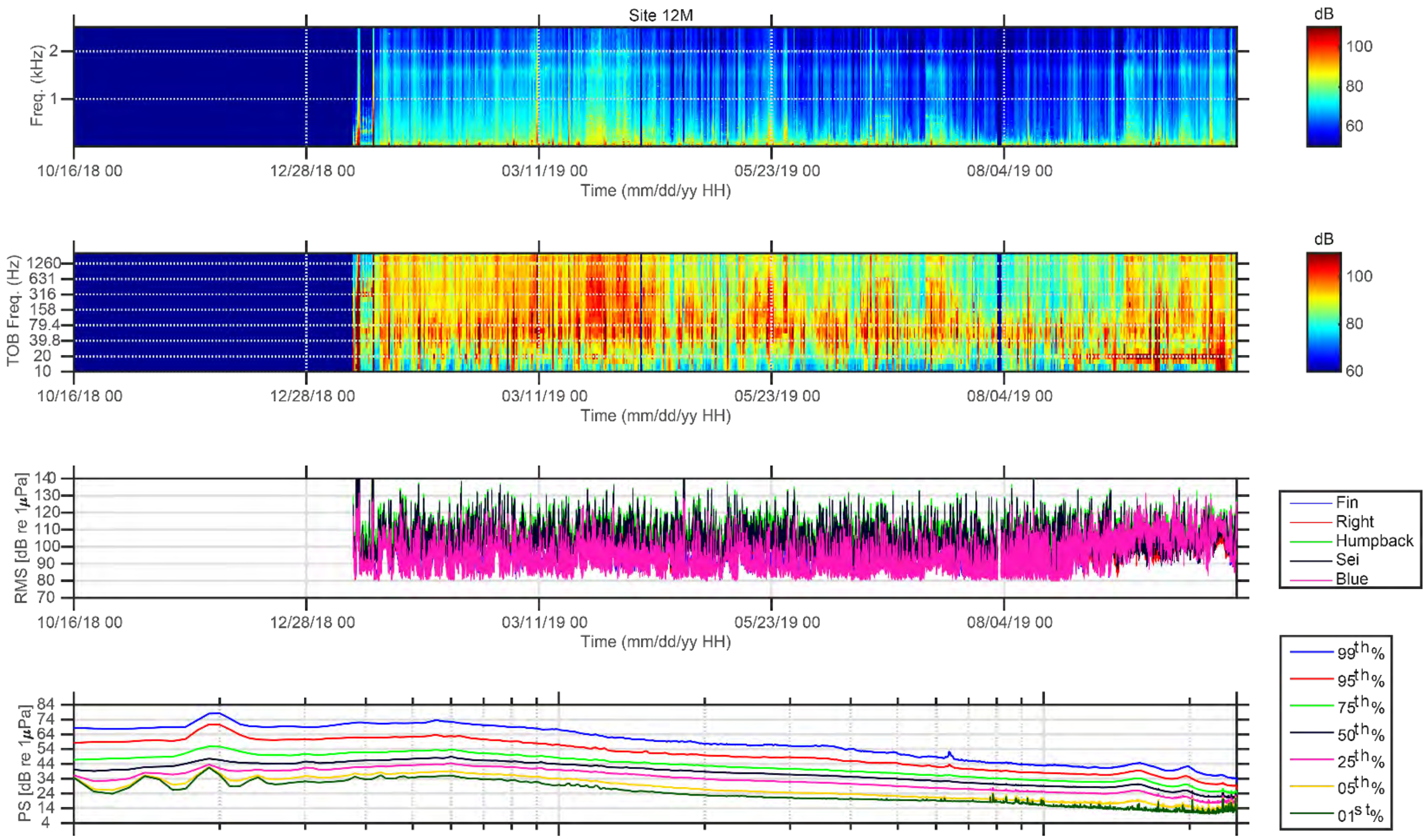

Figure 80. 10-minute averaged ambient noise metrics for site 12M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.

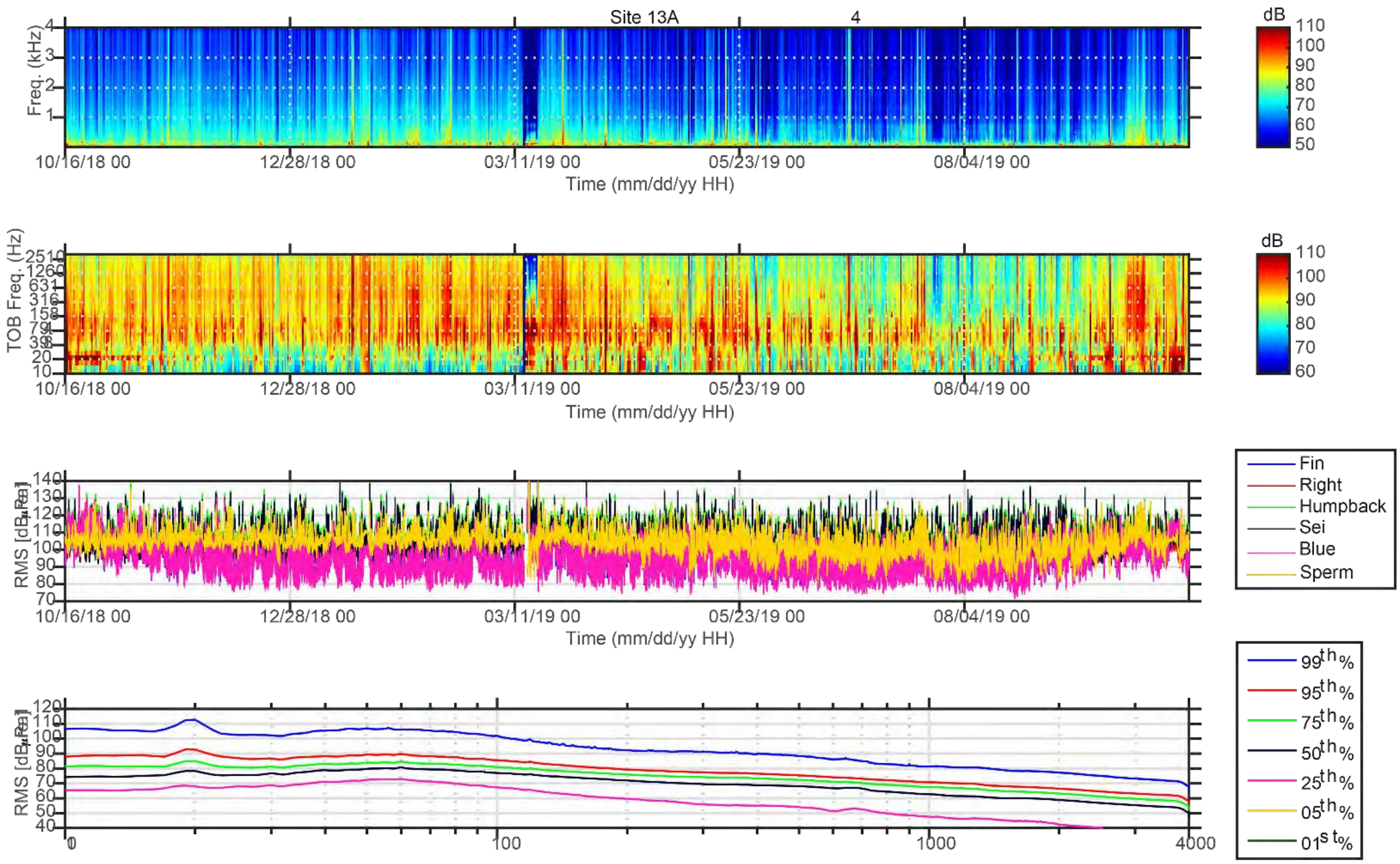

Figure 81. 10-minute averaged ambient noise metrics for site 13A between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band.

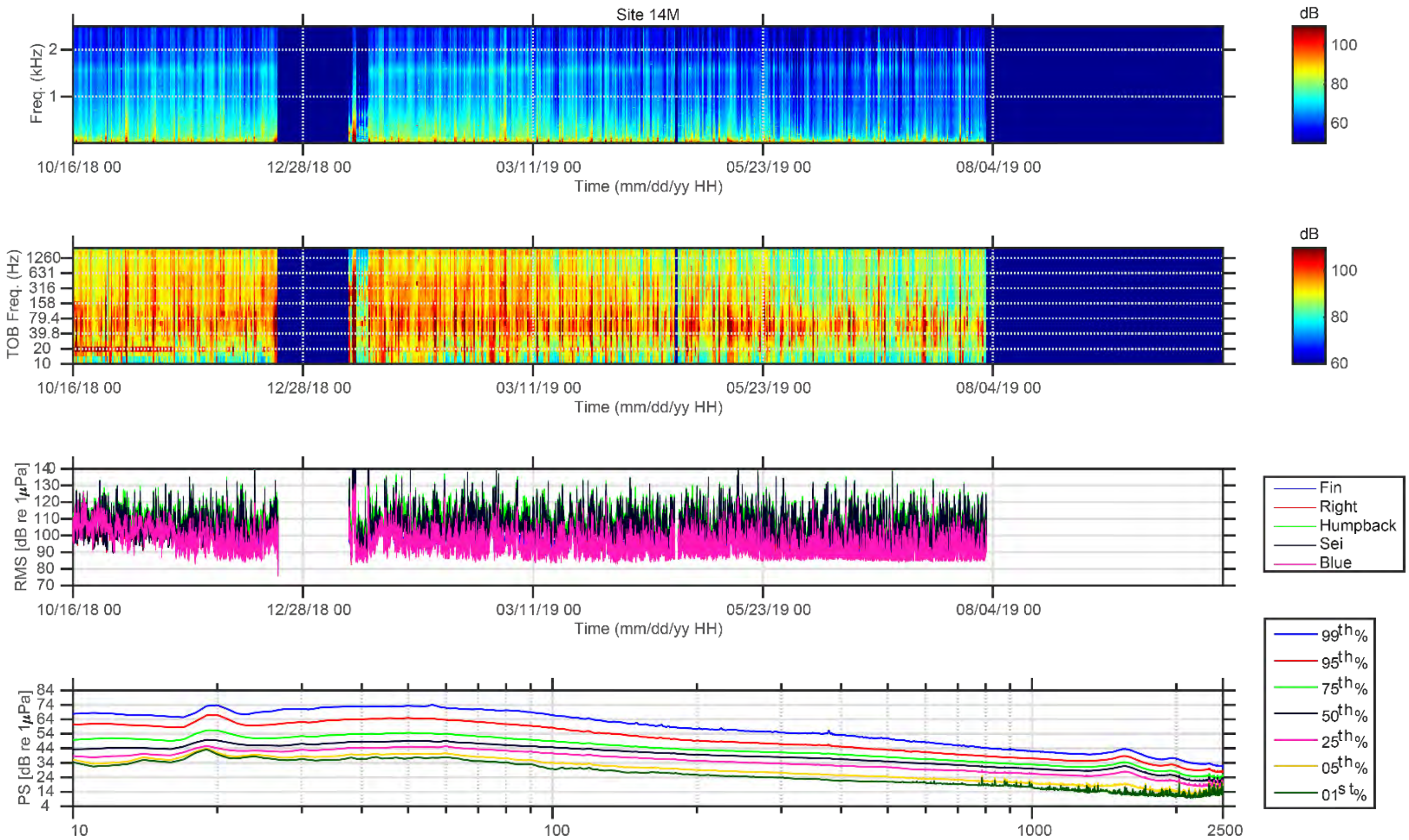

Figure 82. 10-minute averaged ambient noise metrics for site 14M between October 2018-October 2019. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1μPa). The third panel is a time series of noise levels (dB re: 1μPa) within each species frequency band. The fourth panel is a power spectral density plot illustrating percentile (1st, 5th, 25th, 50th, 75th, 95th, and 99th) noise levels (dB re: 1μPa) across a logarithmic frequency scale for the full frequency band. The deep blue gaps in temporal noise data indicate time periods in which there are no sound data.