Year-1
Annual Survey Report for New York Bight Whale Monitoring Passive Acoustic Surveys: October 2017 – October 2018

Contract C009925

Prepared for:

Division of Marine Resources

New York State Department of Environmental Conservation

625 Broadway

Albany, NY 12233

Prepared by:

Bioacoustics Research Program

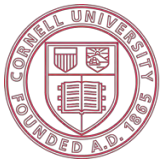
Cornell Lab of Ornithology

Cornell University

159 Sapsucker Woods Road

Ithaca, NY 14850





Cornell University

Suggested Citation:

Estabrook, B. J., K. B. Hodge, D. P. Salisbury, D. Ponirakis, D. V. Harris, J. M. Zeh, S. E. Parks, A. N. Rice. 2019. Year-1 Annual Survey Report for New York Bight Whale Monitoring Passive Acoustic Surveys October 2017- October 2018. Contract C009925. New York State Department of Environmental Conservation. East Setauket, NY.

Document History:

Original version submitted to NYSDEC January 15, 2019

Revised version submitted to NYSDEC March 4, 2019 (including complete Year-1 MARU data)

Second revised version submitted to NYSDEC June 3, 2019 (including complete Year-1 AMAR data)

Third revised version submitted to NYSDEC October 4, 2019 (including edits suggested by NYSDEC)

Table of Contents

List of Figures iii
List of Tables vi
Acronyms and Abbreviations viii
Executive Summary 9
Introduction 10
Background 10
Methods 14
Data Collection: Instrumentation and Survey Design 14
Data Analysis for Focal Species Detection 23
North Atlantic Right Whales 23
Humpback Whales 23
Fin Whales 24
Sei Whales 24
Blue Whales 25
Sperm Whales 25
Evaluation of Whale Call Automated Detector Performance 26
Occurrence Analysis of Focal Whale Species 27
Noise Analysis 28
Ambient Noise Levels 28
Whale Acoustic Masking 29
Results 30
Evaluation of Whale Call Automated Detector Performance 30
Occurrence of Focal Whale Species 35
Deployment-wide Whale Acoustic Occurrence 35
North Atlantic Right Whale Occurrence 40
Humpback Whale Occurrence 46
Fin Whale Occurrence 52
Sei Whale Occurrence 58
Blue Whale Occurrence 64
Sperm Whale Occurrence 70
Ambient Noise Analysis 75

Average Ambient Noise Levels 75
Ambient Noise Analysis: Cumulative Percent Distribution 76
Masking Potential 77
Discussion 92
Species Spatiotemporal Trends 92
Noise Trends 94
Masking Potential 94
Future Work and Directions 95
Acknowledgements 96
Literature Cited 98
Appendix A: Long Term Spectrograms and Noise Statistics per Site and Deployment 110
Appendix B: Minke Whale Opportunistic Presence 125

List of Figures

Figure 1. Instrumentation used for passive acoustic recordings: Cornell's Marine Autonomous Recording Unit 15
Figure 2. Instrumentation used for passive acoustic recordings: JASCO's Autonomous Multichannel Acoustic Recorder 16
Figure 3. Recording effort for each MARU and AMAR site between 16 October 2017 and 16 October 2018 17
Figure 4. Map of the acoustic recording locations within New York Bight 19
Figure 5. Representative spectrogram of North Atlantic right whale up-calls 23
Figure 6. Spectrogram of representative humpback whale song 24
Figure 7. Spectrogram of representative fin whale 20-Hz pulse song 24
Figure 8. Spectrogram of representative sei whale downsweeps 25
Figure 9. Spectrogram of a representative sequence of A-B phrases of a blue whale song 25
Figure 10. Spectrogram of representative sperm whale usual clicks 26
Figure 11. Daily true positive rates of detection algorithms for three target species at varying sensitivity thresholds 34
Figure 12. Daily false positive rates of detection algorithms for three target species at varying sensitivity thresholds 35
Figure 13. Weekly acoustic presence of North Atlantic right whales detected within New York Bight between October 2017-October 2018 41
Figure 14. Monthly acoustic presence of North Atlantic right whales detected within New York Bight between October 2017-October 2018 42
Figure 15. Spatial patterns of monthly presence of North Atlantic right whales in New York Bight 43
Figure 16. Seasonal acoustic presence of North Atlantic right whales detected within New York Bight from Fall 2017 through Summer 2018 44
Figure 17. Spatial patterns of seasonal acoustic presence of North Atlantic right whale upcalls in New York Bight 45
Figure 18. Weekly acoustic presence of humpback whales detected within New York Bight between October 2017-October 2018 47
Figure 19. Monthly acoustic presence of humpback whales detected within New York Bight between October 2017-October 2018 48
Figure 20. Spatial patterns of monthly presence of humpback whales in New York Bight 49
Figure 21. Seasonal acoustic presence of humpback whales detected within New York Bight from Fall 2017 through Summer 2018 50

Figure 22. Spatial patterns of seasonal acoustic presence of humpback whales in New York Bight 51
Figure 23. Weekly acoustic presence of fin whales detected within New York Bight between October 2017-October 2018 53
Figure 24. Monthly acoustic presence of fin whales detected within New York Bight between October 2017-October 2018 54
Figure 25. Spatial patterns of monthly presence of fin whales in New York Bight 55
Figure 26. Seasonal acoustic presence of fin whales detected within New York Bight from Fall 2017 through Summer 2018 56
Figure 27. Spatial patterns of seasonal acoustic presence of fin whales in New York Bight 57
Figure 28. Weekly acoustic presence of sei whales detected within New York Bight between October 2017-October 2018 59
Figure 29. Monthly acoustic presence of sei whales detected within New York Bight between October 2017-October 2018 60
Figure 30. Spatial patterns of monthly presence of sei whales in New York Bight 61
Figure 31. Seasonal acoustic presence of sei whales detected within New York Bight from Fall 2017 through Summer 2018 62
Figure 32. Spatial patterns of seasonal acoustic presence of sei whales in New York Bight 63
Figure 33. Weekly acoustic presence of blue whales detected within New York Bight between October 2017-October 2018 65
Figure 34. Monthly acoustic presence of blue whales detected within New York Bight between October 2017-October 2018 66
Figure 35. Spatial patterns of monthly presence of blue whales in New York Bight 67
Figure 36. Seasonal acoustic presence of blue whales detected within New York Bight from Fall 2017 through Summer 2018 68
Figure 37. Spatial patterns of seasonal acoustic presence of blue whales in New York Bight 69
Figure 38. Weekly acoustic presence of sperm whales detected within New York Bight between October 2017-October 2018 70
Figure 39. Monthly acoustic presence of sperm whales detected within New York Bight between October 2017-October 2018 71
Figure 40. Spatial patterns of monthly presence of sperm whales in New York Bight 72
Figure 41. Seasonal acoustic presence of sperm whales detected within New York Bight from Fall 2017 through Summer 2018 73
Figure 42. Spatial patterns of seasonal acoustic presence of sperm whales in New York Bight 74
Figure 43. Cumulative percent distribution of ambient noise levels for each recording site in different whale frequency bands 77

Figure 44. Estimated detection ranges of North Atlantic right whale upcalls under varying noise conditions 79
Figure 45. Estimated detection ranges of humpback whale calls under varying noise conditions 80
Figure 46. Estimated detection ranges of sei whale downsweeps under varying noise conditions 81
Figure 47. Estimated detection ranges of fin whale 20-Hz pulses under varying noise conditions 82
Figure 48. Estimated detection ranges of blue whale calls under varying noise conditions 83
Figure 49. Estimated detection ranges of sperm whale clicks under varying noise conditions 84
Figure 50. Map of estimated North Atlantic right whale acoustic detection ranges under different noise conditions 86
Figure 51. Map of estimated humpback whale detection ranges under different noise conditions 87
Figure 52. Map of estimated fin whale acoustic detection ranges under different noise conditions 88
Figure 53. Map of estimated sei whale detection ranges under different noise conditions 89
Figure 54. Map of estimated blue whale detection ranges under different noise conditions..... 90
Figure 55. Map of estimated sperm whale acoustic detection ranges under different noise conditions 91
Figure 56. Hourly averaged ambient noise metrics for site 1M between October 2017 and October 2018 111
Figure 57. Hourly averaged ambient noise metrics for site 2M between October 2017 and October 2018 112
Figure 58. Hourly averaged ambient noise metrics for site 3M between October 2017 and October 2018 113
Figure 59. Hourly averaged ambient noise metrics for site 4M between October 2017 and October 2018 114
Figure 60. Hourly averaged ambient noise metrics for site 5M between October 2017 and October 2018 115
Figure 61. Hourly averaged ambient noise metrics for site 6M between October 2017 and October 2018 116
Figure 62. Hourly averaged ambient noise metrics for site 7M between October 2017 and October 2018 117
Figure 63. Hourly averaged ambient noise metrics for site 8A between October 2017 and October 2018 118

Figure 64. Hourly averaged ambient noise metrics for site 9A between October 2017 and October 2018 119
Figure 65. Hourly averaged ambient noise metrics for site 10M between October 2017 and October 2018 120
Figure 66. Hourly averaged ambient noise metrics for site 11A between October 2017 and October 2018 121
Figure 67. Hourly averaged ambient noise metrics for site 12M between October 2017 and October 2018 122
Figure 68. Hourly averaged ambient noise metrics for site 13A between October 2017 and October 2018 123
Figure 69. Hourly averaged ambient noise metrics for site 14M between October 2017 and October 2018 124
Figure 70. Minke whale pulse-train recorded on site 8M on 22 April, 2018 125
Figure 71. Spatial patterns of monthly presence of minke whales in New York Bight 126
Figure 72. Spatial patterns of seasonal presence of minke whales in New York Bight 127
Figure 73. Estimated detection ranges of minke whale pulse trains 128

List of Tables

Table 1. Deployment and Retrieval dates for MARUS and AMARs of each deployment 18
Table 2. Deployment information for MARUs for Year-1. 20
Table 3. Deployment information for AMARs for Year-1. 22
Table 4. Subsampled dates and sites used for the ground-truth dataset 27
Table 5. Referenced signal type, frequency band, and source levels of the target species used for detection range estimation and masking potential. 28
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. 30
Table 7. Summary of human-verified days used for right whale automated detector algorithm evaluation 31

Table 8. Performance of the fin whale 20-Hz pulse 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 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. 31

Table 9. Summary of human-verified days used for fin whale automated detection algorithm evaluation 32

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. 32

Table 6. Summary of human-verified days used for sei whale automated detection algorithm evaluation 33

Table 9. Summary of the total calendar-days in which the focal baleen whale species were detected per deployment for Year-1 (October 2017 – 2018) 37

Table 10. Summary of total days and percent of time in which sperm whale*s* were detected during Year-1 (October 2017 – 2018). 37

Table 11. Summary of the total calendar-days in which the focal whale species were detected for each month between October 2017 and October 2018 38

Table 12. Seasonal daily presence for each focal whale species for each season across all recording sites 38

Table 13. Summary of site-wide percent daily occurrence for each focal species 39

Table 14. Average 10-minute ambient noise levels within each target species frequency band from October 2017 – October 2018. 75

Table 15. Detection range estimates at representative sites for all target baleen whale species .. 85

Table 16. Detection range estimates at representative sites for sperm whales 85

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}	5th Percentile Sound Level Equivalent (dB re: 1 µPa)
L_{95}	95th 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 Bioacoustics Research Program (BRP) 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 (*Balaenoptera borealis*), blue whales (*Balaenoptera musculus*), and sperm whales (*Physeter macrocephalus*).

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 4 months at a 5 kHz sampling frequency, while AMARs recorded continuously for approximately 8 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 to eliminate false positives. Whale presence and noise levels were reported at daily, monthly, and seasonal temporal resolution across Year-1.

All of the focal species were detected in the New York Bight in Year-1. 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. Humpback whales had the lowest daily presence per month in October and highest in February and May. Sei whales were present during all months except September. Fin whales were the most commonly detected large whale species, with presence throughout the year. Peak fin whale presence was bimodal, occurring in winter and again during the summer. Blue whales were only detected at sites in the northern transect, between November and February, with peak daily presence in February. Sperm whales were detected at low levels (<10% of days per month) in all months analyzed on the AMARs.

Ambient noise levels in the NY Bight were 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 Bioacoustics Research Program (BRP) 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-1 field effort, collected between October 2017-October 2018.

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 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 all species, except for 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. Atlantic 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), they 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 Western North Atlantic (WNA) ocean, primarily using the Mid-Atlantic and Gulf of Maine as feeding grounds (Hayes et al. 2019). Humpbacks have been observed in these high 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 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 the 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, while females have rarely been observed north of New England (Waring et al. 2015). The current NOAA 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. 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 of their aerial surveys, the Tetra Tech team observed North Atlantic right whales, humpback whales, fin whales blue whales, and sperm whales, but did not have 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 complimentary value that both methods contribute to understanding habitat use and large-scale spatiotemporal occurrence of the target whale species in New York 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 recording units: Marine Autonomous Recording Units (MARUs) and Autonomous Multichannel Acoustic Recorders (AMARs, JASCO Applied Sciences, 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 an archival digital audio recording system 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 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 shop 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.

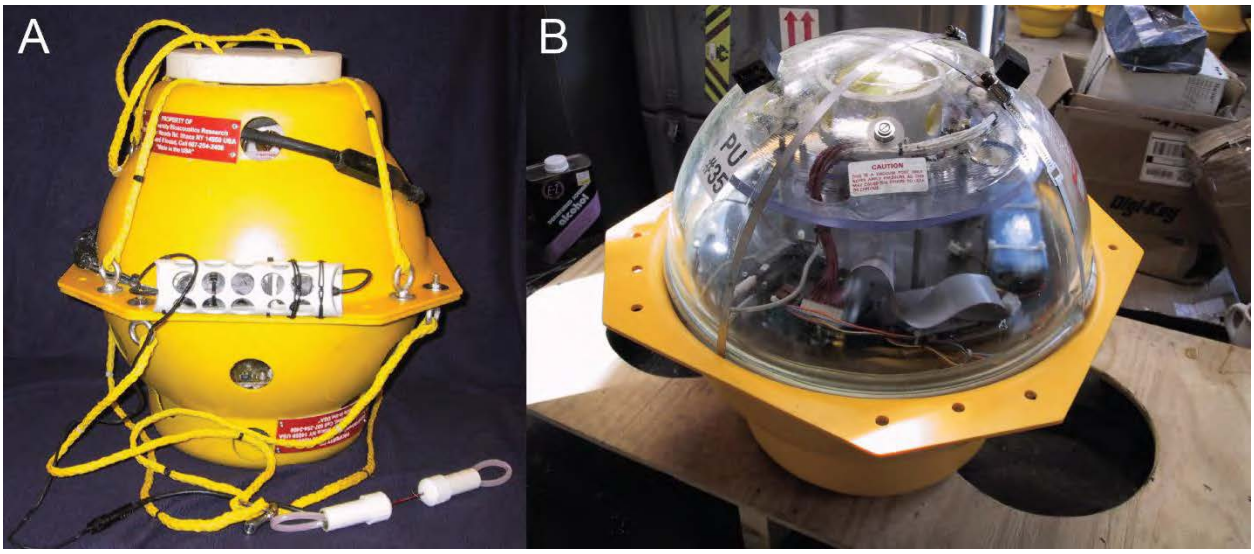


Figure 1. Instrumentation used for passive acoustic recordings: Cornell's Marine Autonomous Recording Unit (MARU), showing A) External and B) Internal views.



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 2017 through October 2018 (

Table 2, Table 3, Figure 3), totaling 3,654 full days of sound data across all sites. Data gaps in the recordings did occur and are detailed below.

During the first survey year, 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 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 2017 and 16 October 2018. Black lines indicate the time period in which the site was recording acoustic data. The white gaps indicate time in which there were no recordings.

The first swap of MARUs was delayed from the scheduled February field trip to mid-April due to unsafe weather conditions. The power of the batteries for most MARUs were depleted by mid-March, resulting in a data gap from then to mid-April. Sites 4M, 5M, and 10M were trawled during deployment-1 (hereafter, M-D1), and sites 3M and 5M during deployment 2 (hereafter, M-D2), resulting in fewer recording days for those sites. The compact flash (CF) cards on which

the data are written in the MARU were corrupt for site 14M in M-D1, as well as sites 2M and 3M during M-D2. Those CF cards were sent to an external company for data recovery, however the corrupt sectors were not able to be repaired, resulting in data loss for those sites. It was determined that the cause of the site 2M corruption was due to water intrusion in the glass MARU sphere. That unit was inspected and repaired. MARU number 304 at site 6M during M-D1 and site 2M during M-D3 recorded a rapid, low-frequency (<40 Hz) pulse, which became evident in the M-D3 recordings and interfered with ambient noise measurement for those sites during M-D1 and M-D2. After investigating the source of the malfunction, it was determined to be caused by saltwater intrusion to the hydrophone signal conductor, which damaged the signal path of the hydrophone. During deployment 3 (M-D3), 33% of the data for site 4M MARU was extracted, stopping in mid-September. The media cards for sites 5M, 10M, and 12M were corrupted, resulting in full data loss. Site 6M was trawled in mid-October, which was approximately 83% of the way through the M-D3 survey period.

During the first AMAR deployment (hereafter referred to as A-D1), sites 8A, 9A, and 11A were successfully deployed and recovered. During the recovery effort of site 15A, the AMAR did not surface, therefore we were unable to retrieve those data. Since the mooring unit from site 15A was not recovered, the next AMAR for that site was not able to be deployed during the second deployment of AMARs (hereafter referred to as A-D2), because the deployment of that unit was dependent on the mooring device returning to the surface. All future AMAR deployment field trips will have an extra mooring configuration available during servicing. Site 8A did not surface during the A-D2 recovery effort.

Going forward, in survey years 2 and 3, the recording schedule of the MARUs and AMARs will be shortened to better align with annual survey deliverable timelines. 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

Deployment Name	Device	Deployment Date	Retrieval Date
M-D1	MARU	14-Oct-17	11-Apr-18
M-D2	MARU	11-Apr-18	15-Jul-18
M-D3	MARU	15-Jul-18	18-Jan-19
A-D1	AMAR	11-Oct-17	15-Jul-18
A-D2	AMAR	15-Jul-18	14-Mar-19

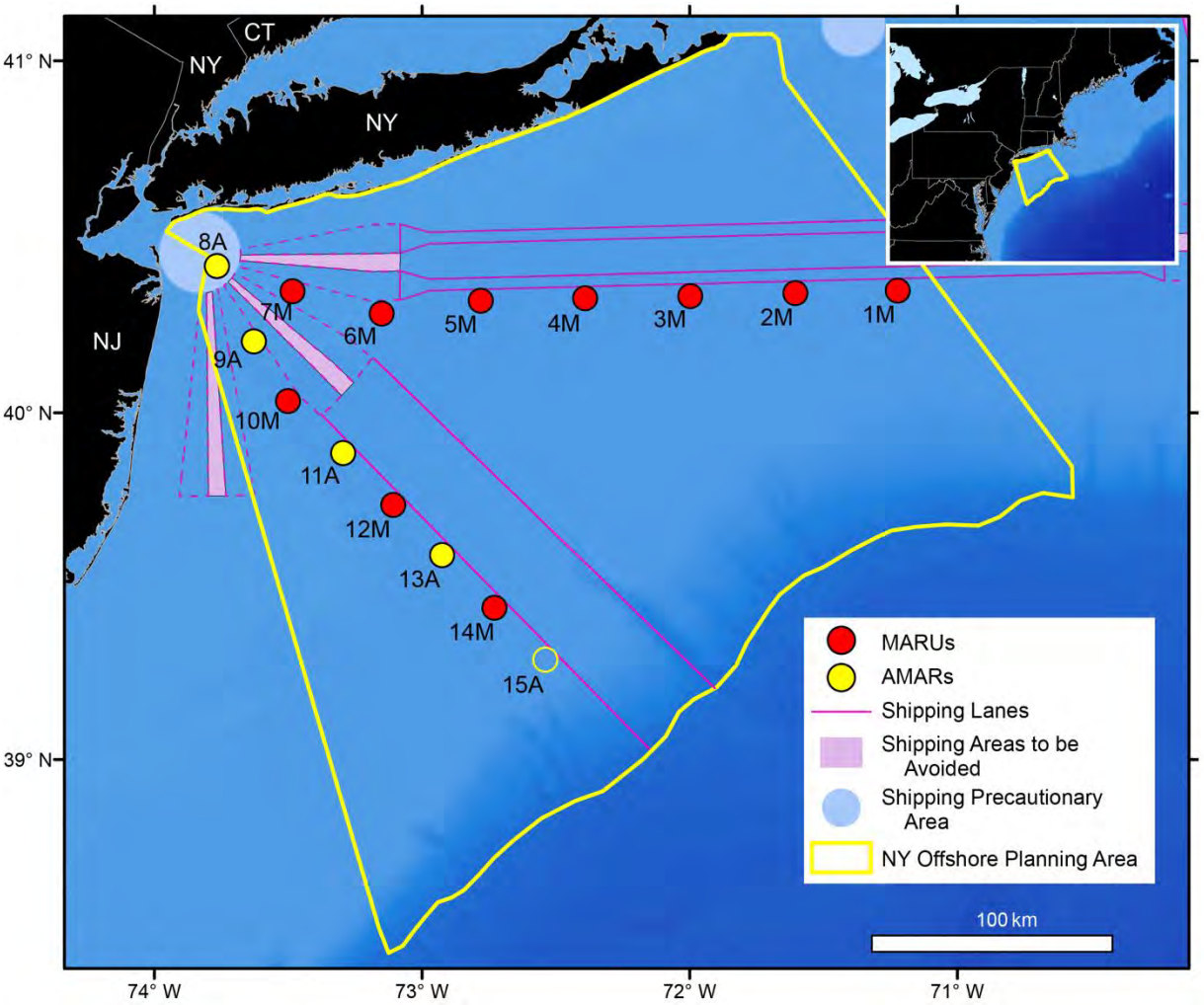


Figure 4. Map of the acoustic recording locations within New York Bight, with sensor location numbers. “A” denotes AMARs (yellow), and “M” denotes MARUs (red). The hollow circle indicates that data were not recovered during the entire Year-1 survey at that site. Inset shows NY Offshore Planning Area at a larger spatial scale for geographical context.

Table 2. Deployment information for MARUs for Year-1.

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
M-D1	1M	309	40.347982	71.224167	90	15-Oct-17	11-Apr-18	16-Oct-17	18-Mar-18	154	87%	
M-D1	2M	303	40.342190	71.606067	84	14-Oct-17	11-Apr-18	16-Oct-17	17-Mar-18	153	85%	Battery died at 17:24 on 3/17/18
M-D1	3M	306	40.333845	71.999408	65	14-Oct-17	11-Apr-18	16-Oct-17	18-Mar-18	154	86%	
M-D1	4M	311	40.327372	72.408000	54	14-Oct-17	Dragged	16-Oct-17	17-Dec-17	63	36%	Dragged, 2017-12-18, Recovered
M-D1	5M	310	40.319978	72.781935	50	14-Oct-17	Dragged	16-Oct-17	23-Feb-18	131	74%	Dragged, 2018-02-24, Recovered
M-D1	6M	304	40.284352	73.152112	40	14-Oct-17	11-Apr-18	16-Oct-17	18-Mar-18	154	86%	
M-D1	7M	308	40.347333	73.484445	30	14-Oct-17	11-Apr-18	16-Oct-17	18-Mar-18	154	86%	
M-D1	10M	301	40.032333	73.499988	49	11-Oct-17	Dragged	16-Oct-17	27-Feb-18	135	75%	Dragged, 2018-02-28, Recovered
M-D1	12M	300	39.734522	73.106817	51	11-Oct-17	10-Apr-18	16-Oct-17	12-Mar-18	148	82%	
M-D1	14M	302	39.438865	72.728550	80	10-Oct-17	10-Apr-18	No Data	No Data	0	0%	Corrupt Flash Drive
M-D2	1M	312	40.348321	71.225644	90	11-Apr-18	19-Jul-18	12-Apr-18	14-Jul-18	94	95%	
M-D2	2M	316	40.342242	71.607933	84	11-Apr-18	18-Jul-18	No Data	No Data	0	0%	Corrupt CF Card - Water intrusion
M-D2	3M	321	40.333843	72.000828	65	11-Apr-18	18-Jul-18	No Data	No Data	0	0%	Dragged in early April - corrupt CF card
M-D2	4M	315	40.327631	72.408339	54	11-Apr-18	No Response	No Data	No Data	0	0%	No Response during recovery effort
M-D2	5M	313	40.319907	72.782415	50	11-Apr-18	18-Jul-18	12-Apr-18	14-Apr-18	3	3%	Dragged on 4/15/2018

Table 2, continued. Deployment information for MARUs for Year-1.

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
M-D2	6M	320	40.284681	73.153109	40	11-Apr-18	18-Jul-18	12-Apr-18	14-Jul-18	94	96%	
M-D2	7M	317	40.347790	73.486217	30	11-Apr-18	18-Jul-18	12-Apr-18	26-Jun-18	76	78%	Stopped recording on 6/27/2018
M-D2	10M	318	40.031789	73.500126	49	10-Apr-18	15-Jul-18	12-Apr-18	14-Jul-18	94	98%	
M-D2	12M	314	39.733770	72.105267	51	10-Apr-18	15-Jul-18	12-Apr-18	14-Jul-18	94	98%	
M-D2	14M	319	39.438872	72.729047	80	10-Apr-18	15-Jul-18	12-Apr-18	14-Jul-18	94	98%	
M-D2	6M	320	40.284681	73.153109	40	11-Apr-18	18-Jul-18	12-Apr-18	14-Jul-18	94	96%	
M-D3	2M	304	40.342630	71.608480	84	19-Jul-18	13-Jan-19	No Data	No Data	0	0%	Internal noise - malfunctioning hydrophone assembly
M-D3	3M	307	40.333930	72.001300	64	19-Jul-18	13-Jan-19	20-Jul-18	16-Oct-18	89	50%	
M-D3	4M	303	40.327810	72.407870	53	18-Jul-18	13-Jan-19	20-Jul-18	15-Sep-18	58	32%	Stopped recording on 9/16/2018 - 33% data
M-D3	5M	301	40.319910	72.782500	50	18-Jul-18	13-Jan-19	No Data	No Data	0	0%	Corrupt CF card (power pin corrosion) - no data
M-D3	6M	311	40.284090	73.152300	40	18-Jul-18	1-Oct-18	20-Jul-18	1-Oct-18	74	99%	Trawled around 3 Oct - partial data
M-D3	7M	308	40.348060	73.485660	30	18-Jul-18	13-Jan-19	16-Jul-18	16-Oct-18	93	52%	
M-D3	10M	300	40.032310	73.499230	49	15-Jul-18	18-Jan-19	No Data	No Data	0	0%	CF card failed to mount - no data
M-D3	12M	302	39.733530	73.104520	51	15-Jul-18	18-Jan-19	No Data	No Data		0%	CF card corrupt
M-D3	14M	309	39.438770	72.728320	80	15-Jul-18	17-Jan-19	20-Jul-18	16-Oct-18	89	48%	

Table 3. Deployment information for AMARs for Year-1.

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-D1	8A	421	39.884280	73.293273	28	11-Oct-17	15-Jul-18	16-Oct-17	14-Jul-18	272	100%	
A-D1	9A	436	40.203050	73.628742	38	11-Oct-17	15-Jul-18	16-Oct-17	14-Jul-18	272	100%	
A-D1	11A	430	40.417230	73.766032	49	11-Oct-17	15-Jul-18	16-Oct-17	14-Jul-18	272	100%	
A-D1	13A	437	39.591833	72.923667	63	10-Oct-17	15-Jul-18	16-Oct-17	14-Jul-18	272	100%	
A-D1	15A	NA	39.289855	72.539843		10-Oct-17	Not Recovered	No Date	No Data	0	0%	No response during attempted recovery
A-D2	8A	395	40.417390	73.763080	28	16-Jul-18	Not Recovered	No Data	No Data	0	0%	
A-D2	9A	399	40.203180	73.628470	38	15-Jul-18	14-Mar-19	16-Jul-18	16-Oct-18	93	100%	
A-D2	11A	401	39.883450	73.291870	49	15-Jul-18	14-Mar-19	16-Jul-18	16-Oct-18	93	100%	
A-D2	13A	397	39.591820	72.922080	63	15-Jul-18	14-Mar-19	16-Jul-18	16-Oct-18	93	100%	
A-D2	15A	NA				Not deployed		No Data	No Data	0	0%	No replacement mooring available for deployment

DATA ANALYSIS FOR FOCAL SPECIES DETECTION

To evaluate temporal patterns of whale acoustic presence, we used a combination of automated detectors and manual human analyst browsing to record 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 Sound Analysis Software (Bioacoustics Research Program 2017). All target signals that were used to determine presence were subject to a second verification by a different analyst 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), the predominant call type of the species (Mellinger et al. 2007, Parks and Clark 2007). 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 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. Nevertheless, 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). 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. Detections were reviewed by analysts until an upcall for a site and day was found. 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.

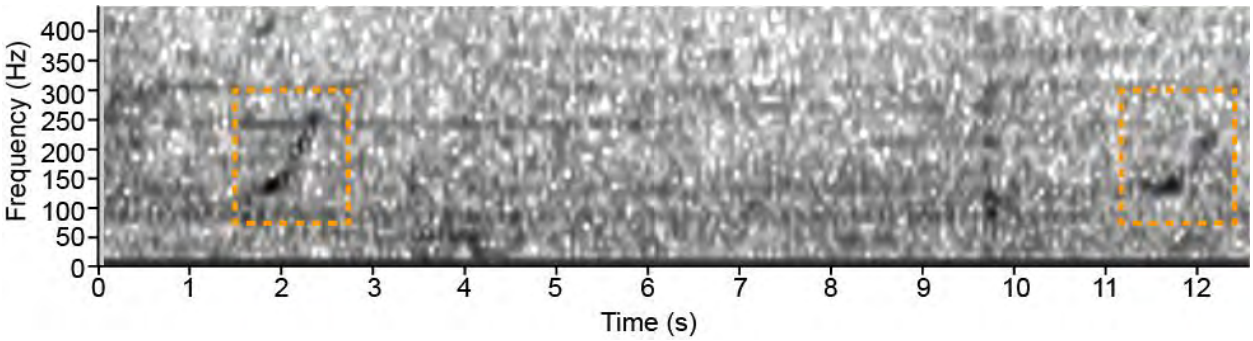


Figure 5. Representative spectrogram of North Atlantic right whale up-calls from site 12M on 14 April 2018. The two calls shown here are indicated by dashed orange boxes.

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 manually review spectrograms in search of target humpback whale sounds. Spectrogram settings included a 5-minute page duration, frequency range of 10–600 Hz, and a FFT size of 512. Humpback vocalizations (Figure 6) were marked on a daily basis per site.

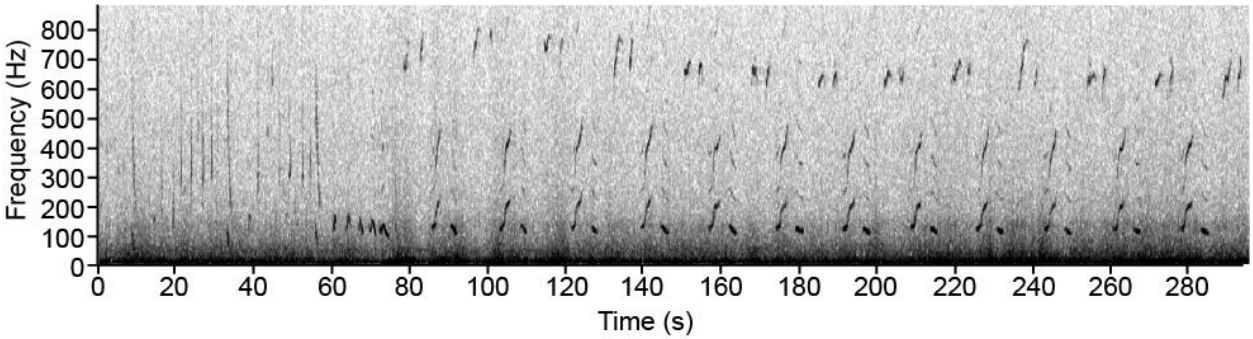


Figure 6. Spectrogram of representative humpback whale song, recorded from site 1M on 6 March 2018.

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 identify 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. Examplars comprised fin whale 20-Hz pulses with high a signal-to-noise ratio. Each detection was reviewed until a true positive (TP) detection was identified for each day and site. The 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.

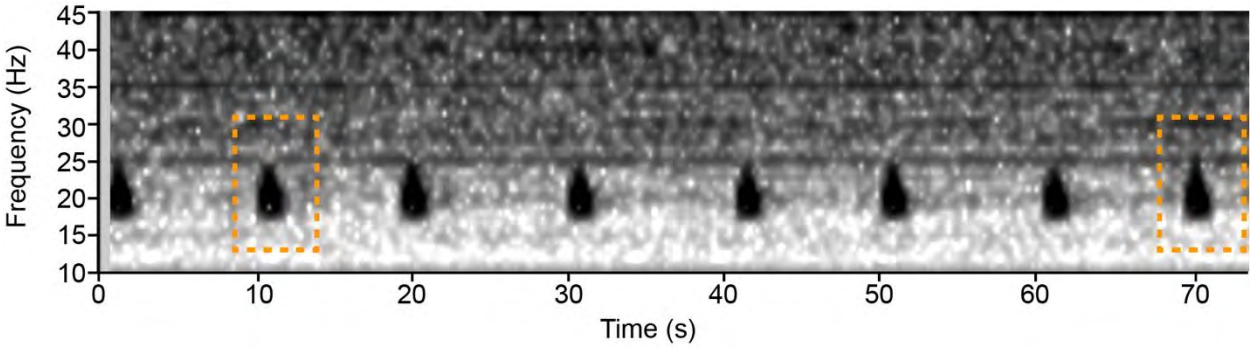


Figure 7. Spectrogram of representative fin whale 20-Hz pulse song, recorded at site 7M on 26 December 2017. Two of the pulses are indicated by dashed orange boxes.

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, 6 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.

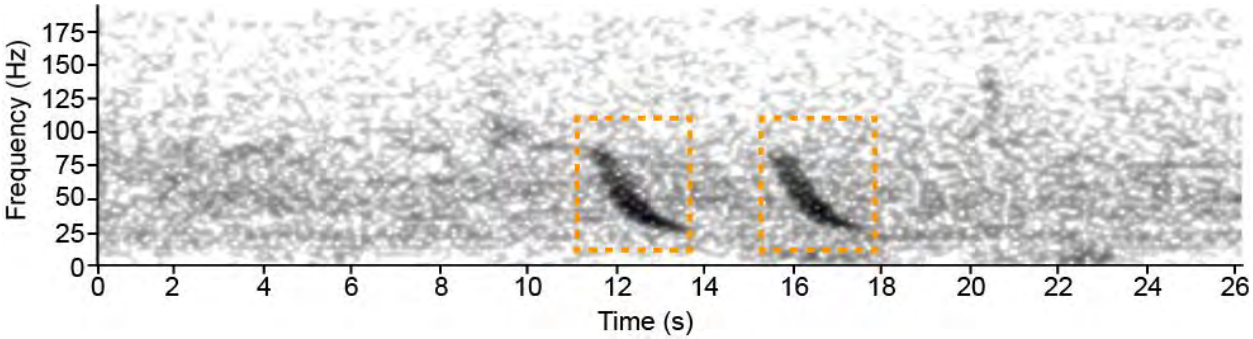


Figure 8. Spectrogram of representative sei whale downsweeps, recorded at site 1M on 26 April 2018. The two calls are indicated by a dashed orange box.

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 minutes and a frequency range of 10–25 Hz were used. The FFT size and window were set to 512 points.

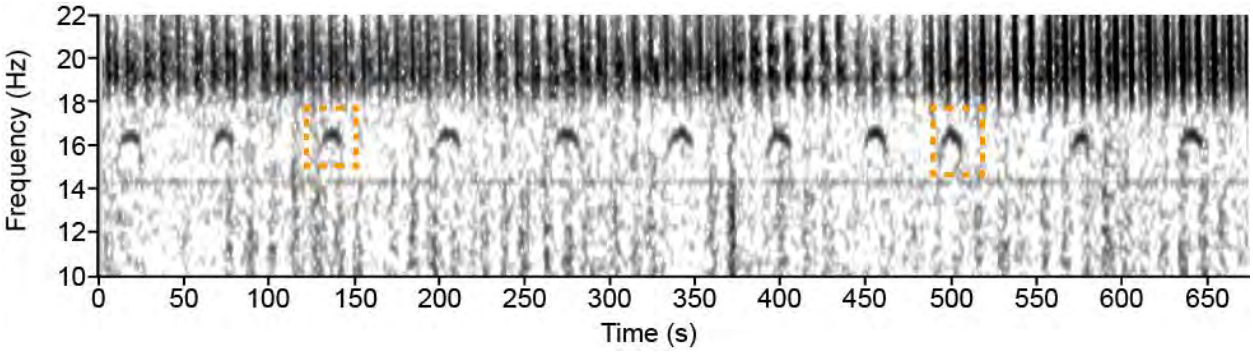


Figure 9. Spectrogram of a representative sequence of A-B phrases of a blue whale song, from site 1M on 1 November 2017. Two of the phrases are indicated by dashed orange boxes.

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. Sperm whale usual clicks were detected by manually reviewing spectrograms in Raven Pro. Sequences of 5 or more usual clicks 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 more 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.

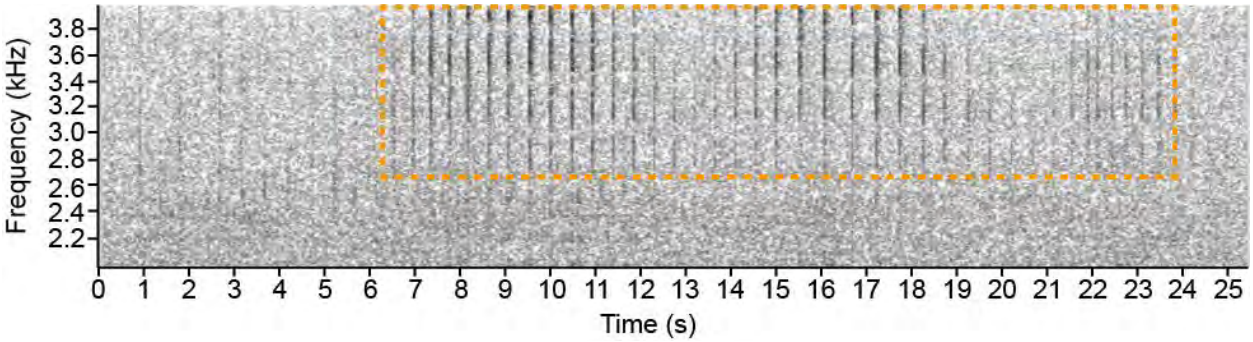


Figure 10. Spectrogram of representative sperm whale usual clicks, recorded at site 13A on 6 February 2018. A "usual click" sequence is indicated by a dashed orange box.

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 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 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', each 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 containing 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 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 month, season, and site 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 re: 1 µPa [rms]) 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:

$$L_{eq} = 10log_{10}\frac{1}{T}\int_{0}^{T}\left(\frac{P_m^2(t)}{P_{ref}^2}\right)dt \quad (1)$$

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, please 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 hear each other. 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:

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

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 $17\log_{10}R$ 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 quiet (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 7**Error! Reference source not found.**; 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, the fin whale detector had a TPR that ranged from 0.11 (threshold = 0.95) to 0.98 (threshold = 0.25). Are a threshold of 0.75, the TPR was 0.48 and the false positives per hour was 0.44. Given the high number of false positives, it was reasonable to use a threshold cutoff of 0.75 (Table 8). 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 9; Figure 11 panel B, Figure 12 panel B). 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 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 11; Figure 11 panel C, Figure 12 panel C). 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

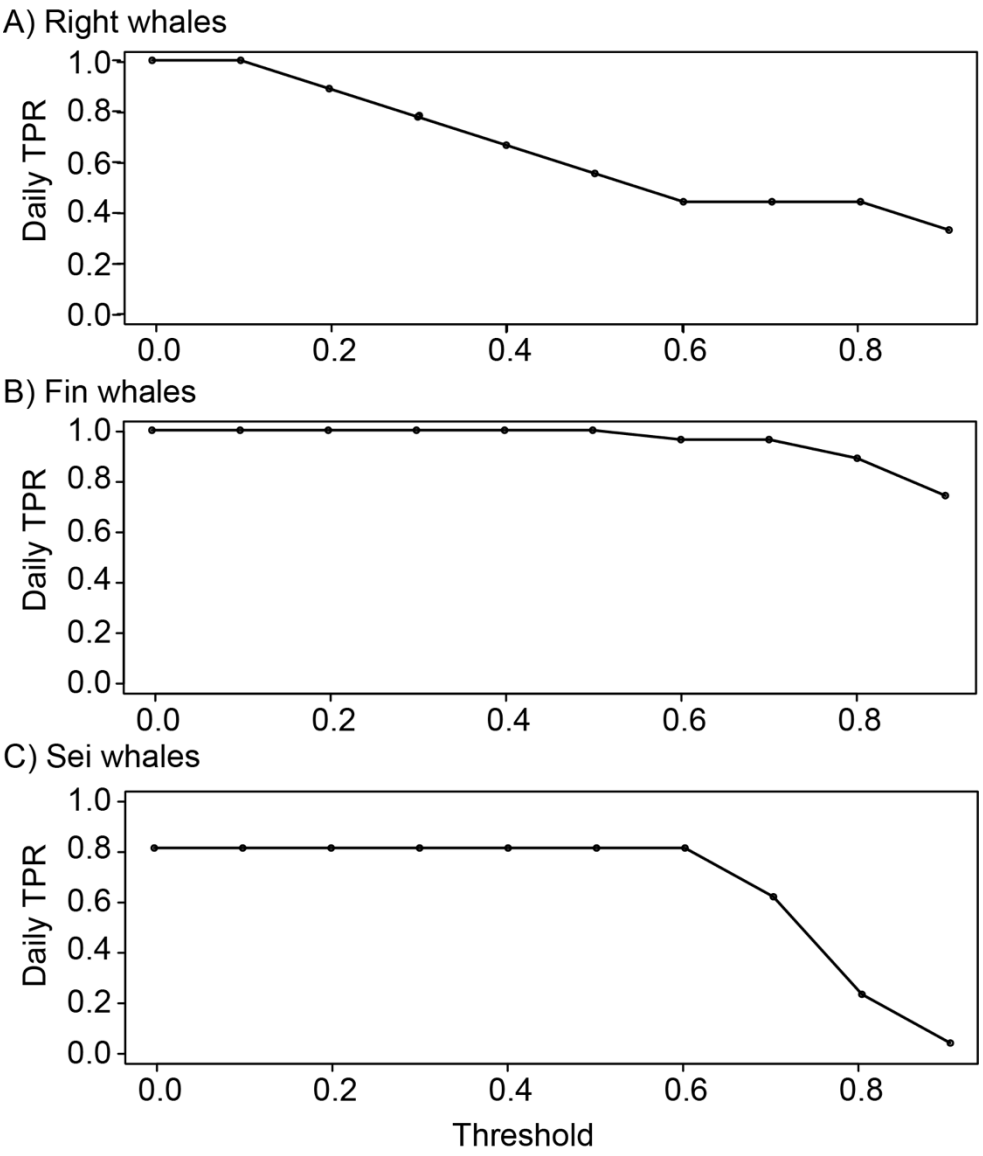


Figure 11. Daily true positive rates of detection algorithms for three target species at varying sensitivity thresholds: A) Right whales, B) Fin whales, C) Sei Whales.

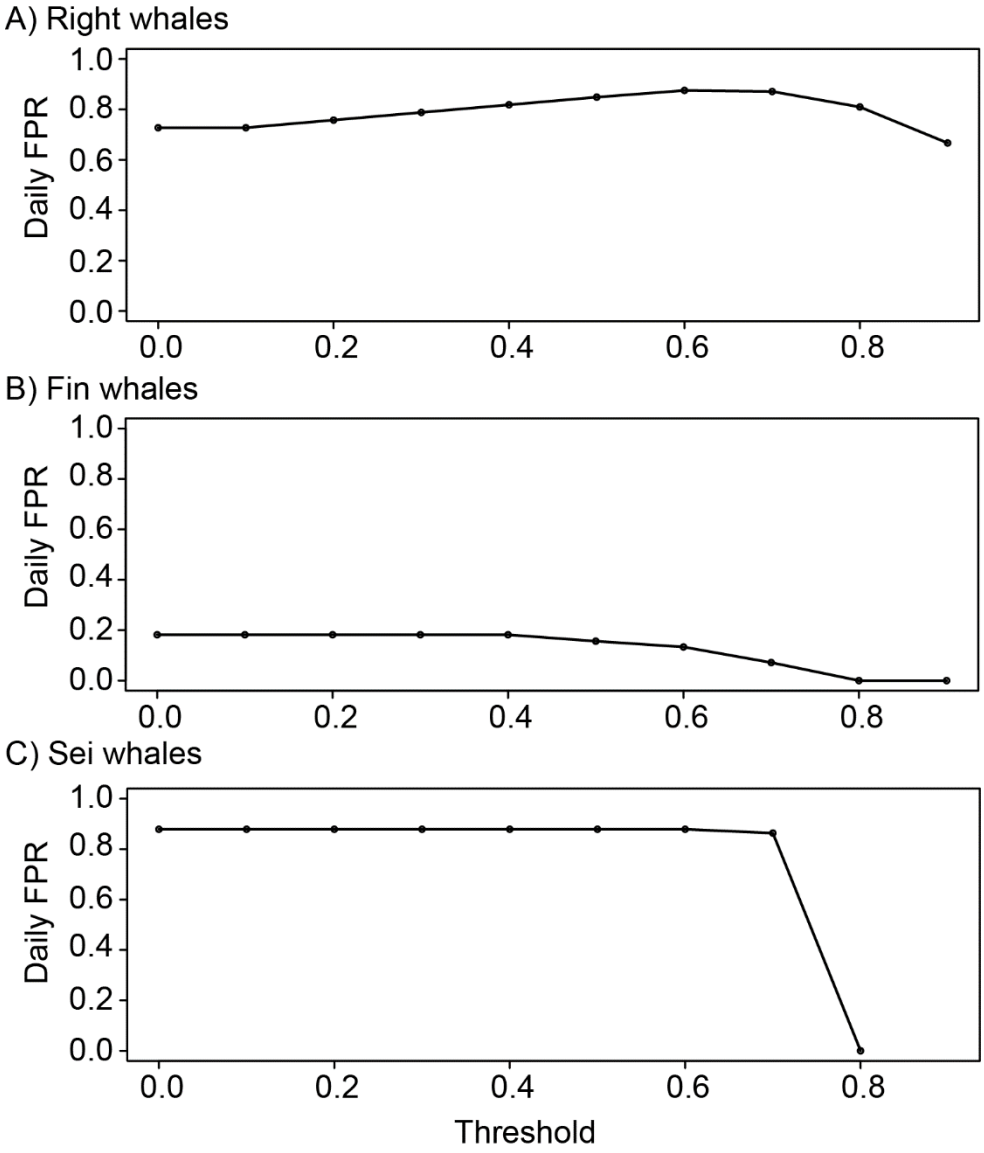


Figure 12. Daily false positive rates of detection algorithms for three target species at varying sensitivity thresholds: A) Right whales, B) Fin whales, C) Sei Whales.

OCCURRENCE OF FOCAL WHALE SPECIES

Deployment-wide Whale Acoustic Occurrence

During the M-D1 (October 2017 – March 2018), a total of 1,246 days of sound were recorded across all MARUs, comprising 154 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 A-D1 (16 Oct 2017 – 14 July 2018), 1,088 site-days were recorded, comprising 272 site-days during which the six focal species were detected. The M-D2 data comprised 549 site-days of sound (April – July 2017) and 94 calendar days, during which right, sei, fin, and humpback whales were detected. The M-D3 and A-D2 data presented in this report encompass the time period in which units were deployed (20 July 2018) through the end

of the Year-1 survey (15 October 2018). All six whale species demonstrated seasonal variability in acoustic presence in the survey area (Table 12, Table 13, Table 14, Table 15).

Table 12. Summary of the total calendar-days in which the focal baleen whale species were detected per deployment for Year-1 (October 2017 – 2018), and the corresponding percentage of site-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-D1 & A-D1	272	137	50	197	72	264	97	124	46	27	10
M-D2	94	33	35	85	90	91	97	45	48	0	0
M-D3 & A-D2	92	11	12	91	99	92	100	5	5	0	0
Total	458	181	40	373	81	447	98	174	38	27	6

Table 13. Summary of total days and percent of time in which sperm whales were detected during Year-1 (October 2017 – 2018).

Deployment	**Start Date**	**End Date**	**Calendar Days**	**Presence Days**	**% Days**
A-D1	11-Oct-17	15-Jul-18	272	113	42
A-D2	15-Jul-18	16-Oct-18	92	64	70
Total			364	177	49

Table 14. Summary of the total calendar-days in which the focal whale species were detected for each month between October 2017 and October 2018 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-17	16	2	12	4	25	16	100	8	50	0	0	1	6
Nov-17	30	25	83	11	37	30	100	9	30	3	10	8	27
Dec-17	31	31	100	28	90	31	100	11	35	7	23	5	16
Jan-18	31	24	77	26	84	31	100	12	39	9	29	15	48
Feb-18	28	12	43	28	100	28	100	9	32	8	29	19	68
Mar-18	31	22	71	25	81	31	100	24	77	0	0	13	42
Apr-18	30	19	63	25	83	30	100	30	100	0	0	10	33
May-18	31	14	45	29	94	29	94	27	87	0	0	23	74
Jun-18	30	7	23	29	97	30	100	7	23	0	0	16	53
Jul-18	30	3	10	28	93	30	100	7	23	0	0	15	50
Aug-18	31	4	13	31	100	31	100	2	6	0	0	26	84
Sep-18	30	3	10	29	97	30	100	0	0	0	0	21	70
Oct-18	15	3	20	15	100	15	100	1	7	0	0	5	33
Total	364	169	46	308	85	362	99	147	40	27	7	177	49

Table 15. Seasonal daily presence for each focal whale species for each season 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 2017	77	58	43	28	77	10	14
Winter 2018	90	58	79	45	90	17	47
Spring 2018	91	40	83	64	89	0	49
Summer 2018	91	10	88	9	91	0	62
Fall 2018	15	3	15	7	15	0	5

Table 16. Summary of site-wide 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	336	13	4	100	30	245	73	23	7	24	45	-	-
2M	153	12	8	29	19	134	88	18	12	17	32	-	-
3M	242	20	8	80	33	220	91	16	7	8	15	-	-
4M	121	8	7	33	27	108	89	5	4	2	4	-	-
5M	134	36	27	39	29	88	66	8	6	0	0	-	-
6M	322	41	13	146	45	134	42	1	0	0	0	-	-
7M	318	35	11	85	27	96	30	2	1	0	0	-	-
8A	272	13	5	45	17	69	25	18	7	0	0	14	5
9A	364	52	14	91	25	182	50	32	9	0	0	58	16
10M	229	59	26	107	47	162	71	8	3	0	0	-	-
11A	364	44	12	153	42	329	90	41	11	1	2	75	21
12M	242	50	21	106	44	204	84	12	5	0	0	-	-
13A	364	45	12	200	55	349	96	69	19	1	2	82	23
14M	94	9	10	53	56	88	94	45	48	0	0	-	-

North Atlantic Right Whale Occurrence

North Atlantic right whales were detected during every month of the survey period except September 2018, with daily presence per month ranging from 10% in July and September 2018, to 100% in December 2017, and peak presence between November and January (Figure 13, Figure 14). However even during the maximum number of days per week of presence, right whales were never detected for all 7 days within a week (Figure 13). At both weekly and monthly scales, right whale presence was dynamic, and presence was rarely consistent between weeks or months (Figure 13, Figure 14).

It is unclear whether the November-January period of peak detections represents northward movement (to the feeding grounds) versus southward movement (to the Mid-Atlantic or calving grounds). The number of data gaps in April -October 2018 increased, but despite this, the number of daily and monthly detections decreased as well (Figure 13, Figure 14, Figure 15).

In January, right whale presence was highest at sites 5-14, however, the number of detections was considerably lower at sites 1-4 (Figure 13, Figure 14, Figure 15), so it is unclear what these data mean for interpreting movement patterns as right whales move along the northeastern corner of the NY Offshore planning area: whether they move southeast and out of the detection range of these sensors, or whether they change their calling behavior as they approach the eastern end of Long Island.

North Atlantic right whale seasonal percent daily presence was highest during the fall and winter of 2017 (75% and 64% days, respectively), and gradually declined from spring (44%) through summer (11%) (Figure 16). Summer had the fewest right whale detections (Figure 16), and these were primarily in the middle of the planning area (Figure 17).

North Atlantic right whales (Figure 31) were detected more at nearshore sites (sites 5M – 10M) than offshore, with the highest percent daily detection occurred at site 5M (27%) and 10M (26%). Sites 1M through 4M, in the northern transect, had relatively lower occurrence, with daily presence ranging from 4% to 8 % throughout the survey.

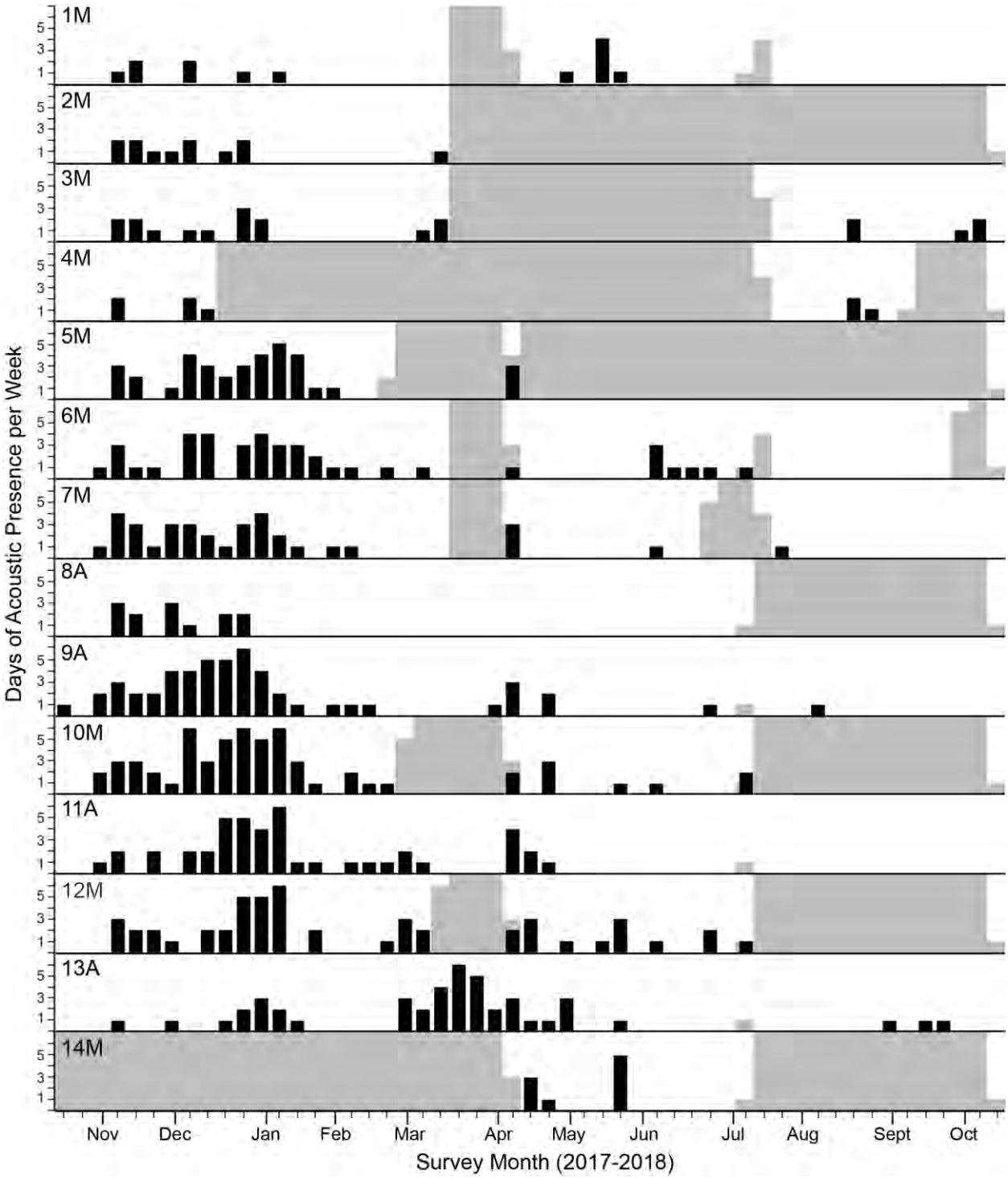


Figure 13. Weekly acoustic presence of North Atlantic right whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed right whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

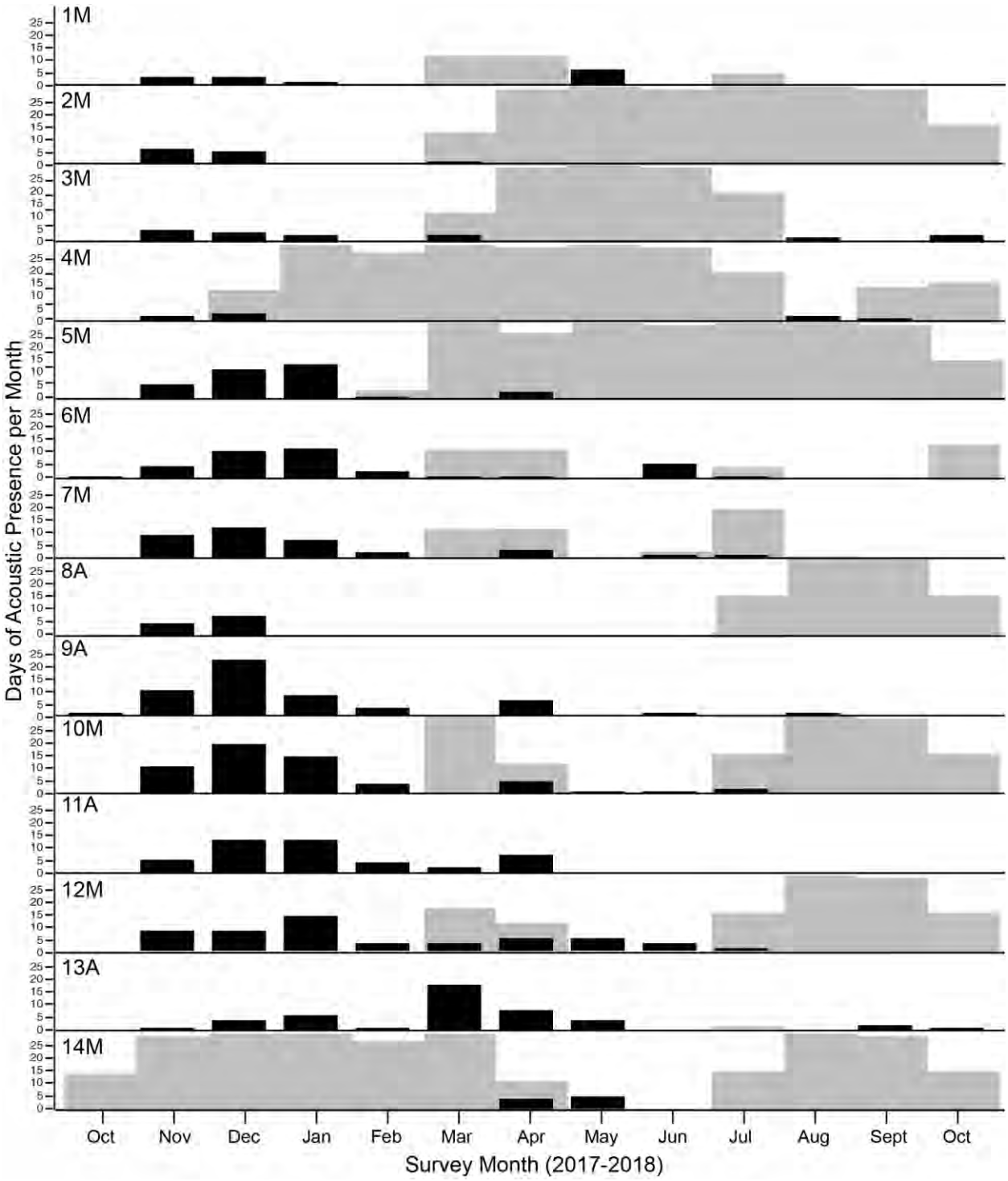


Figure 14. Monthly acoustic presence of North Atlantic right whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed right whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

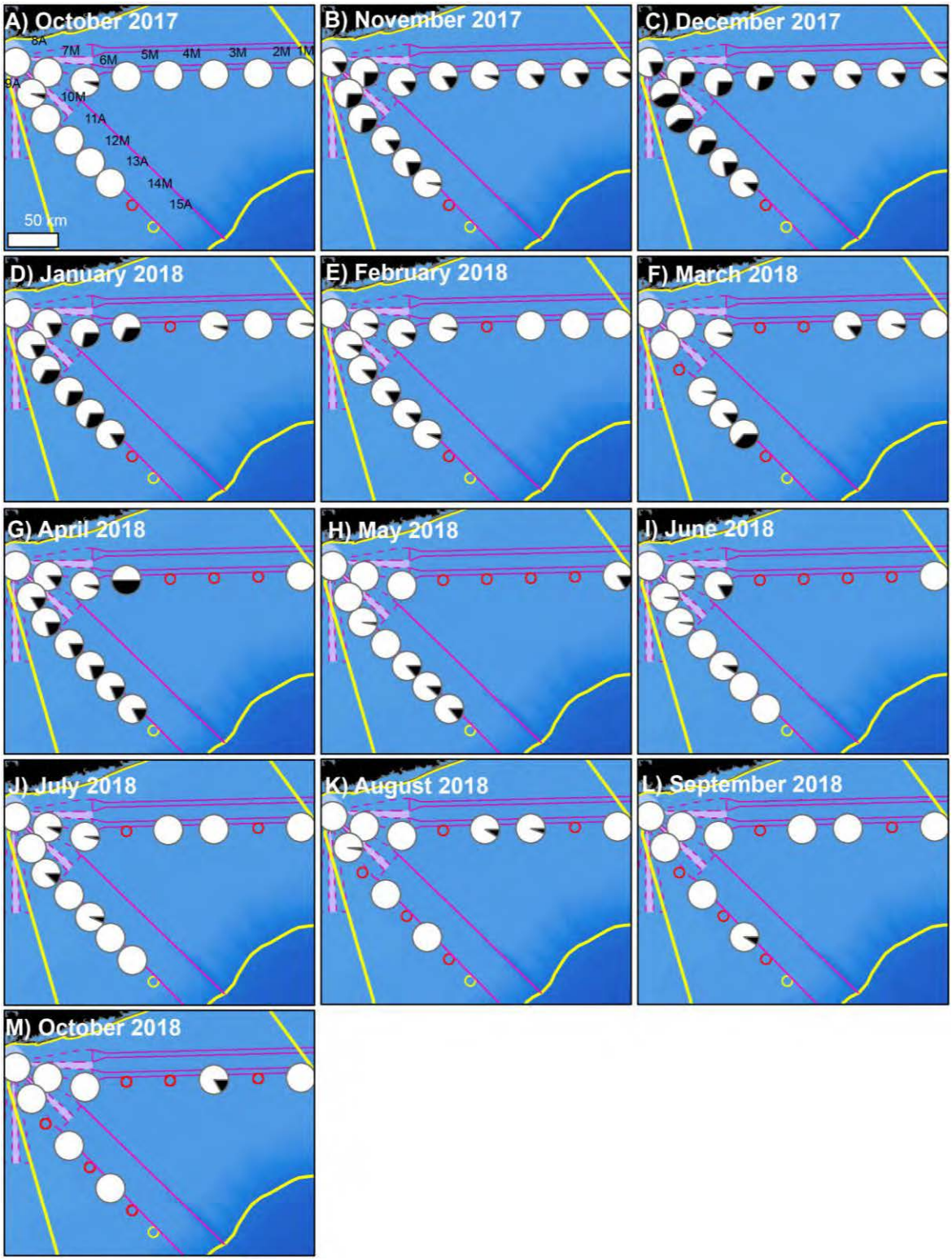


Figure 15. Spatial patterns of monthly presence of North Atlantic right whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

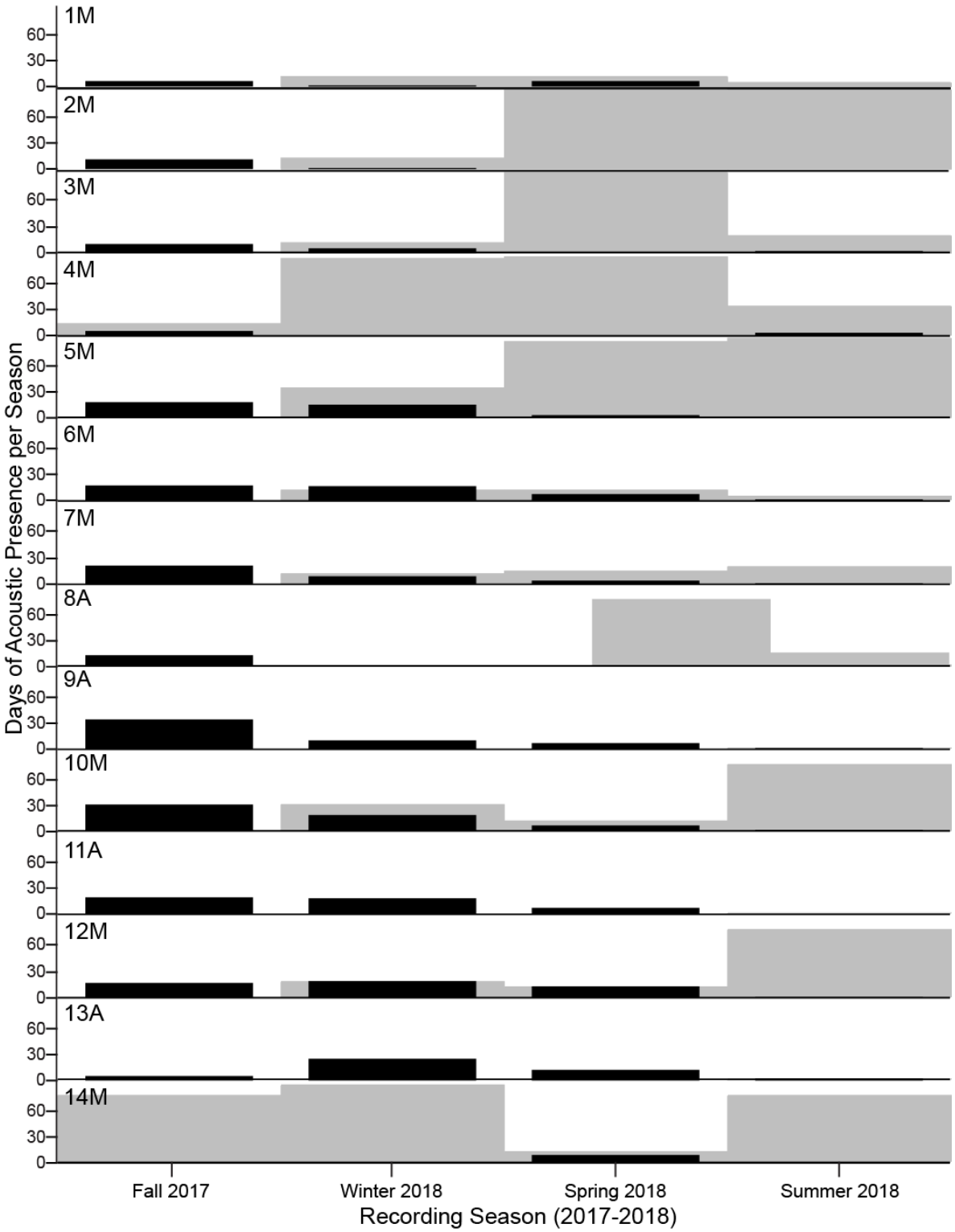


Figure 16. Seasonal acoustic presence of North Atlantic right whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

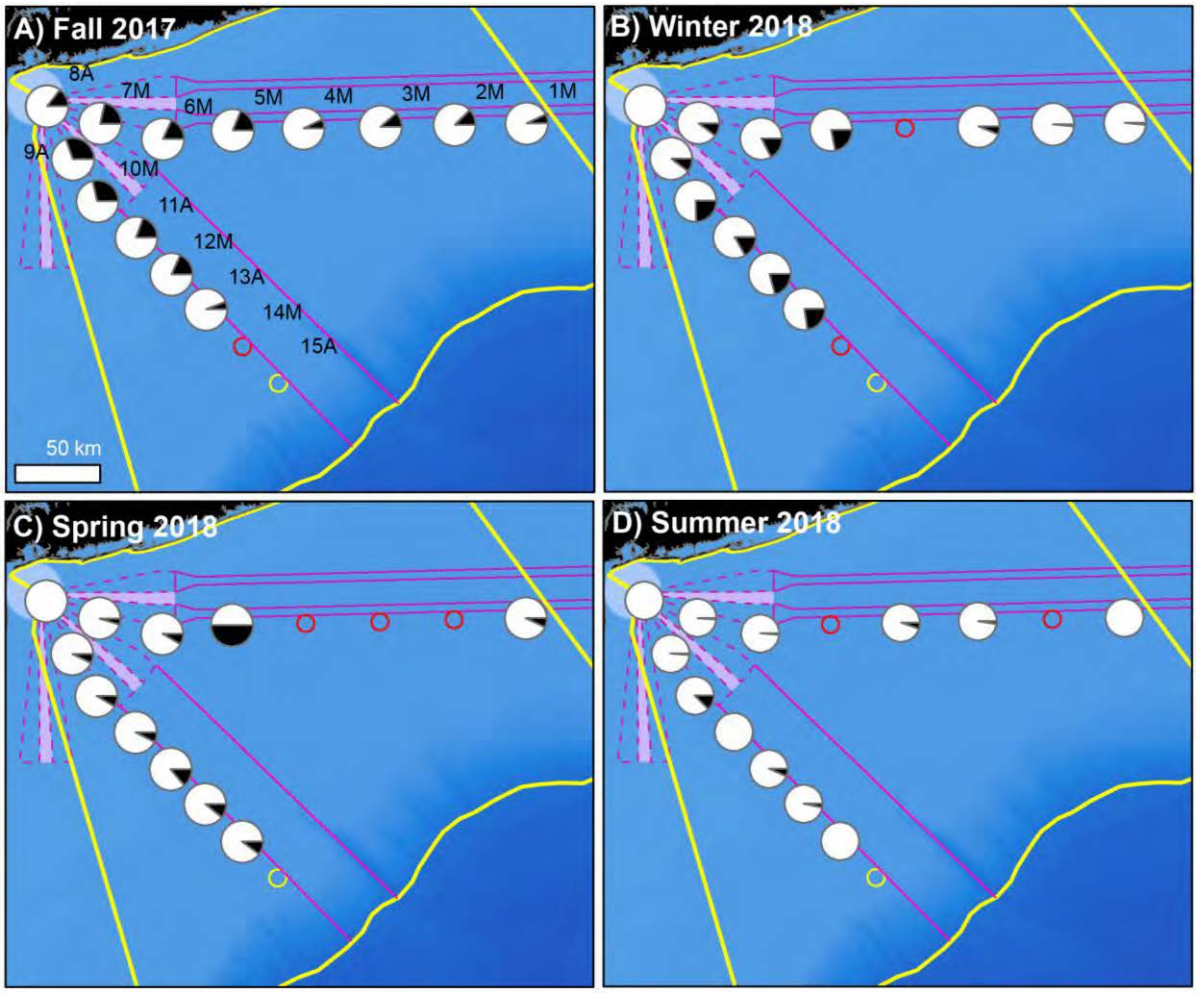


Figure 17. Spatial patterns of seasonal acoustic presence of North Atlantic right whale upcalls in New York Bight, shown as percentage of days per season on each recording unit,. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – 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.

Humpback Whale Occurrence

Humpback whales were detected in the majority of weeks (Figure 18) and every month (Figure 19). during the survey period. Humpback whales (Figure 32) were detected across both transects, with the least occurrence at site 8A (17%), and the highest occurrence between sites 10M and 14M along the southern transect (47 % - 56 % daily presence). Daily presence per month was lowest in October 2017 (25%) and highest in February 2018 (100%) (Figure 18, Figure 19). Humpback whales were detected across nearly all sensors throughout the year (Figure 19, Figure 20).

Though humpback whale daily presence per week was highest in December through February at sites 5-13, there were increased detections during individual weeks in December and February, but not January (Figure 18), suggestive of a change in either calling behavior of individuals in the area, multiple cohorts moving through the region, or changing noise conditions (reducing their detectability).

Increases in humpback whale detections at weekly (Figure 18), monthly (Figure 19, Figure 20), and seasonal (Figure 21, Figure 22) time-scales were not uniform across all sites within the survey area. For example, increases in detections at sites 5-14 occurred with lower levels of detections in sites 1-4, and increases in detections at sites 1-4 coincided with decreased detections at sties 5-14 (Figure 18), though this pattern is less clear at the monthly time resolution (Figure 19).

Seasonally, humpback whale presence was high throughout the year, ranging from 56% presence in fall 2017 to 100% presence in fall 2018 (Figure 21), with more detections at sites 5-14 (Figure 21, Figure 22).

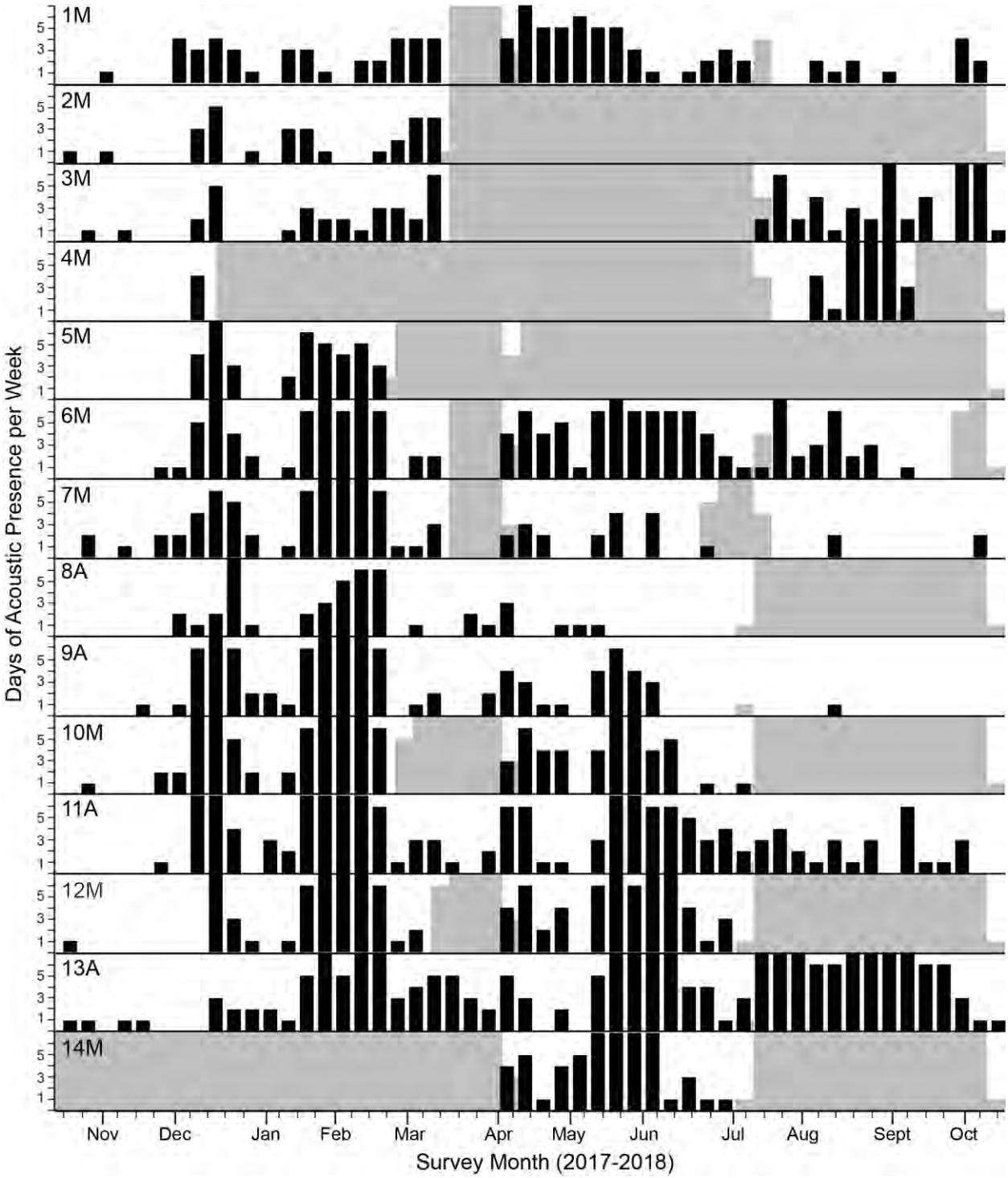


Figure 18. Weekly acoustic presence of humpback whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed humpback whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

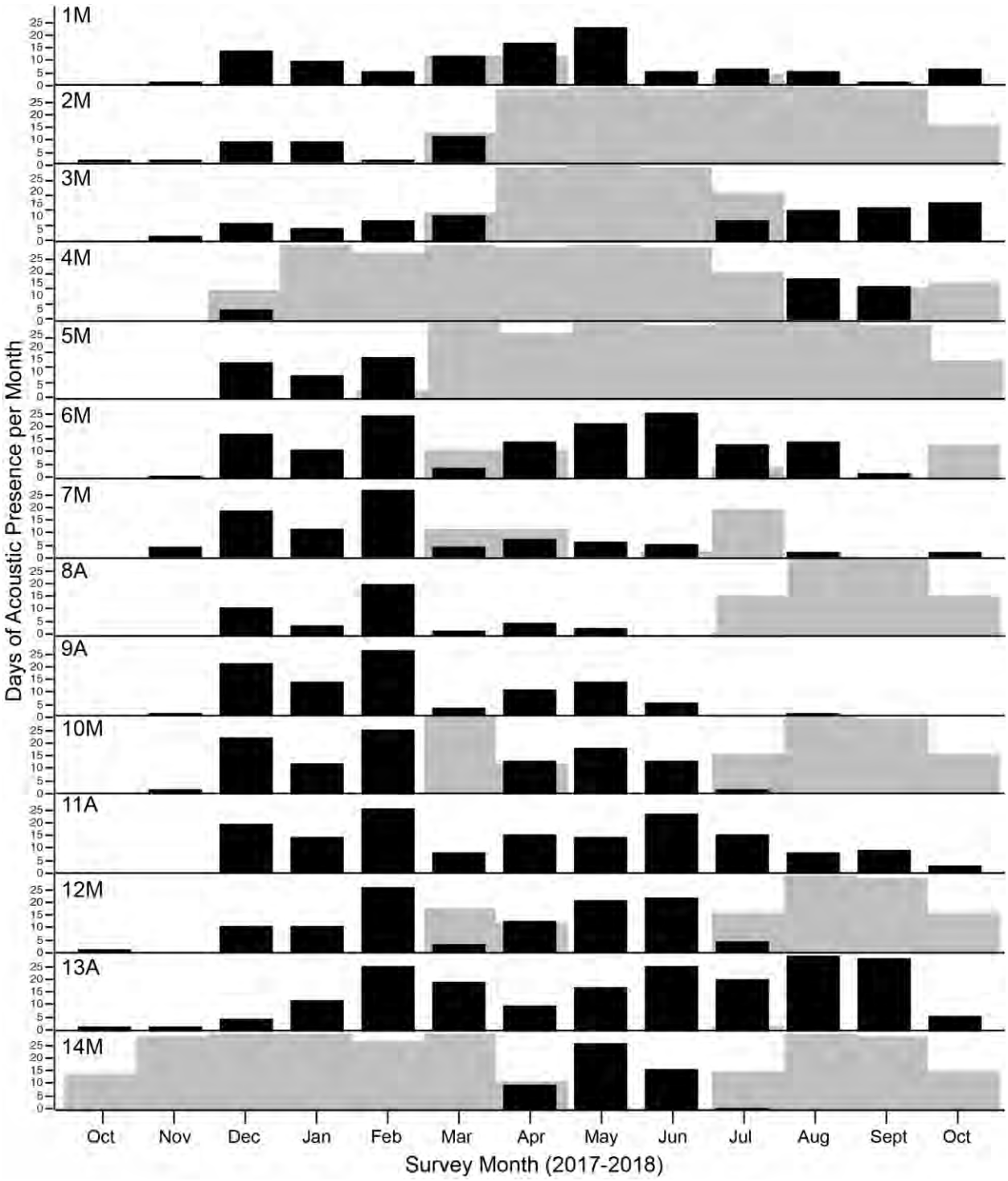


Figure 19. Monthly acoustic presence of humpback whales detected within New York Bight between October 2017-October 2018, shown as number of days per month with confirmed humpback whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

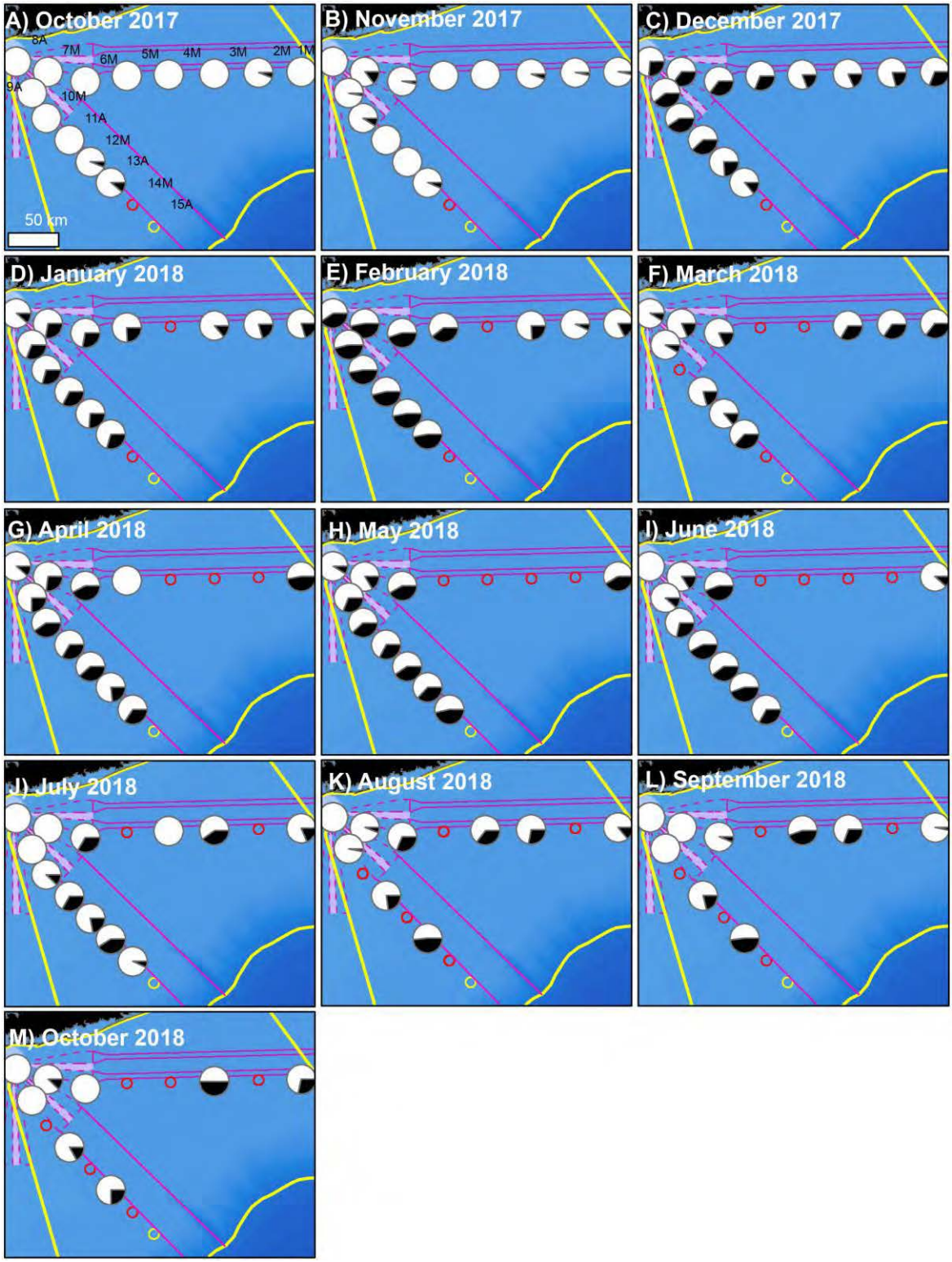


Figure 20. Spatial patterns of monthly presence of humpback whales in New York Bight, shown as percentage of days per month on each recording unit, . Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

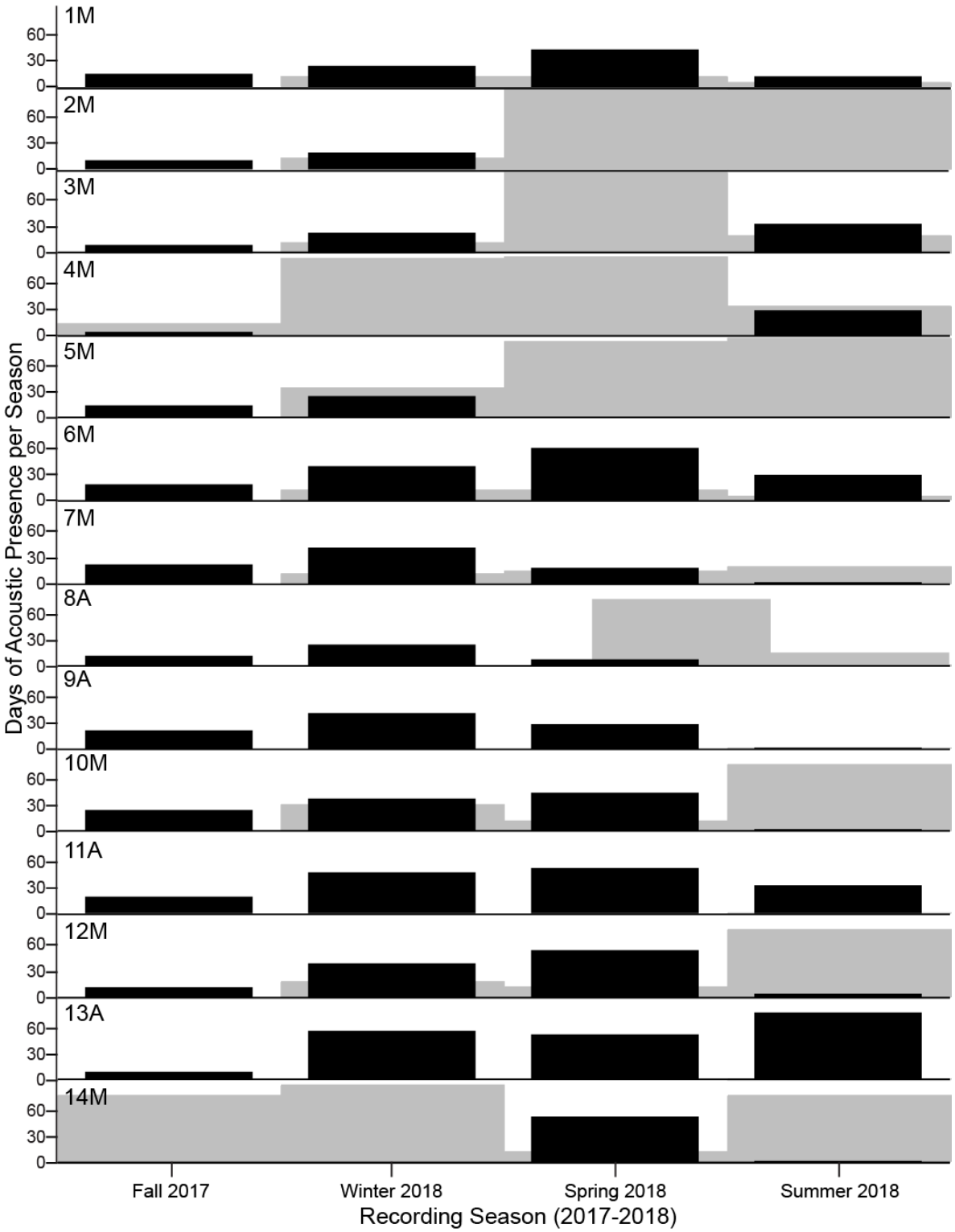


Figure 21. Seasonal acoustic presence of humpback whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

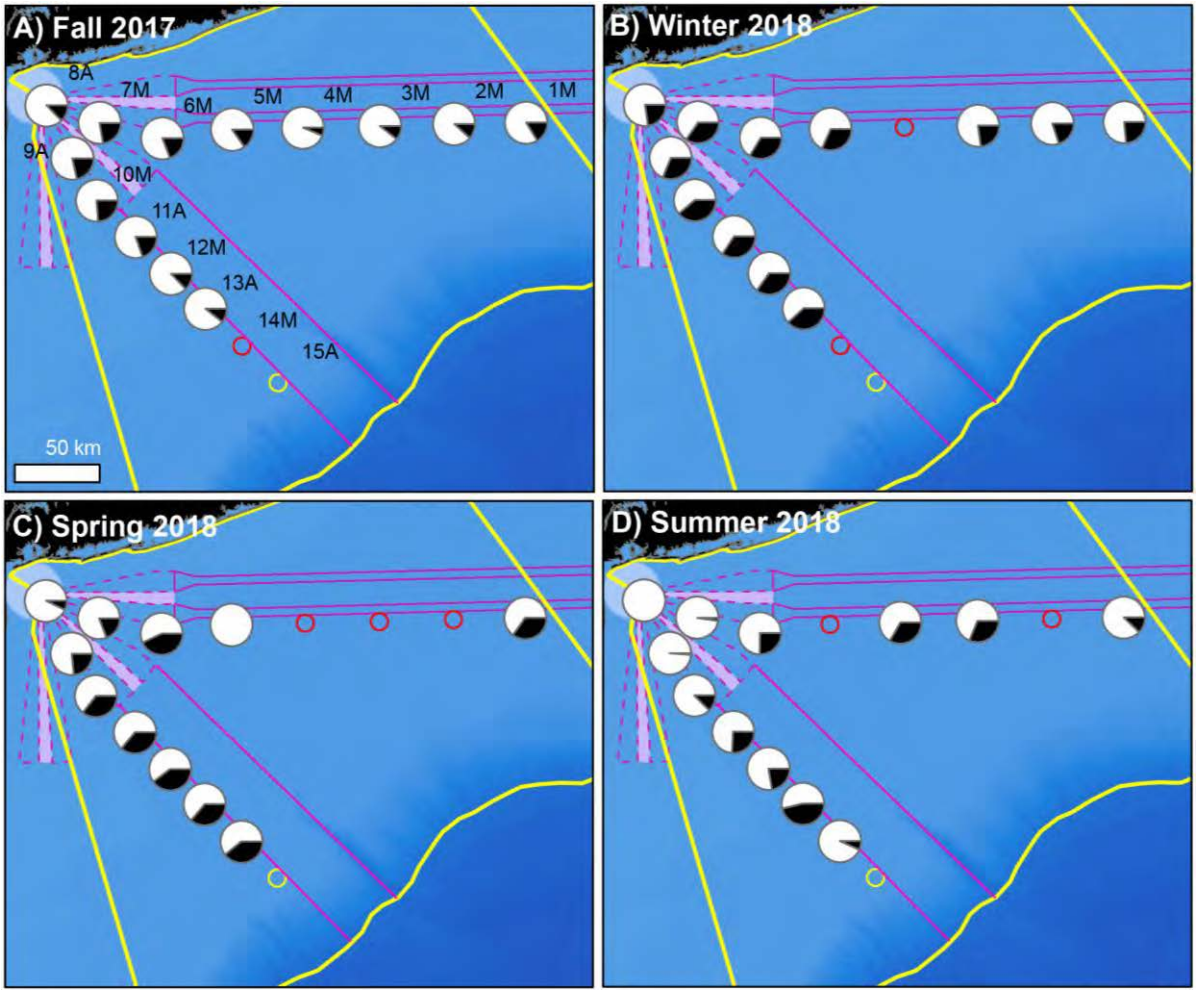


Figure 22. Spatial patterns of seasonal acoustic presence of humpback whales in New York Bight, shown as percentage of days per season on each recording unit, . Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (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.

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 during the survey period (Figure 23), and in every month of the year (Figure 24, Figure 25). Site 11A had the highest number of daily detections through the Year-1 recording period, with whales detected every day except during late March through mid-July. Many of the outer recording sites in the array- 1M, 2M, 3M, 4M, 10M, 12M– all showed 100% daily presence per week for the last two weeks of October 2017, and then a sudden decrease to in the early November, before returning to nearly continuous presence for the remainder of the winter (Figure 23). Interestingly, sites 5M, 6M, 7M, 8A, and 9A exhibited a completely different pattern of occurrence during this time period, with either sporadic weeks with many days of detections (e.g., Site 7M) or low-level presence (6M, 8A) (Figure 23). These short-term changes in daily detections are not readily visible at a monthly temporal resolution (Figure 24).

At a monthly scale, peak occurrence is primarily in December-February for all sites, and then a secondary peak in June for sites 10M-14M, and August/September for Sites 1M-6M (Figure 24). 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 25). The more-southerly sites have higher number of days with detections than more centralized sites (Figure 25).

Seasonally, fin whale presence is lowest in the spring (Figure 26), with detections concentrated towards the southwestern units in the survey array (Figure 27). However, the seasonal pattern of detections further demonstrate that fin whales are broadly detected across the project area for much of the year (Figure 26, Figure 27).

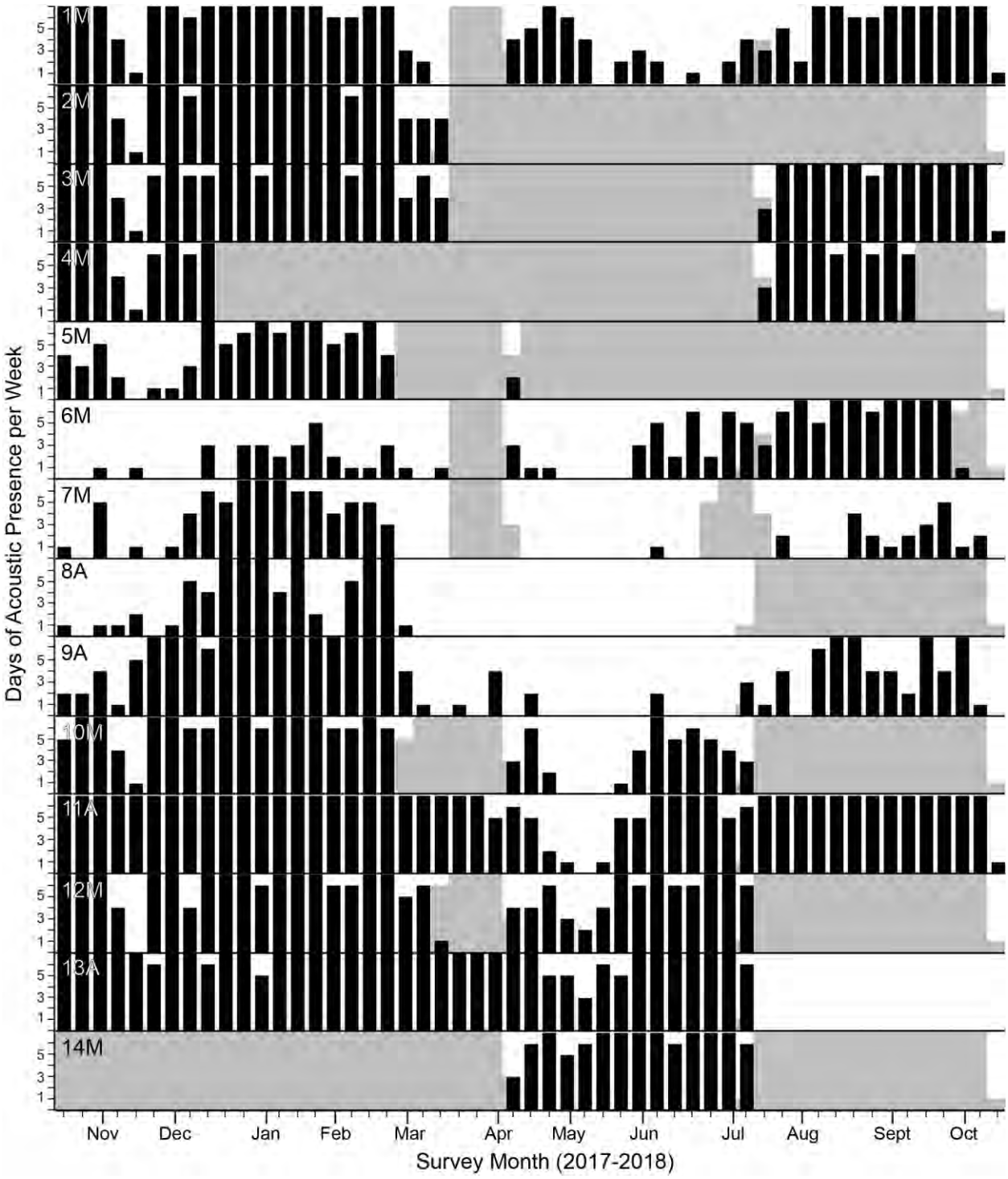


Figure 23. Weekly acoustic presence of fin whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed fin whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

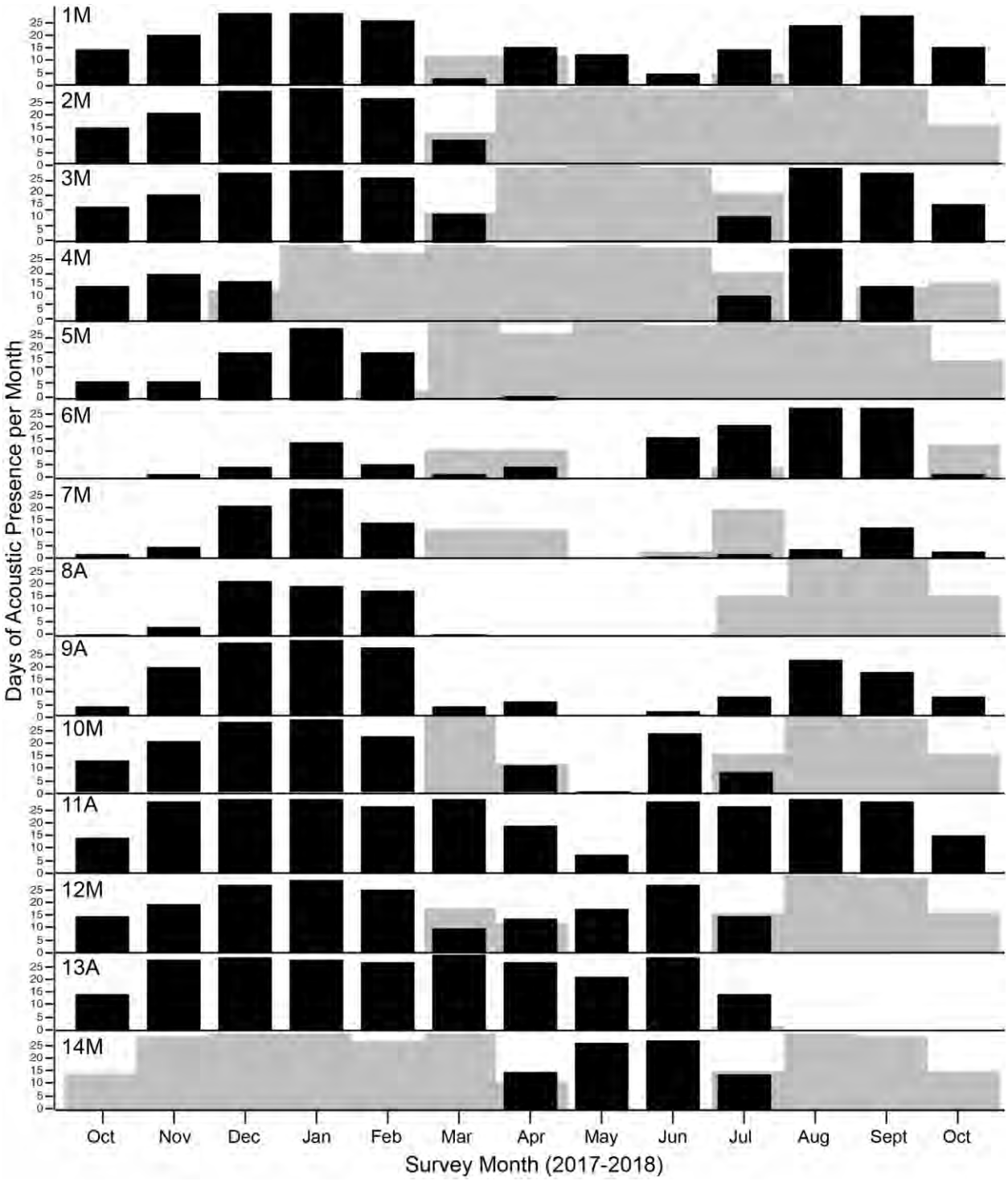


Figure 24. Monthly acoustic presence of fin whales detected within New York Bight between October 2017-October 2018, shown as number of days per month with confirmed fin whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

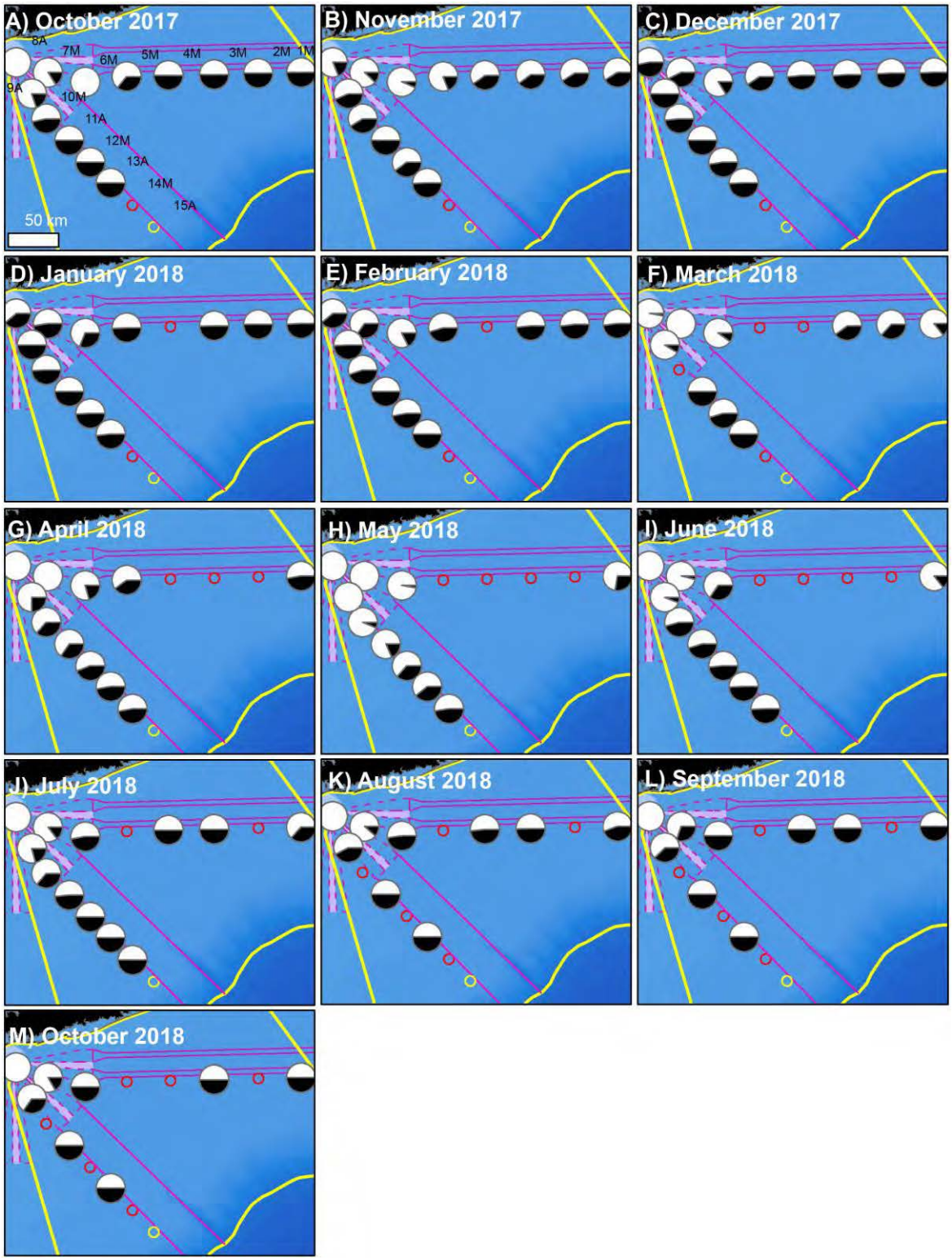


Figure 25. Spatial patterns of monthly presence of fin whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

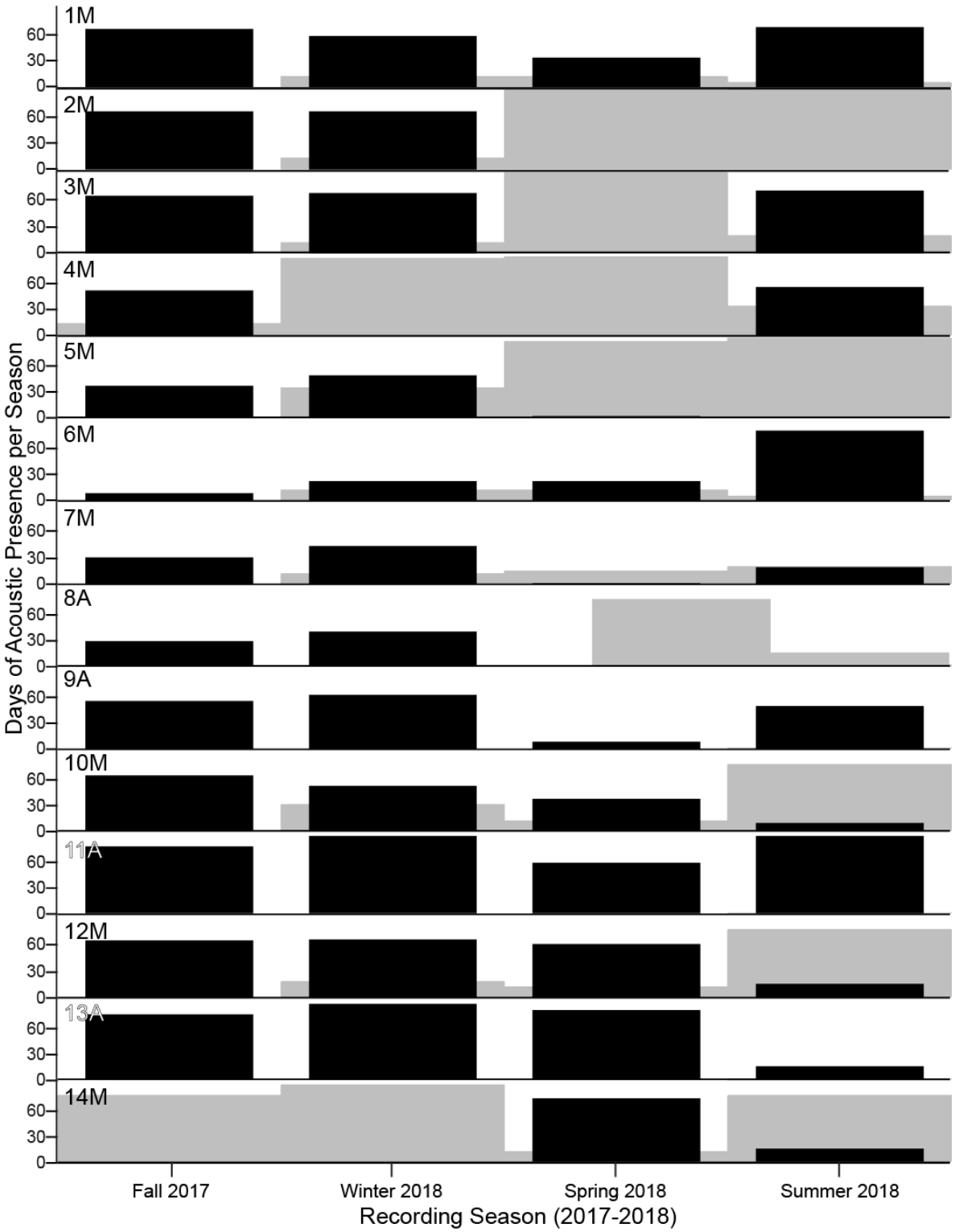


Figure 26. Seasonal acoustic presence of fin whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

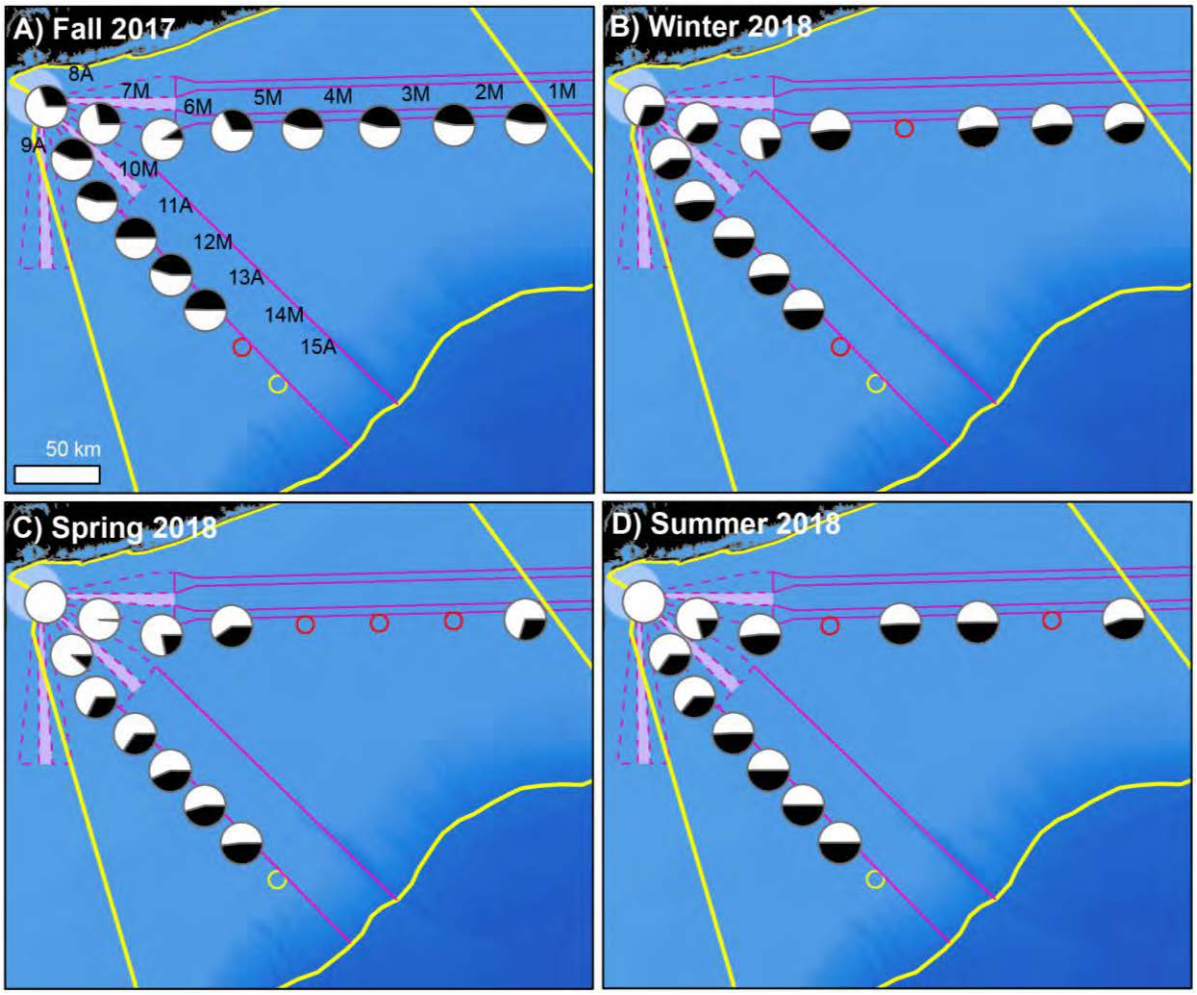


Figure 27. Spatial patterns of seasonal acoustic presence of fin whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – 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.

Sei Whale Occurrence

Compared with the other baleen whale species, sei whales had a lower overall number of daily detections in NY Bight. October through early March had low weekly presence, with less than four days of presence per week (Figure 28). Sei whale occurrence did not appear to follow any pattern during this time period. However, sei whales were detected with a higher level of occurrence in mid-March through late May at sites 9A, 11A, 13A, and 14M (Figure 28). Sites 11A and 13A each had three consecutive weeks of acoustic presence every day of the week (Figure 28). Only site 11A and 13A had any sei whale detections in mid-July through October (Figure 28).

Across the entire survey area, sei whales were detected in all months except September 2018, though presence was low in October 2017-February 2018, and June-October 2018 (Figure 29). Sei whale detections did not exhibit any strong spatial patterns in monthly occurrence for most of the year, though the southern-most sites had the highest detections in April and May (Figure 30).

Sei whale percent daily presence was highest during the spring and lowest summer (Figure 31), with low-level acoustic occurrence across the entire survey area in Fall 2017 and Winter 2018, and higher occurrence along the southern transect line in Spring 2018 (Figure 32).

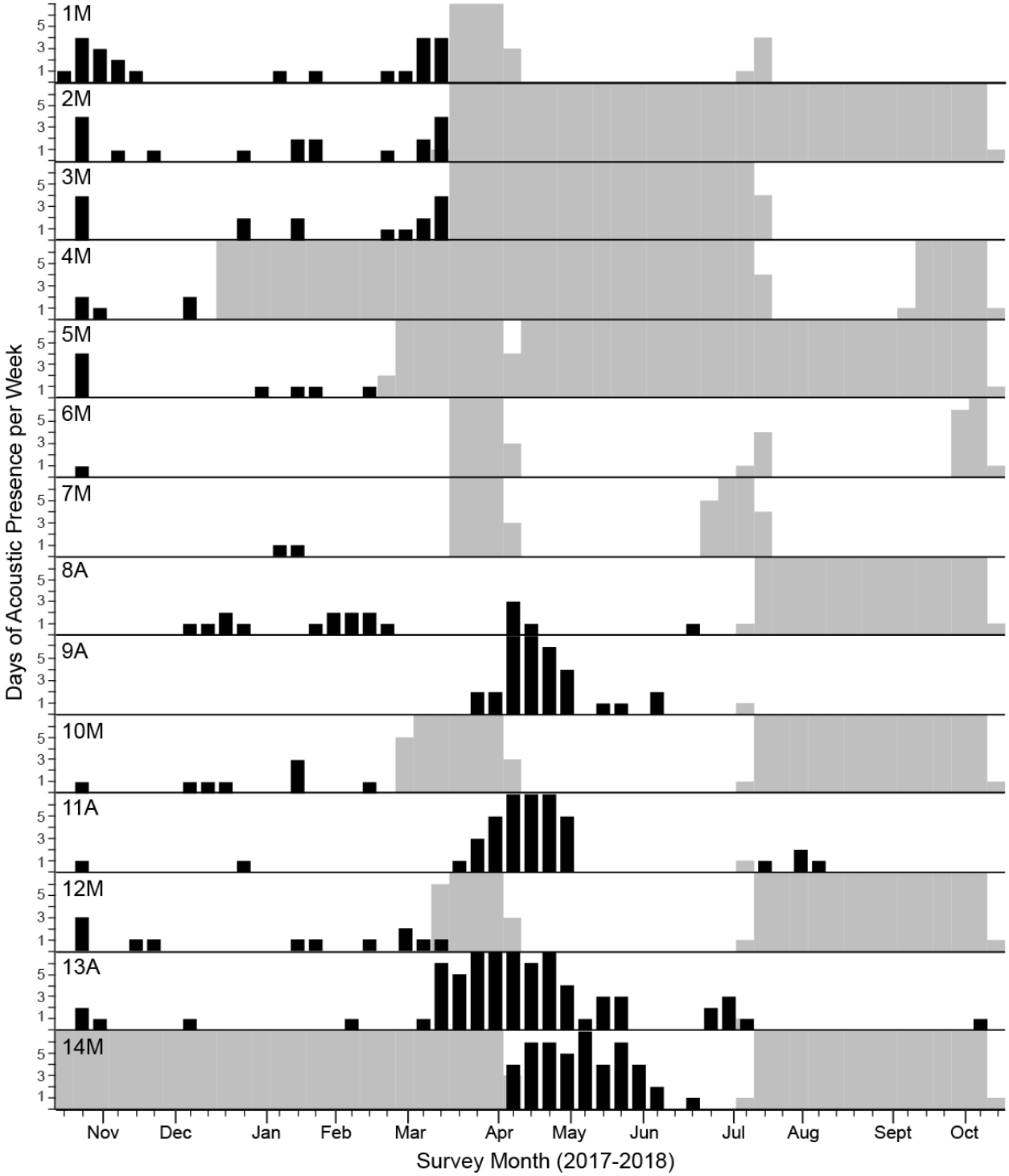


Figure 28. Weekly acoustic presence of sei whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed sei whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

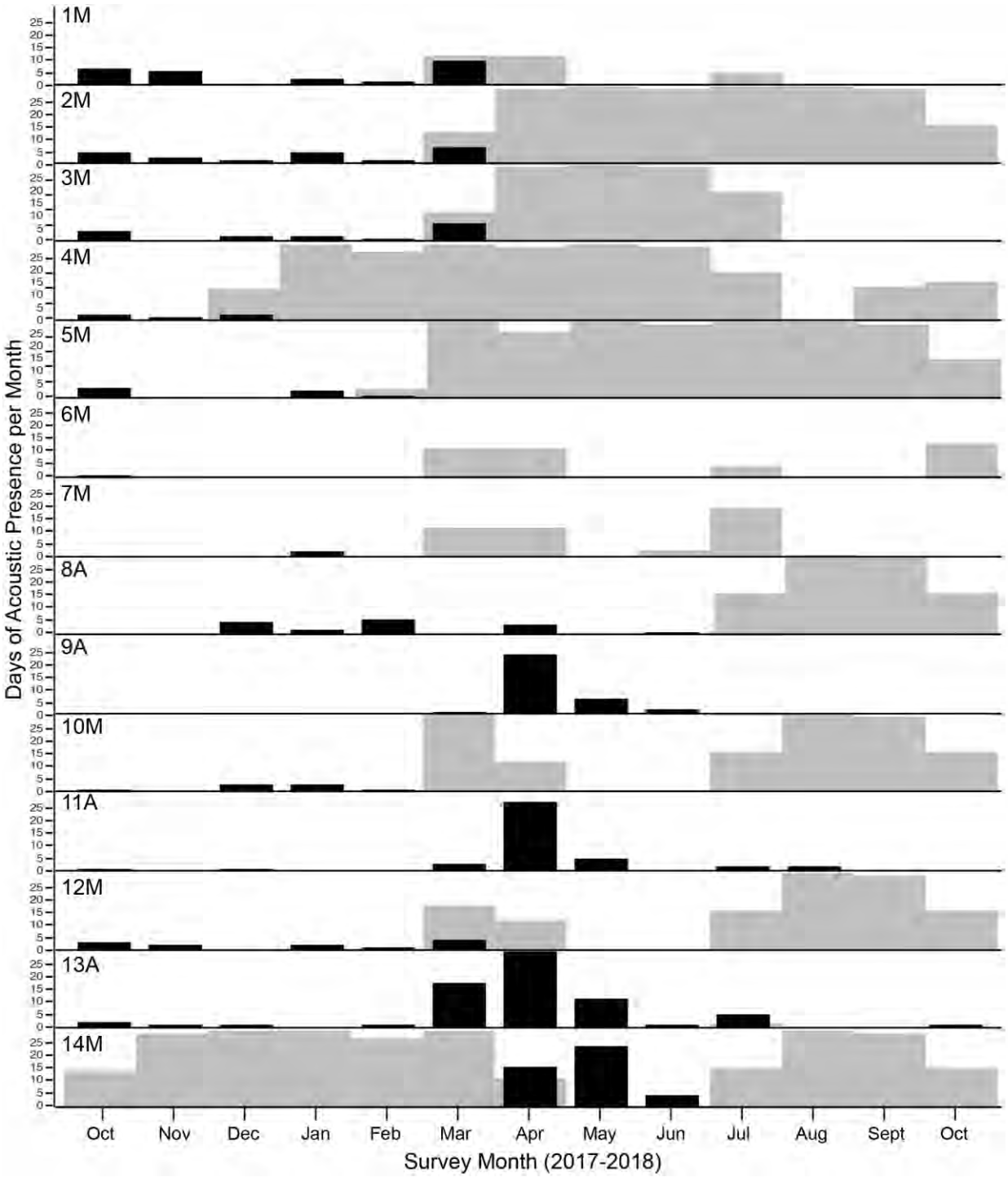


Figure 29. Monthly acoustic presence of sei whales detected within New York Bight between October 2017-October 2018, shown as number of days per month with confirmed sei whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

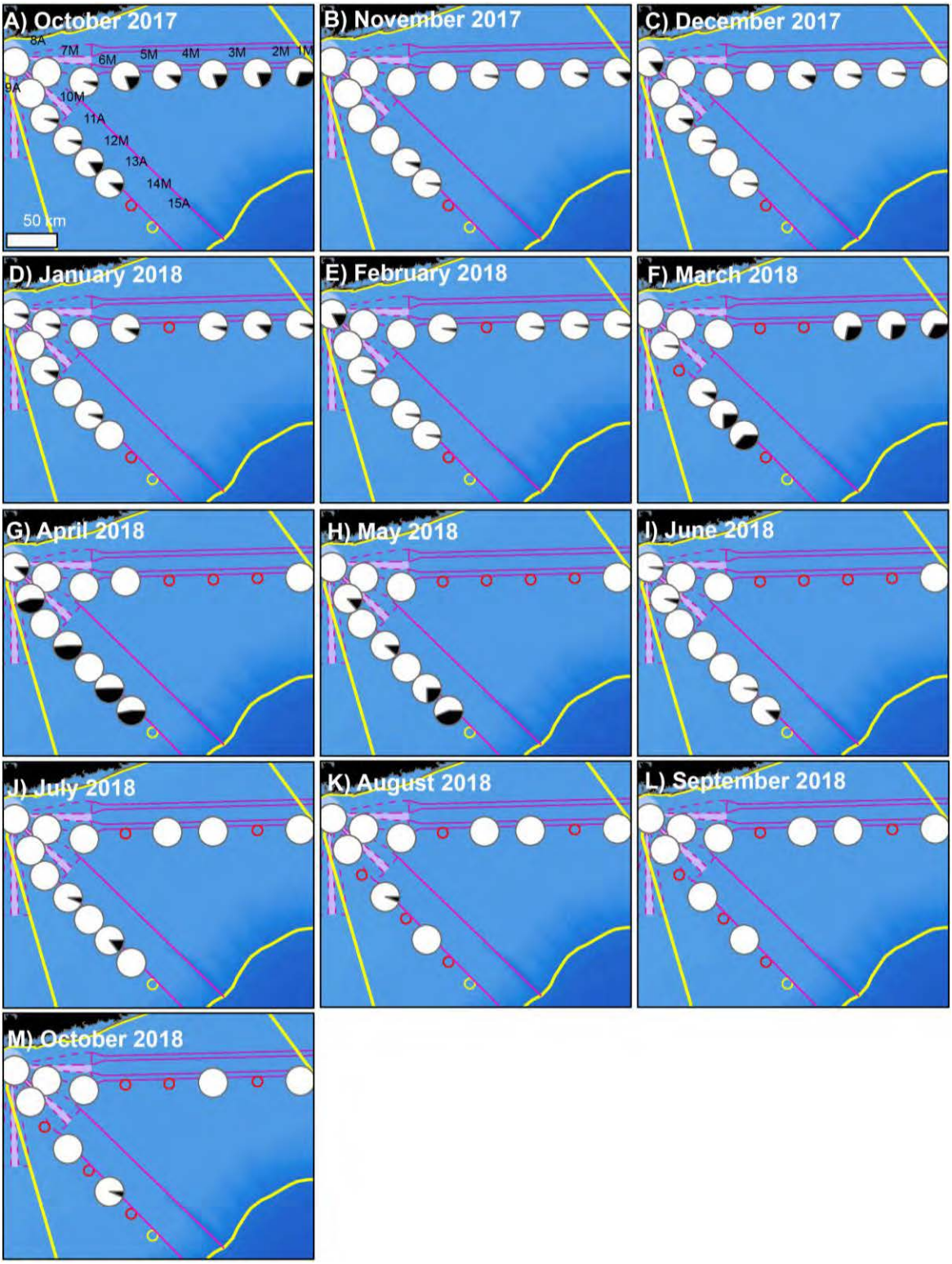


Figure 30. Spatial patterns of monthly presence of sei whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there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

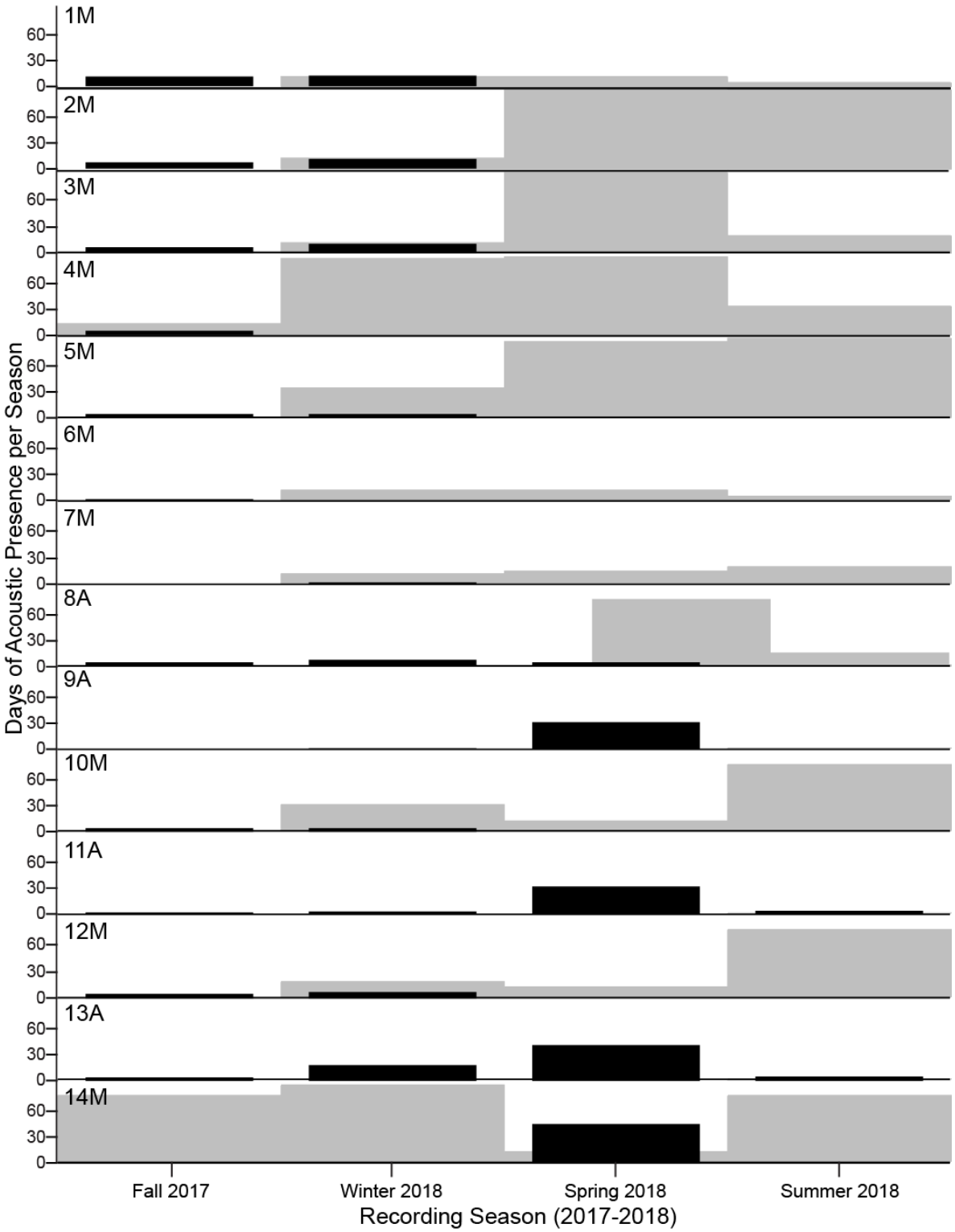


Figure 31. Seasonal acoustic presence of sei whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

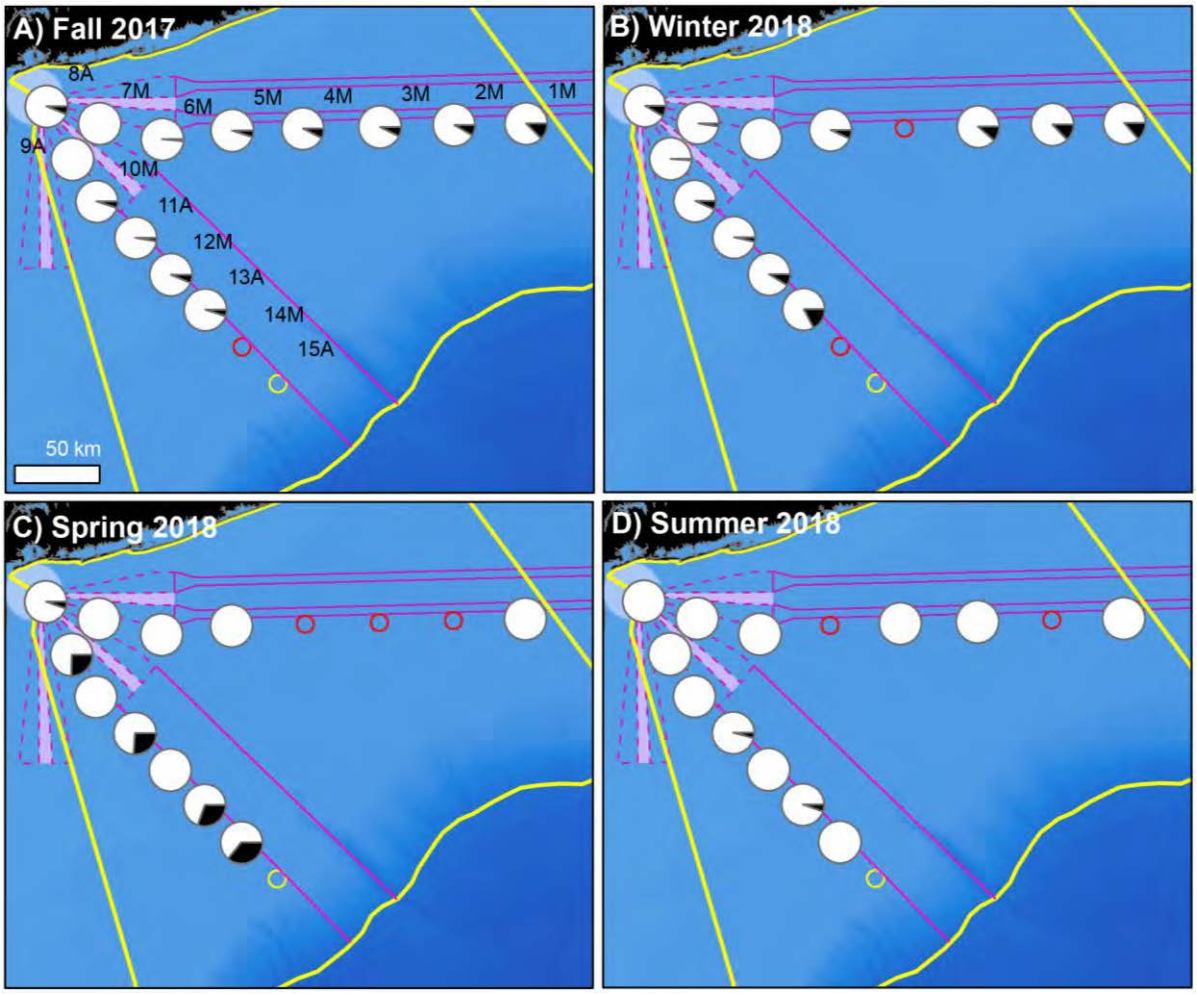


Figure 32. Spatial patterns of seasonal acoustic presence of sei whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – 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.

Blue Whale Occurrence

Blue whales were the least frequently detected species within NY Bight. They were only detected between November and February (Figure 33, Figure 34). In November through January, there were three short weekly periods of occurrence in the area on sites 1M, 2M and 3M, with weekly occurrence reaching as a high as five days in early December at Site 1M (Figure 33). There were two other daily detections on the southern transect line in January and February (Figure 33, Figure 34, Figure 35), and it is unclear whether these are the same animals detected at Sites 1M-3M, or whether they are a different individual or individuals. There were no detections after mid-February (Figure 33, Figure 34). Seasonally, blue whales were only detected in Fall 2017 and Winter 2018 (Figure 36, Figure 37).

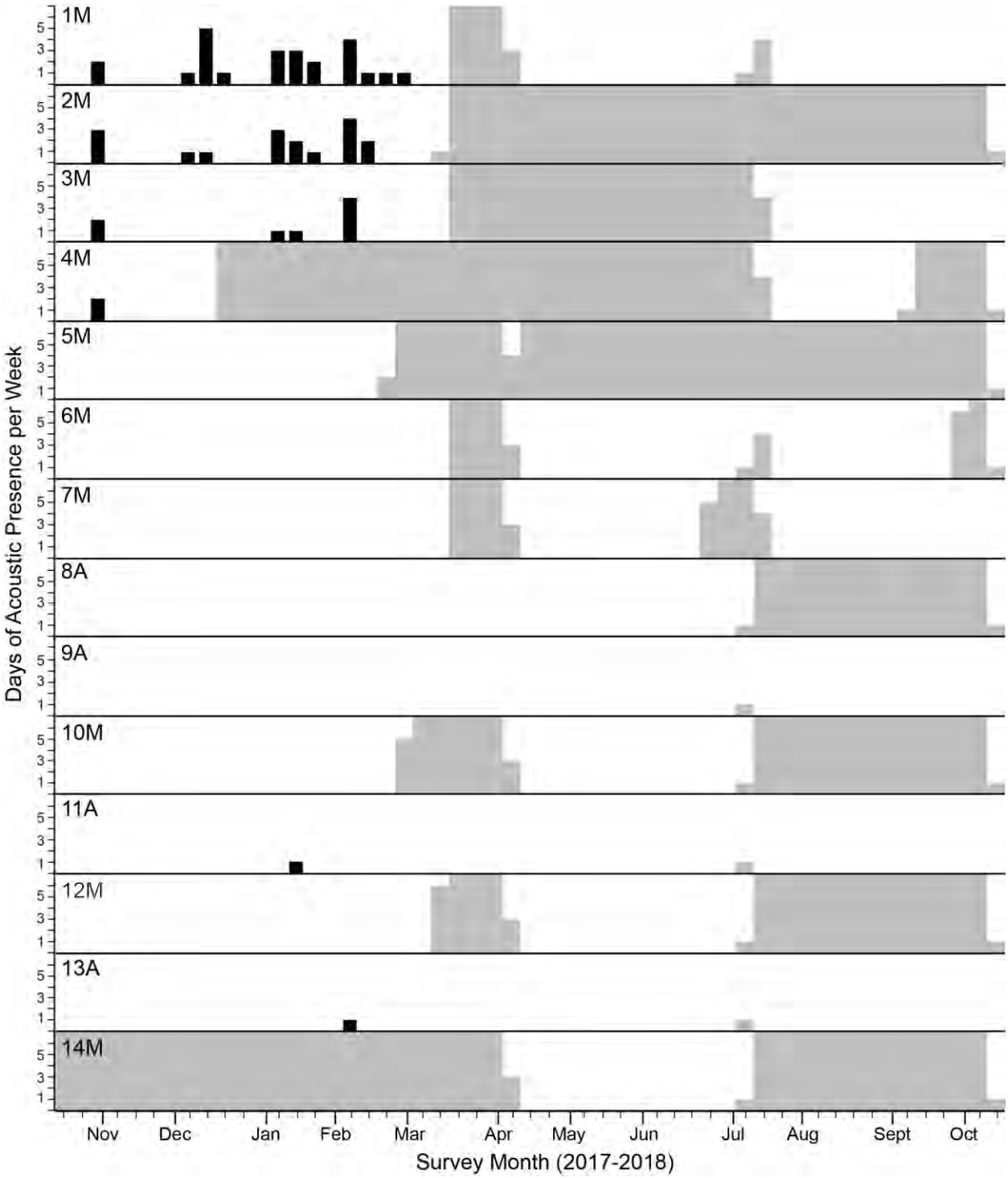


Figure 33. Weekly acoustic presence of blue whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed blue whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each week during which there are no sound data.

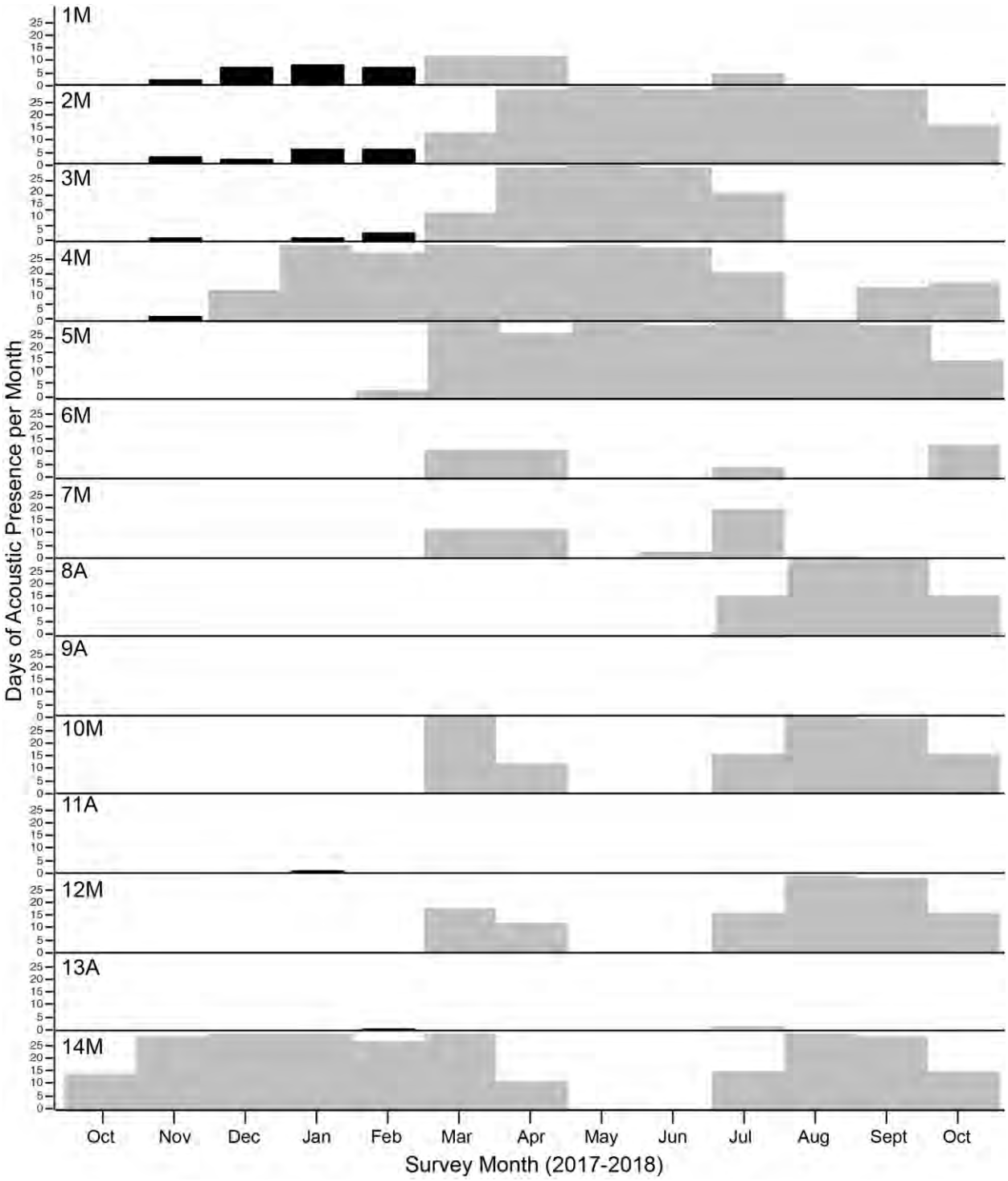


Figure 34. Monthly acoustic presence of blue whales detected within New York Bight between October 2017-October 2018, shown as number of days per month with confirmed blue whale acoustic detections across all sensors (black bars). Gray bars indicate the number of days for each month during which there is no sound data.

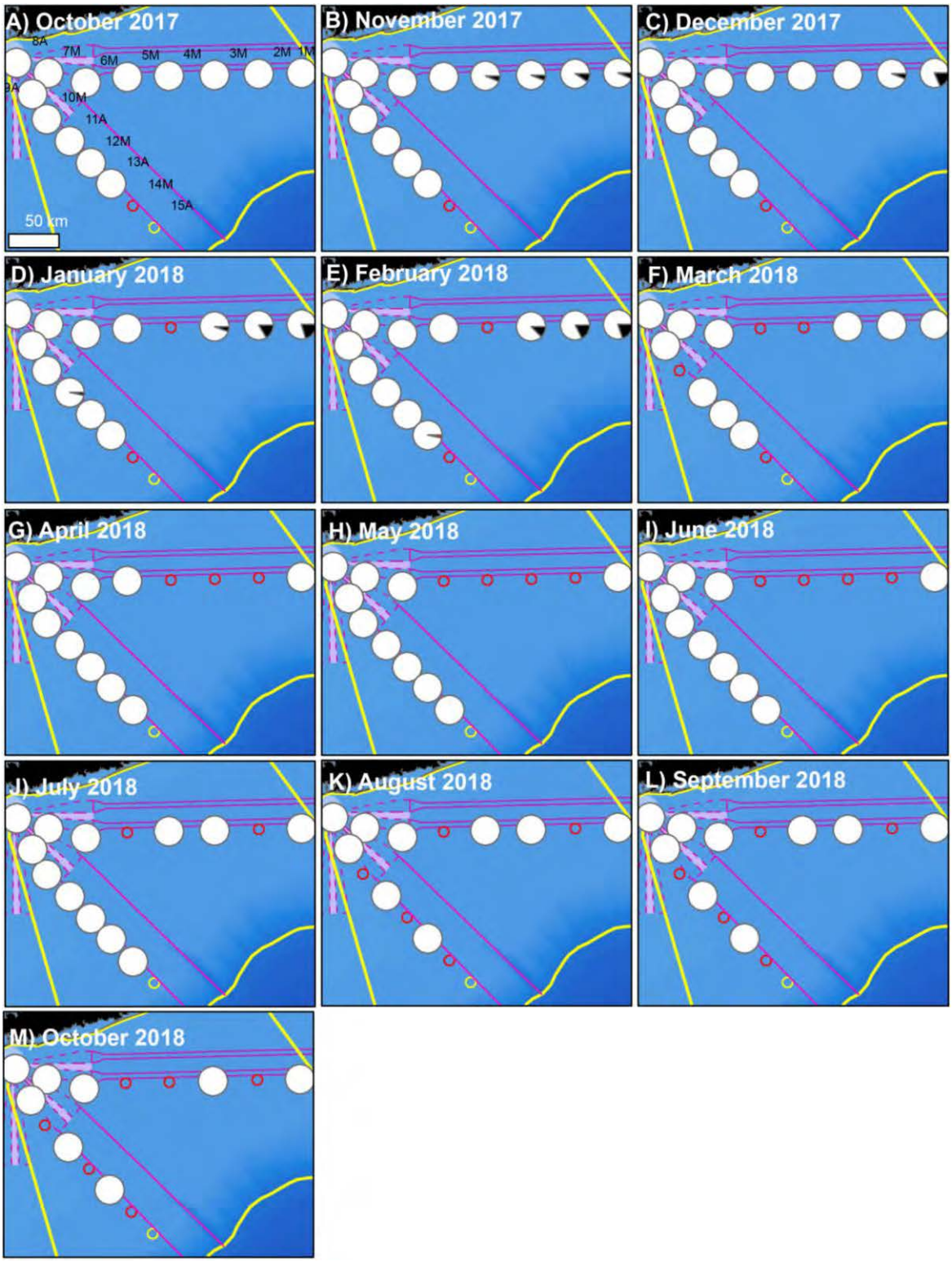


Figure 35. Spatial patterns of monthly presence of blue whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Hollow circles denote AMAR (in yellow) and MARU (in red) site locations in which there are no data for that season.

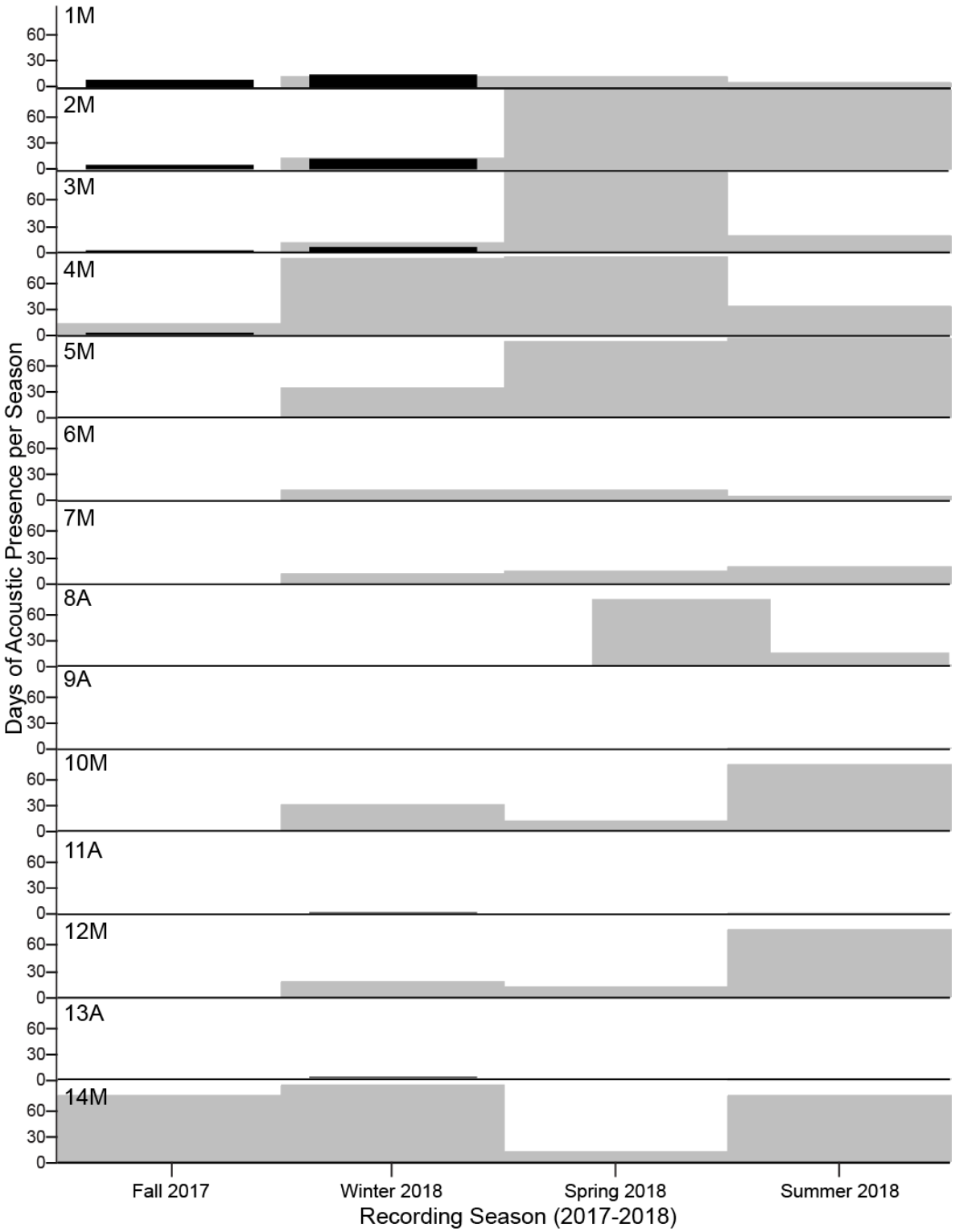


Figure 36. Seasonal acoustic presence of blue whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all sensors for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

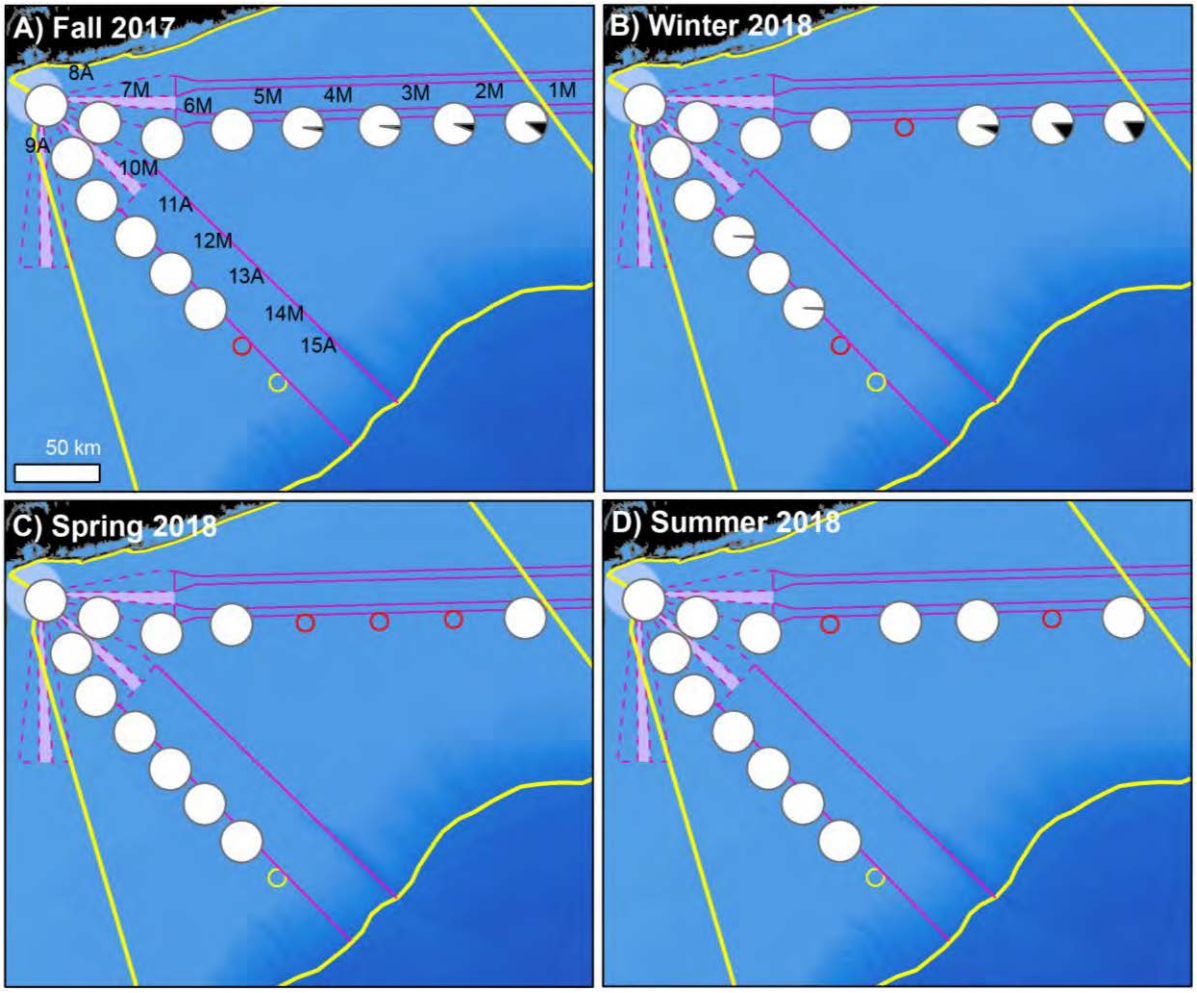


Figure 37. Spatial patterns of seasonal acoustic presence of blue whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – 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.

Sperm Whale Occurrence

Sperm whales were detected throughout the year on the four AMAR sites, with many weeks exhibiting multiple days of detections (Figure 38). Daily detections were the highest at Sites 11A and 13A (Figure 38). Surprisingly, clicks that met our criteria for sperm whales (as defined in the methods section), were detected on 18 days at site 8A, the most in-shore site; though this site still recorded the lowest number of detections. The weekly detections on 11A and 13A exhibited several cycles with increases, a peak, and then decreases, whereas the detections on 8A and 9A primarily showed low levels of activity. Detections were the lowest in October-December (Figure 38, Figure 39) across all sites (Figure 40). In January-March, sperm whales were detected at all four AMAR sites, and only at one site in October 2017 (Figure 39, Figure 40). Seasonally, sperm whales were detected more during winter, spring and summer, and least during the fall (Figure 41), with the majority of detections on 11A and 13A (Figure 41, Figure 42).

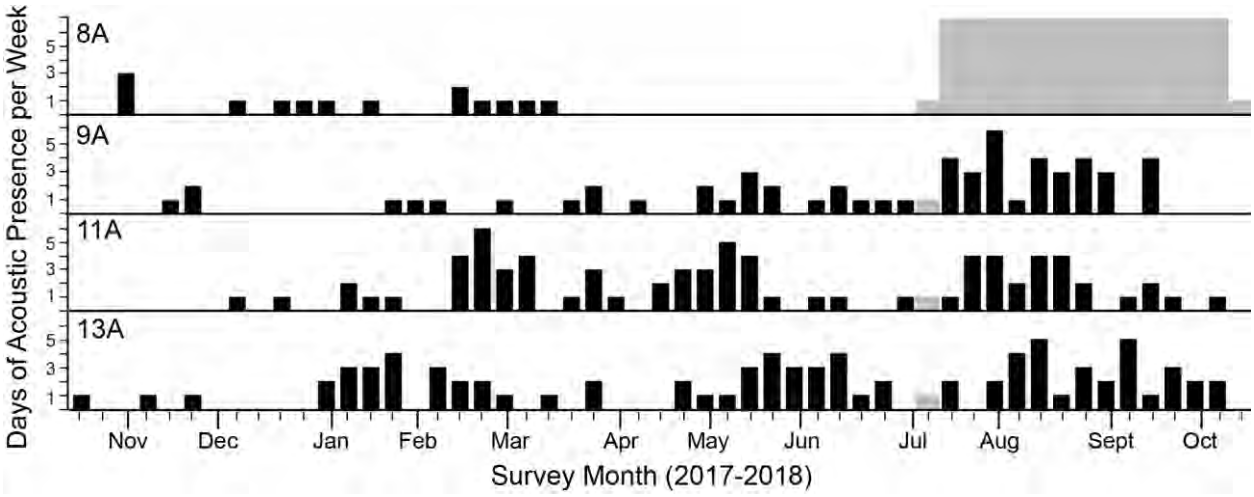


Figure 38. Weekly acoustic presence of sperm whales detected within New York Bight between October 2017-October 2018, shown as number of days per week with confirmed sperm whale acoustic detections across all AMARs. Gray bars indicate the number of days for each week during which there are no sound data.

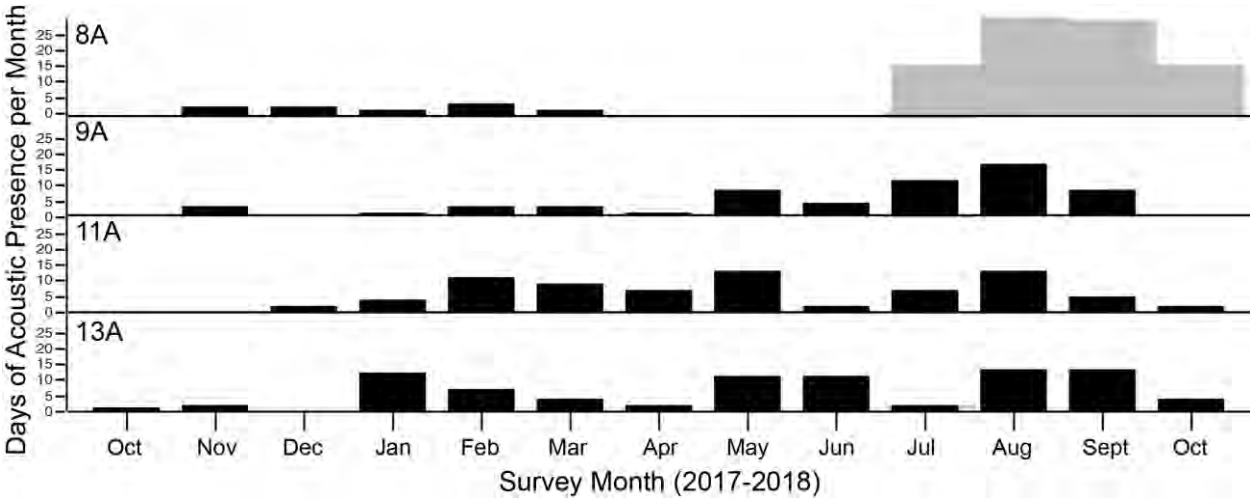


Figure 39. Monthly acoustic presence of sperm whales detected within New York Bight between October 2017-October 2018, shown as number of days per month with confirmed sperm whale acoustic detections across all AMARs (black bars). Gray bars indicate the number of days for each month during which there are no sound data.

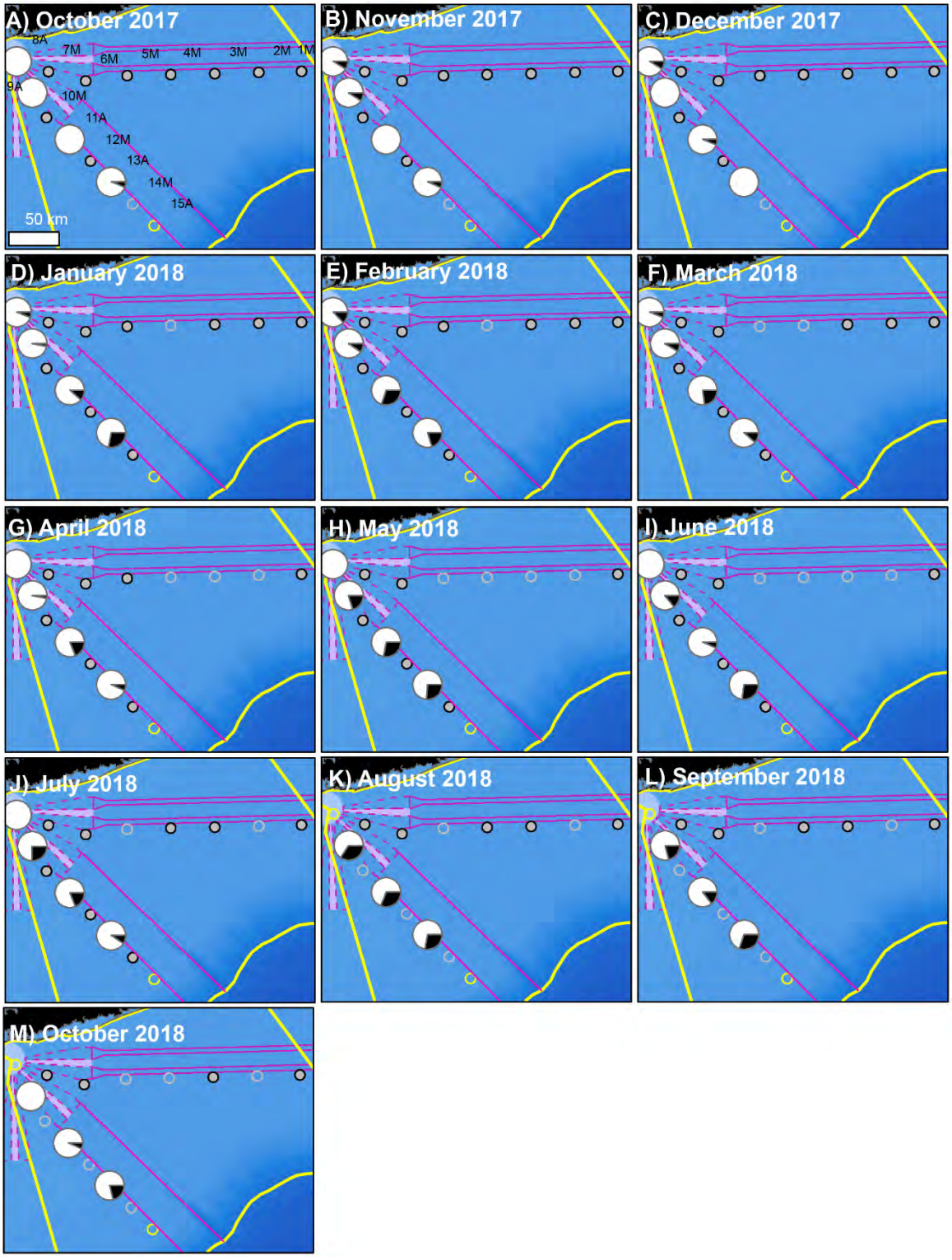


Figure 40. Spatial patterns of monthly presence of sperm whales in New York Bight, shown as percentage of days per month on each recording unit. Black indicates the proportion of presence, white indicates no detections. Only AMARs were analyzed for sperm whale presence; MARUs were not included in the analysis and are greyed out for clarity. Hollow circles denote AMAR (in yellow) and MARU (in grey) site locations in which there are no data for that season.

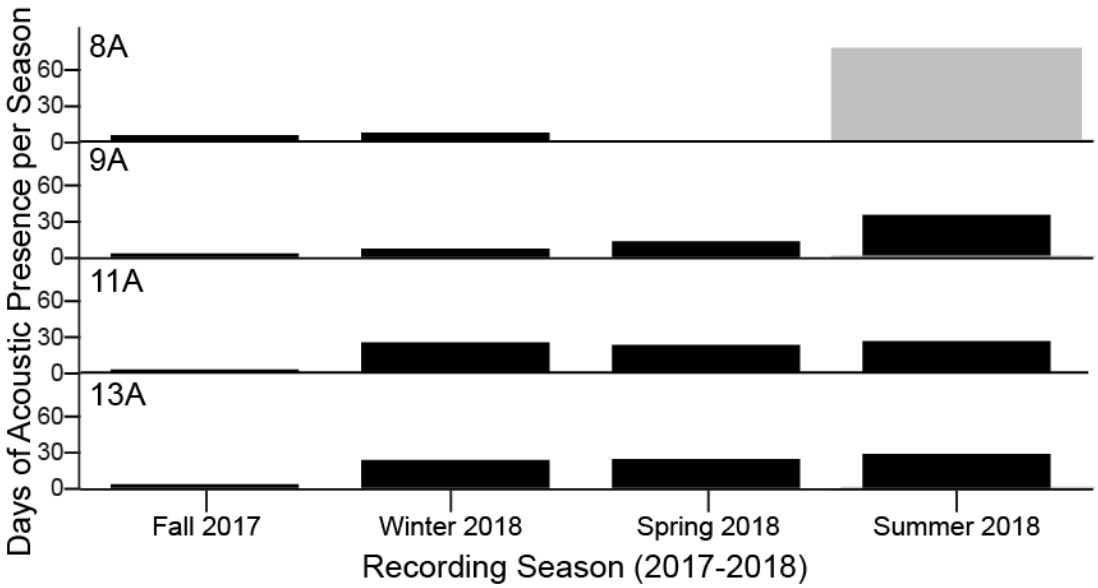


Figure 41. Seasonal acoustic presence of sperm whales detected within New York Bight from Fall 2017 through Summer 2018, shown as number of days per month with confirmed right whale acoustic detections across all AMARs for Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July - September). Gray bars indicate the number of days for each season during which there are no sound data.

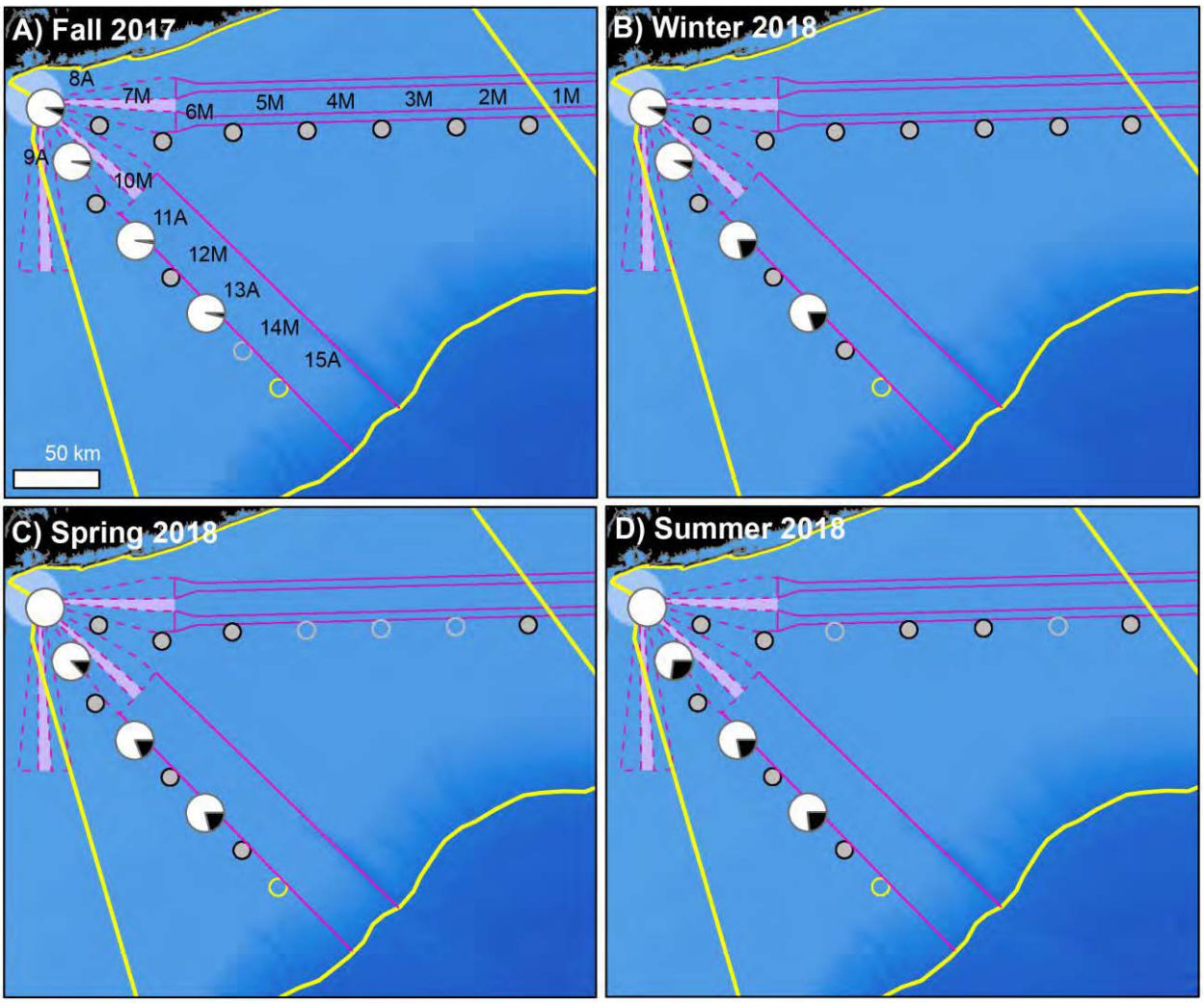


Figure 42. Spatial patterns of seasonal acoustic presence of sperm whales in New York Bight, shown as percentage of days per season on each recording unit. Black indicates the proportion of presence, white indicates no detections. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July-September). Only AMARs were analyzed for sperm whale presence; MARUs were not included in the analysis and are greyed out for clarity. Hollow circles denote AMAR (in yellow) and MARU (in grey) site locations in which there are no data for that season

AMBIENT NOISE ANALYSIS

Average Ambient Noise Levels

Median 10-minute average ambient noise levels across all whale bands ranged between 80 dB (blue whale frequency band) and 112 dB (humpback whale band). Within the right whale, humpback whale, and sei whale frequency bands (between 28 and 708 Hz), site 6M recorded the lowest median ambient noise levels and site 2M recorded the highest median ambient noise levels (Table 17). Median noise levels within the right whale frequency band (70 – 244 Hz) across MARU and AMAR sites ranged from 96 (6M) to 107 dB (2M), with the highest 95th percentile noise level of 118 dB at sites 1M, 2M, and 3M. Within the humpback whale frequency band (28 – 708 Hz), the highest 95th percentile noise level was also recorded at sites 1M, 2M and 3M (124 dB). Median noise levels within the humpback whale band ranged between 102 (6M) to 112 dB (2M and 3M). Median noise levels within the sei whale frequency band (28 – 89 Hz) ranged from 98 dB (site 6M) to 109 dB (site 2M). The highest median noise levels in the fin and blue whale bands occurred at site 3M (103 dB and 102 dB, respectively). Median noise levels in the sperm whale band at the AMAR sites had little variation, ranging from 94 dB to 99 dB. For additional ambient noise analyses, please see Appendix A.

Table 17. Average 10-minute ambient noise levels within each target species frequency band from October 2017 – October 2018. Ambient noise levels are represented as Sound Level Equivalent (Leq, 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	118	106	94	124	111	100	123	108	96
2M	118	107	100	124	112	106	123	109	99
3M	118	106	93	124	112	101	121	108	95
4M	115	103	92	121	110	101	119	105	95
5M	116	105	98	123	110	103	119	104	94
6M	108	96	88	114	102	94	111	98	90
7M	115	102	90	119	106	95	116	99	87
8A	116	104	92	122	110	97	118	104	93
9A	114	102	92	119	107	96	117	102	90
10M	115	104	95	120	109	100	117	103	95
11A	113	102	93	119	108	99	114	102	94
12M	115	104	95	120	109	100	117	103	95
13A	114	103	94	119	108	100	114	103	95
14M	112	99	92	117	105	99	115	102	95
15A	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 14, continued. Average 10-minute ambient noise levels within each target species frequency band from October 2017 – July 2018. Ambient noise levels are represented as Sound Level Equivalent (Leq, 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	113	100	87	111	99	86			
2M	113	102	93	111	101	91			
3M	115	103	91	114	102	90			
4M	114	99	88	113	97	85			
5M	114	93	86	113	91	85			
6M	105	87	81	104	84	80			
7M	100	82	72	97	80	72			
8A	117	97	82	117	95	81	104	94	82
9A	109	90	76	108	87	75	104	96	82
10M	111	95	85	111	94	83			
11A	113	97	84	112	96	82	111	99	89
12M	111	95	85	111	94	83			
13A	113	95	83	113	94	81	107	98	88
14M	105	93	88	103	91	86			
15A	NA	NA	NA	NA	NA	NA	NA	NA	NA

Ambient Noise Analysis: Cumulative Percent Distribution

The cumulative percent distribution plots illustrate the variation in ambient noise levels across sites within the frequency band of each target species (

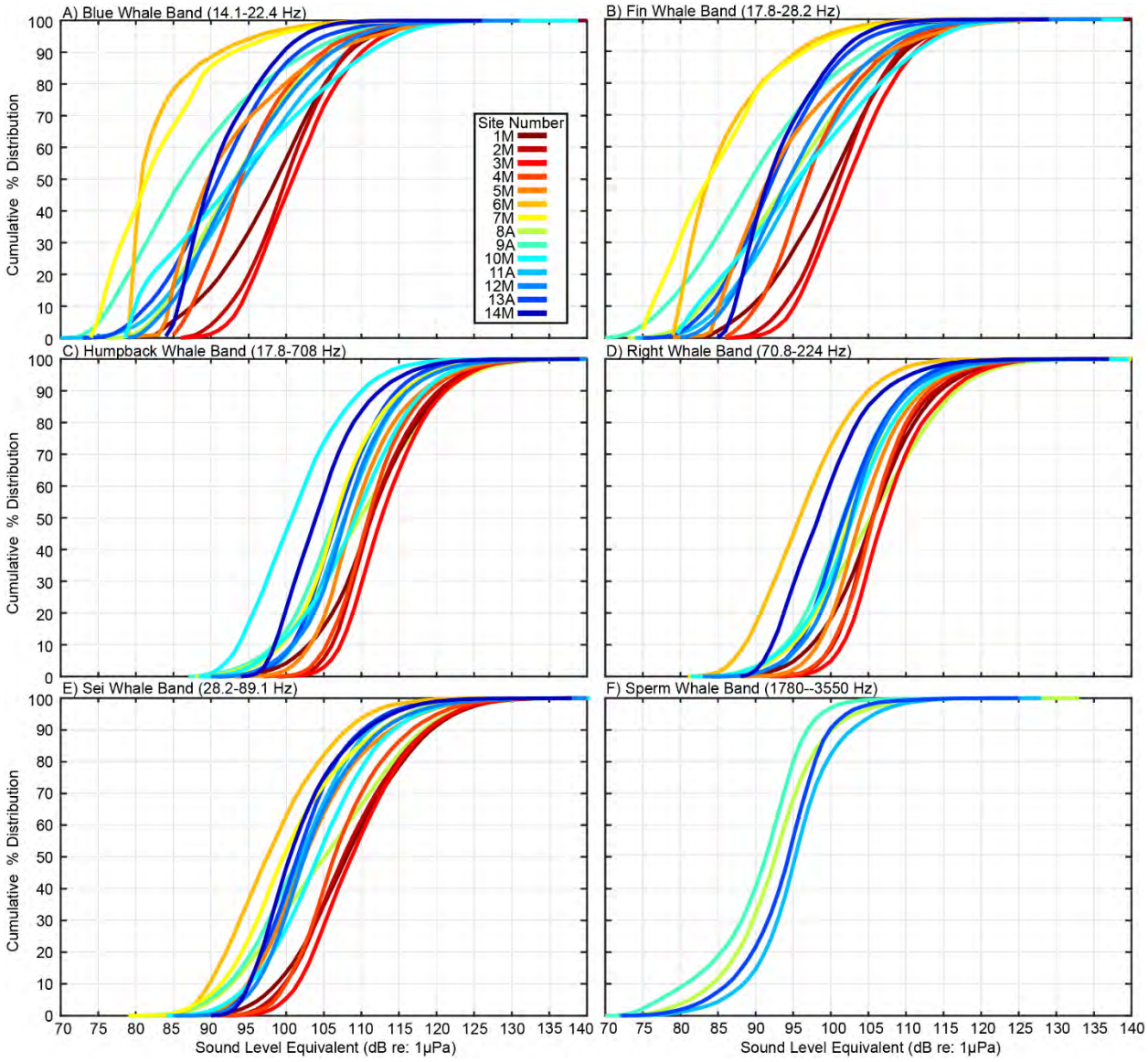


Figure 43). In the blue whale (

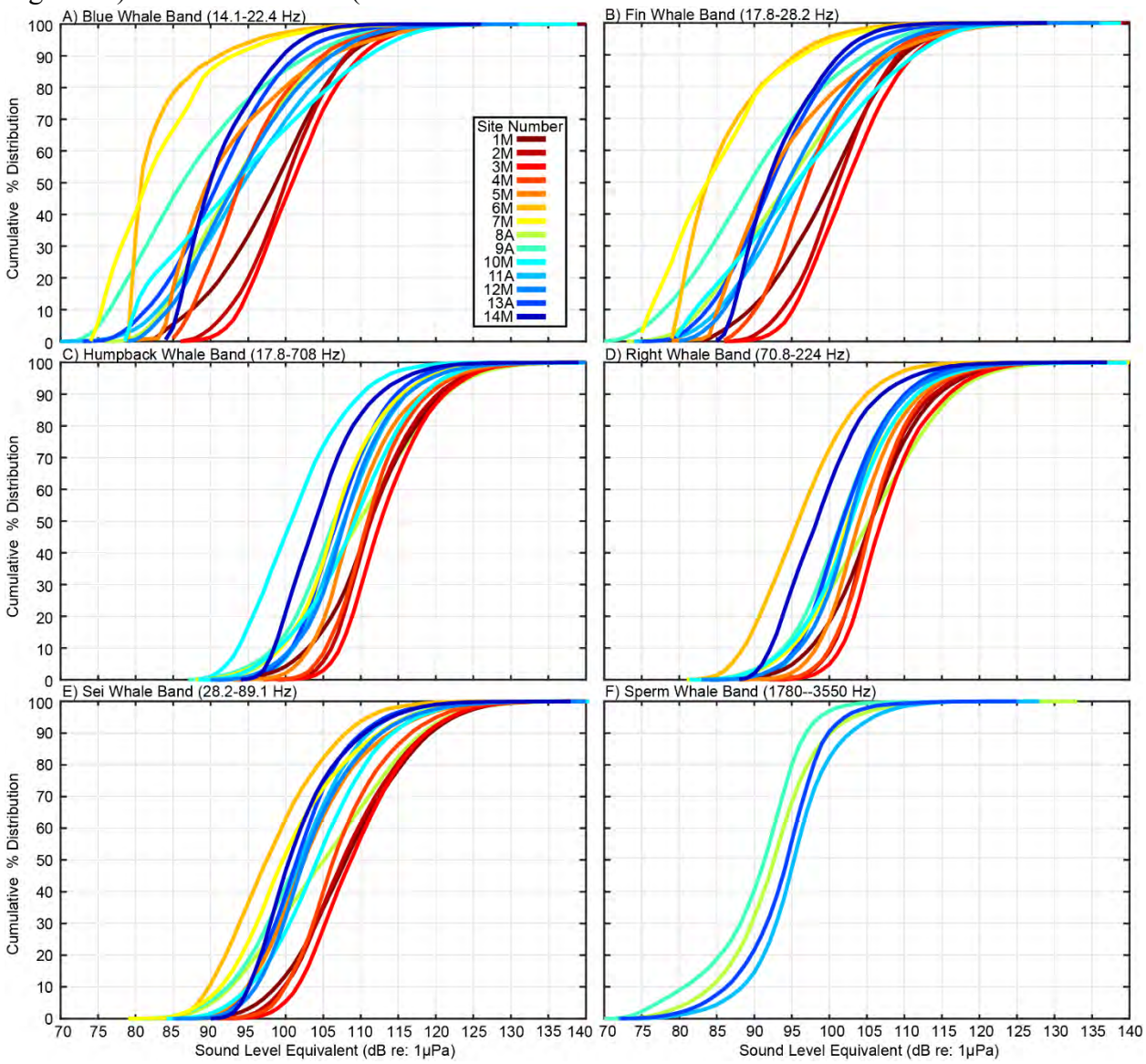


Figure 43A) and fin whale (

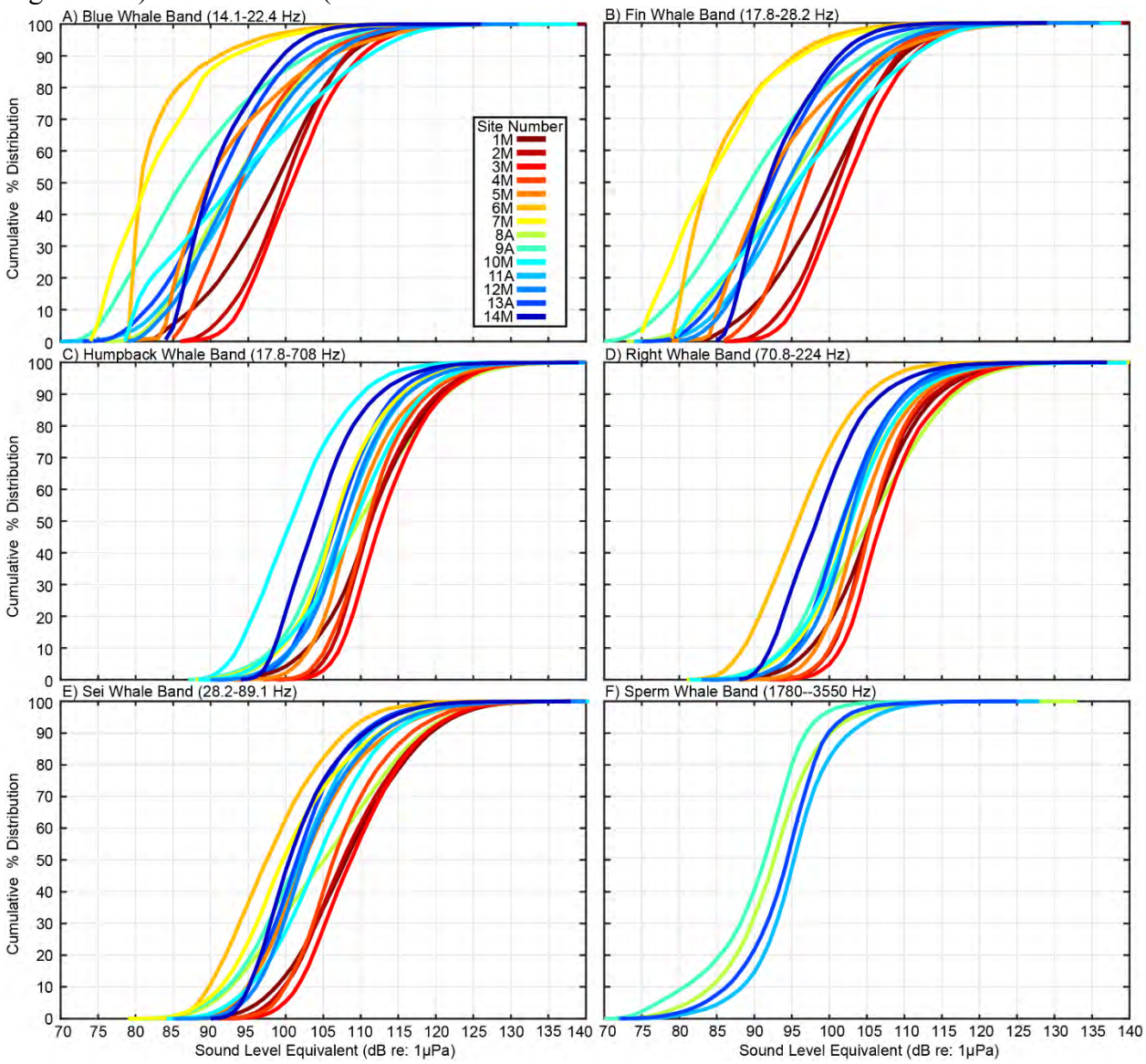


Figure 43B) frequency bands, sites 6M and 7M recorded the lowest noise levels, with measured noise levels below 87 dB approximately 50% of the time. Site 3M recorded the highest noise levels within those two frequency bands, with noise levels exceeding 100 dB 50% of the time.

For humpback whales (

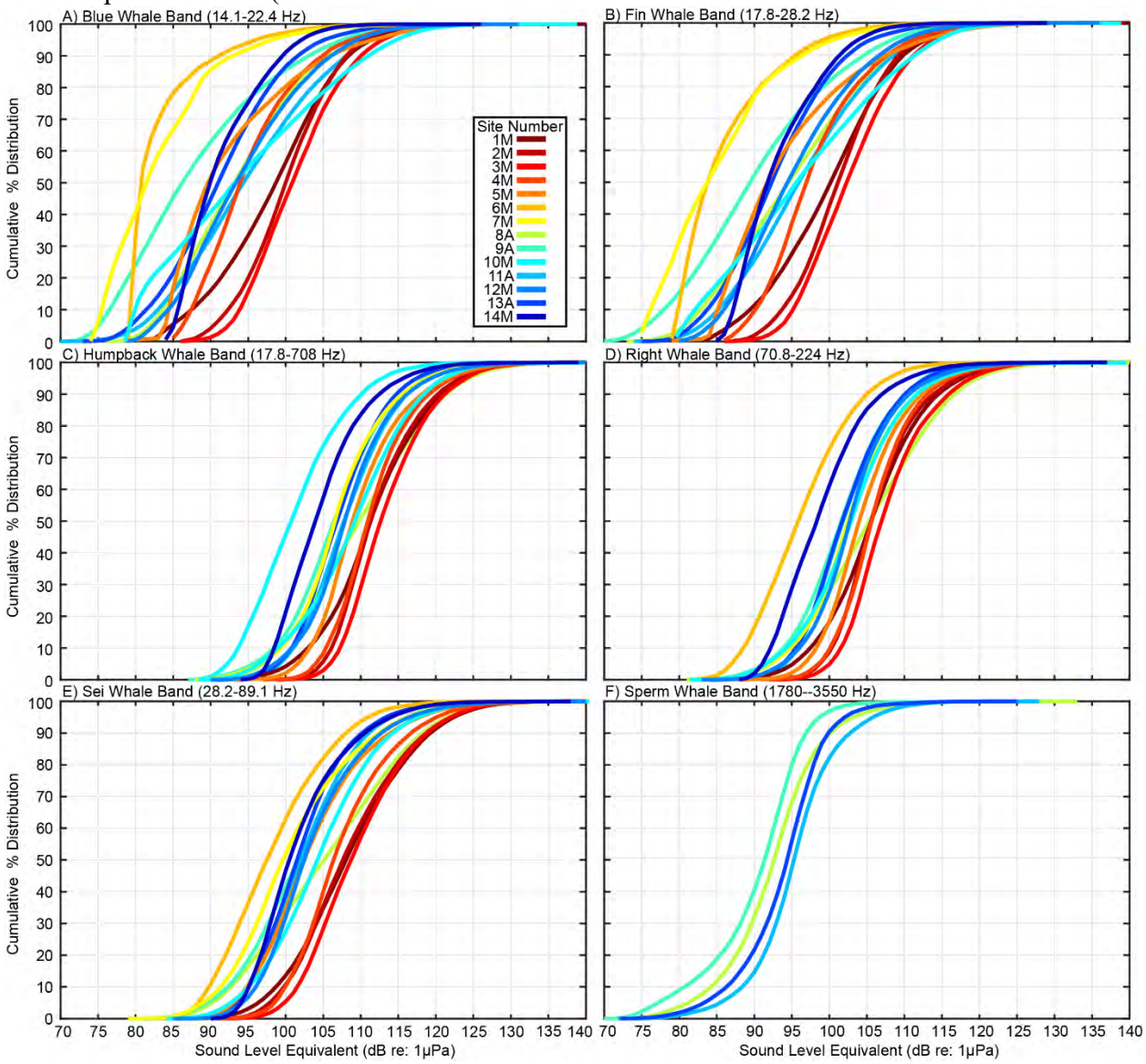


Figure 43C), site 10M was quietest overall, with noise levels less than 100 dB approximately 50% of the recording period. Site 3M recorded the highest noise levels, with noise exceeding 112

dB 50% of the time. For right whales (

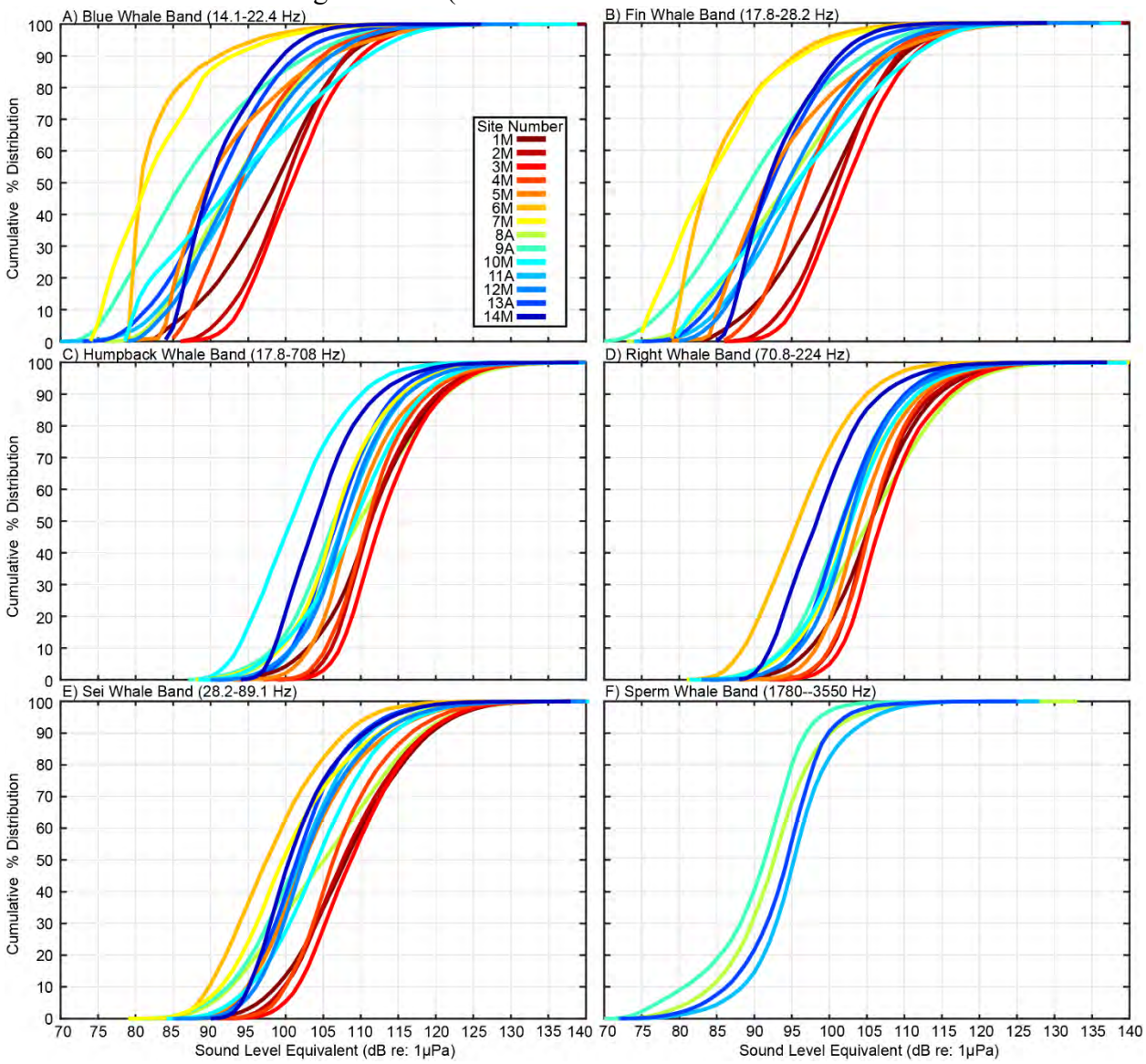


Figure 43D) and sei whales (

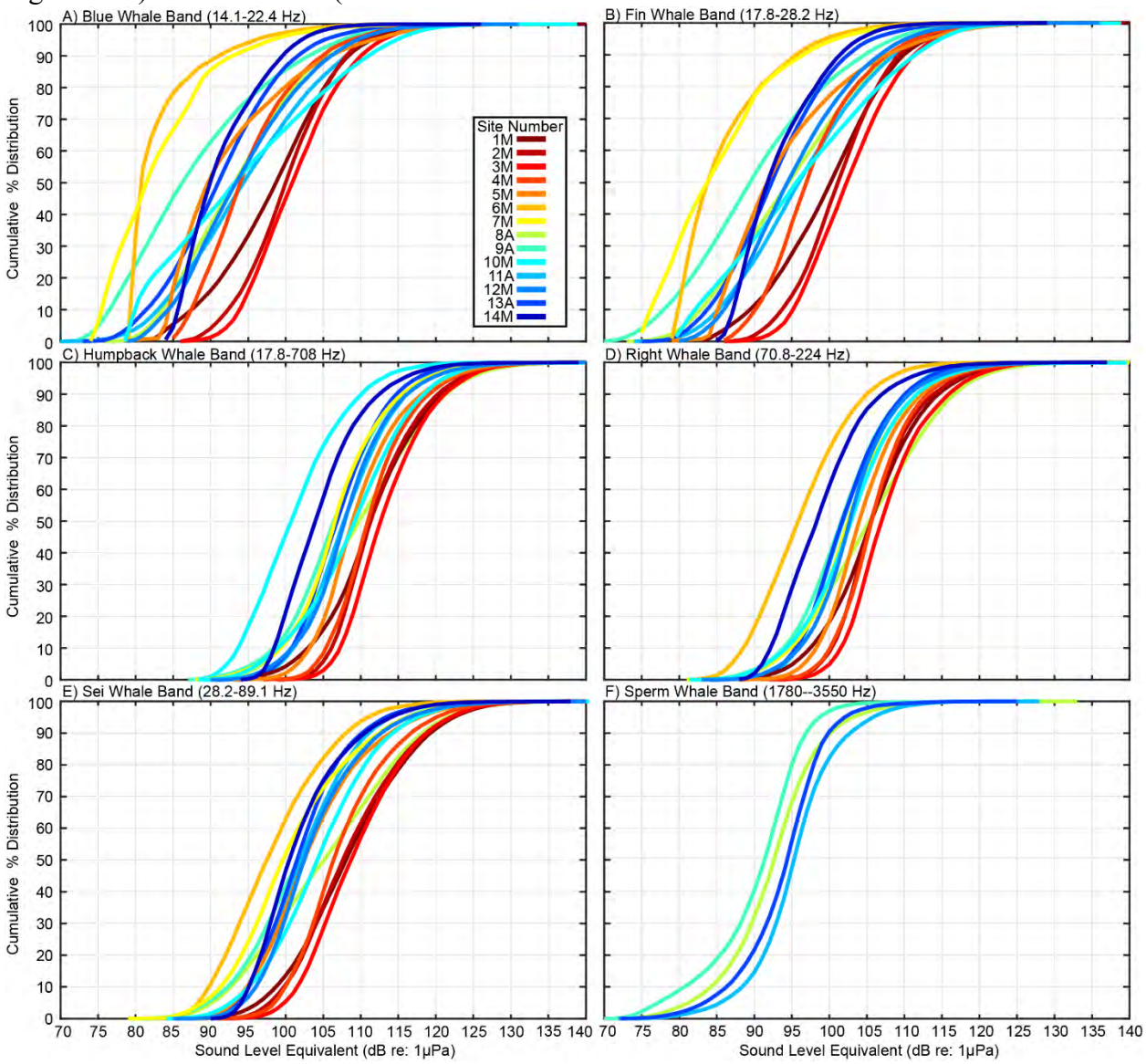


Figure 43E), site 6M recorded the lowest noise level, followed by site 14M (also see Table 17). For those same species frequency bands, sites 1M, 2M, and 3M recorded the highest noise levels, with noise levels exceeding 100 dB at least 50% of the time throughout Year-1. For noise levels within the sperm whale frequency band, we only measured noise levels at the AMAR sites, since they had a high enough sample rate to encompass the sperm whale frequency band. Noise levels in that band were similar across the four AMAR sites, with the highest noise levels at site 11A, exceeding 96 dB 50% of the time, and lowest at site sites 9A and 13A, where noise levels exceeded 92 dB 50% of the time.

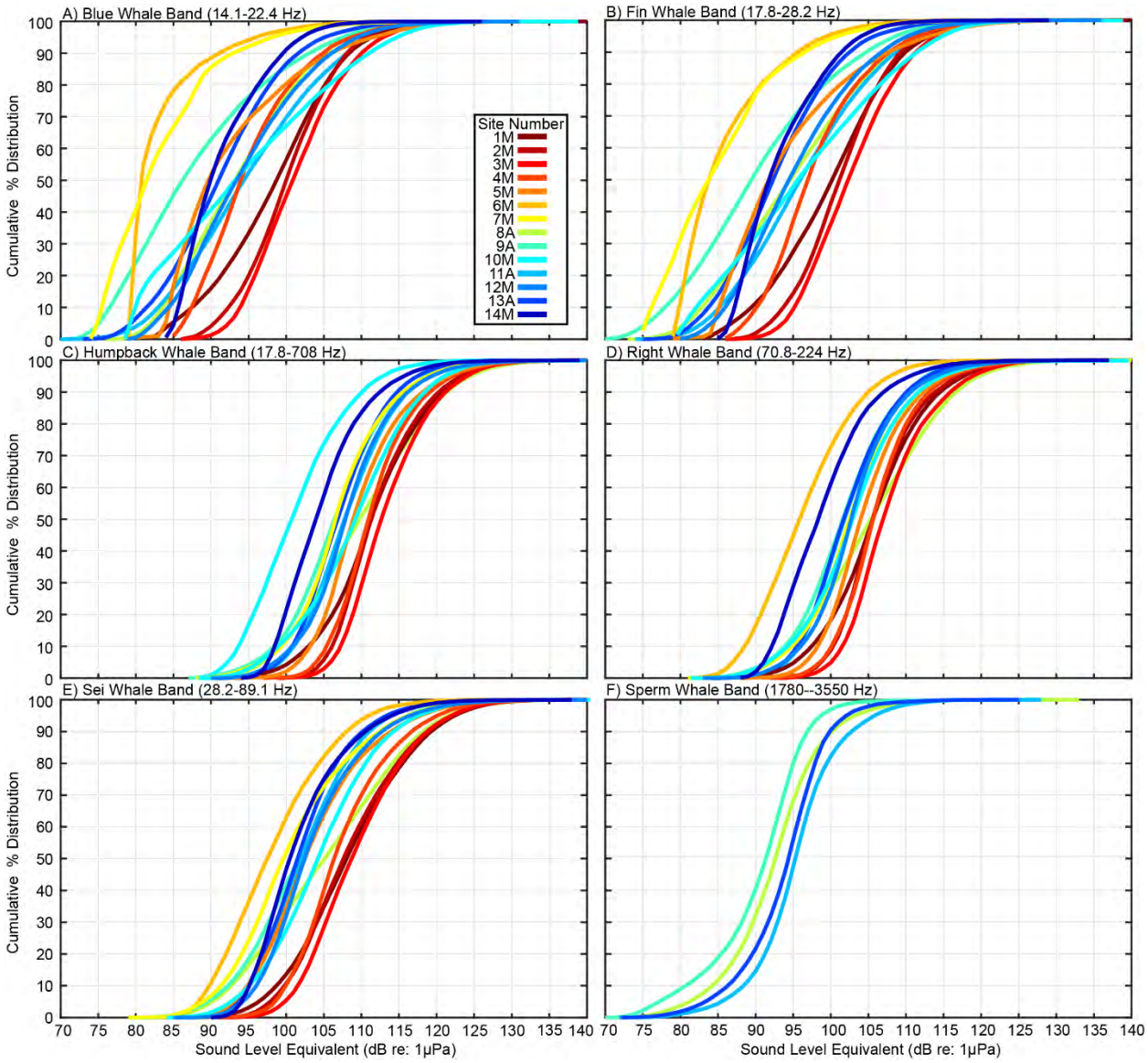


Figure 43. Cumulative percent distribution of ambient noise levels for each recording site in different whale frequency bands, measured in 10-minute averages. A) blue whale, B) fin whale, C) humpback whale, D) right whale, E) sei whale, and F) sperm whale frequency bands.

Masking Potential

Masking potential was evaluated using preliminary detection range models as a function of the ambient noise environment. To 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 18, Table 19 and Figure 54 - Figure 55 for range estimates of representative sites). For North Atlantic right whales (Figure 44), the estimated detection range at the quietest site (6M) based on median (L_{50}) noise levels is approximately 15 km, while the range at the louder site (2A) is approximately 2 km. Therefore, the range in which an upcall is detectable is estimated to be much smaller near site 2A than site 6M. During the 5th percentile noise conditions (referred to as L_{95}) at site 6M, upcalls are estimated to be detectable

up to 30 km. For humpback whales, the same two sites were compared (Figure 45), resulting in an estimated detection range at site 6M (L_{50} = 97 dB) of approximately 4 km, and 1 km at site 2A (L_{50} = 110 dB), given the median noise levels. In the 5th percentile noise conditions (L_{95}) at site 6M (L_{95} = 95 dB), humpback signals are estimated to be detectable out to 11 km. In the sei whale frequency band (45 – 112 Hz), sites 6M and 2M (Figure 46) recorded the lowest and highest median noise levels, respectively. Estimated detection range for sei whale downsweeps during median noise levels is approximately 25 km for site 6M (L_{50} = 98 dB) and < 6 km at site 2M (L_{50} = 109 dB). During the 5th percentile noise levels (L_{95} = 90 dB) at site 6M, sei whale signals are estimated to be detectable to ranges >65 km. Fin whale 20-Hz pulses can be detected over potentially very large distances (Figure 47), where estimated detection range at site 6M (L_{50} = 91 dB) exceeds 250 km. During the lowest ambient noise conditions (L_{95} = 80 dB) the pulses are estimated to be detectable at ranges exceeding 800 km, however, these ranges are dependent on the bathymetry and noise conditions out to such distances. At the loudest (L_{50} = 104 dB) site (3M), fin whale 20-Hz pulses are estimated to be detectable out to 50 km. Similarly, blue whale (Figure 48) song was estimated to be detectable over a range of 1,000 km during median noise levels (L_{50} = 84 dB) at site 7M, and approximately 130 km at site 3M (L_{50} = 102 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.

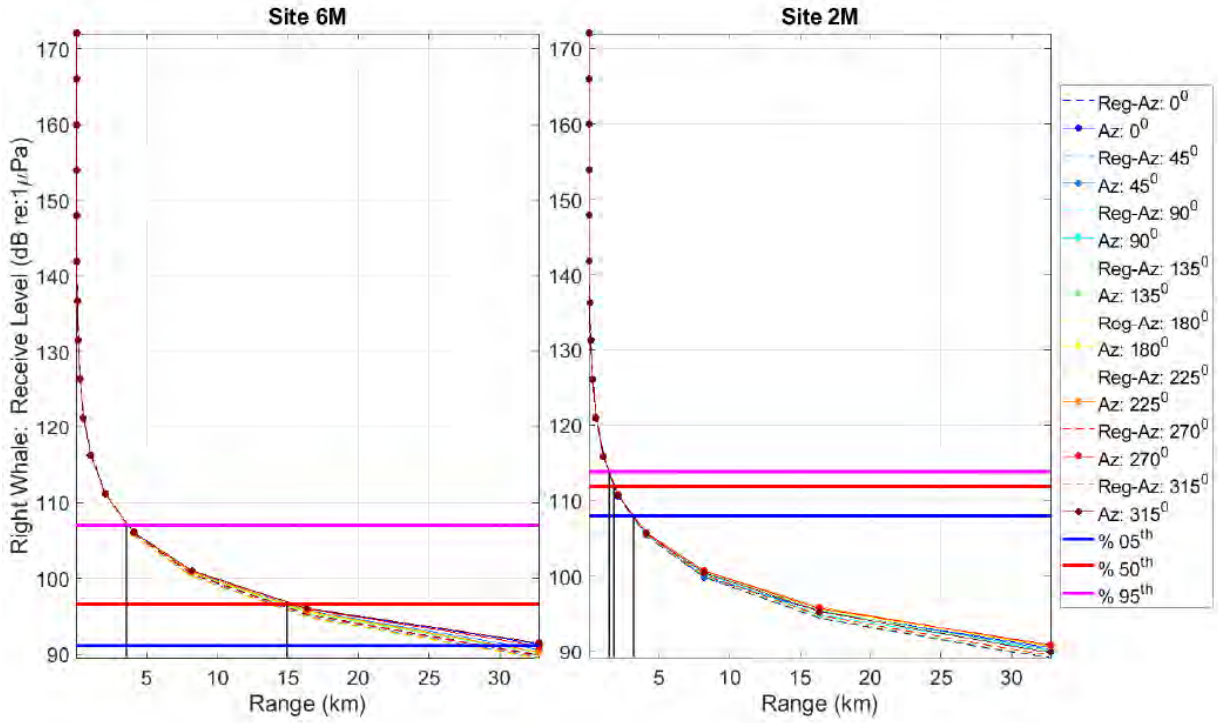


Figure 44. Estimated detection ranges of North Atlantic right whale upcalls under varying noise conditions(in km), given the estimated source level of 172 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (2M) in the right whale frequency band (71 – 224 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

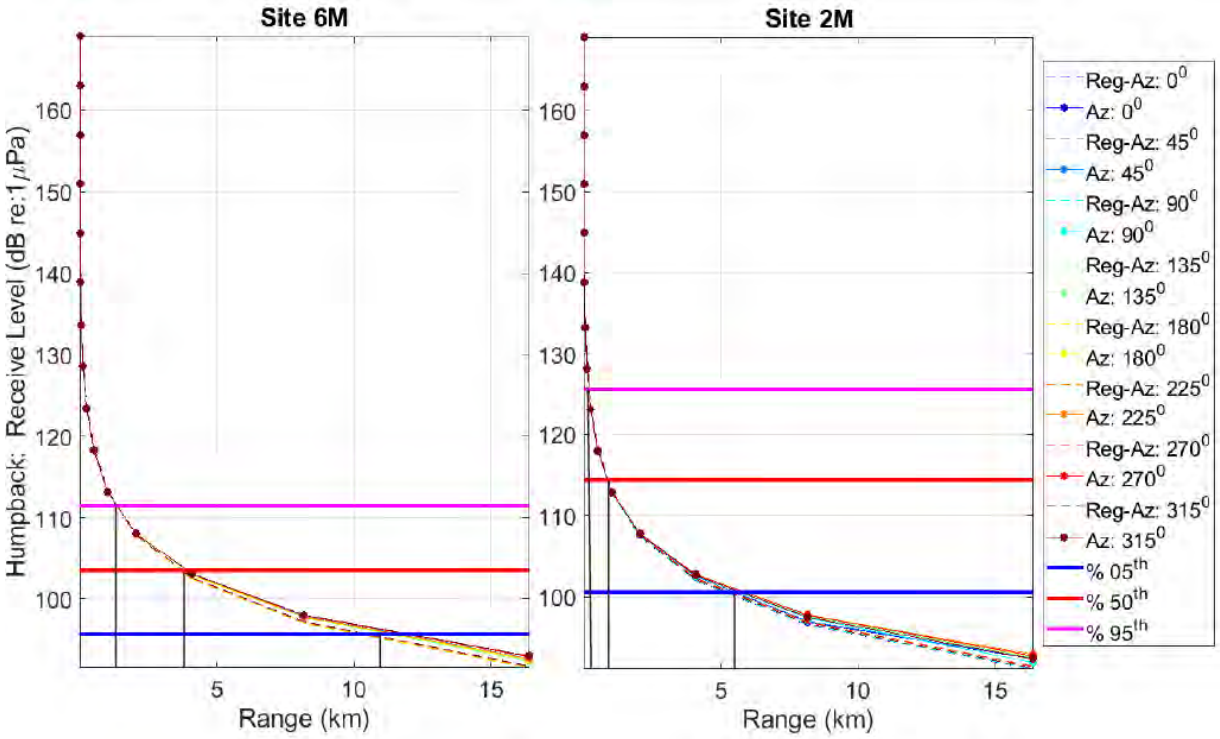


Figure 45. Estimated detection ranges of humpback whale calls under varying noise conditions (in km), given the estimated source level of 169 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (8A) in the humpback whale frequency band (28 – 708 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

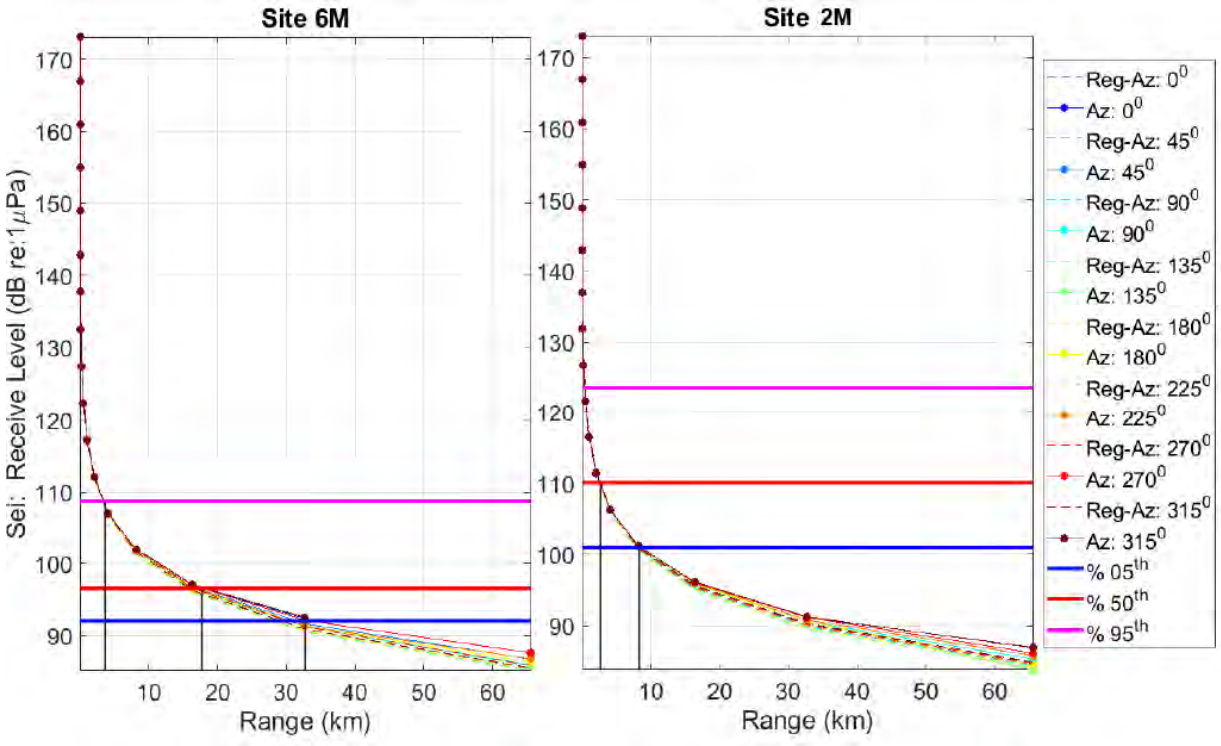


Figure 46. Estimated detection ranges of sei whale downsweeps under varying noise conditions (in km), given the estimated source level of 173 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (3M) in the sei whale frequency band (45 – 112 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

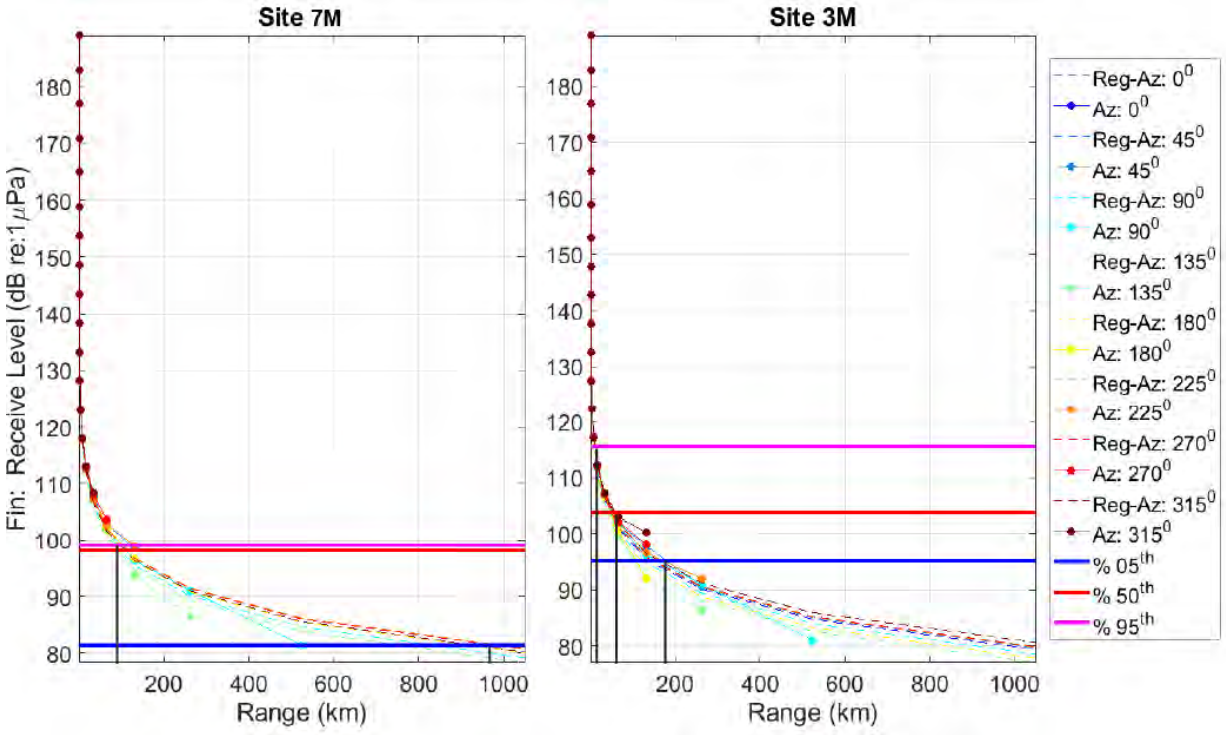


Figure 47. Estimated detection ranges of fin whale 20-Hz pulses under varying noise conditions (in km), given the estimated source level of 189 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (3M) in the fin whale frequency band (18 – 28 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

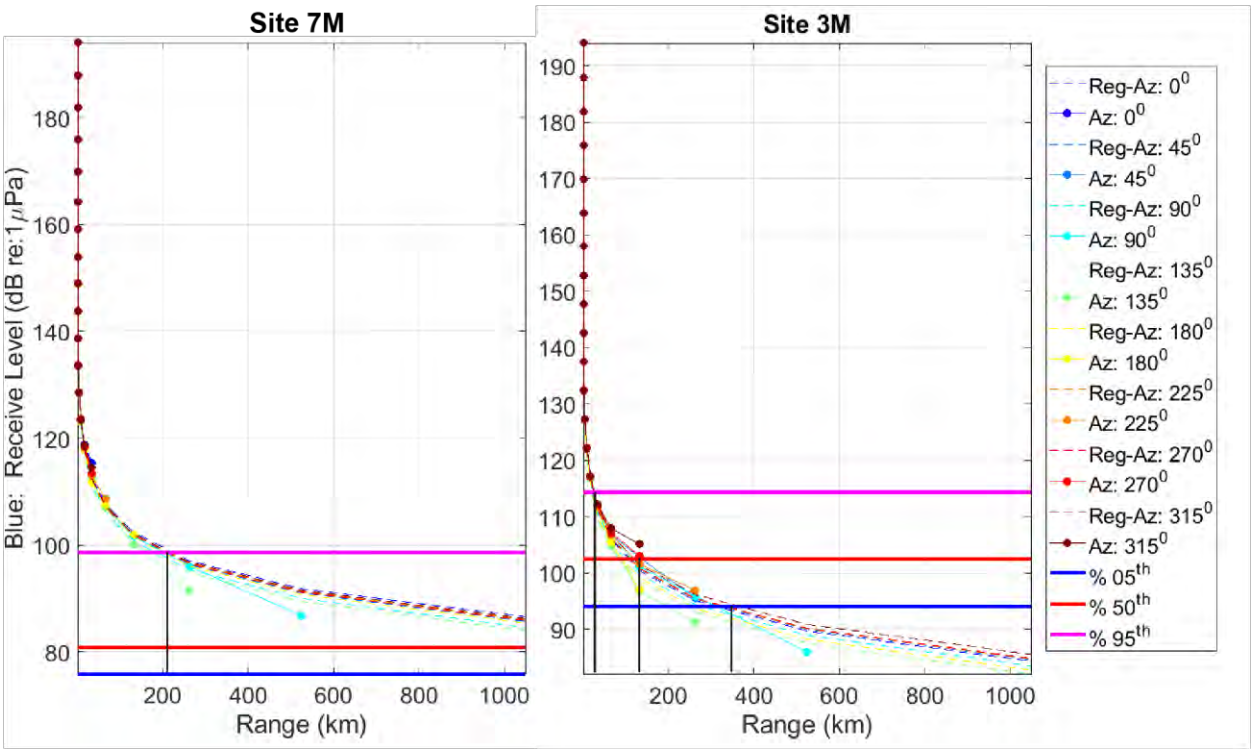


Figure 48. Estimated detection ranges of blue whale calls under varying noise conditions(in km), given the estimated source level of 194 dB re: 1µPa @ 1m for the lowest noise (7M) and highest (3M) sites within the blue whale frequency band (14 – 22 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

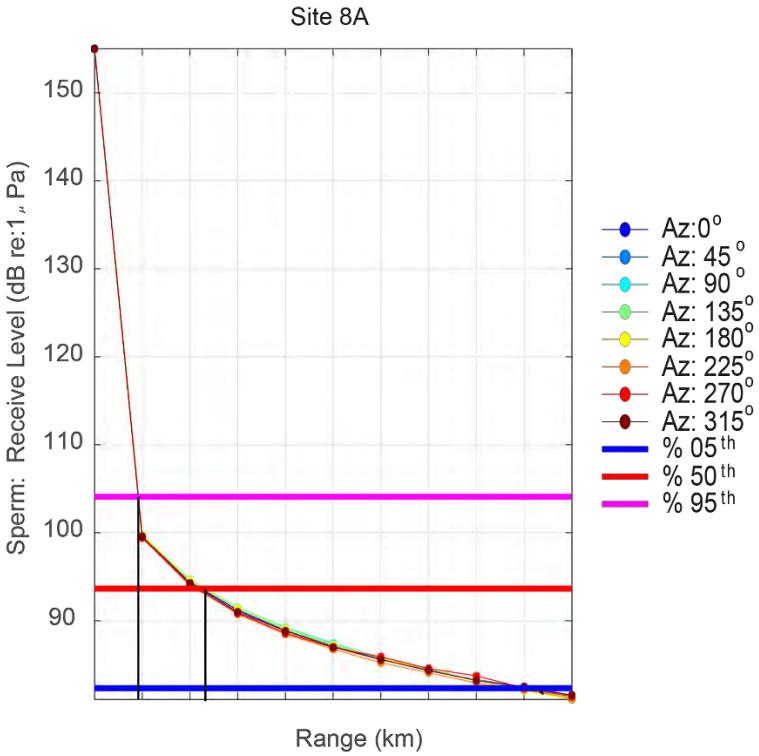


Figure 49. Estimated detection ranges of sperm whale clicks under varying noise conditions (in km), given the estimated source level of 194 dB re: 1µPa @ site 8A within the blue whale frequency band (14 – 22 Hz) between October 2017 and July 2018. All AMARs had similar noise values. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.

Table 18. Detection range estimates at representative sites for all target baleen whale species based on median noise levels

Site	North Atlantic Right Whale Detection Range (km)	Humpback Whale Detection Range (km)	Fin Whale Detection Range (km)	Sei Whale Detection Range (km)	Blue Whale Detection Range (km)
1M	4	1	80	6	149
4M	6	2	98	9	188
8A	7	2	131	9	241
12M	6	2	125	11	200
14M	9	3	170	13	279

Table 19. Detection range estimates at representative sites for sperm whales based on median noise levels

Site	Sperm Whale Detection Range (km)
8A	1
9A	2
11A	1
13A	1

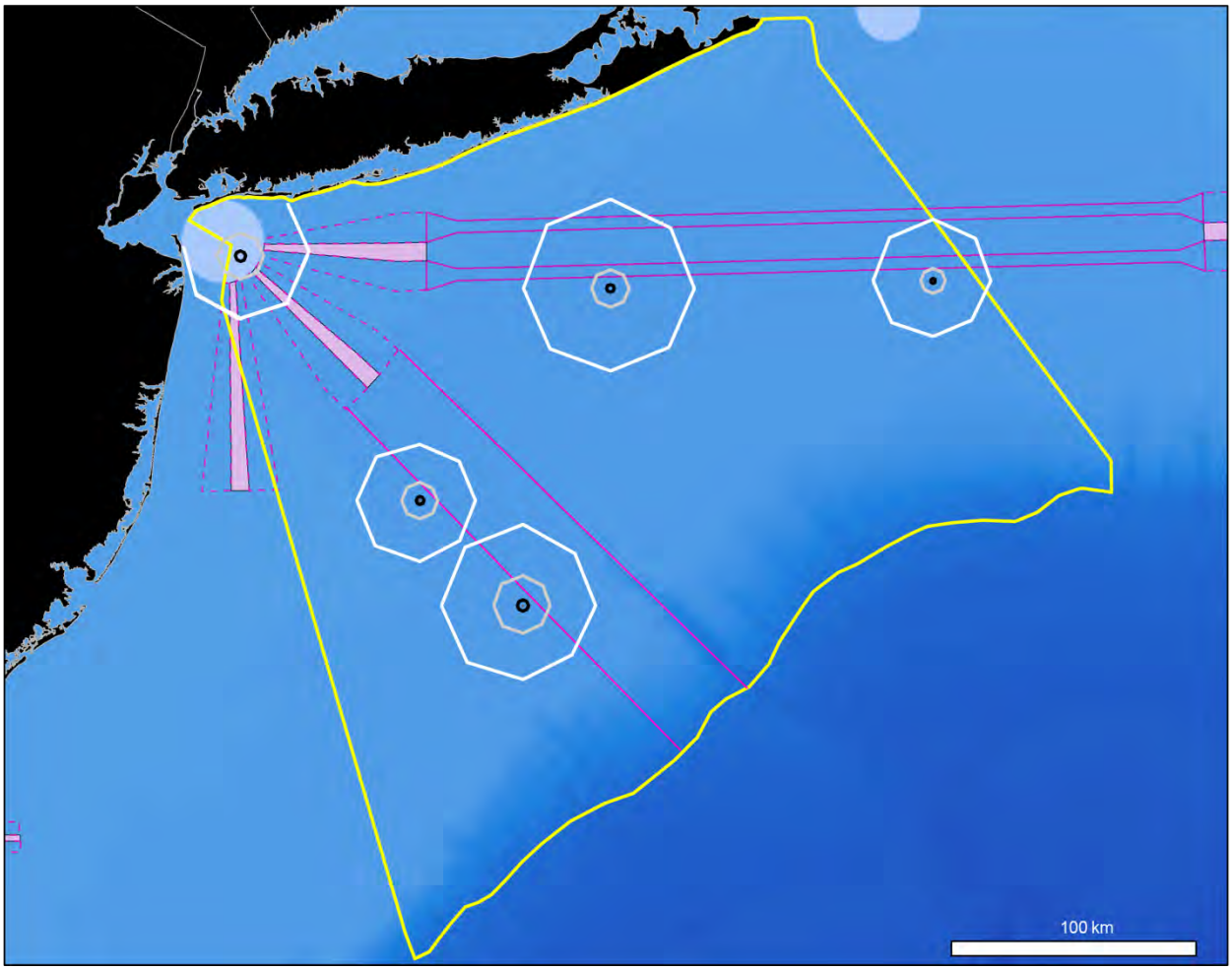


Figure 50. Map of estimated North Atlantic right whale acoustic detection ranges under different noise conditions for representative sites 1M, 4M, 8A, 12M, and 14M. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

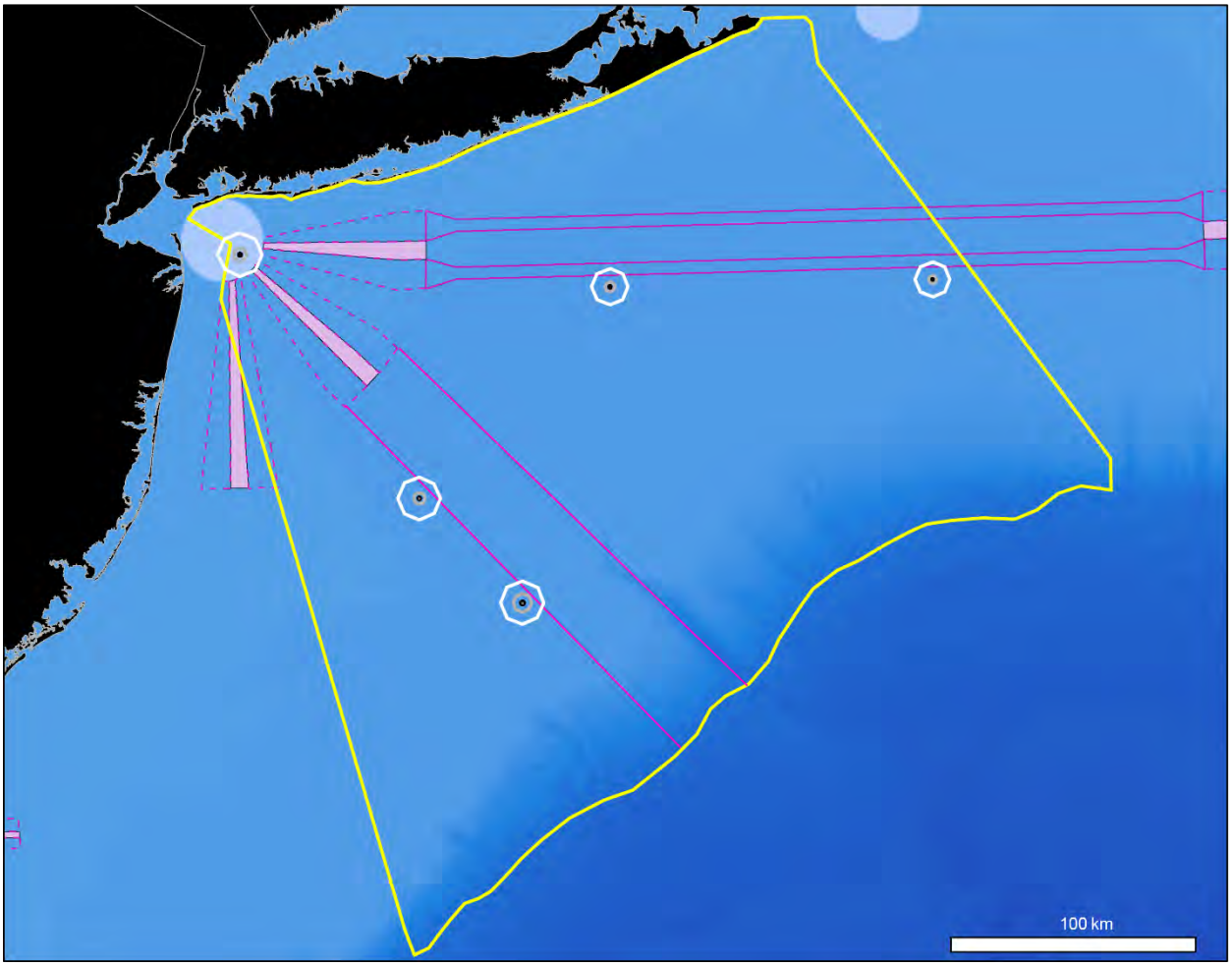


Figure 51. Map of estimated humpback whale detection ranges under different noise conditions for representative sites 1M, 4M, 8A, 12M, and 14M. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

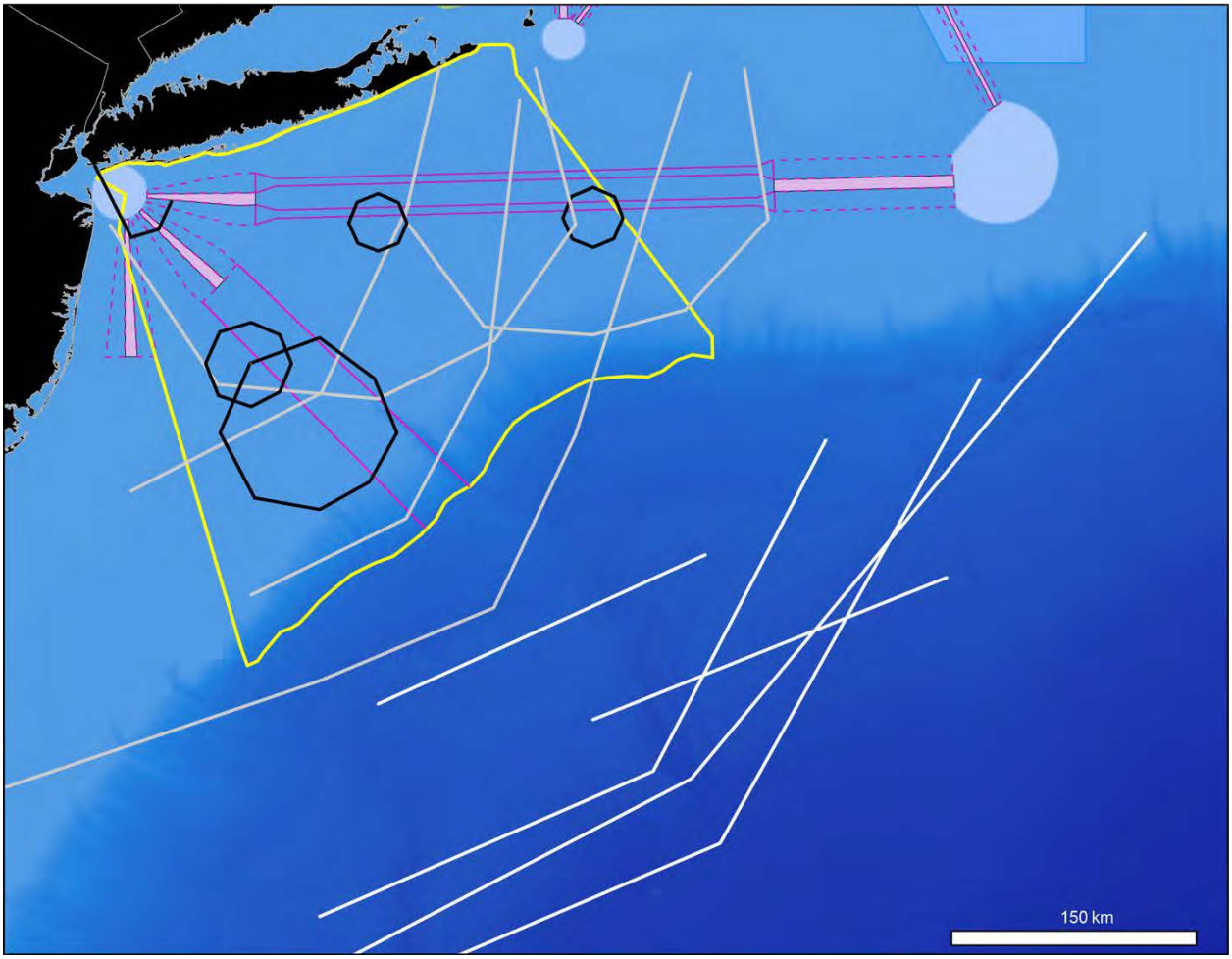


Figure 52. Map of estimated fin whale acoustic detection ranges under different noise conditions for representative sites 1M, 4M, 8A, 12M, and 14M. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

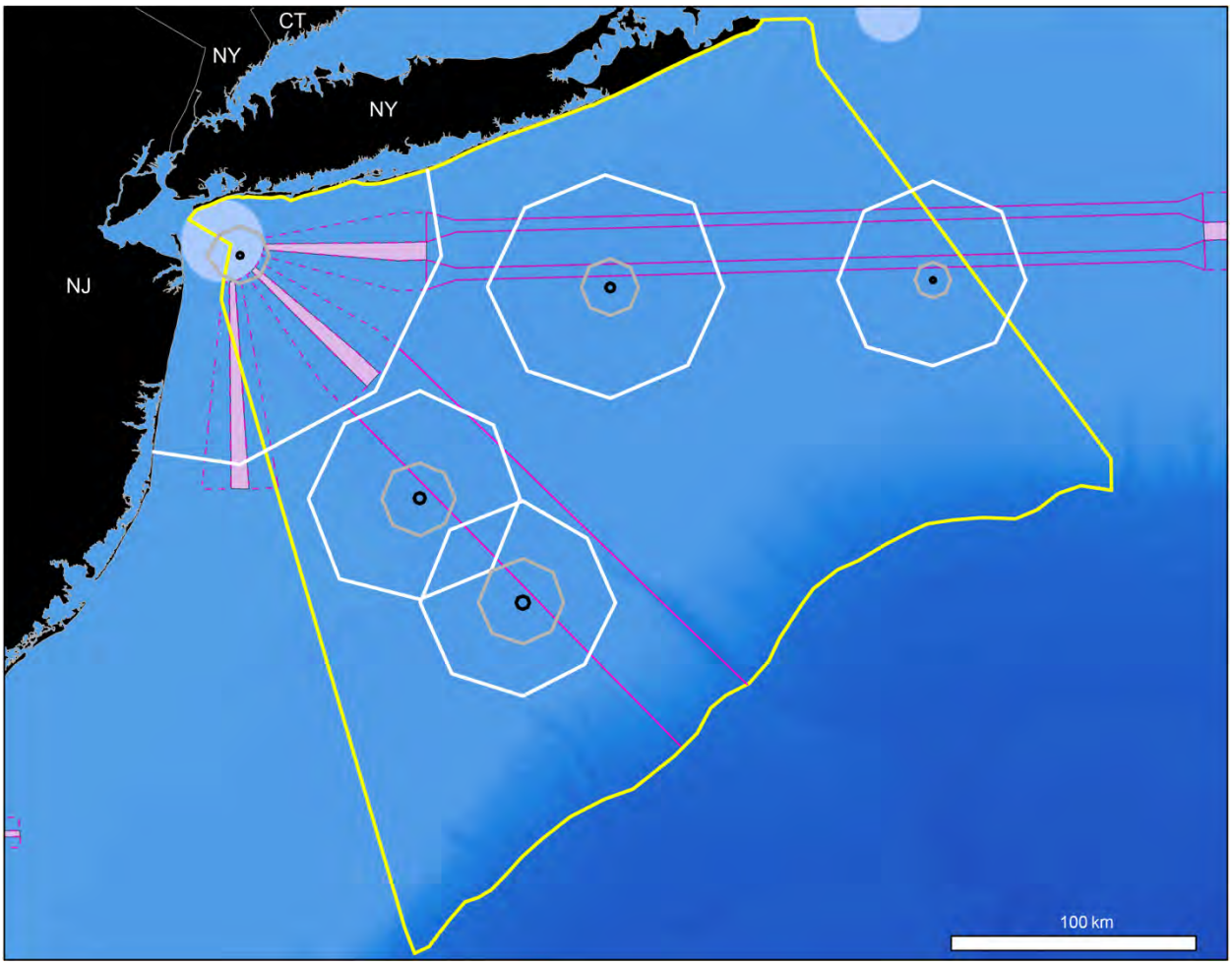


Figure 53. Map of estimated sei whale detection ranges under different noise conditions for representative sites 1M, 4M, 8A, 12M, and 14M. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

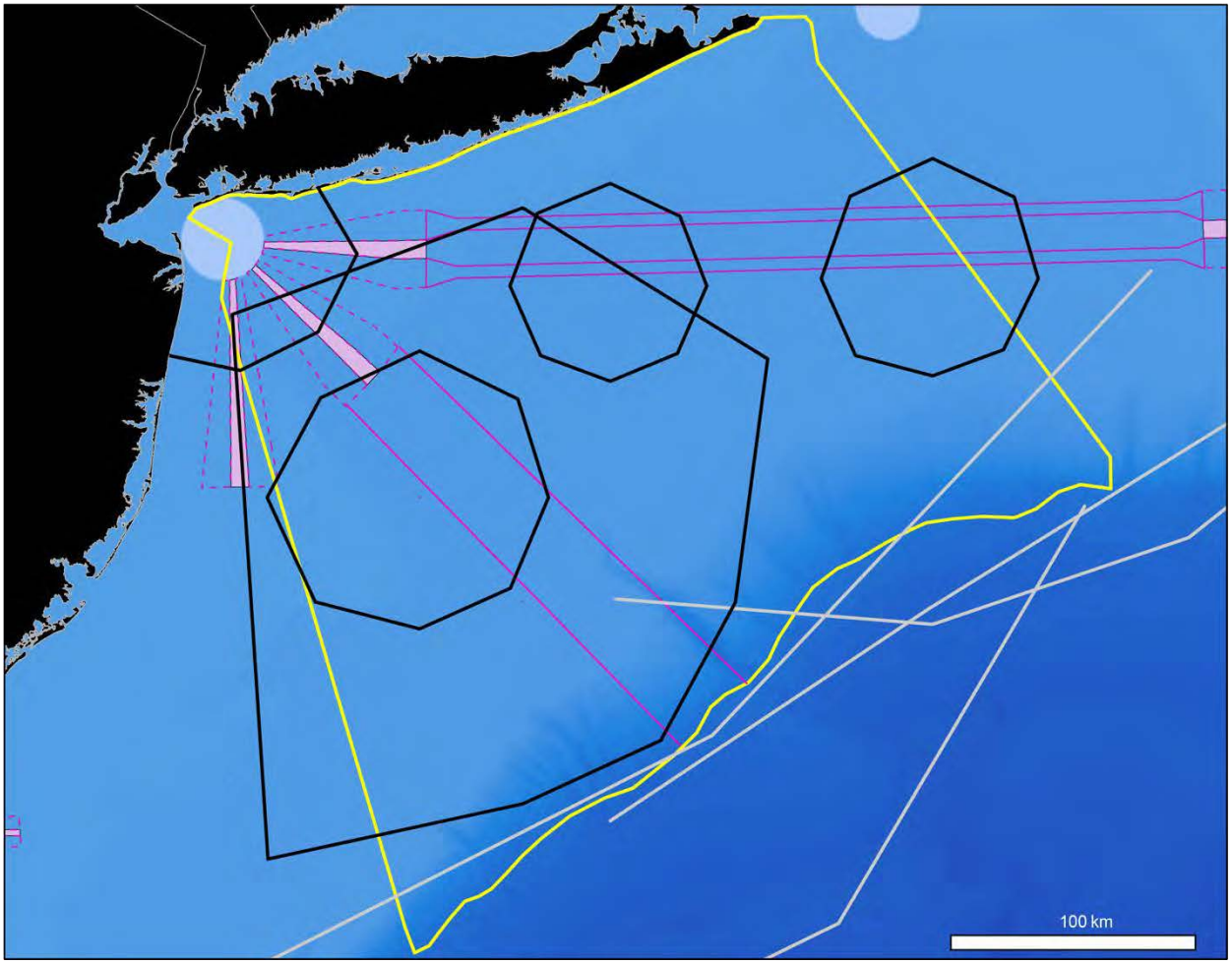


Figure 54. Map of estimated blue whale detection ranges under different noise conditions for representative sites 1M, 4M, 8A, 12M, and 14M. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels. Note that at this spatial scale, detection ranges for the lowest 5th percentile noise conditions are >500 km and outside the bounds of the map (and not shown here).

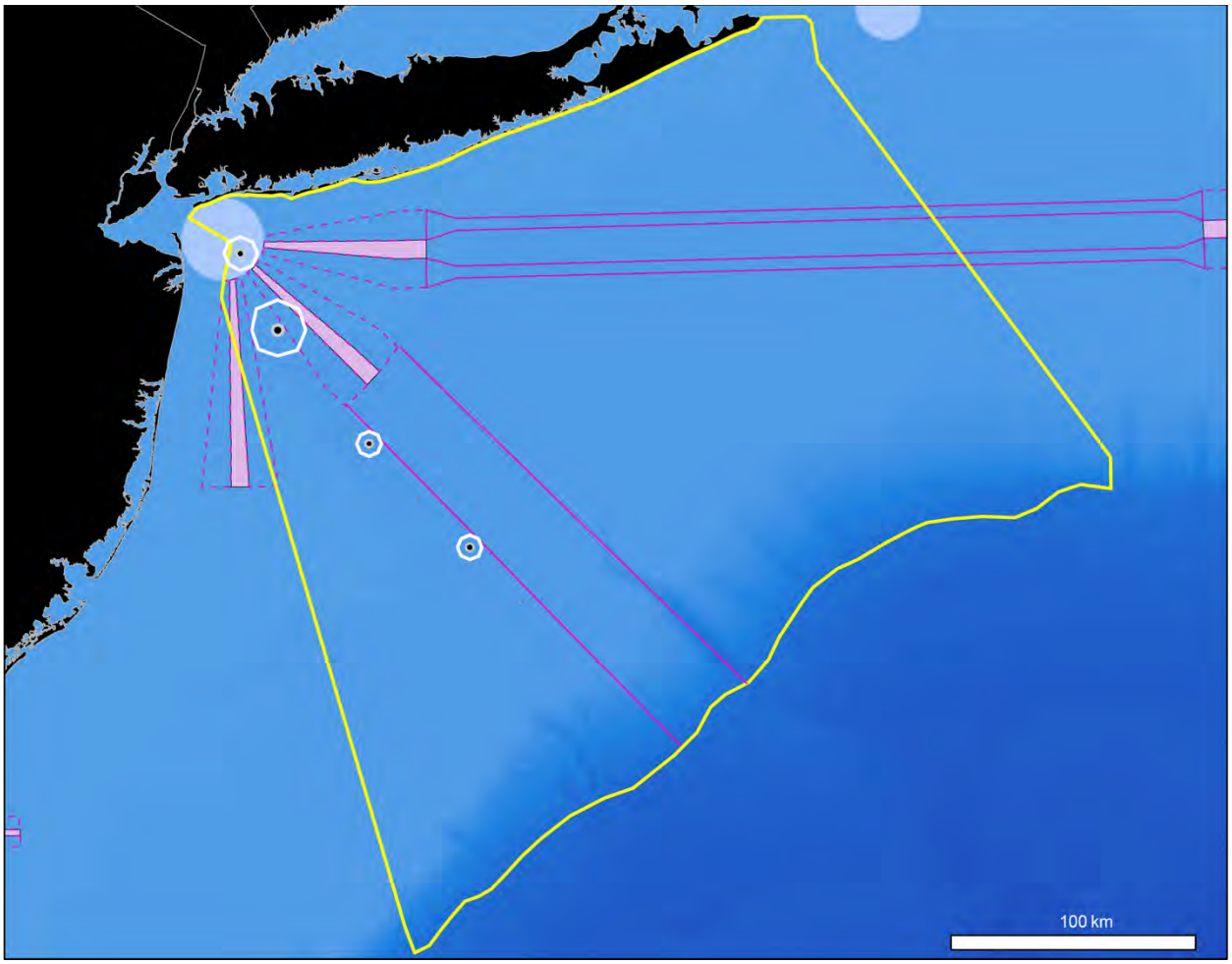


Figure 55. Map of estimated sperm whale acoustic detection ranges under different noise conditions for AMAR sites 8A, 9A, 11A, and 13A. The black lines indicate range based on the 95th percentile noise levels, the grey lines indicate ranges based on median noise levels, and the white lines indicate ranges based on the 5th percentile noise levels.

Discussion

Species Spatiotemporal Trends

Passive acoustic monitoring successfully detected calls from all six priority large whale species in New York Bight during the Year-1 acoustic survey. While false negative detection rates during periods of high anthropogenic noise events from shipping make it challenging to refine spatial residency patterns, we do see extensive presence of all of the six focal whale species at the daily presence temporal resolution.

North Atlantic right whales were detected in the NY Offshore Planning Area in all months of the Year-1 survey. The fewest right whale detections occurred in October, but then increase in in November and December which could represent the majority of the southward migration. However, in the winter of 2017-2018, there were a low number of whales sighted in the southeast, and no calves born. This may mean that the number of migrating whales was particularly low during the 2017-2018 winter season and may not be representative of standard right whale habitat usage in the NY Bight. It is interesting that whales were in the Bight in February-July, since this corresponds to the time period where they have previously been observed in in the more northerly feeding grounds in Cape Cod Bay, and further north in the Gulf of Maine (Bort et al. 2015, Clark et al. 2010, Davis et al. 2017, Mayo et al. 2018, Nichols et al. 2008). With the recent observation of right whales feeding in the nearby Massachusetts and Rhode Island wind planning area (Leiter et al. 2017, Stone et al. 2017), it is possible right whales could be feeding in New York Bight. Determining the behavior of right whales in this habitat, and the seasonal and spatial availability of their primary prey, *Calanus finmarchicus,* in the NY would be necessary to determine habitat usage patterns for this species (Albouy-Boyer et al. 2016, Jiang et al. 2007). With increased mortality rates in recent years, the overlap of North Atlantic right whales with the extensive shipping activity warrants concern. Even though only two serious injuries of North Atlantic right whales have been documented in close proximity to the NY Offshore Planning Area (Hayes et al. 2019), there still may be risk of ship strikes or entanglement. Because the detection probability of right whales using acoustics is higher compared to observations through aerial surveys (Clark et al. 2010), the number of right whale aerial observations during this time period (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018) likely under-samples the total number of right whales in NY Bight at any given time.

Similar to what has been previously reported (Morano et al. 2012b, Muirhead et al. 2018), fin whale detections regularly occur within the Bight. In fact, they are the most regularly detected of all whale species in the area, due to high call detection rates and large detection ranges. Both fin whales and humpback whales have been regularly observed during the concurrent aerial surveys (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). Fin whales are detected within the study region nearly all the time, with 8A in Spring and Summer having no detections. The lack of fin whale detections on some sensors in certain months suggests that the high level of detections on multiple sensors is not just due to the fin whales' large detection range but may also represent multiple whales present within the habitat.

Humpback whales were acoustically detected in the area in all months, though the acoustic detection rates were highest between December and July. This trend, in part, may be driven by humpback whale singing behavior, where individuals produce high signal rates and higher amplitudes during the winter and early spring. Song is not regularly detected during the summer

and fall, and the non-song social signals produced by humpbacks are lower amplitude and produced less regularly, decreasing the likelihood of acoustic detections in the summer and fall (Murray et al. 2014, Stanistreet et al. 2013, Vu et al. 2012). Humpback whales were detected across the entire region throughout the year. The results presented here primarily focus mostly on detections of humpback whale song, with fewer detections of non-song vocalizations, so it is likely that these Year-1 results may be an underestimate of the occurrence of humpback whales in NY Bight. Humpback whale social sounds have a significantly lower source level and are produced less frequently than song (Fournet et al. 2018a, Fournet et al. 2018b), so lower detection rates of social sounds would be expected compared to song. The wide-ranging occurrence throughout NY Bight may reflect the humpback whales' use of the region for producing song in the context of advertisement, or the fact that humpback whales have a diverse diet compared to other whale species (Hayes et al. 2019), so NY Bight may also represent a good feeding ground for humpback whales.

Sei whales were detected less regularly, and were most commonly detected in March-May across the shelf. Highest detections in Spring 2019, primarily at sites 8A-13M. Recorders along the coast of Long Island (sites 1M-5M) had detections in October-March. It is unclear whether these trends represent multiple pulses of whales moving through, or different portions of the population. The acoustic presence data are suggestive of an inshore-offshore movement between Fall-Spring, however, this is difficult to infer from data gaps. These acoustic survey data show that sei whales are more than just occasional visitors to NY Bight, and occur there in most months of the year, in some capacity. In contrast to findings described by Mitchell (1975), the occurrence of sei whales throughout much of the year suggests that the occurrence of sei whales in the NY Offshore Planning Area is more than just a brief migration period to and from northern waters. With the aerial surveys, there were no confirmed sei whale observations in NY Bight in Year-1 (Tetra Tech and Smultea Sciences 2018), and only a single sighting in NY Bight in Year 2 (in April 2018) (Tetra Tech and LGL 2019). The contrast in aerial sightings and the relatively high amount of acoustic presence suggests a lower detection rate for sei whales during aerial surveys than using acoustic recorders.

Blue whales were the most infrequently detected species within the NY Bight. Blue whales were only detected between November and February, and in the Northern and Northeastern area of the Offshore Planning area across many of the Long Island units (1M-3M). From these trends, while it is clear that blue whales are detectable in NY Bight, there are two challenges in interpreting these data. Firstly, as mentioned earlier, the large estimated acoustic detection range of blue whales in this study means that even though bottom-mounted recorders in NY Bight were detecting blue whales, those whales may have been vocalizing from well outside of the NY Offshore Planning Area. However, with the acoustic track of a blue whale described during the previous 2008-2009 Cornell passive acoustic cetacean survey in NY Bight (Muirhead et al. 2018), these data demonstrate that a blue whale has occurred on the shelf within the NY Bight. Additionally, the Tetra Tech aerial surveys identified 4 individual blue whales in January-February 2018 at the shelf edge within the NY Offshore Planning Area (Tetra Tech and LGL 2019, Tetra Tech and Smultea Sciences 2018). Consequently, the acoustic detections of blue whales may not be limited to occurrence offshore. Blue whales were not detected in October, or during spring-summer. It is unclear if blue whales have a relatively nearshore migration in the winter, but then transit south in the central Atlantic to feed (Silva et al. 2013).

Sperm whales were detected in all seasons of the Year-1 survey on the north-south transect of AMARs along the Ambrose-Hudson Canyon shipping lanes. Daily presence was highest in summer on units 9A,11A, and 13A (data from 8A were missing from summer), but there did not appear to be substantial differences in presence as a function of position along the shelf. Fall had the lowest amount of presence on all 4 sensors. Winter and spring presence was higher on the farther offshore units (11A and 13A) compared to the more inshore units. These data contrast the seasonal findings of sperm whales along the Atlantic coast by Stanistreet et al. (2018), where they observed the highest detections in the spring, however, this could be due to different recordings areas on the shelf edge, or that their recorders were not on the shelf as here in NY Bight. Though the number of detections was low, it is particularly interesting that putative detections of sperm whales were recorded at site 8A (near the entrance to the Lower Harbor Estuary) in the Fall and Winter. These sounds satisfied the criteria for our working definition of sperm whale sounds, and while it is unlikely these sounds were produced by other odontocetes (due to their low frequency range) or anthropogenic objects (which often exhibit regular temporal patterning and pronounced doppler shift), further analysis of these click properties could help discern whether these sounds are truly from sperm whales. Corroborating evidence is needed to confirm these findings. Certainly the observation of sperm whales in shallower waters relatively close to Long Island (Scott and Sadove 1997), corroborates our acoustic evidence for sperm whales near sites 8A and 9A. Given the proximity of our recording units near the inshore portion of the Hudson Canyon, it is possible that sperm whales may be foraging well up into the canyon. The short acoustic detection range of the omnidirectional component of sperm whale usual clicks (Figure 55) also suggests that individuals were relatively close to the sensors on which they were acoustically detected.

Noise Trends

Overall, site 8A recorded the highest noise levels among the recording sites. Site 8A is located nearest to the New York harbor and experiences the highest volume of shipping traffic among the sites, where it is at the terminus of the three major shipping lanes in the NY Bight. Noise levels at each site were relatively consistent throughout the survey period, though several loud shipping events stand out (See Appendix A). Site 6M, which is located slightly south of the Nantucket-Ambrose TSS, recorded the lowest median noise levels. Median ambient noise levels were highest within the humpback whale frequency band, which is the broadest of the species bands (28 – 708 Hz). The humpback whale frequency band overlaps with the right whale and sei whale bands.

Masking Potential

Based on the estimated detection ranges for each species, ambient noise levels that were recorded during this survey period in the NY Bight have a strong influence on the detection range of a target species' signal to both recording devices as well as conspecifics. The higher ambient noise levels can drastically decrease the signal-to-noise ratio of the sound, thus reducing the spatial area over which it can be detected. It is important to understand how whales behaviorally and physiologically respond during periods of increased noise, as these changes may also impact the acoustic detectability of the calls that whale produce. For example, whales

may reduce call production rates during periods of increased noise, or maintain normal calling behavior, which would result in a reduction of acoustic detectability. Alternatively, whales might increase the amplitude or production rate of their calls, both behavioral modifications that would reduce the masking effects of noise both to conspecifics and passive acoustic monitoring systems. The ecological consequences of short- and long-term masking are still not fully understood for whales but are important to consider for species that regularly use the NY Bight.

Future Work and Directions

We will ensure that detection data from this project across all three survey years are directly comparable to provide insight into inter-annual variability in species detections. However, we may modify assumptions going into our detection, statistical, or sound propagation models as new approaches become available and/or analyses develop over the project duration. For example, in the case of the North Atlantic right whale detector, we will continue to modify the parameters and algorithm to improve detector performance.

The results from the first year of data collection show that a substantial amount of data are being collected, and multiple species of interest are being detected. These data are allowing the description of the daily, monthly, and seasonal presence of the six large whale species found in NY Bight, as outlined in the project objectives. Upon completion of the surveys for the remaining years of data, we will conduct interannual, spatial, and temporal statistical analyses of baleen whale occurrence and noise trends in NY Bight.

There are also several ways in which the data analysis could be expanded using the existing Year-1 dataset. The collected data could be analyzed at a finer temporal resolution to assess diel patterns in calling activity. Further, the number of detected calls could be analyzed, rather than daily presence, giving a more detailed insight into how the level of calling activity varies across time and space. For those species where an automatic detection protocol is already in place, this would be a relatively straightforward extension, though detector performance would have to be re-quantified to reflect that the analysis had changed to focusing on numbers of detected calls, rather than daily presence. For those species where manual browsing is currently the optimal method to assess daily presence, automatic detectors may need to be developed in order to count calls as, given the length of the project and the number of instruments, manual browsing will be too time consuming if every call is to be counted.

While it is clear that the instruments have the potential to collect a multi-year dataset, which can be assessed at a range of temporal resolutions (as described above), the current survey design has a reduced ability to make conclusions about spatial patterns of these species. The preliminary detection range results show that for right whales, humpback whales, and sperm whales, detection ranges are within tens of kilometers, or less, of the instruments. This means that conclusions about levels of whale calling activity (whether assessed using daily presence or numbers of calls) can only be made in the local areas surrounding the instruments. While we acknowledge that the initial survey design was driven by a priority to learn about the distribution of these species in direct relation to the shipping lanes, the current distribution of instruments presents a challenge to meet the other project objectives, specifically describing the spatial distribution of (1) calling occurrence of focal whale species and (2) ambient noise levels across NY Bight. Some conclusions can be made about masking potential for the species (the final

project objective) but only in close proximity to the shipping lanes, where the instruments are currently located. It is not possible to make conclusions about whale calling occurrence, ambient noise and masking potential across the Bight in general unless the instruments were to be reconfigured to incorporate other areas of the Bight, following animal monitoring survey design principles (e.g., discussed in Buckland et al. 2015).

Masking potential will be modeled using the best available sound propagation models and supporting software during analysis to better understand the noise contribution of shipping activity near in the NY Bight Traffic Separation Schemes and their potential to mask target signals across the recording sites.

Further, we can currently only compare our results with the aerial surveys where the spatial effort of the two survey types overlap, which is limited given that the aerial surveys do achieve Bight-wide coverage. A more direct comparison could be made if the acoustic survey was also designed to cover more locations across NY Bight.

Finally, passive acoustic data can be used to estimate animal density (reviewed in Marques et al. 2013), following similar animal surveying methods that have been traditionally used with sightings data, including aerial surveys. Counting calls as described above can be a first step to applying these density estimation methods to passive acoustic data (e.g., Harris et al. 2018, Marques et al. 2011). However, there are several other vital parameters that need to be estimated such as the probability of detecting species' calls, which allows calls missed by the detection process (i.e., calls with a low source level, or made at a greater distance) to be accounted for. Another key parameter often required for passive acoustic density estimation is the call production rate, which allows an estimated absolute abundance, or density, of calls (accounting for missed calls) to be converted into an absolute abundance, or density, of animals. Just as with density estimates from visual data, it is then possible to use these estimates in density surface models (Miller et al. 2013), which use spatial and temporal covariates to investigate the patterns of calling whale activity, and produce distribution maps. Thomas et al. (2013) give an example using fin whale call densities to produce density surface models through time and space. Call densities were used in this case as no appropriate call rate parameter was available to estimate animal densities.

Although animal density methods have been demonstrated using passive acoustic data, a dedicated density estimation study would require careful survey design so that the whole study area of interest was adequately monitored through time and space (using the same design principles mentioned above), as well as planning how to estimate detection probability and call production rates for the species of interest.

Acknowledgements

This work could not have been completed without major contributions from several key individuals. Special thanks to Captain Fred Channel and Derek Jaskula for deploying and recovering recording devices in a wide range of seafaring conditions, and to Peter Dugan for optimizing and running automated detection algorithms on the audio data.

Literature Cited

Albouy-Boyer, S., S. Plourde, P. Pepin, C. L. Johnson, C. Lehoux, P. S. Galbraith, D. Hebert, G. Lazin, C. Lafleur. 2016. Habitat modelling of key copepod species in the Northwest Atlantic Ocean based on the Atlantic Zone Monitoring Program. *Journal of Plankton Research* 38:589-603.

Ambler, J. B. 2011. *Whales and the People Who Watch Them: Baleen Whales in Virginia's Near-shore Waters and the Educational and Conservation Potential of Whale Watching*. Ph.D. Dissertation, George Mason University.

Aoki, K., M. Amano, M. Yoshioka, K. Mori, D. Tokuda, N. Miyazaki. 2007. Diel diving behavior of sperm whales off Japan. *Marine Ecology Progress Series* 349:277-287.

Au, W. W. L., A. A. Pack, M. O. Lammers, L. M. Herman, M. H. Deakos, K. Andrews. 2006. Acoustic properties of humpback whale songs. *Journal of the Acoustical Society of America* 120:1103-1110.

Barco, S. G., W. A. McLellan, J. M. Allen, R. A. Asmutis-Silva, R. Mallon-Day, E. M. Meagher, D. A. Pabst, J. Robbins, R. E. Seton, W. M. Swingle, M. T. Weinrich, P. J. Clapham. 2002. Population identity of humpback whales (*Megaptera novaeangliae*) in the waters of the US mid-Atlantic states. *Journal of Cetacean Research and Management* 4:135-141.

Baumgartner, M. F., S. M. Van Parijs, F. W. Wenzel, C. J. Tremblay, H. C. Esch, A. M. Warde. 2008. Low frequency vocalizations attributed to sei whales (*Balaenoptera borealis*). *Journal of the Acoustical Society of America* 124:1339-1349.

Bioacoustics Research Program. 2017. *Raven Pro 2.0: Interactive Sound Analysis Software*. Cornell Lab of Ornithology. Available at: http://www.birds.cornell.edu/brp/raven/RavenOverview.html, Ithaca, NY.

Bort, J., S. M. Van Parijs, P. T. Stevick, E. Summers, S. Todd. 2015. North Atlantic right whale *Eubalaena glacialis* vocalization patterns in the central Gulf of Maine from October 2009 through October 2010. *Endangered Species Research* 26:271-280.

Brown, D. M., J. Robbins, P. L. Sieswerda, R. Schoelkopf, E. C. M. Parsons. 2018. Humpback whale (*Megaptera novaeangliae*) sightings in the New York-New Jersey Harbor Estuary. *Marine Mammal Science* 34:250-257.

Buckland, S. T., E. A. Rexstad, T. A. Marques, C. S. Oedekoven. 2015. *Distance Sampling: Methods and Applications*. Springer, Cham.

Calupca, T. A., K. M. Fristrup, C. W. Clark. 2000. A compact digital recording system for autonomous bioacoustic monitoring. *Journal of the Acoustical Society of America* 108:2582.

Campbell-Malone, R., S. G. Barco, P.-Y. Daoust, A. R. Knowlton, W. A. McLellan, D. S. Rotstein, M. J. Moore. 2008. Gross and histologic evidence of sharp and blunt trauma in North Atlantic right whales (*Eubalaena glacialis*) killed by vessels. *Journal of Zoo and Wildlife Medicine* 39:37-55.

CETAP. 1982. A Characterization of Marine Mammals and Turtles in the Mid- and North-Atlantic Areas of the U.S. Outer Continental Shelf, Final ReportBureau of Land Management, Washington, DC.

Cholewiak, D., C. W. Clark, D. Ponirakis, A. Frankel, L. T. Hatch, D. Risch, J. E. Stanistreet, M. Thompson, E. Vu, S. M. Van Parijs. 2018. Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. *Endangered Species Research* 36:59-75.

Christian, M., V. M. Hendrick. 2007. Seasonal occurrence of North Atlantic right whale (*Eubalena glacialis*) vocalizations at two sites on the Scotian Shelf. *Marine Mammal Science* 23:856-867.

Clapham, P., R. M. Pace. 2001. Defining triggers for temporary area closures to protect right whales from entanglements: issues and optionsU.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Region, Northeast Fisheries Science Center, Woods Hole, MA.

Clark, C. W., P. J. Clapham. 2004. Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late spring *Proceedings of the Royal Society of London B: Biological Sciences* 271:1051-1057.

Clark, C. W., W. T. Ellison, B. L. Southall, L. Hatch, S. M. Van Parijs, A. Frankel, D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series* 395:201-222.

Clark, C. W., M. W. Brown, P. Corkeron. 2010. Visual and acoustic surveys for North Atlantic right whales, *Eubalaena glacialis*, in Cape Cod Bay, Massachusetts, 2001-2005: Management implications. *Marine Mammal Science* 26:837-854.

Conn, P. B., G. K. Silber. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. *Ecosphere* 4:43.

Corkeron, P., S. D. Kraus. 2018. Baleen whale species at risk of extinction. *Nature* 554:169.

Davies, K. T. A., S. W. Brillant. 2019. Mass human-caused mortality spurs federal action to protect endangered North Atlantic right whales in Canada. *Marine Policy* 104:157-162.

Davis, G. E., M. F. Baumgartner, J. Gurnee, J. Bell, C. Berchok, J. Bort Thornton, S. Brault, G. Buchanan, R. A. Charif, D. Cholewiak, C. W. Clark, P. Corkeron, J. Delarue, K. Dudzinski, L. Hatch, J. Hildebrand, L. Hodge, H. Klinck, S. Kraus, B. Martin, D. K. Mellinger, H. Moors-Murphy, S. Nieukirk, D. Nowacek, S. Parks, A. Read, A. N. Rice, D. Risch, A. Širović, M. Soldevilla, K. Stafford, J. Stanistreet, E. Summers, S. Todd, A. Warde, S. M. V. Parijs. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. *Scientific Reports* 7:13460.

Diogou, N., D. M. Palacios, S. L. Nieukirk, J. A. Nystuen, E. Papathanassiou, S. Katsanevakis, H. Klinck. 2019. Sperm whale (*Physeter macrocephalus*) acoustic ecology at Ocean Station PAPA (Gulf of Alaska) – Part 1: Detectability and seasonality. *Deep Sea Research I* DOI:10.1016/j.dsr.2019.05.007.

Dugan, P., M. Pourhomayoun, Y. Shiu, R. Paradis, A. Rice, C. Clark. 2013. Using high performance computing to explore large complex bioacoustic soundscapes: case study for right whale acoustics. *Procedia Computer Science* 20:156-162.

Dugan, P. J., D. W. Ponirakis, J. A. Zollweg, M. S. Pitzrick, J. L. Morano, A. M. Warde, A. N. Rice, C. W. Clark, S. M. Van Parijs. 2011. SEDNA – bioacoustic analysis toolbox. *IEEE OCEANS 2011*:1-10.

Dugan, P. J., H. Klinck, M. A. Roch, T. A. Helble. 2016. RAVEN X: High performance data mining toolbox for bioacoustic data analysis. *arxiv*:1610.03772.

Edwards, E. F., C. Hall, T. J. Moore, C. Sheredy, J. V. Redfern. 2015. Global distribution of fin whales *Balaenoptera physalus* in the post-whaling era (1980-2012). *Mammal Review* 45:197-214.

Erbe, C. 2015. The maskogram: a tool to illustrate zones of masking. *Aquatic Mammals* 41:434-443.

Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, R. Dooling. 2016. Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin* 103:15-38.

Fournet, M. E. H., C. M. Gabriele, F. Sharpe, J. M. Straley, A. Szabo. 2018a. Feeding calls produced by solitary humpback whales. *Marine Mammal Science* 34:851-865.

Fournet, M. E. H., L. P. Matthews, C. M. Gabriele, D. K. Mellinger, H. Klinck. 2018b. Source levels of foraging humpback whale calls. *Journal of the Acoustical Society of America* 143:EL105-EL111.

Goold, J. C., S. E. Jones. 1995. Time and frequency domain characteristics of sperm whale clicks. *Journal of the Acoustical Society of America* 98:1279-1291.

Harris, D., J. L. Miksis-Olds, L. Thomas, J. Vernon. 2018. Fin whale density and distribution estimation using acoustic bearings derived from sparse arrays. *Journal of the Acoustical Society of America* 143:2980-2993.

Hatch, L., C. Clark, R. Merrick, S. Van Parijs, D. Ponirakis, K. Schwehr, M. Thompson, D. Wiley. 2008. Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. *Environmental Management* 42:735-752.

Hatch, L. T., C. W. Clark, S. M. Van Parijs, A. S. Frankel, D. W. Ponirakis. 2012. Quantifying loss of acoustic communication space for right whales in and around a U.S. National Marine Sanctuary. *Conservation Biology* 26:983-994.

Hayes, S. A., E. Josephson, K. Maze-Foley, P. E. Rosel (eds) 2017. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2016. NOAA Technical Memorandum NMFS-NE-241. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Hayes, S. A., E. Josephson, K. Maze-Foley, P. E. Rosel (eds) 2019. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2018. NOAA Technical Memorandum NMFS-NE-258. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Hodge, K. B., C. A. Muirhead, J. L. Morano, C. W. Clark, A. N. Rice. 2015. North Atlantic right whale occurrence in two wind planning areas along the mid-Atlantic U.S. coast: implications for management. *Endangered Species Research* 28:225-234.

Jaquet, N., S. Dawson, L. Douglas. 2001. Vocal behavior of male sperm whales: Why do they click? *Journal of the Acoustical Society of America* 109:2254-2259.

Jiang, M. S., M. W. Brown, J. T. Turner, R. D. Kenney, C. A. Mayo, Z. B. Zhang, M. Zhou. 2007. Springtime transport and retention of *Calanus finmarchicus* in Massachusetts and Cape Cod Bays, USA, and implications for right whale foraging. *Marine Ecology Progress Series* 349:183-197.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, B. Würsig. 2008. *Sperm whale seismic study in the Gulf of Mexico: Synthesis report*. OCS Study MMS 2008-006. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior, New Orleans, LA.

Johnson, A., G. Salvador, J. Kenney, J. Robbins, S. Kraus, S. Landry, P. Clapham. 2005. Fishing gear involved in entanglements of right and humpback whales. *Marine Mammal Science* 21:635-645.

Knowlton, A. R., S. D. Kraus. 2001. Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. *Journal of Cetacean Research and Management* 2:193-208.

Knowlton, A. R., M. W. Brown. 2007. Running the gantlet: Right whales and vessel strikes. Pages 409-435 in The Urban Whale: North Atlantic Right Whales at the Crossroads (S. D. Kraus, and R. M. Rolland, eds.). Harvard University Press, Cambridge, MA.

Kraus, S. D. 1990. Rates and potential causes of mortality in North Atlantic right whales (*Eubalaena glacialis*). *Marine Mammal Science* 6:278-291.

Kraus, S. D., M. W. Brown, H. Caswell, C. W. Clark, M. Fujiwara, P. K. Hamilton, R. D. Kenney, A. R. Knowlton, S. Landry, C. A. Mayo, W. A. McLellan, M. J. Moore, D. P. Nowacek, D. A. Pabst, A. J. Read, R. M. Rolland. 2005. North Atlantic right whales in crisis. *Science* 309:561-562.

Kraus, S. D., R. M. Rolland. 2007. Right whales in the urban ocean. Pages 1-38 in The Urban Whale: North Atlantic Right Whales at the Crossroads (S. D. Kraus, and R. M. Rolland, eds.). Harvard University Press, Cambridge, MA.

Leiter, S. M., K. M. Stone, J. L. Thompson, C. M. Accardo, B. C. Wikgren, M. A. Zani, T. V. N. Cole, R. D. Kenney, C. A. Mayo, S. D. Kraus. 2017. North Atlantic right whale *Eubalaena glacialis* occurrence in offshore wind energy areas near Massachusetts and Rhode Island, USA. *Endangered Species Research* 34:45-59.

Madsen, P. T., R. Payne, N. U. Kristiansen, M. Wahlberg, I. Kerr, B. Møhl. 2002. Sperm whale sound production studied with ultrasound time/depth-recording tags. *Journal of Experimental Biology* 205:1899-1906.

Marques, T. A., L. Munger, L. Thomas, S. Wiggins, J. A. Hildebrand. 2011. Estimating North Pacific right whale (*Eubalaena japonica*) density using passive acoustic cue counting. *Endangered Species Research* 13:163-172.

Marques, T. A., L. Thomas, S. W. Martin, D. K. Mellinger, J. A. Ward, D. J. Moretti, D. Harris, P. L. Tyack. 2013. Estimating animal population density using passive acoustics. *Biological Reviews* 88:287-309.

Mayo, C. A., L. Ganley, C. A. Hudak, S. Brault, M. K. Marx, E. Burke, M. W. Brown. 2018. Distribution, demography, and behavior of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, Massachusetts, 1998-2013. *Marine Mammal Science* 34:979-996.

McDonald, M. A., J. A. Hildebrand, S. Mesnick. 2009. Worldwide decline in tonal frequencies of blue whale songs. *Endangered Species Research* 9:13-21.

Mellinger, D. K., C. W. Clark. 2003. Blue whale (*Balaenoptera musculus*) sounds from the North Atlantic. *Journal of the Acoustical Society of America* 114:1108-1119.

Mellinger, D. K., S. L. Nieukirk, H. Matsumoto, S. L. Heimlich, R. P. Dziak, J. Haxel, M. Fowler, C. Meinig, H. V. Miller. 2007. Seasonal occurrence of North Atlantic right whale (*Eubalaena glacialis*) vocalizations at two sites on the Scotian Shelf. *Marine Mammal Science* 23:856-867.

Meyer-Gutbrod, E. L., C. H. Greene, P. J. Sullivan, A. J. Pershing. 2015. Climate-associated changes in prey availability drive reproductive dynamics of the North Atlantic right whale population. *Marine Ecology Progress Series* 535:243-258.

Meyer-Gutbrod, E. L., C. H. Greene. 2018. Uncertain recovery of the North Atlantic right whale in a changing ocean. *Global Change Biology* 24:455-464.

Miller, D. L., M. L. Burt, E. Rexstad, L. Thomas. 2013. Spatial models for distance sampling data: recent developments and future directions'. *Methods in Ecology and Evolution* 4:1001-1010.

Mitchell, E. 1975. Preliminary report on Nova Scotia fishery for sei whales (*Balaenoptera borealis*). *Reports of the International Whaling Commission* 25:218-225.

Morano, J. L., A. N. Rice, J. T. Tielens, B. J. Estabrook, A. Murray, B. Roberts, C. W. Clark. 2012a. Acoustically detected year-round presence of right whales in an urbanized migration corridor. *Conservation Biology* 26:698-707.

Morano, J. L., D. P. Salisbury, A. N. Rice, K. L. Conklin, K. L. Falk, C. W. Clark. 2012b. Seasonal changes in fin whale song in the Western North Atlantic Ocean. *Journal of the Acoustical Society of America* 132:1207-1212.

Muirhead, C. A., A. M. Warde, I. S. Biedron, A. N. Mihnovets, C. W. Clark, A. N. Rice. 2018. Seasonal acoustic occurrence of blue, fin, and North Atlantic right whales in the New York Bight. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28:744-753.

Murray, A., A. N. Rice, C. W. Clark. 2014. Extended seasonal occurrence of humpback whales in Massachusetts Bay. *Journal of the Marine Biological Association of the U.K.* 94:1117-1125.

National Oceanic and Atmospheric Administration (NOAA). 2016. Endangered and threatened species; Critical habitat for endangered North Atlantic right whale. *Federal Register* 81:4838-4874.

New York State Department of Environmental Conservation (NYSDEC). 2005. *Comprehensive Wildlife Conservation Strategy: A Strategy for Conserving New York's Fish and Wildlife Resources*. NYSDEC, Albany, NY. Available at: https://www.dec.ny.gov/docs/wildlife_pdf/cwcs2005.pdf.

New York State Department of Environmental Conservation (NYSDEC), New York State Department of State (NYSDOS). 2015. New York Ocean Action Plan; 2015 - 2025. Pages 123-123 New York State Department of Environmental Conservation, Albany, NY.

Nichols, O. C., R. D. Kenney, M. W. Brown. 2008. Spatial and temporal distribution of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, and implications for management. *Fishery Bulletin* 106:270-280.

Normandeau Associates Inc., APEM Ltd. 2018. *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy. First Annual Report: 2016-2017*. NYSERDA, Albany, NY.

Northeast Fisheries Science Center (NEFSC), Southeast Fisheries Science Center (SEFSC). 2016. *Annual Report of a Comprehensive Assessment of Marine Mammal, Marine Turtle, and Seabird Abundance and Spatial Distribution in US Waters of the Western North Atlantic Ocean – AMAPPS II*. Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Woods Hole, MA.

Oliveira, C., M. Wahlberg, M. A. Silva, M. Johnson, R. Antunes, D. M. Wisniewska, A. Fais, J. Gonçalves, P. T. Madsen. 2016. Sperm whale codas may encode individuality as well as clan identity. *The Journal of the Acoustical Society of America* 139:2860-2869.

Pace, R. M., P. J. Corkeron, S. D. Kraus. 2017. State–space mark–recapture estimates reveal a recent decline in abundance of North Atlantic right whales. *Ecology and Evolution* 27:8730-8741.

Parks, S. E., P. L. Tyack. 2005. Sound production by North Atlantic right whales (*Eubalaena glacialis*) in surface active groups. *Journal of the Acoustical Society of America* 117:3297-3306.

Parks, S. E., C. W. Clark. 2007. Acoustic communication: social sounds and the potential impacts of noise. Pages 310-332 in The Urban Whale: North Atlantic Right Whales at the Crossroads (S. D. Kraus, and R. M. Rolland, eds.). Harvard University Press, Cambridge, MA.

Parks, S. E., I. Urazghildiiev, C. W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. *Journal of the Acoustical Society of America* 125:1230-1239.

Parks, S. E., M. Johnson, D. Nowacek, P. L. Tyack. 2011. Individual right whales call louder in increased environmental noise. *Biology Letters* 7:33-35.

Parks, S. E., J. D. Warren, K. Stamieszkin, C. A. Mayo, D. Wiley. 2012. Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions. *Biology Letters* 8:57-60.

Payne, R., D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. *Annals of the New York Academy of Sciences* 188:110-141.

Pendleton, D. E., P. J. Sullivan, M. W. Brown, T. V. N. Cole, C. P. Good, C. A. Mayo, B. C. Monger, S. Phillips, N. R. Record, A. J. Pershing. 2012. Weekly predictions of North Atlantic right whale *Eubalaena glacialis* habitat reveal influence of prey abundance and seasonality of habitat preferences. *Endangered Species Research* 18:147-161.

Record, N. R., J. A. Runge, D. E. Pendleton, W. M. Balch, K. T. A. Davies, A. J. Pershing, C. L. Johnson, K. Stamieszkin, R. Ji, Z. Feng, S. D. Kraus, R. D. Kenney, C. A. Hudak, C. A. Mayo, C. Chen, J. E. Salisbury, C. R. S. Thompson. 2019. Rapid climate-driven circulation changes threaten conservation of endangered North Atlantic right whales. *Oceanography* 32:162-169.

Rice, A. N., J. T. Tielens, B. J. Estabrook, C. A. Muirhead, A. Rahaman, M. Guerra, C. W. Clark. 2014. Variation of ocean acoustic environments along the western North Atlantic coast: A case study in context of the right whale migration route. *Ecological Informatics* 21:89-99.

Richardson, W. J., C. R. Greene, C. I. Malme, D. H. Thomson. 1995. *Marine Mammals and Noise, 1st ed.* Academic Press, San Diego.

Risch, D., C. W. Clark, P. J. Dugan, M. Popescu, U. Siebert, S. M. Van Parijs. 2013. Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. *Marine Ecology Progress Series* 489:279-295.

Risch, D., M. Castellote, C. W. Clark, G. E. Davis, P. J. Dugan, L. E. Hodge, A. Kumar, K. Lucke, D. K. Mellinger, S. L. Nieukirk, C. M. Popescu, C. Ramp, A. J. Read, A. N. Rice, M. A. Silva, U. Siebert, K. M. Stafford, H. Verdaat, S. M. Van Parijs. 2014. Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. *Movement Ecology* 2:24.

Roberts, J. J., B. D. Best, L. Mannocci, E. Fujioka, P. N. Halpin, D. L. Palka, L. P. Garrison, K. D. Mullin, T. V. N. Cole, C. B. Khan, W. A. McLellan, D. A. Pabst, G. G. Lockhart. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Scientific Reports* 6:22615.

Rolland, R. M., S. E. Parks, K. E. Hunt, M. Castellote, P. J. Corkeron, D. P. Nowacek, S. K. Wasser, S. D. Kraus. 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B: Biological Sciences* 279:2363-2368.

Romagosa, M., O. Boisseau, A.-C. Cucknell, A. Moscrop, R. McLanaghan. 2015. Source level estimates for sei whale (*Balaenoptera borealis*) vocalizations off the Azores. *Journal of the Acoustical Society of America* 138:2367-2372.

Salisbury, D. P., C. W. Clark, A. N. Rice. 2016. Right whale occurrence in the coastal waters of Virginia, U.S.A.: implications of endangered species presence in a rapidly developing energy market. *Marine Mammal Science* 32:509-519.

Schulz, T. M., H. Whitehead, S. Gero, L. Rendell. 2011. Individual vocal production in a sperm whale (*Physeter macrocephalus*) social unit. *Marine Mammal Science* 27:149-166.

Scott, T. M., S. S. Sadove. 1997. Sperm whale, *Physeter macrocephalus*, sightings in the shallow shelf waters off Long Island, New York. *Marine Mammal Science* 13:317-321.

Silva, M. A., R. Prieto, I. Jonsen, M. F. Baumgartner, R. S. Santos. 2013. North Atlantic blue and fin whales suspend their spring migration to forage in middle latitudes: building up energy reserves for the journey? *PLOS ONE* 8:e76507.

Širović, A., J. A. Hildebrand, S. M. Wiggins. 2007. Blue and fin whale call source levels and propagation range in the Southern Ocean. *Journal of the Acoustical Society of America* 122:1208-1215.

Soldevilla, M. S., A. N. Rice, C. W. Clark, L. P. Garrison. 2014. Passive acoustic monitoring on the North Atlantic right whale calving grounds. *Endangered Species Research* 25:115-140.

Stanistreet, J. E., D. Risch, S. M. Van Parijs. 2013. Passive acoustic tracking of singing humpback whales (*Megaptera novaeangliae*) on a Northwest Atlantic feeding ground. *PLOS ONE* 8:e61263.

Stanistreet, J. E., D. P. Nowacek, J. T. Bell, D. M. Cholewiak, J. A. Hildebrand, L. E. W. Hodge, S. M. Van Parijs, A. J. Read. 2018. Spatial and seasonal patterns in acoustic detections of sperm whales *Physeter macrocephalus* along the continental slope in the western North Atlantic Ocean. *Endangered Species Research* 35:1-13.

Stone, K. M., S. M. Leiter, R. D. Kenney, B. C. Wikgren, J. L. Thompson, J. K. D. Taylor, S. D. Kraus. 2017. Distribution and abundance of cetaceans in a wind energy development area offshore of Massachusetts and Rhode Island. *Journal of Coastal Conservation* 21:527-543.

Teloni, V., J. P. Mark, M. J. Patrick, M. T. Peter. 2008. Shallow food for deep divers: dynamic foraging behavior of male sperm whales in a high latitude habitat. *Journal of Experimental Marine Biology and Ecology* 354:119-131.

Tetra Tech, Smultea Sciences. 2018. *Year 1 Annual Survey Report for New York Bight Whale Monitoring Aerial Surveys March 2017 – February 2018*. New York State Department of Environmental Conservation, East Setauket, NY.

Tetra Tech, LGL. 2019. *Year 2 Annual Survey Report for New York Bight Whale Monitoring Aerial Surveys, March 2018 – February 2019*. New York State Department of Environmental Conservation, East Setauket, NY.

Thomas, L., L. Matias, D. Mellinger. 2013. *Density Estimation for Cetaceans from Acoustic Fixed sensors using separate, non-linked devices.* . ONR Technical Report. Available at: https://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/marine-mammals-biology/Annual-Report-FY13

Tremblay, C. J., S. M. V. Parijs, D. Cholewiak. 2019. 50 to 30-Hz triplet and singlet down sweep vocalizations produced by sei whales (*Balaenoptera borealis*) in the western North Atlantic Ocean. *Journal of the Acoustical Society of America* 145:3351-3358.

Urazghildiiev, I. R., C. W. Clark, T. P. Krein, S. E. Parks. 2009. Detection and recognition of North Atlantic right whale contact calls in the presence of ambient noise. *IEEE Journal of Oceanic Engineering* 34:358-368.

Vu, E. T., D. Risch, C. W. Clark, S. Gaylord, L. T. Hatch, M. A. Thompson, D. N. Wiley, S. M. Van Parijs. 2012. Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean. *Aquatic Biology* 14:175-183.

Ward-Geiger, L. I., G. K. Silber, R. D. Baumstark, T. L. Pulfer. 2005. Characterization of ship traffic in right whale critical habitat. *Coastal Management* 33:263 - 278.

Waring, G. T., E. Josephson, K. Maze-Foley, P. E. Rosel (eds) 2010. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2010. NOAA Technical Memorandum

NMFS-NE-219. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Waring, G. T., E. Josephson, K. Maze-Foley, P. E. Rosel (eds) 2015. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2014. NOAA Technical Memorandum NMFS-NE-231. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Watkins, W. A., W. E. Schevill. 1977. Sperm whale codas. *Journal of the Acoustical Society of America* 62:1485-1490.

Watwood, S. L., P. J. O. Miller, M. Johnson, P. T. Madsen, P. L. Tyack. 2006. Deep-diving foraging behaviour of sperm whales (*Physeter macrocephalus*). *Journal of Animal Ecology* 75:814-825.

Weirathmueller, M. J., W. S. D. Wilcock, D. C. Soule. 2013. Source levels of fin whale 20 Hz pulses measured in the Northeast Pacific Ocean. *Journal of the Acoustical Society of America* 133:741-749.

Wenzel, F. W., D. K. Mattila, P. J. Clapham. 1988. *Balaenoptera musculus* in the Gulf of Maine. *Marine Mammal Science* 4:172-175.

Whitehead, H., L. Weilgart. 1991. Patterns of visually observable behaviour and vocalizations in groups of female sperm whales. *Behaviour*:275-296.

Whitt, A. D., K. Dudzinski, J. R. Laliberté. 2013. North Atlantic right whale distribution and seasonal occurrence in nearshore waters off New Jersey, USA, and implications for management. *Endangered Species Research* 20:59-69.

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 1-hour time bins. Spectrograms were generated with both linear (Figure 56, Figure 69, first panel) and 1/3 octave (Figure 56, Figure 69, 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 $1/3^{rd}$ octaves were selected to represent the frequency band in which each target species hearing is potentially most sensitive (Table 5).

Time series plots (Figure 56, Figure 69, third panel) are presented to illustrate the variation in average-hourly 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 56, Figure 69, 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 1^{st}, 25^{th}, 50^{th}, 75^{th}, and 99^{th} 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 1M – 5M (Figure 56, Figure 57, Figure 58, Figure 59, Figure 60), 9A (Figure 64), 10M (Figure 65), 11A (Figure 66), 12M (Figure 67), and 13A (Figure 68). 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, particularly at sites 1M, 2M, 3M, 5M, 7M, 10M, 12M, 11A, and 13A. The higher noise levels below 100 Hz at all sites are likely attributed to anthropogenic noise (e.g., shipping).

Site 1M

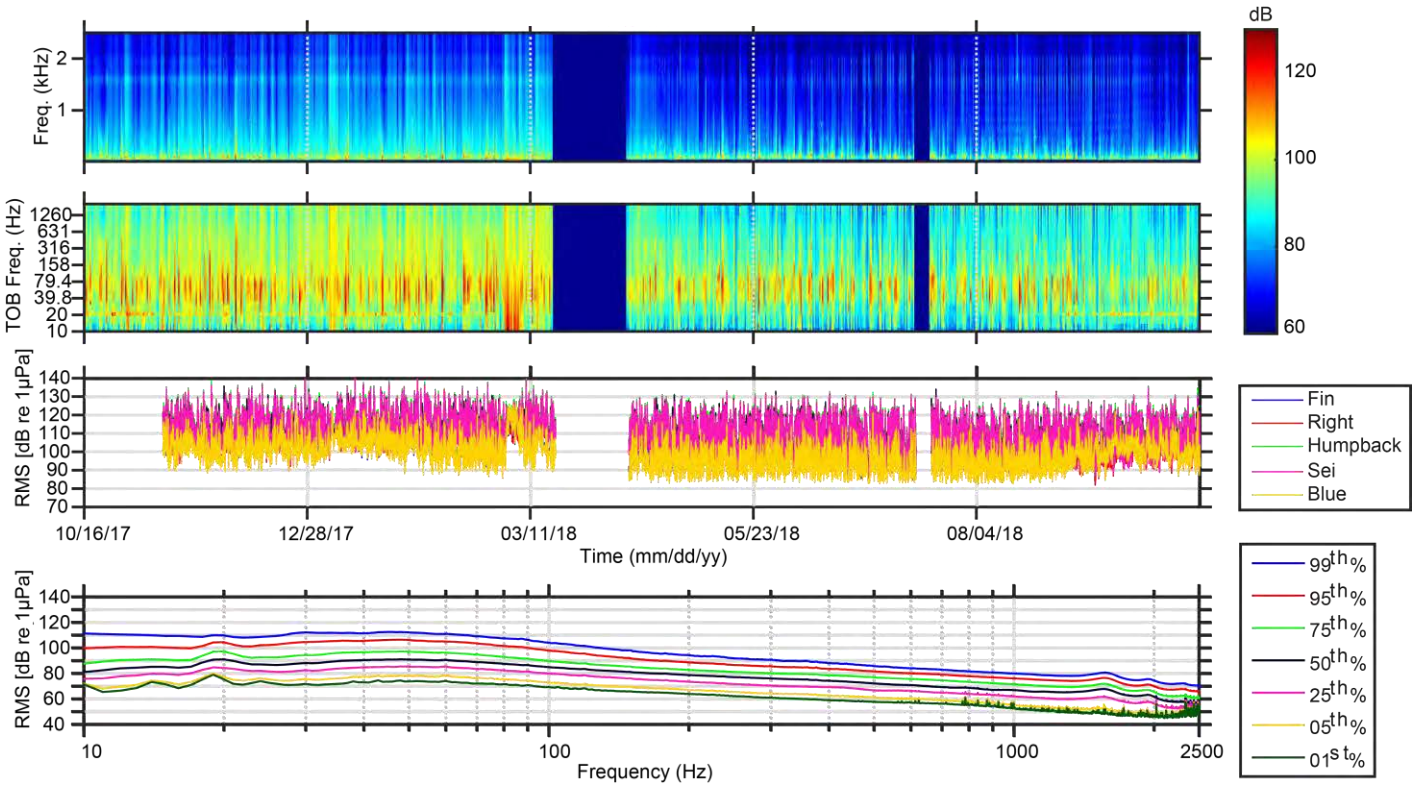


Figure 56. Hourly averaged ambient noise metrics for site 1M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

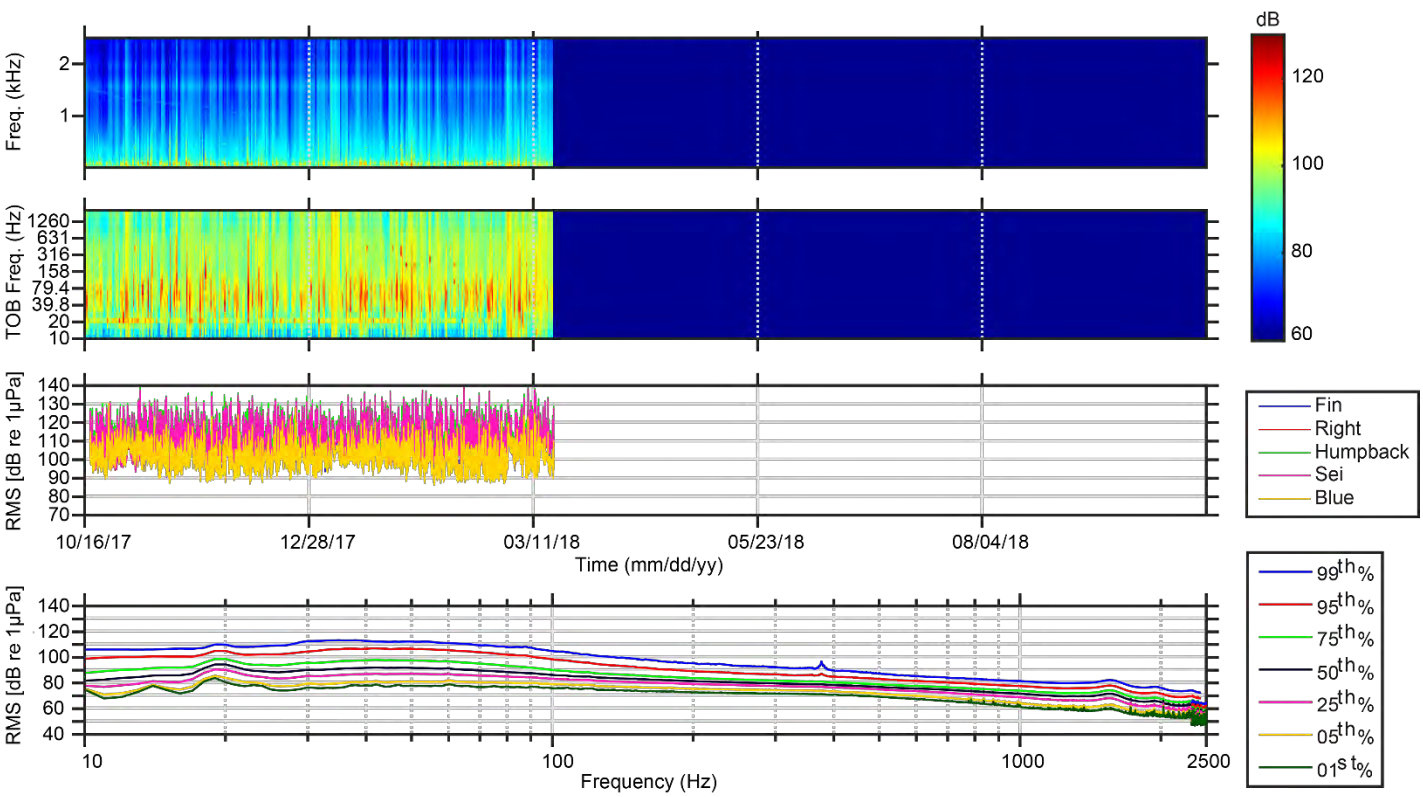


Figure 57. Hourly averaged ambient noise metrics for site 2M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

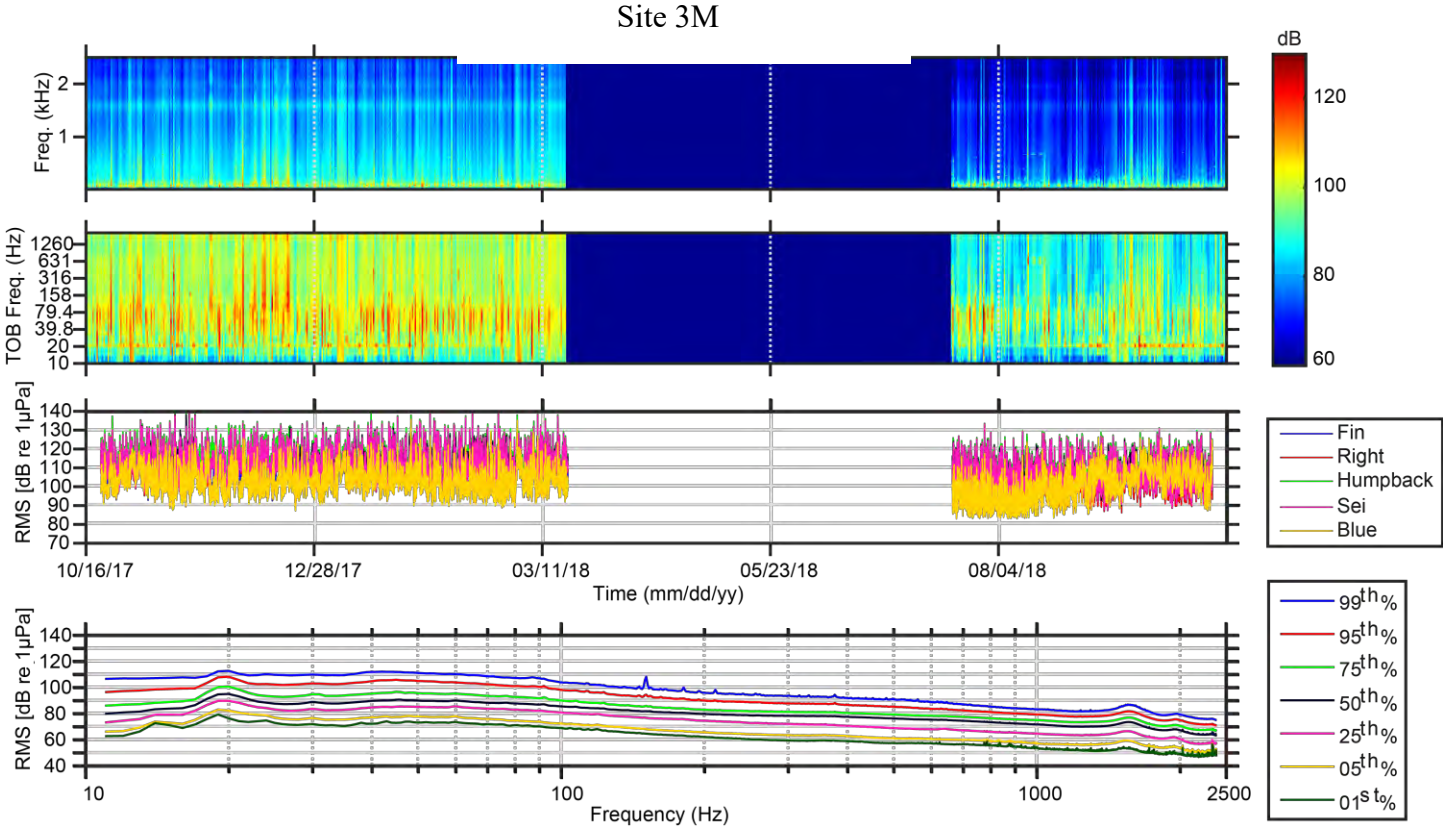


Figure 58. Hourly averaged ambient noise metrics for site 3M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

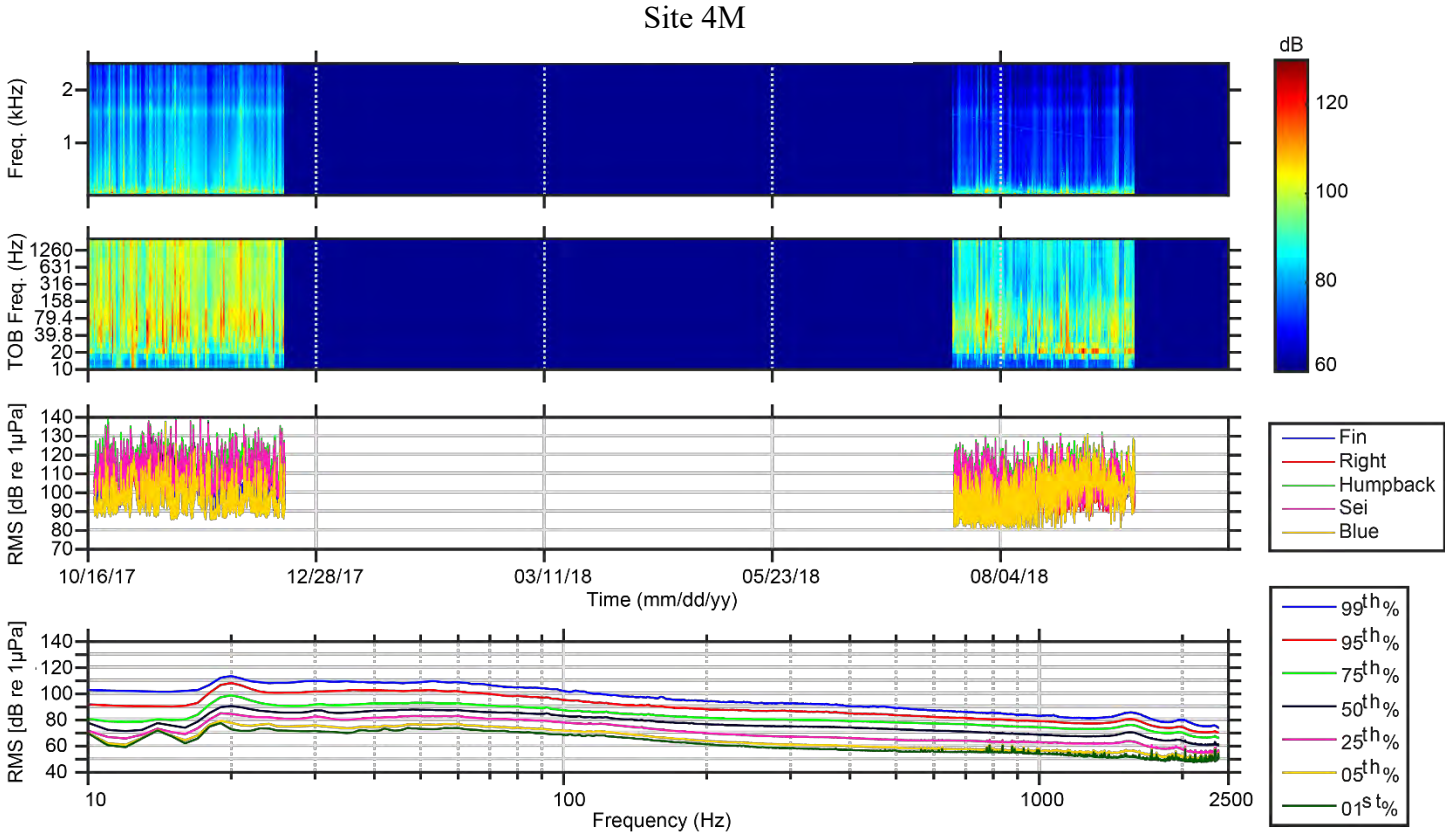


Figure 59. Hourly averaged ambient noise metrics for site 4M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

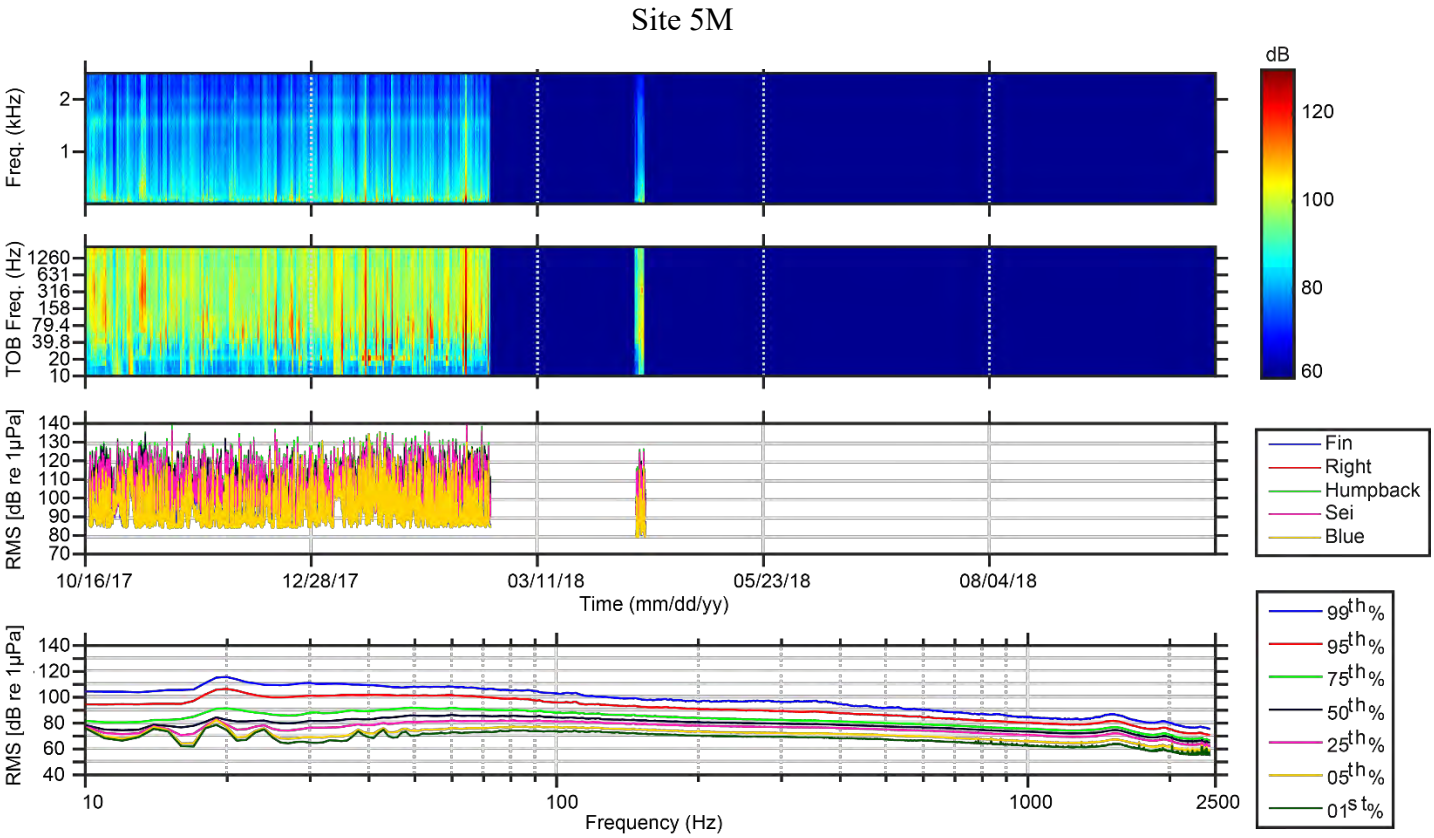


Figure 60. Hourly averaged ambient noise metrics for site 5M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

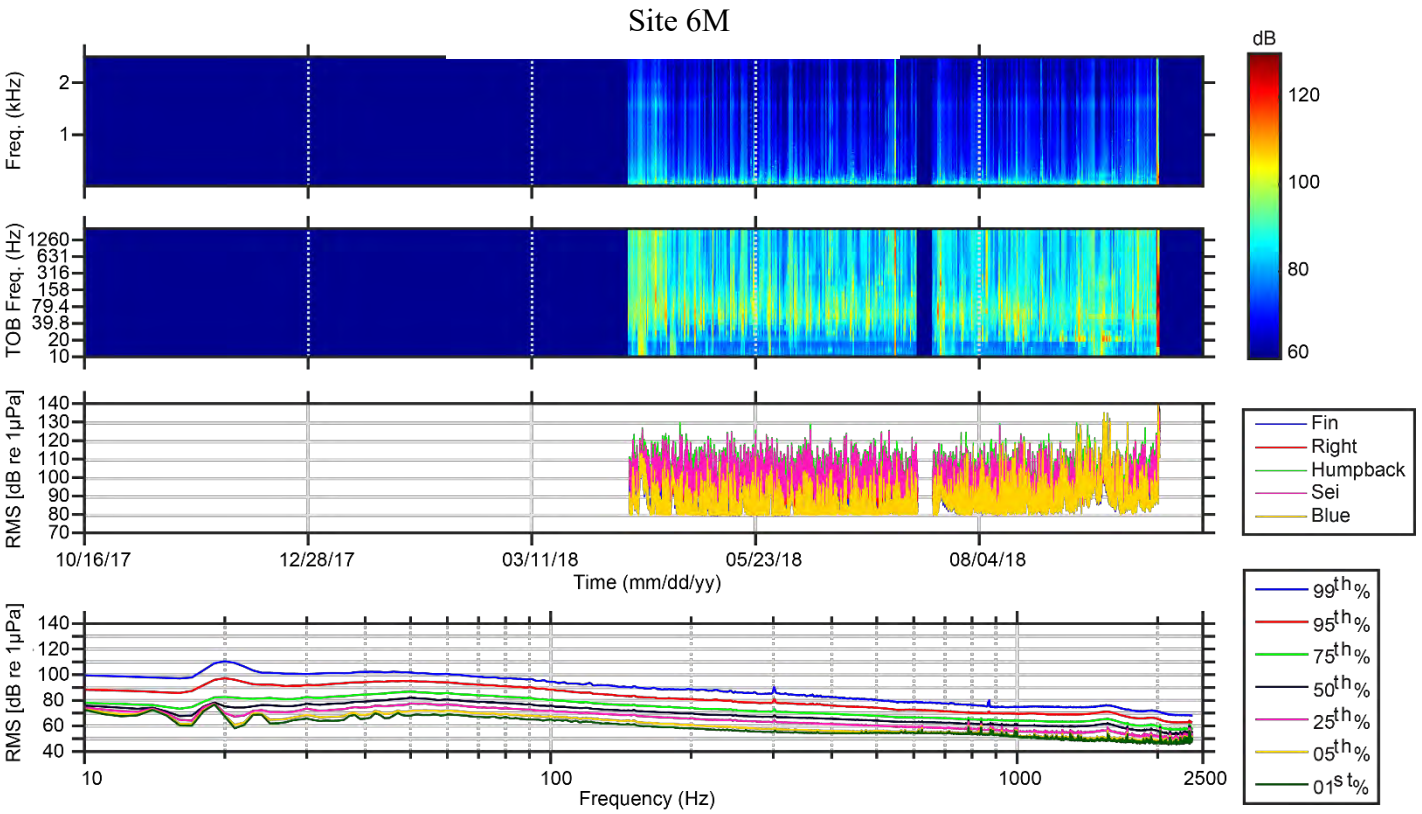


Figure 61. Hourly averaged ambient noise metrics for site 6M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 7M

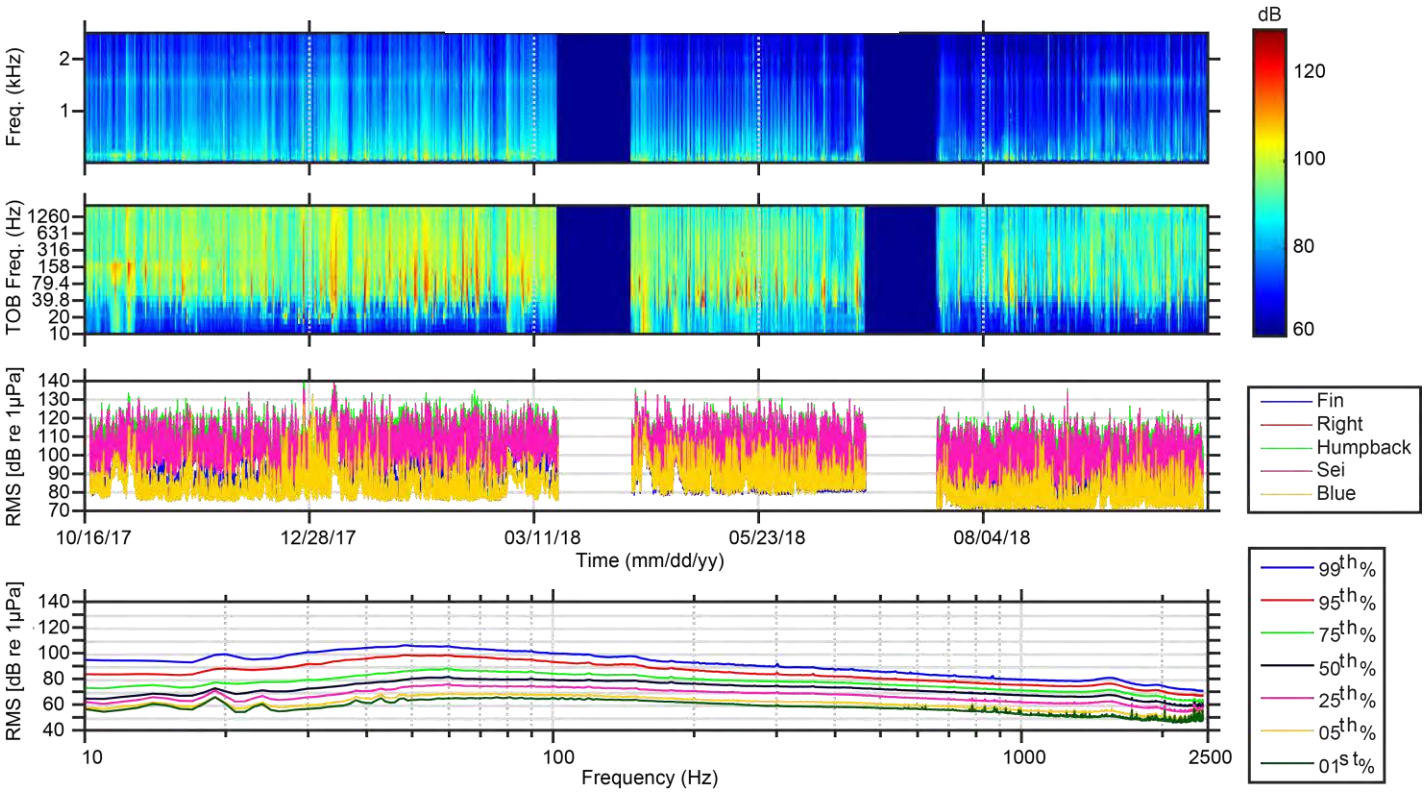


Figure 62. Hourly averaged ambient noise metrics for site 7M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 8A

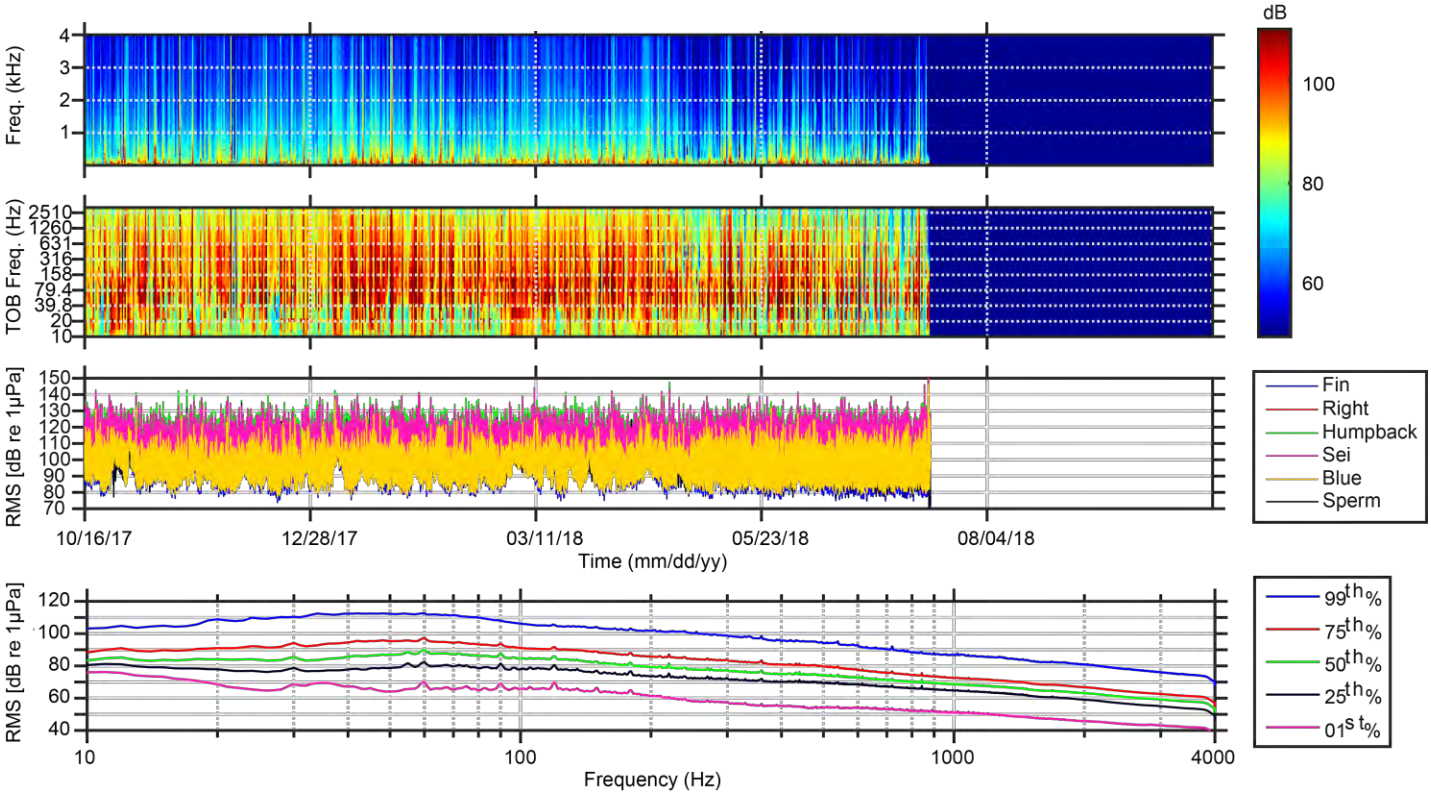


Figure 63. Hourly averaged ambient noise metrics for site 8A between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 9A

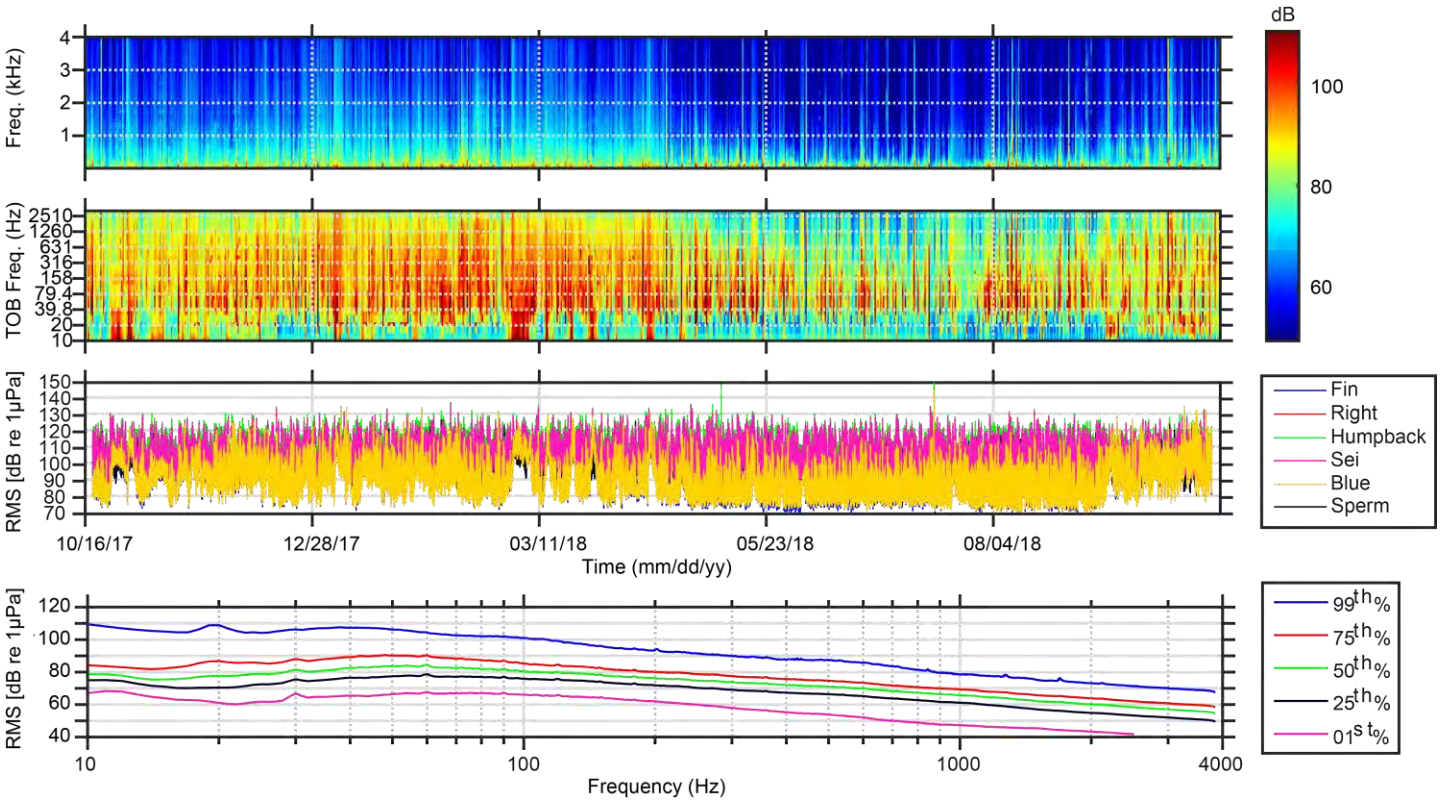


Figure 64. Hourly averaged ambient noise metrics for site 9A between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 10M

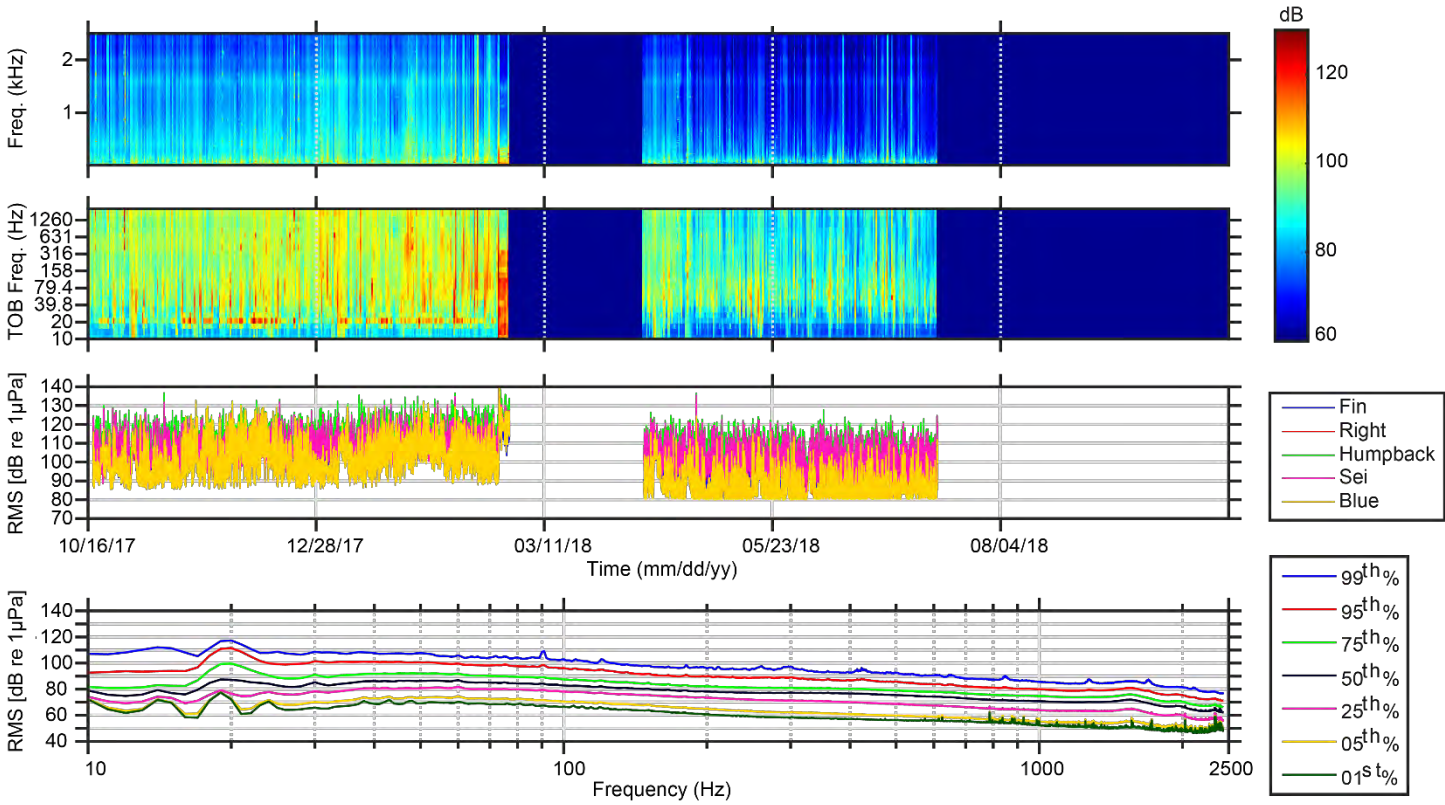


Figure 65. Hourly averaged ambient noise metrics for site 10M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

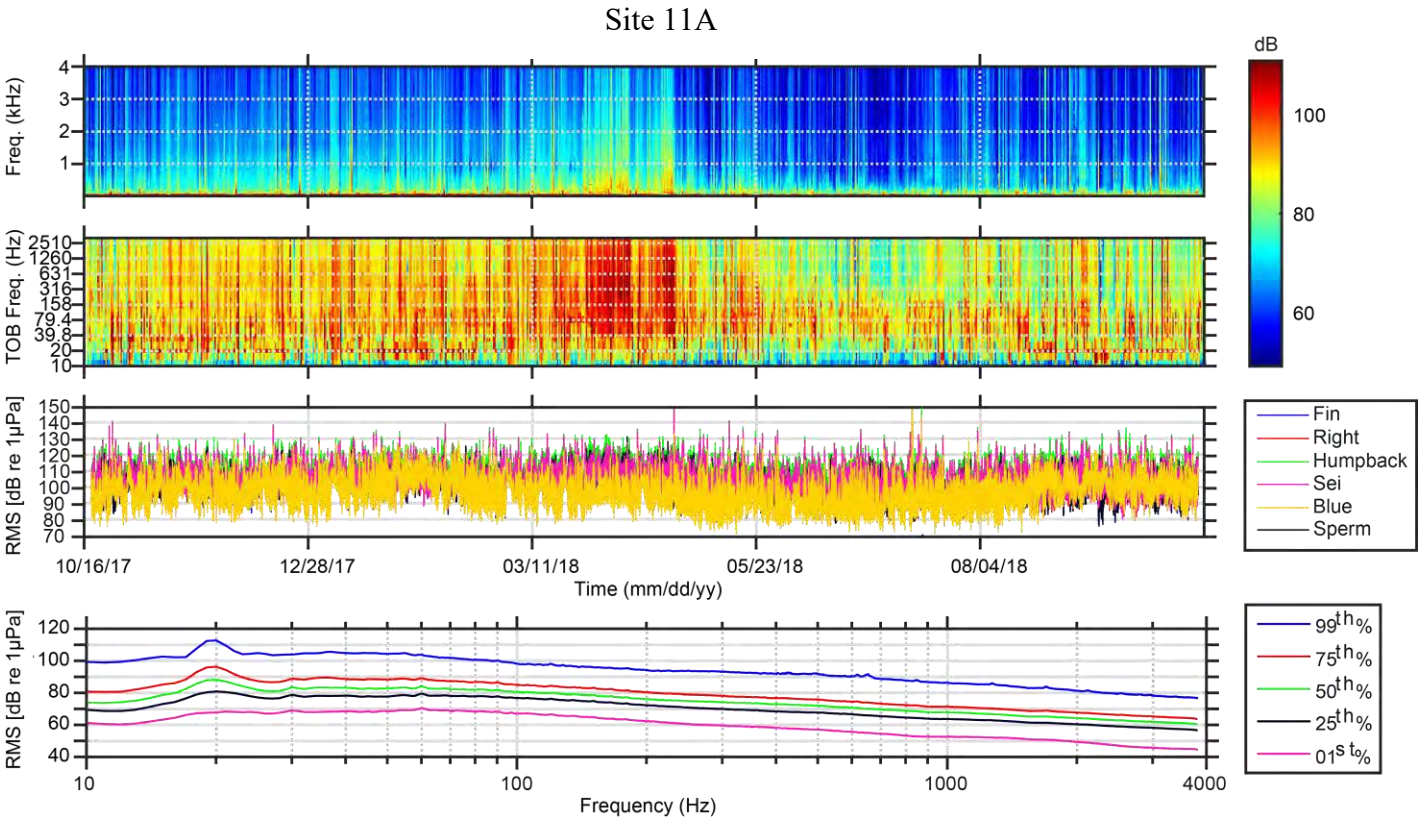


Figure 66. Hourly averaged ambient noise metrics for site 11A between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 12M

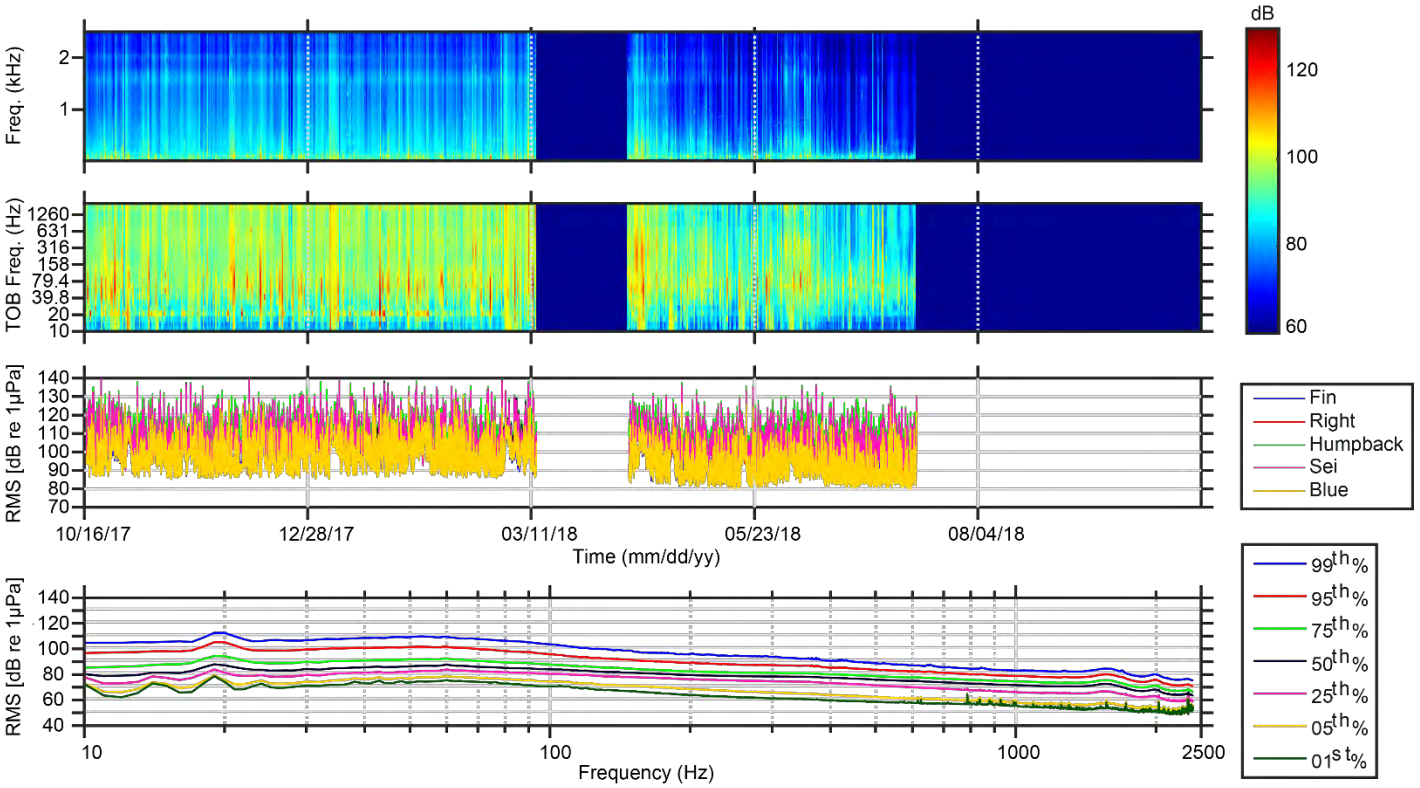


Figure 67. Hourly averaged ambient noise metrics for site 12M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 13A

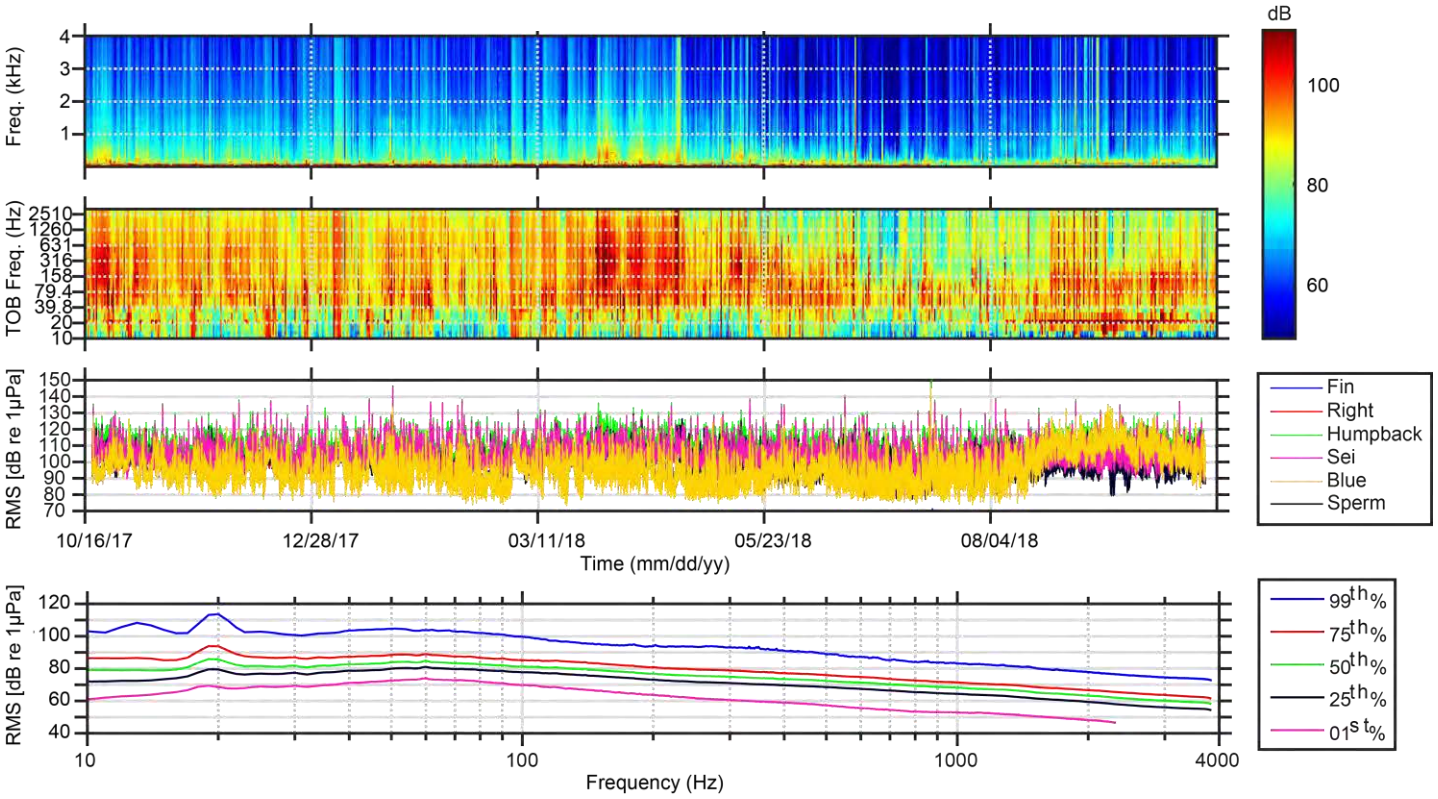


Figure 68. Hourly averaged ambient noise metrics for site 13A between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Site 14M

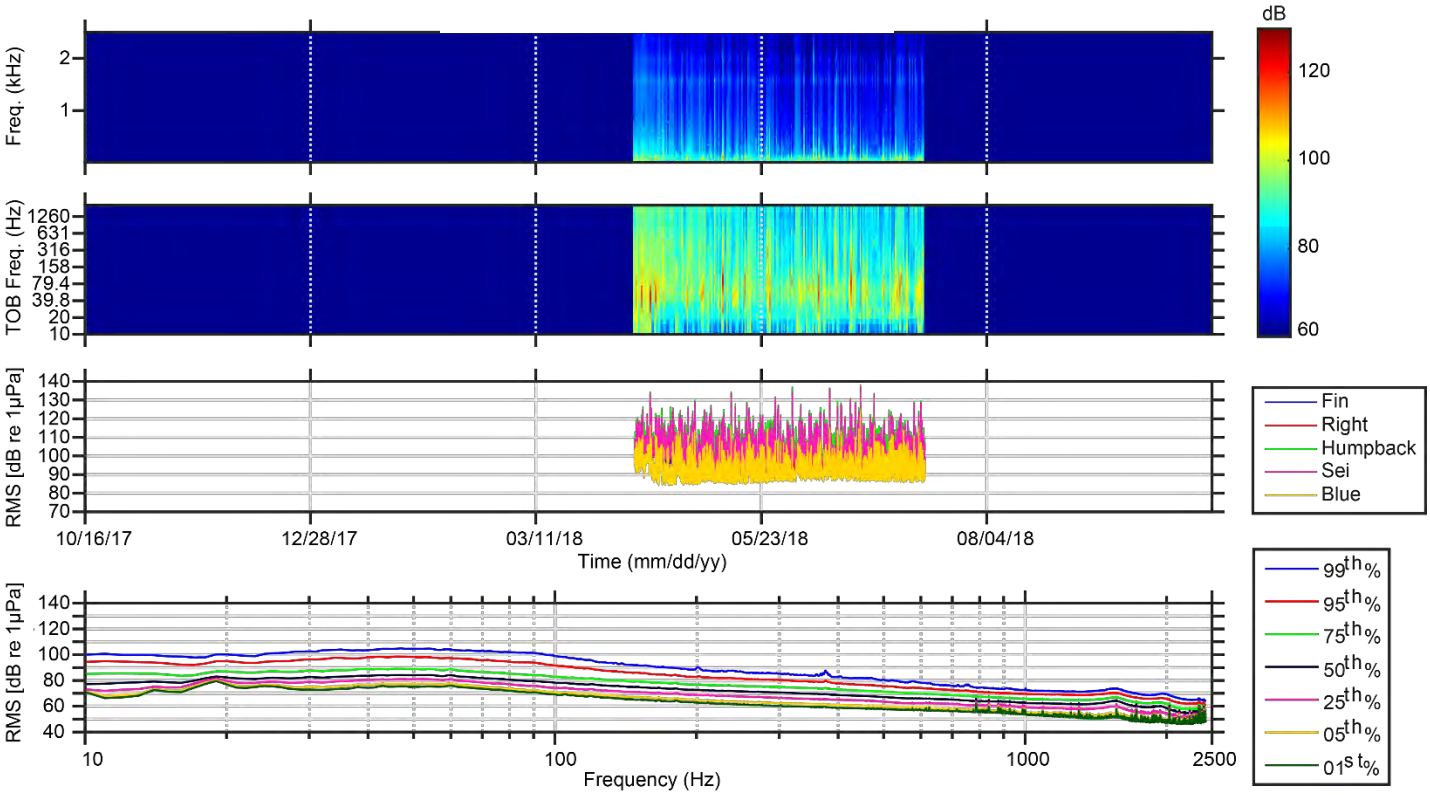


Figure 69. Hourly averaged ambient noise metrics for site 14M between October 2017 and October 2018. The first panel is a spectrogram with a linear frequency scale. The second panel is a spectrogram with a 1/3 Octave frequency scale. The colormap of both spectrograms reflects noise levels (dB re: 1µPa). 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.

Appendix B: Minke Whale Opportunistic Presence

Data on minke whales in the Western North Atlantic Ocean are lacking, particularly in New York Bight (Risch et al. 2014, Risch et al. 2013). Here, we report on the detection of minke whales on MARUs from October 2017 through July 2018.

Minke whales produce a series of pulsed signals, called a "pulse train" (Figure 70), which are the most well-understood vocalization of North Atlantic minke whales and are commonly used to indicate minke whale presence (Risch et al. 2014, Risch et al. 2013). Since we did not have enough minke whale signals in the ground truth dataset to evaluate minke whale detector performance, we manually browsed the spectrograms during the humpback analysis and searched for minke whale pulse trains. As a result, we now have enough minke whale signals to run the MATLAB-based detector algorithm and identify the appropriate threshold to use in upcoming analyses. Daily presence per site was marked.

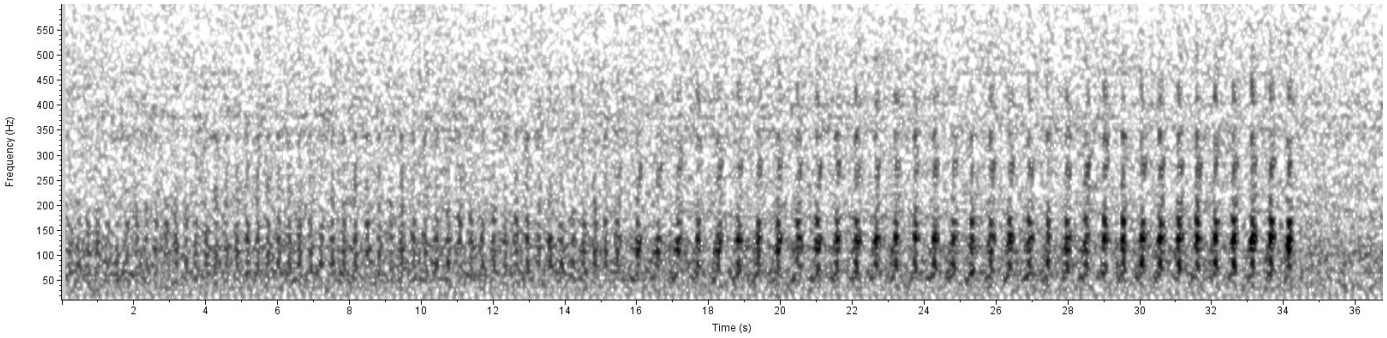


Figure 70. Minke whale pulse-train recorded on site 8M on 22 April, 2018

Minke whale daily presence occurred in all months except December, with the highest daily acoustic detections during April (11%). Minke whales were detected primarily on the western and northern sensors, with some detections on the eastern margin of the study area (Figures 63 & 64). The estimated propagation range (Figure 64) for minke whale pulse trains at site 6M (L_{50} = 100 dB) is approximately 6 km, and < 1 km at site 2M (L_{50} = 112 dB). During the 5th percentile noise levels, minke whale pulse trains are estimated to be received as far as 12 km at site 6M (94 dB).

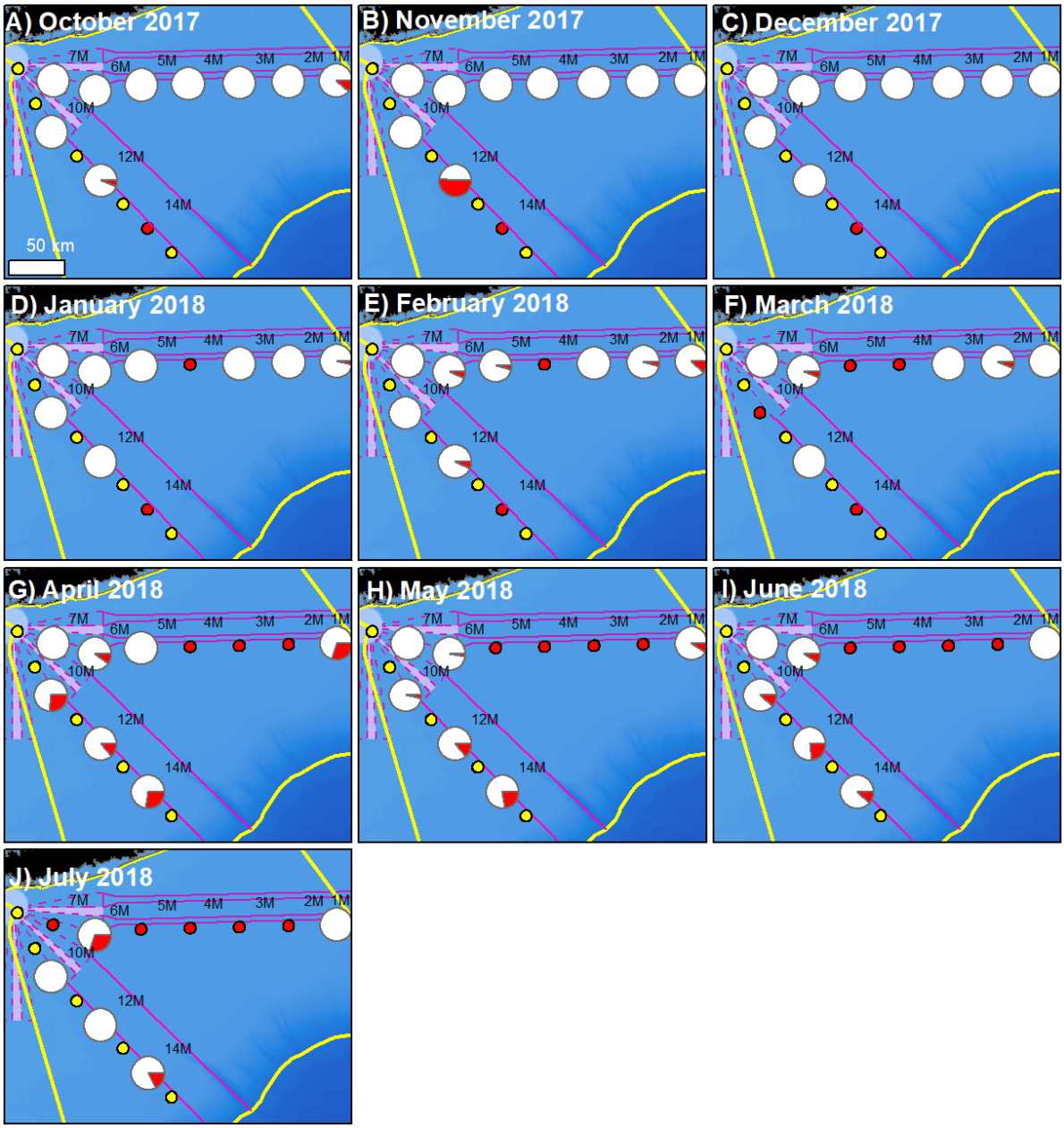


Figure 71. Spatial patterns of monthly presence of minke whales in New York Bight, shown as a percentage of days per month on each recording unit. The small yellow circles denote AMAR site locations and the small red circles denote MARU sites in which there are no data for that month.

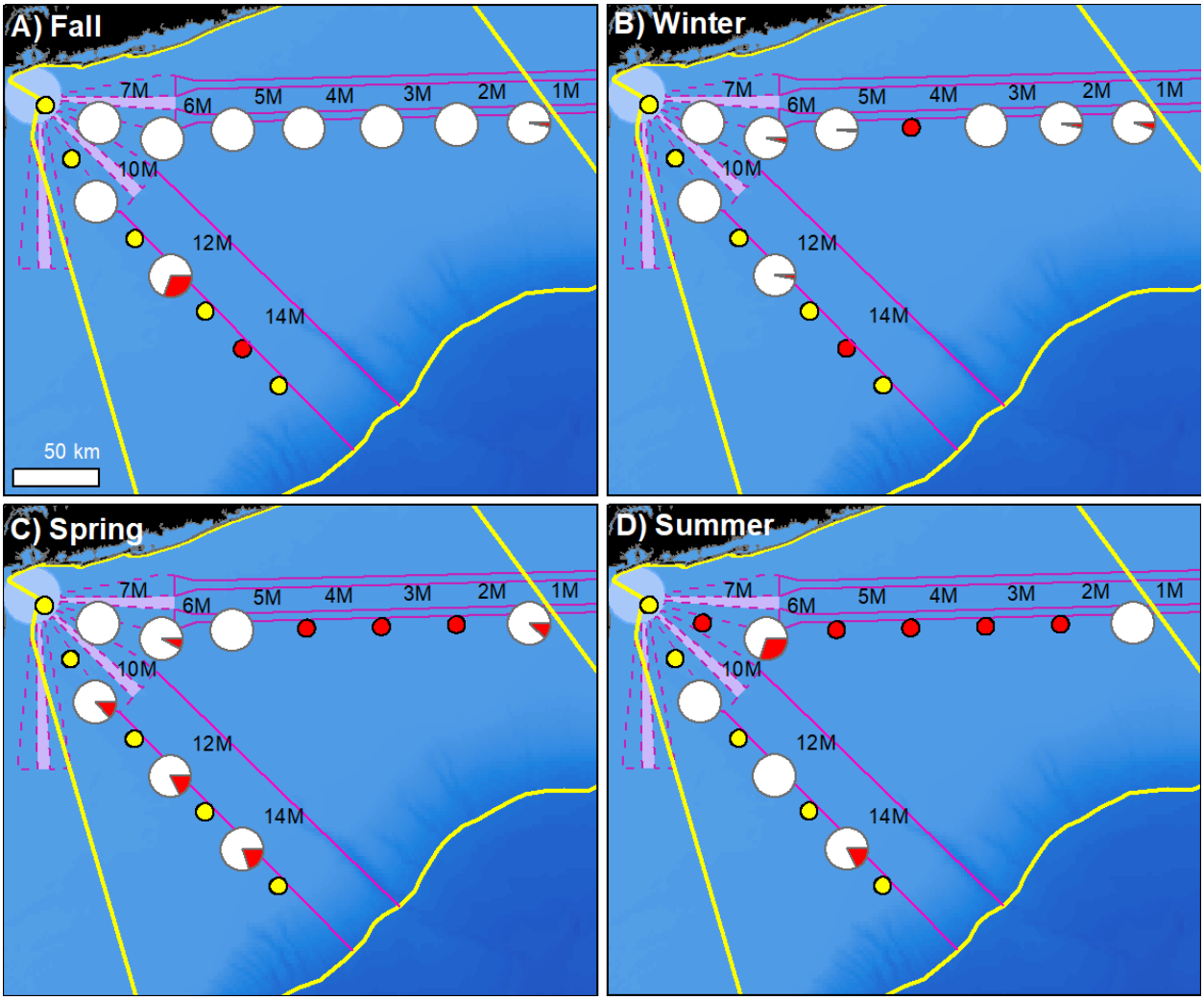


Figure 72. Spatial patterns of seasonal presence of minke whales in New York Bight, shown as a percentage of days per season on each recoding unit. A) Fall (October – December), B) Winter (January – March), C) Spring (April – June), and D) Summer (July). The small yellow circles denote AMAR site locations and the small red circles denote MARU sites in which there are no data for that month.

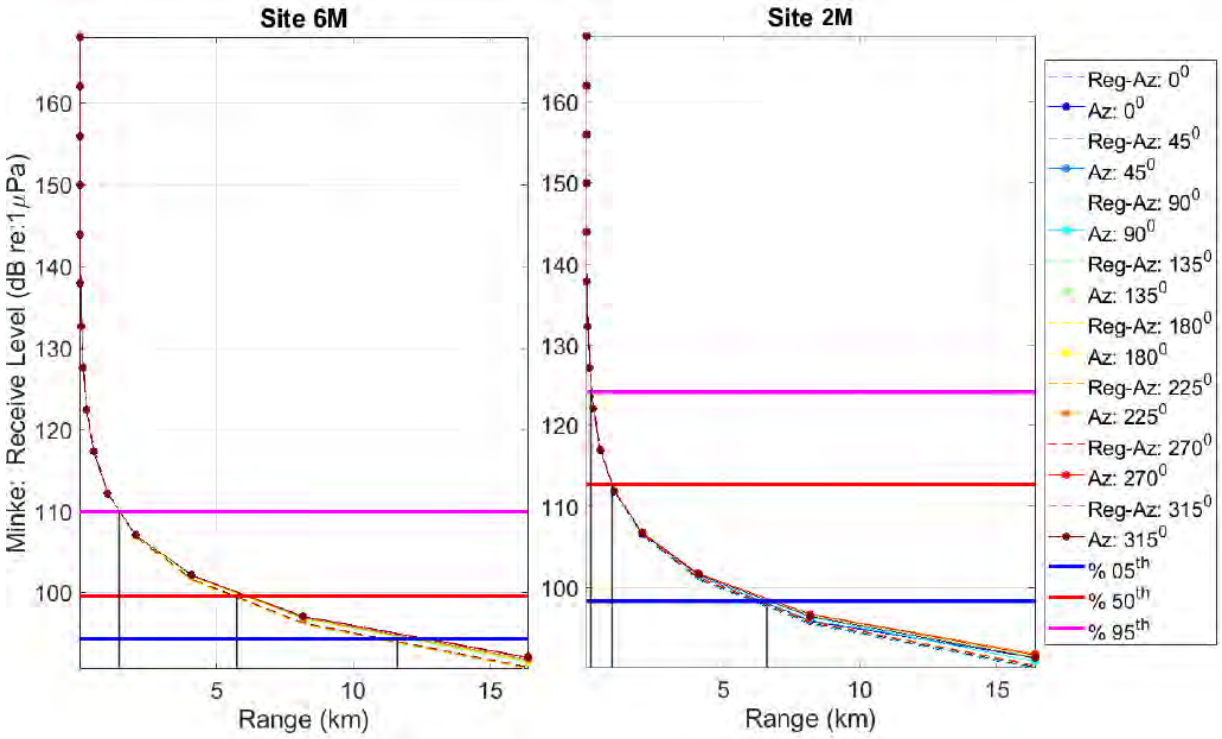


Figure 73. Estimated detection ranges of minke whale pulse trains (in km), given the estimated source level of 168 dB re: 1µPa @ 1m for the site with the lowest noise (6M) and highest noise (8A) in the minke whale frequency band (45 – 355 Hz) between October 2017 and July 2018. Each solid curved line represents the detection range per azimuth; the dashed curved lines represent the regression of range per azimuth. The pink, red, and blue straight lines illustrate the 95th, 50th, and 5th percentiles noise levels, respectively, per site. The solid black vertical lines mark the ranges at which the target signal can be received based on the 5th, 50th, and 95th percentiles of noise levels.