OCS Study
BOEM 2022-059

Passive Acoustic Telemetry as a Tool to Monitor the Baseline Presence and Persistence of Highly Migratory Fish Species in Popular Recreational Fishing Grounds within the Southern New England Wind Energy Area

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ABOUT THE COVER

Shortfin mako tagged with acoustic transmitter. Photo credit: J. Kneebone

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List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
Chl_a	chlorophyll a
cm	centimeter
Dtx	number of detections
EFH	Essential Fish Habitat
FL	fork length
HMS	highly migratory pelagic fishes
MATOS	Mid-Atlantic Acoustic Telemetry Observation System
mV	millivolts
PI	Principal Investigator
Res	residences
RI	residency index
SD	standard deviation
SST	sea surface temperature
T	temperature
Tx	unique transmitters (Tx)
WEA	wind energy area

1 Introduction

The offshore waters of southern New England have long supported populations of highly migratory pelagic fishes (HMS) and the fisheries that target them. In addition to serving as important feeding grounds and migratory corridors for numerous HMS along the U.S. East Coast, southern New England represents historical commercial and recreational fishing grounds for iconic species such as swordfish (*Xiphias gladius*), Atlantic bluefin tuna (*Thunnus thynnus*), white marlin (*Kajikia albidus*), and shortfin mako sharks (*Isurus oxyrinchus*). This region is also ecologically-important for many HMS, and contains Essential Fish Habitat (EFH) for at least 13 HMS including albacore tuna (*T. alalunga*), Atlantic bluefin tuna, skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*T. albacares*), blue shark (*Prionace glauca*), shortfin mako shark, common thresher shark (*Alopias vulpinus*), porbeagle shark (*Lamna nasus*), white shark (*Carcharodon carcharias*), dusky shark (*Carcharhinus obscurus*), sandbar shark (*C. plumbeus*), tiger shark (*Galeocerdo cuvier*), and sand tiger shark (*Carcharias taurus*). Extensive recreational HMS fisheries also continue to occur in this region, with hundreds of active vessels participating in the fishery each year. Much of that recreational fishing effort occurs within popular fishing areas that have been leased for offshore wind development (Kneebone and Capizzano 2020).

Recreational fishing for HMS is a popular activity in southern New England with upwards of 10,000 directed trips conducted by private and charter fishing vessels from June to October each year (Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division October 10, 2019). Due to the diversity of HMS present seasonally in the southern New England region, the recreational fishery encounters several species. Recent fishery survey data indicate that bluefin tuna, yellowfin tuna, white marlin, mahi mahi (*Coryphaena hippurus*), and pelagic sharks (blue shark, shortfin mako, common thresher) are the most commonly targeted species (Kneebone and Capizzano 2020). Preliminary fishery survey data also indicate that recreational fishing effort for HMS occurs throughout the southern New England WEAs, however, some locations experience markedly higher fishing effort than others (Kneebone and Capizzano 2020).

With the prospect of wind energy development in southern New England, considerable effort has been made to collect baseline data and assess potential impacts on certain fish species (e.g., Atlantic cod, *Gadus morhua*) and the local fisheries that target them. To date, little effort has been made to assessing baseline conditions or the potential impacts on HMS and recreational HMS fisheries in the region. For example, it is not known whether turbine presence will affect the residency or movements of HMS in wind energy areas (WEAs), whether HMS foraging success will be impacted, or if HMS will be completely displaced from WEAs due to effects of pre-construction surveying, turbine construction, turbine operation, or electromagnetic fields generated during operation (MADMF 2018). There is also an incomplete understanding of how recreational fishing activities (i.e., fishing methods) will be impacted by offshore wind development, including the extent to which fishing effort may be disrupted due to the displacement of target species from popular fishing areas that fall within the lease areas (MADMF 2018). Given the abundance of HMS in southern New England and the magnitude of recreational fishing for several species, it is imperative that steps be taken to understand how HMS may be impacted by wind energy. Establishing a cost-effective system to monitor HMS in WEAs in both the short- (i.e., months to years) and long-term (i.e., years to decades) is needed to accomplish this goal. Indeed, the Research Priorities White Paper (MADMF 2018) identifies HMS as key indicator species for monitoring the effects of offshore wind development, with bluefin tuna and sharks (with focus on the blue shark) identified as priority species for research. Given the ecological importance of southern New England to several HMS and the limited effort that has been expended towards monitoring HMS in the WEAs, increased attention to this diverse group of fish is necessary to adequately understand and address potential offshore wind energy impacts.

1.1 Project Objectives

The overall objective of this project was to use passive acoustic telemetry to monitor the baseline location (presence) and persistence of HMS in popular recreational fishing areas within southern New England wind energy lease areas while describing the environmental conditions potentially associated with their presence in this region. Passive acoustic telemetry is a popular and powerful tool for studying the movement patterns and habitat use of marine fish over fine- and broad-scale spatial extents (e.g., Heupel et al. 2006, Kneebone et al. 2014abc, Bruce et al. 2019) and has been used previously to document baseline animal presence in WEAs along the U.S. East Coast (e.g., Frisk et al. 2019. Haulsee et al. 2020, Secor et al. 2020). Our specific objectives were to:

(1) Conduct for-hire trips on charter sportfishing vessels to tag HMS, with particular focus on Atlantic bluefin tuna, shortfin mako, and blue shark, with acoustic transmitters within three areas that support the highest level of recreational fishing effort for HMS within southern New England WEAs,

(2) Work cooperatively with commercial fishermen to deploy and maintain an array of 15 acoustic receivers that will monitor the presence and persistence of HMS within those popular recreational fishing areas in the WEAs,

(3) Use receiver 'detection' data to establish baseline information on the presence, persistence, and habitat use of key HMS (and other opportunistically detected marine species) in these popular recreational fishing areas that may be impacted by offshore wind development,

(4) Use receiver detection data obtained from acoustic receivers deployed throughout the broader Atlantic (obtained through partnerships with regional telemetry data sharing programs) to collect information on spatial distributions of HMS beyond the confines of the WEAs,

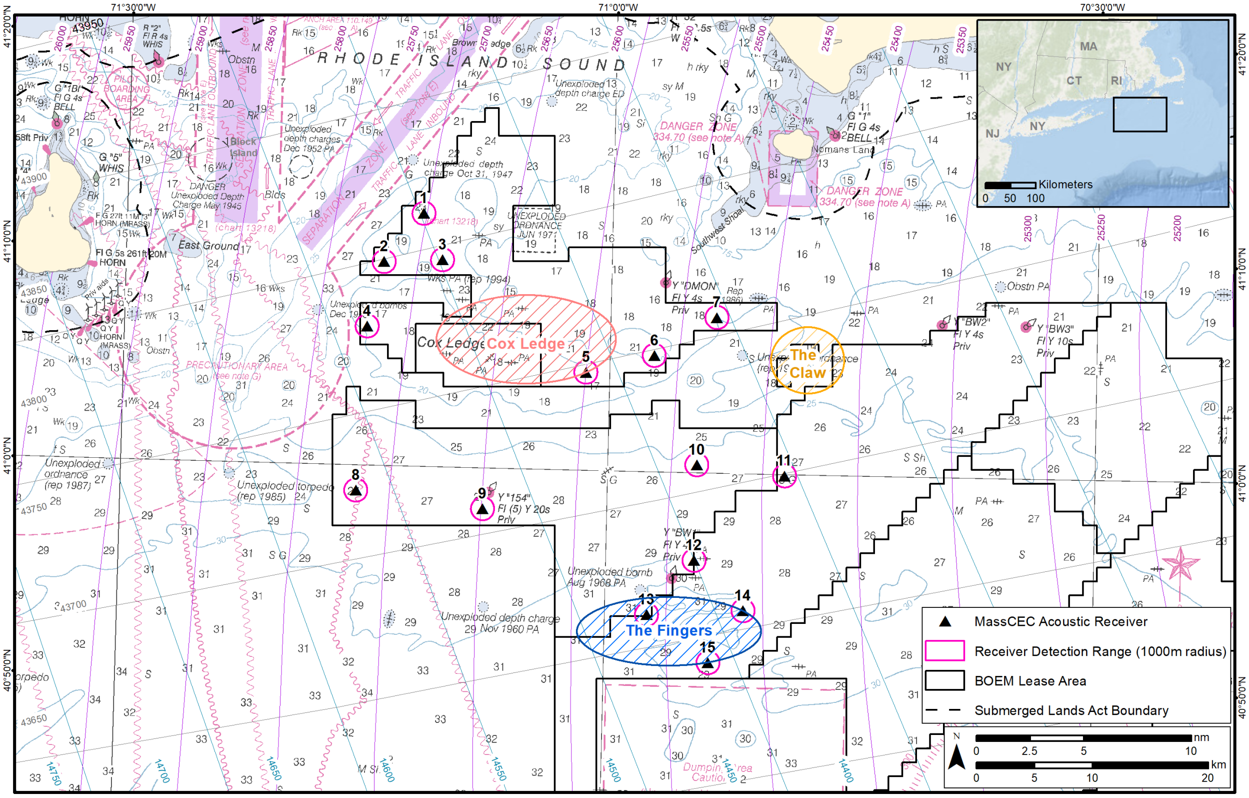
(5) Opportunistically monitor the presence and persistence of other acoustically-tagged marine species within the acoustic receiver array through cooperation with other project Principal Investigators (PIs) and regional acoustic telemetry data sharing programs, and

(6) Evaluate the efficacy of passive acoustic telemetry as a method for monitoring the presence of HMS, and other marine species, both prior to (i.e., baseline) and during the construction and operation phases of wind energy projects in southern New England.

2 Methods

2.1 Study Area

Acoustic tagging and monitoring efforts for HMS were conducted throughout the southern New England region both in and around the southern New England WEA (Figure 1). To achieve our main objective of documenting HMS presence, persistence, and movements at the three most popular HMS recreational fishing locations that occur within the southern New England WEA (Kneebone and Capizzano 2020), acoustic receivers were placed at areas known as Cox Ledge (OCS-A 0486), The Claw (OCS-A 0487, OCS-A 0500), and The Fingers (OCS-A 500) (Figure 1). Individual acoustic receiver locations were selected based on the desire to minimize potential interaction with commercial fishing gear, particularly mobile fishing gear, and maximize the coverage of the popular recreational fishing area. When appropriate, receivers were placed on LORAN TD lines ending in ‘0’ or ‘5’ according to a longstanding, informal agreement within the fishing industry designed to minimize interaction between fixed and mobile fishing gear. Input was also sought from commercial fishermen on acoustic receiver locations that would minimize potential interaction with commercial fishing gear.



Data: NOAA NOS Chart 12300

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Date: 9/23/2022

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Figure 1. Map of the study site showing the location of the 15 acoustic receiver stations in relation to existing wind energy lease areas and three popular HMS recreational fishing locations in southern New England as identified in Kneebone and Capizzano (2020).

2.2 Acoustic Receiver Deployment and Maintenance

VEMCO acoustic receivers (INNOVASEA Systems Inc., Halifax, Nova Scotia, Canada) were deployed to continuously monitor for the presence of tagged HMS during the periods of July 7 to December 21, 2020 and May 17 to December 8, 2021. Due to the vast area over which receivers were deployed and logistical challenges, multiple trips were needed to deploy and recover the 15 total receivers in each year, which led to unequal deployment durations across all receiver stations (Table 1). In each year, both VEMCO VR2-AR acoustic release and VR2-Tx receivers were deployed. In addition to logging 'detections' from acoustic transmitters, acoustic receivers recorded average ambient noise (mV at 69 kHz), water temperature (°C), tilt angle (degrees), and depth (m; VR2-AR only) every hour throughout their deployment. VR2-AR receivers were rigged for benthic deployment on a 2-meter section of 7/16" rope and an 11" hard float and moored in place with 30 – 35 kg cast iron plates (Figure 2). VR2-Tx receivers were deployed using rope, anchors, and surface floats as described in Figure 2. When hauled for the season, receivers were downloaded, cleaned, and had their batteries replaced. Due to limited funding, range testing was not conducted for this study. However, anticipated detection range (50% probability of detection) for V16 transmitters in the water depths monitored is estimated at 800 – 1200 m.

Table 1. Metadata for the 15 acoustic receivers that were deployed seasonally in the southern New England WEA during 2020 and 2021.

-	-	-	-	2020				2021			
Station #	**Latitude**	**Longitude**	**Depth (m)**	**Receiver type**	**Date deployed**	**Date hauled**	**Days deployed**	**Receiver type**	**Date deployed**	**Date hauled**	**Days deployed**
1	41.20	-71.20	40	VR2AR	7/7/2020	12/21/2020	167	VR2AR	5/17/2021	12/4/2021	201
2	41.16	-71.24	40	VR2AR	7/7/2020	12/21/2020	167	VR2AR	5/17/2021	12/4/2021	201
3	41.16	-71.18	38	VR2AR	7/7/2020	12/21/2020	167	VR2AR	5/17/2021	12/8/2021	205
4	41.11	-71.25	35	VR2AR	7/7/2020	12/21/2020	167	VR2AR	5/17/2021	12/4/2021	201
5	41.08	-71.02	35	VR2AR	7/7/2020	12/12/2020	158	VR2AR	5/17/2021	12/4/2021	201
6	41.09	-70.96	37	VR2AR	7/7/2020	12/12/2020	158	VR2AR	5/17/2021	12/4/2021	201
7	41.12	-70.89	36	VR2AR	7/7/2020	12/12/2020	158	VR2AR	5/17/2021	12/4/2021	201
8	40.98	-71.26	49	VR2Tx	7/7/2020	12/7/2020	154	VR2Tx	6/17/2021	12/8/2021	175
9	40.97	-71.13	51	VR2AR	7/7/2020	12/21/2020	167	VR2AR	5/17/2021	12/4/2021	201
10	41.01	-70.91	47	VR2AR	7/7/2020	12/12/2020	158	VR2Tx	7/1/2021	12/8/2021	161
11	41.00	-70.82	49	VR2Tx	7/7/2020	12/21/2020	167	VR2Tx	7/1/2021	12/8/2021	161
12	40.93	-70.91	53	VR2AR	7/9/2020	12/12/2020	156	VR2AR	6/23/2021	12/4/2021	164
13	40.89	-70.96	55	VR2AR	7/9/2020	12/12/2020	156	VR2AR	6/23/2021	Missing	Missing
14	40.89	-70.86	54	VR2AR	7/9/2020	12/12/2020	156	VR2AR	6/23/2021	12/4/2021	164
15	40.85	-70.89	55	VR2AR	7/9/2020	12/12/2020	156	VR2AR	6/23/2021	Missing	Missing

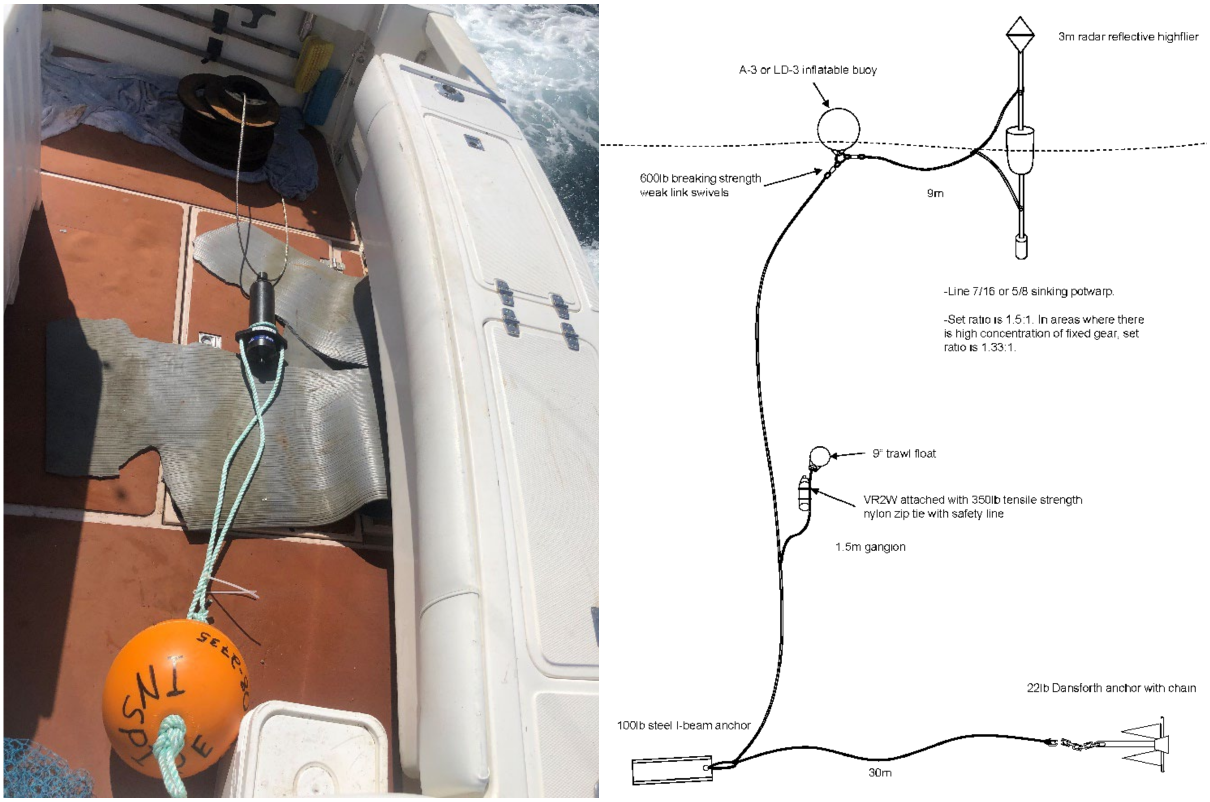


Figure 2. Mooring configuration used to deploy VEMCO VR2-AR receivers (left) and VR2-TX acoustic receivers (right). Designs were based on previous studies and field-use by the Massachusetts Division of Marine Fisheries.

2.3 Acoustic Transmitter Deployment (Tagging)

Sixty VEMCO acoustic transmitters (model V16-4H, 16 mm diameter, nominal transmission delay = 80-160 seconds, expected longevity = 2,435 days; 30 internal, 30 external) were deployed on individual HMS during for-hire trips aboard charter sportfishing vessels in July and August of 2020, and June and July of 2021. The location of fishing/sampling during each trip was selected based on the target species and fishing method (e.g., sharks vs. bluefin tuna) and efforts were made to tag individuals with transmitters as close to the acoustic receiver array as possible. All HMS were captured on hook-and-line (rod-and-reel) fishing gear using standard recreational sportfishing techniques. Blue shark, shortfin mako, and bluefin tuna were targeted during all sampling trips, however, sandbar and smooth hammerhead sharks were tagged opportunistically if encountered. All capture and tagging activities were approved under the New England Aquarium Animal Care and Use Policy 2020-07.

2.3.1 Internal Tagging

Acoustic transmitters were surgically implanted into juvenile bluefin tuna and shortfin mako using standard techniques. Bluefin tuna were brought aboard the vessel using a knotless, rubber dip net and placed on their side on a cool, wet, rubber mat. A wet towel was also placed over the eyes to calm the fish during the procedure. The vessel's raw seawater deck hose was then positioned anterior to the mouth or above the gill arch opening to deliver ambient seawater to the gills during surgery. Upon retrieval to the side of the vessel, shortfin mako sharks were tail roped and secured by applying pressure to the tail rope and leader on which they were caught. The sharks were then placed in tonic immobility alongside the vessel or with their caudal region brought through the vessel's tuna door, the head and gills remaining in the water at all times.

Once the animals were secured, a local anesthetic (lidocaine; dose = 2 mg kg^{-1}) was administered subcutaneously and allowed to react 1 minute before incising. Using a fresh scalpel, an initial incision was made traversing only the dermis and a 15-mm trocar was used to penetrate the body cavity. The acoustic transmitter was then inserted, and the wound was closed with two to three interrupted, monofilament, absorbable sutures. The fork length (FL) was measured (cm) from the tip of the snout to the fork in the tail over the body and the animal was released. Sex determinations were made for shortfin mako sharks via the presence/absence of claspers (male). All surgical tools were disinfected prior to and after each surgery.

2.3.2 External Tagging

Acoustic transmitters were externally attached to sharks that were too large to safely conduct surgical procedures. External V16-4H transmitters were encapsulated in a polyvinyl chloride 'shark' case and were rigged with multi-strand stainless cable covered in heat shrink tubing and a titanium anchor. The overall length of the tether ranged from 8 to 15 cm and was scaled based on the size of the animal to be tagged. During tagging, sharks were brought alongside the vessel and the tag was applied in the dorsal musculature using a tagging pole equipped with a stainless-steel applicator needle. Following tagging, the FL of the shark was measured or estimated, the sex was noted, and the hook was either removed or cut in half using bolt cutters. Some individuals were tagged while they were free swimming next to the tagging vessel; length was estimated for each of these fish and sex was assessed via visual observation of claspers when possible.

2.4 Data Analysis

Raw acoustic detections and archived environmental data downloaded from acoustic receivers were compiled into a database for analysis. Due to high mobility of HMS and the 80 – 160 second nominal transmission delay, single detection events were considered valid and retained for analysis. Since acoustic receivers were deployed seasonally, data obtained in 2020 and 2021 were analyzed separately. All analyses were performed in R (version 4.1.2; R Core Team 2021), primarily with *tidyverse* packages (Wickham et al. 2019).

2.4.1 Presence and Persistence

To evaluate the presence and persistence of tagged HMS at each acoustic receiver station, as well as within the full receiver array, periods of residency were calculated using the *VTrack* (Campbell et al. 2012) package. A residency event was defined as any time in which an individual was detected at least once at a receiver station. Residences ended when individuals were not detected (i.e., absent) for at least 24 hours or if that individual was detected on another receiver, whichever occurred first. For each individual, the total number of residencies over all receiver stations was summed over the period of June 1 to November 30 (i.e., when HMS were observed in the acoustic receiver array) and a residency index (RI) was calculated by dividing the cumulative number of residences by the cumulative amount of time (days) all receivers were deployed when that individual was available for detection (March et al. 2010). In the year of tagging, individuals were defined as being available for detection from the date of tagging to November 30; for individuals tagged in 2020 that were detected in 2021, this period spanned from the date of receiver deployment to November 30. To examine the amount of time individuals were detected, the duration of each residency event was calculated as the time between the first and last detection. The frequency and duration of residency events were then summarized by species in each year. To examine the relative number of residences at each receiver station, the total number of residences observed over all species was divided by the total number of days in which receivers were deployed during the period of June 1 to November 30. All RI values were multiplied by 100 to avoid comparison of small decimal values. The amount of time that elapsed between release and the first residence was also calculated for each detected individual. Detection histories were also created to visually demonstrate the presence of each individual and species over time and in relation to acoustic receiver stations.

2.4.2 Movement Patterns

To qualitatively describe the movements and connectivity of tagged individuals throughout the southern New England region, straight line (horizontal) movements (i.e., inferred transitions) between release locations and the location of the first receiver detection, as well as between individual receiver stations, were mapped. Preliminary review of acoustic detection data revealed that numerous individuals were detected sporadically throughout the season, with several days (to weeks) often elapsing between detection events. Since the location of the animal during unobserved periods could not be determined, only movements between receiver stations occurring within 72 hours were considered direct transitions. This time step was selected based on the duration of residency periods documented by this study as well as the anticipated movement rates of the tagged species and the overall area of the acoustic receiver array. The number of transitions between receiver stations was summed by species and year and mapped to demonstrate the nature and frequency of movements within the study site. All analyses and maps were created using the *sf* (Pebesma 2018) package in R.

2.4.3 Environmental Conditions

To establish the baseline environmental conditions under which HMS were present in the study area, bottom water temperature, sea surface temperature (SST), and surface chlorophyll a concentration were determined for each acoustic detection. Bottom water temperature data were sourced from the hourly water temperature data logged by each acoustic receiver. Daily Multi-sensor Ultra-high Resolution SST data at 0.01°C resolution were downloaded using the '*rerddap*' package (Chamberlain 2021) and an SST was assigned to each detection based on the SST interpolated at the location of the detecting receiver on that calendar date. To examine animal presence in relation to thermal stratification, the difference between the bottom water temperature and SST was calculated (ΔT). Chlorophyll a data were obtained from the NOAA VIIRS, Science Quality, Global, Level 3, 4.17 km, daily interpolated model accessed via *rerddap*. Kernel density plots were created using the geom_density function in R package *ggplot* to describe the range of environmental conditions in which each species was detected over the study period.

2.5 Data Sharing

Metadata from acoustic transmitters (transmitter number, tagging date, tagging location, transmitter longevity, species) and receivers (receiver number, deployment dates, location) were uploaded and shared via the Mid-Atlantic Acoustic Telemetry Observation System (MATOS). All acoustic receiver detection data logged throughout the study were also shared via MATOS. Permission was sought from transmitter owners and/or entities that detected HMS transmitters on their own receivers to use the data in this report. Basic summary statistics and detection history plots were created to describe the presence of opportunistically-detected animals/species.

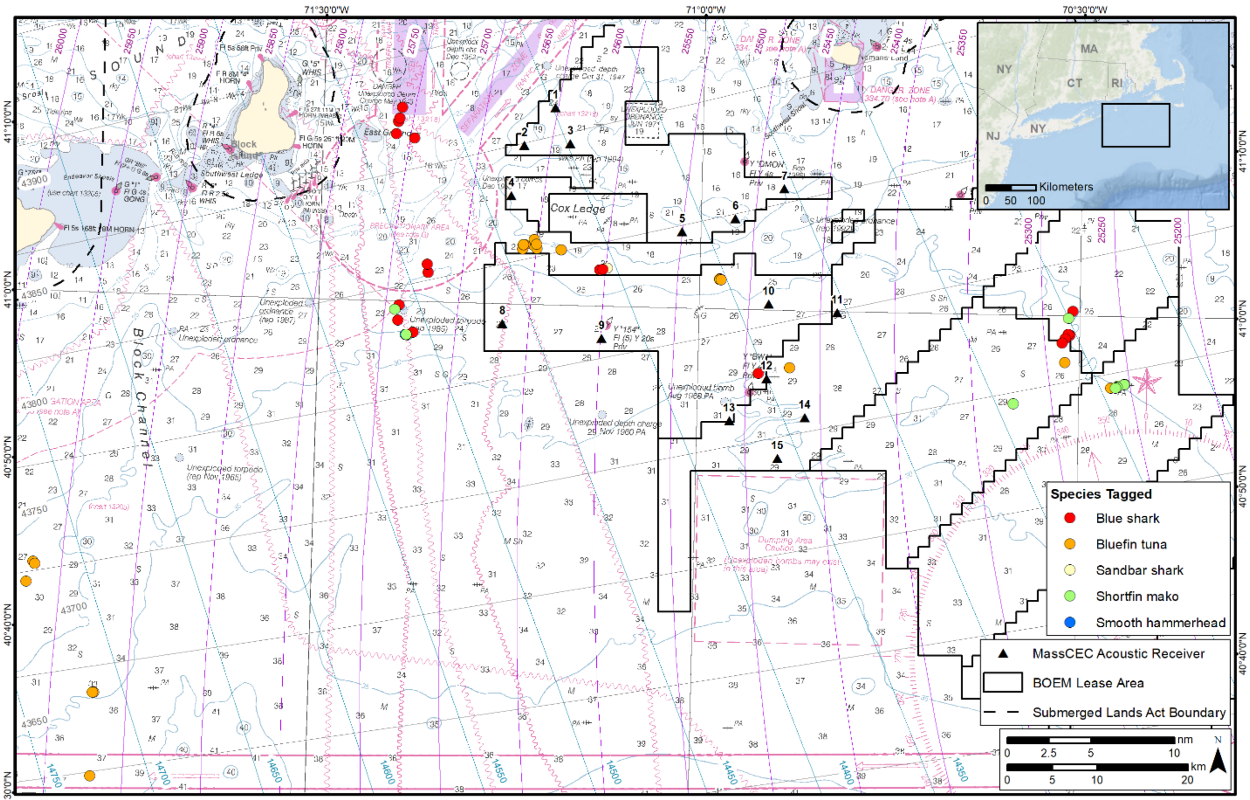
3 Results

3.1 Transmitter Deployments

Acoustic transmitters were deployed on blue sharks (n=21), shortfin mako sharks (n=12), a sandbar shark (n=1), a smooth hammerhead shark (n=1), and bluefin tuna (n=25) during July and August 2020 (n=29) and June and July 2021 (n=31) (Table 2; Figure 3). All blue sharks, seven shortfin mako sharks, and single sandbar and smooth hammerhead sharks received external transmitters, while all bluefin tuna and five shortfin mako sharks were tagged with internal transmitters.

Table 2. Metadata from the 60 HMS that were tagged during the study. FL = fork length

-	-	Sex			Size	Tag Placement	
Species	**# Tagged**	**Male**	**Female**	**Unknown**	**FL (cm)**	**External**	**Internal**
Blue shark	21	20	1	-	120–244	21	0
Shortfin mako	12	6	4	2	100–180	7	5
Bluefin tuna	25	-	-	25	64–104	0	25
Sandbar shark	1	1	0	-	122	1	0
Smooth hammerhead	1	0	1	-	183	1	0



Data: NOAA NOS Chart 12300

Document Name: MassCEC_receivers_species_tags_June2022

Date: 6/21/2022

Figure 3. Location of tagging (colored circle) for the 60 HMS monitored as part of this study. Station numbers for individual receiver locations (black triangles) are presented for reference.

3.2 Acoustic Receiver Deployments and Maintenance

All 15 acoustic receivers deployed in 2020 were successfully recovered and downloaded. In 2021, 13 of the 15 receivers were recovered; VR2-AR receivers at Station 13 and 15 could not be located during recovery trips in December 2021 and were presumed lost (Table 1).

3.3 Presence and Persistence of Tagged HMS

Of the 60 tagged HMS, 35 (58%) were detected by the receiver array, 17 of the 29 (59%) tagged in 2020 and 18 of the 31 (58%) tagged in 2021 (Table 3). The single tagged sandbar and smooth hammerhead sharks were not detected. A total of 1,296 detections were recorded for the 35 detected individuals, 610 detections in 2020 and 686 detections in 2021. Eight individuals (two blue sharks, three shortfin mako sharks, and two bluefin tuna) tagged in 2020 were detected in 2021. Of these, three individuals (one blue shark, one shortfin mako shark, and one bluefin tuna) were not previously detected in 2020. Blue sharks were detected between June 27 and September 16, shortfin mako sharks between July 2 and October 13, and bluefin tuna between June 20 and November 21 (Figure 4). In the year in which they were tagged, HMS were first detected from 0.9 to 89.1 (Mean ± SD: 23.1 ± 23.7) days after release; three individuals (one blue shark, one shortfin mako shark, one bluefin tuna) tagged in 2020 were not detected until 2021, 297, 327, and 370 days after tagging, respectively. Tagged HMS were detected by 14 of 15 receiver stations in 2020 and all 13 recovered receivers in 2021 (Table 4; Figure 5). Over the course of the study, Station 1 logged the most detections, residences, and detected the greatest number of transmitters, which corresponds to individual fish. However, HMS presence at each station (and popular fishing location) was variable both within and between years (Tables 4 and 6).

Table 3. Summary of the number of transmitters that were deployed and detected for each species. Numbers shown in parentheses represent the number of individuals tagged in 2020 that were detected in 2021.

Species	2020		2021		Total		
	Tagged	Detected	Tagged	Detected	Tagged	Detected	% Detected
Blue shark	13	9	8	6(2)	21	15	71%
Shortfin mako shark	8	4	4	3(3)	12	7	58%
Bluefin tuna	8	4	17	9(2)	25	13	52%
Sandbar shark	0	0	1	0	1	0	0%
Smooth hammerhead shark	0	0	1	0	1	0	0%
Total	*29*	*17*	*31*	*18*	*60*	*35*	*58%*

Table 4. Summary of the number of detections (Dtx), residences (Res), and unique transmitters (Tx) observed at each receiver station by species and year. Numbers in parentheses represent the number of fish tagged in 2020 that were detected in 2021. 'X' denotes that the receiver was missing. Refer to Figure 1 for the location of each station.

Species >	**Blue shark**						**Shortfin mako**						**Bluefin tuna**					
Year >	**2020**			**2021**			**2020**			**2021**			**2020**			**2021**		
Type >	**Dtx**	**Res**	**Tx**	**Dtx**	**Res**	**Tx**	**Dtx**	**Res**	**Tx**	**Dtx**	**Res**	**Tx**	**Dtx**	**Res**	**Tx**	**Dtx**	**Res**	**Tx**
Station 1	117	12	5	14	3	3	0	0	0	24	3	3	0	0	0	26	5	3
Station 2	66	4	4	31	4	4	0	0	0	17	2	2	0	0	0	32	7	3
Station 3	36	7	4	0	0	0	0	0	0	17	4	2	0	0	0	22	5	4
Station 4	9	2	1	0	0	0	0	0	0	12	2	3	3	1	1	13	6	4
Station 5	7	1	1	14	1	2	0	0	0	26	5	4	4	1	1	6	3	3
Station 6	10	2	2	0	0	0	0	0	0	13	2	2	2	0	1	2	1	1
Station 7	0	0	0	2	1	1	0	0	0	54	6	4	0	0	0	8	2	2
Station 8	42	4	3	0	0	0	0	0	0	19	2	2	4	1	1	54	10	8
Station 9	24	3	2	24	2	3	50	2	2	7	3	2	0	0	0	15	5	4
Station 10	34	3	4	39	2	2	0	0	0	0	0	0	0	0	0	26	7	5
Station 11	21	2	2	58	5	5	9	1	1	0	0	0	0	0	0	28	5	4
Station 12	2	0	1	17	1	1	8	2	1	0	0	0	0	0	0	8	4	2
Station 13	50	5	5	X	X	X	4	0	2	X	X	X	6	1	1	X	X	X
Station 14	43	6	3	37	3	3	0	0	0	0	0	0	10	2	2	21	3	3
Station 15	30	4	3	X	X	X	15	1	1	X	X	X	4	1	1	X	X	X
Total	491	55	9	236	22	8(2)	86	6	4	189	29	6(3)	33	7	4	261	63	12(3)

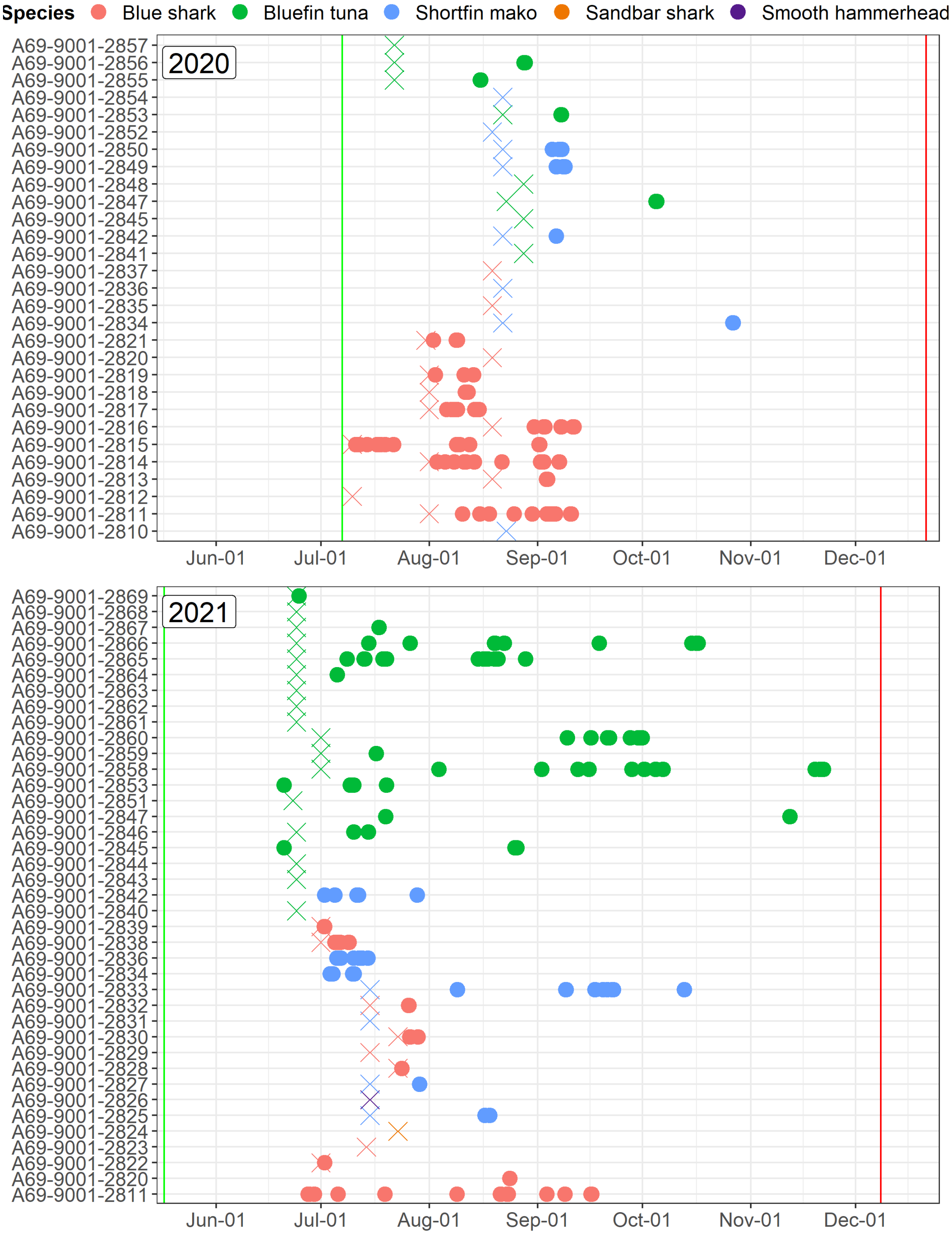


Figure 4. Detection history for 60 HMS tagged with acoustic transmitters in 2020 (n=29) and 2021 (n=31). Green vertical lines represent the time when receivers were deployed, and the red vertical lines represent when the receivers were removed for the season. Colored 'Xs' represent the time of tagging for each individual. In 2021, detected individuals that were tagged in 2020 have no 'X' in their detection history.

Figure 5. Detection history of each species on each receiver station. Colored circles indicate when that species was observed at a given station. Colored vertical lines represent the time individuals of each species were first tagged in each year. Black 'Xs' represent the time when the receiver was deployed and the red 'Xs' represent the time it was removed for the season.

A total of 182 residences were documented over the study, including 68 in 2020 (17 transmitters detected) and 114 in 2021 (26 transmitters detected) (Tables 5 and 6; Figure 6). Residences lasted from 2 to 1,368 minutes (22.8 hours), with blue sharks having the most, and longest, duration residences over the course of the study. Bluefin tuna residence durations were the shortest of all detected species in both 2020 and 2021. Residency index values ranged from 0 (absent, not detected) to 0.720 and were variable between species and years.

Table 5. Summary of the number and duration of residences and residency index values documented for each species in each year of the study. Numbers in parentheses indicate the number of fish tagged in 2020 that were detected in 2021. Residency Index (RI) values were calculated by dividing the cumulative number of residences by the cumulative amount of time (days) all receivers were deployed. *Assumes that no other individuals tagged in 2020 were available for detection.

-	Number of Individuals		Residences			Residency Index (RI)			
Species & Year	**At large***	**Detected**	**#**	**Min Duration (min)**	**Max Duration (min)**	**Min**	**Max**	**Mean**	**SD**
2020	-	-	-	-	-	-	-	-	-
Blue shark	13	9	55	2	784	0	0.600	0.247	0.239
Shortfin mako	8	4	6	14	247	0	0.198	0.066	0.086
Bluefin tuna	8	4	7	4	153	0	0.151	0.056	0.065
2021	-	-	-	-	-	-	-	-	-
Blue shark	10(2)	8	22	2	1,368	0	0.504	0.114	0.153
Shortfin mako	7(3)	6	29	2	1,069	0	0.553	0.211	0.188
Bluefin tuna	20(3)	12	63	2	630	0	0.720	0.156	0.238
Sandbar shark	1	0	0	-	-	0	-	-	-
Smooth hammerhead	1	0	0	-	-	0	-	-	-

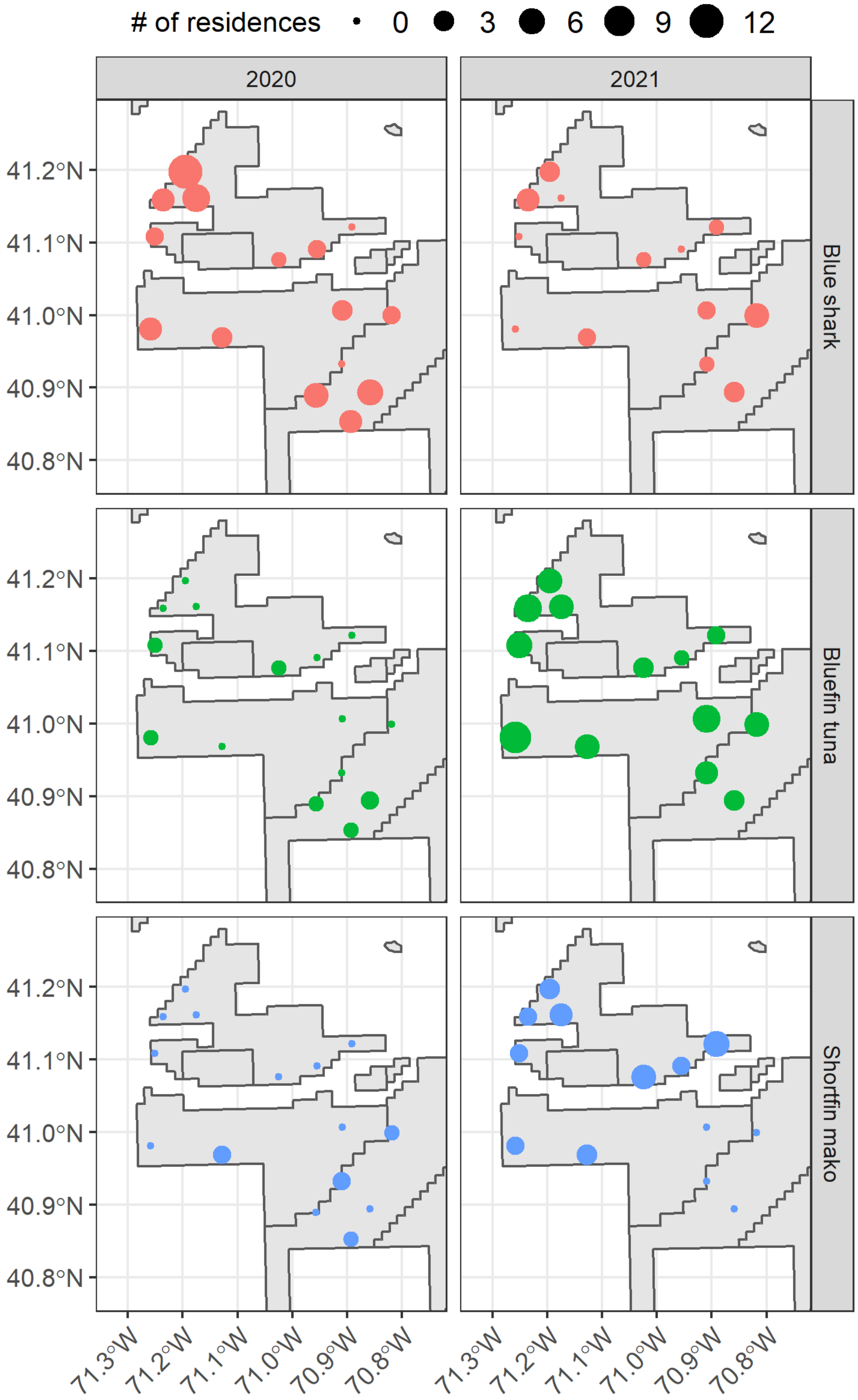


Figure 6. Number of residences observed at each receiver station by species in each year of the study. Note that receiver stations 13 and 15 were lost in 2021 and no data were recovered.

Table 6. Summary of the residency index (RI) at each receiver station over all species in each year of the study. 'X' denotes that the receiver was missing. Refer to Figure 1 for the location of each station.

Species >	Blue shark		Shortfin mako		Bluefin tuna		All species	
Year >	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Station 1	0.082	0.015	0.000	0.015	0.000	0.025	0.082	0.056
Station 2	0.027	0.020	0.000	0.010	0.000	0.035	0.027	0.066
Station 3	0.048	0.000	0.000	0.020	0.000	0.025	0.048	0.045
Station 4	0.014	0.000	0.000	0.010	0.007	0.030	0.021	0.040
Station 5	0.007	0.005	0.000	0.025	0.007	0.015	0.014	0.045
Station 6	0.014	0.000	0.000	0.010	0.000	0.005	0.014	0.015
Station 7	0.000	0.005	0.000	0.030	0.000	0.010	0.000	0.045
Station 8	0.027	0.000	0.000	0.012	0.007	0.061	0.034	0.073
Station 9	0.021	0.010	0.014	0.015	0.000	0.025	0.034	0.051
Station 10	0.021	0.013	0.000	0.000	0.000	0.046	0.021	0.059
Station 11	0.014	0.033	0.007	0.000	0.000	0.033	0.021	0.066
Station 12	0.000	0.006	0.014	0.000	0.000	0.025	0.014	0.031
Station 13	0.034	X	0.000	X	0.007	X	0.041	X
Station 14	0.041	0.019	0.000	0.000	0.014	0.019	0.055	0.037
Station 15	0.027	X	0.007	X	0.007	X	0.041	X

3.4 Movement Patterns

Tagged HMS exhibited extensive movements throughout the study site, both from release locations into the receiver array and between individual stations within the receiver array (Figures 7 and 8). In many instances, individuals were first detected by receivers that were closest to the tagging location. However, several individuals were first detected on more distant receivers (on the other side of the array) weeks to months after release, indicating that they moved through the array undetected or traversed around the periphery of the array before entering the study site. Movement networks also demonstrated that each species exhibited direct movements between receiver stations over 72-hour periods, with directed movements/transitions occurring between most receiver stations. However, movement patterns of each species were variable between 2020 and 2021. Movements were also documented between each of the popular fishing locations.

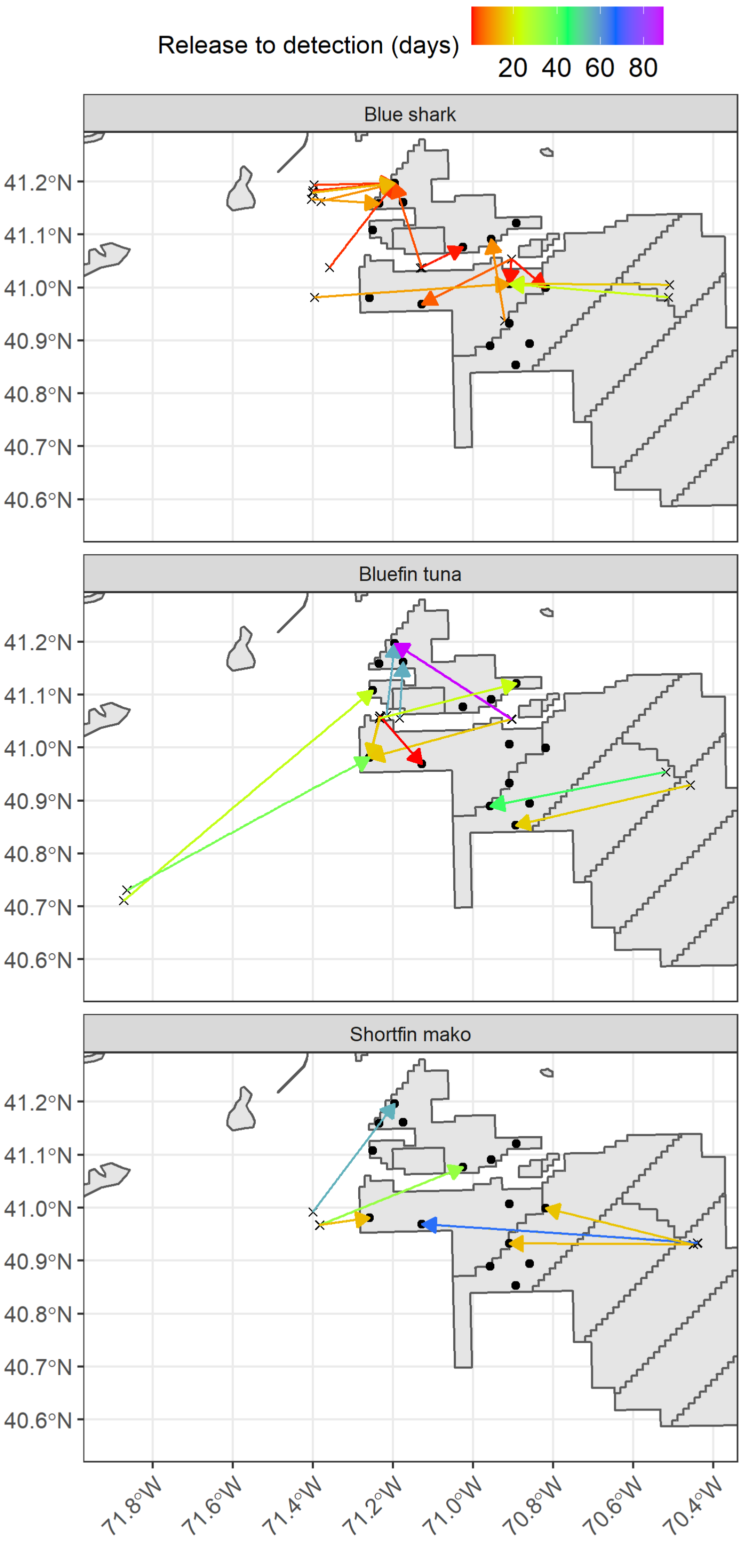


Figure 7. Movements of 32 tagged HMS from the release location to the location of the first detection within the acoustic receiver array in the year in which they were tagged. Arrows denote the direction of movement and are color coded by the amount of time that elapsed from release to the first detection.

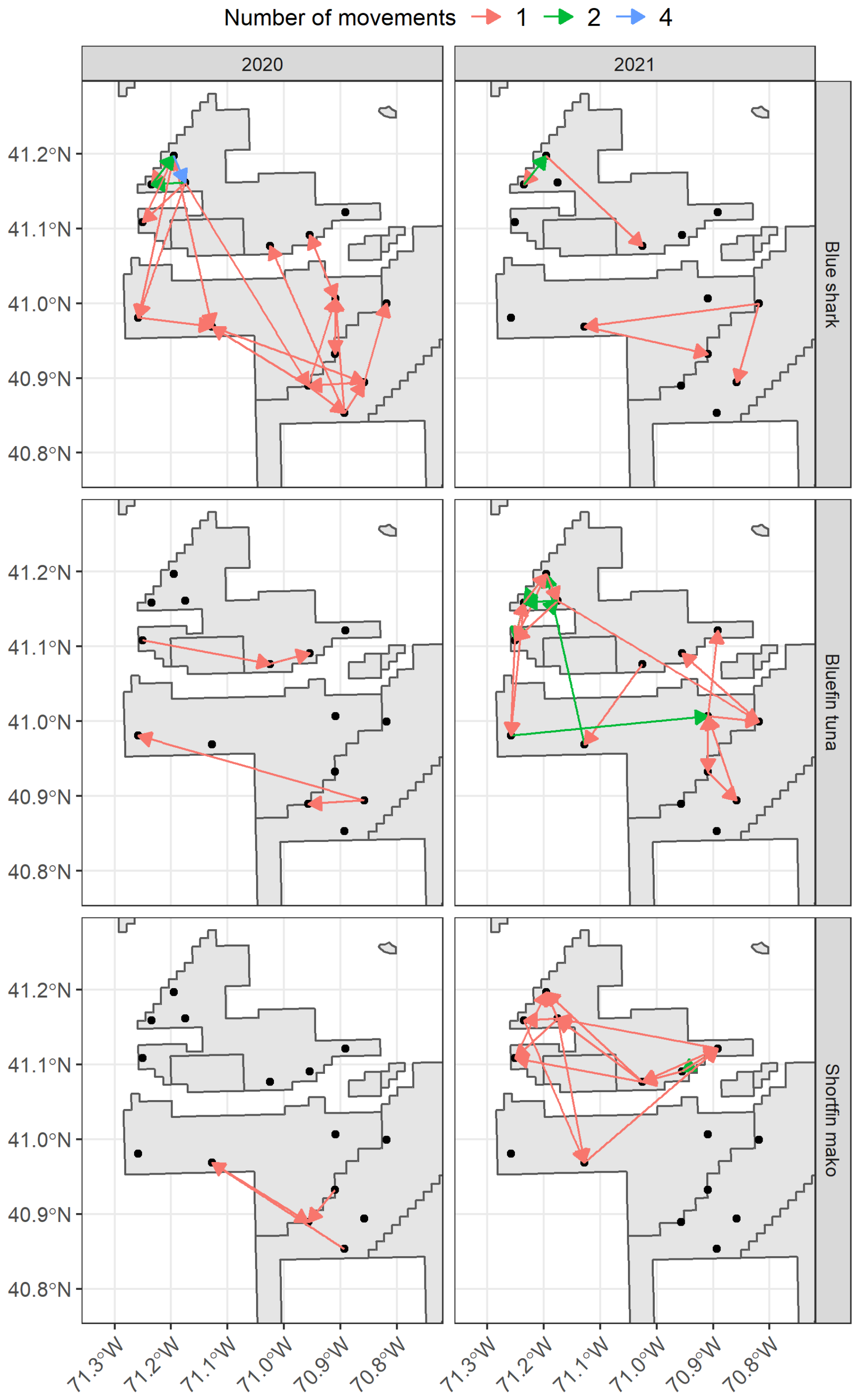


Figure 8. Network plots demonstrating direct movements (transitions) of each species between receiver stations that occurred within a 72-hour period. The head of the arrow represents the direction of the movement, and the color of the arrow/line indicates the frequency of movements/transitions that occurred between two receivers. Black dots represent the location of acoustic receivers. Note that receiver stations 13 and 15 were lost in 2021 (see Figure 1 for station locations).

3.4.1 HMS Data Received from MATOS/other Research Projects

Detection data were obtained for 37 tagged individuals, including 10 blue sharks, 10 shortfin mako sharks, one sandbar shark, one smooth hammerhead, and 15 bluefin tuna, via participation in MATOS and via direct data sharing with other project PIs (Table 7; Figures 9 and 10). The vast majority of detection events occurred on acoustic receivers deployed in southern New England, including receivers deployed within the southern New England WEA. However, detections were available outside the southern New England region as far south as North Carolina and as far north as the Scotian Shelf.

Table 7. Summary of acoustic detection data obtained for 37 tagged individuals in cooperation with MATOS and other project PIs. The number of individuals, number of detections obtained, and number of detecting receiver stations are provided for each species.

Species	Individuals	Detections	Receivers
Blue shark	10	535	16
Shortfin mako shark	10	360	26
Sandbar shark	1	19	3
Smooth hammerhead shark	1	149	6
Bluefin tuna	15	156	17

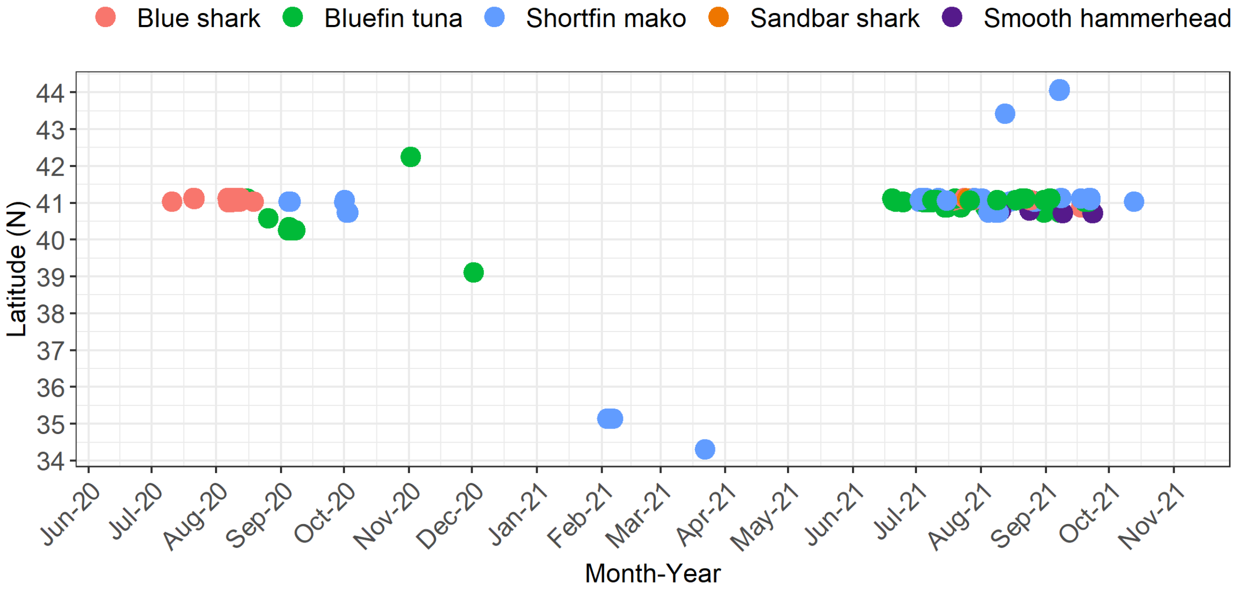
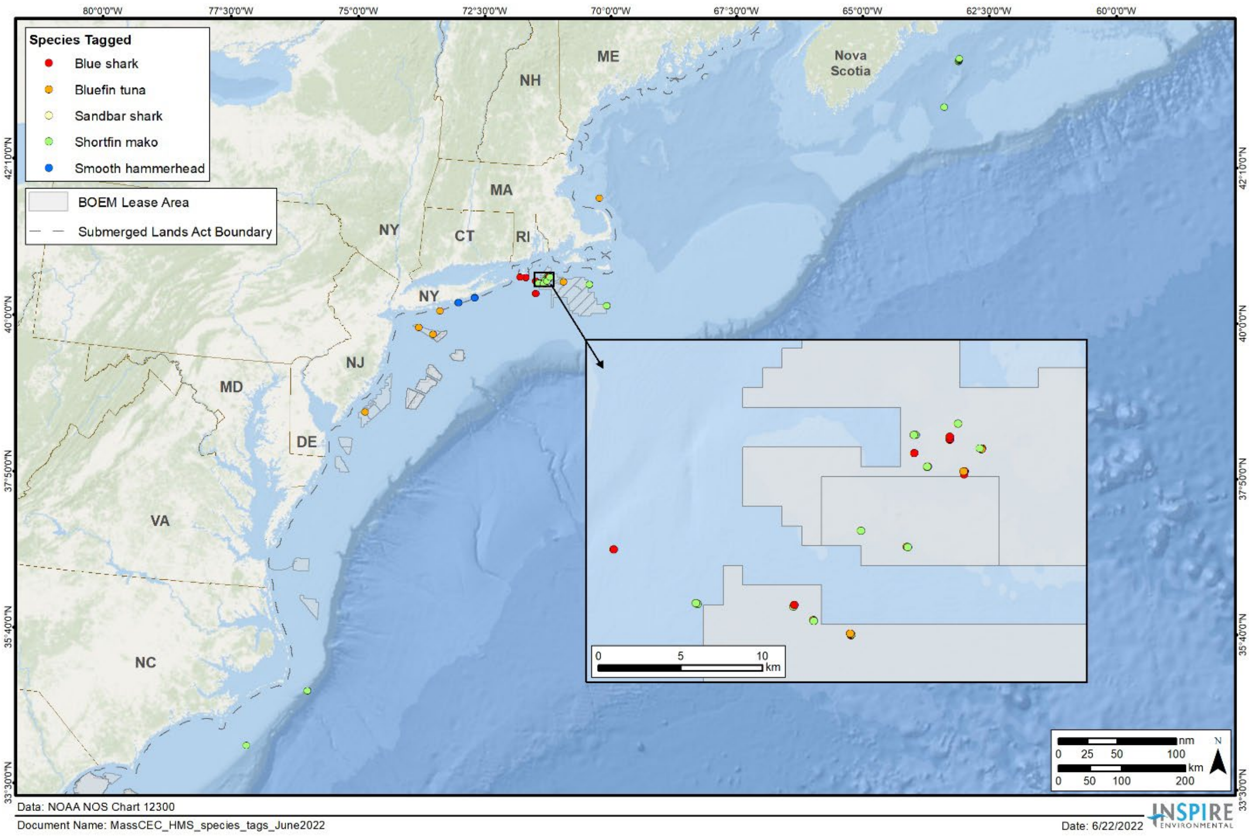


Figure 9. Detection history for 37 tagged HMS that were detected by acoustic receivers not affiliated with this project. Detection data were obtained through participation in the Mid-Atlantic Acoustic Telemetry Observation System (MATOS) or via direct communication with other project PIs.



Data: NOAA NOS Chart 12300

Document Name: MassCEC_HMS_species_tags_June2022

Date: 6/22/2022

Figure 10. Detection locations of individuals tagged during this study and detected outside of the study array. Detection data were obtained via participation in the Mid-Atlantic Acoustic Telemetry Observation System (MATOS) or via personal communication with other study PIs.

3.5 Environmental Conditions

Tagged HMS were detected over a range of environmental conditions that are typically evident in southern New England during the summer and fall (Table 8). Since the depth of the animal (in the water column) could not be determined at the time of acoustic detection, it was not possible to assign an exact temperature to each record. Thus, bottom and sea surface temperatures place bounds on the conditions in which HMS were observed in the study area. Density plots revealed that blue shark, shortfin mako, and bluefin tuna were typically observed in bottom temperatures from 8 to 18 °C, with blue sharks being observed most frequently in waters between 9 and 11 °C (Figure 11). These species were also observed most frequently in waters with SSTs ranging from 19 to 24 °C and chlorophyll a concentrations ranging from 0.4 to 1.0 mg ml^{-1} (Figure 11). Blue sharks, and to a lesser extent shortfin makos, were observed most frequently in heavily stratified waters (surface warmer than the bottom), while bluefin tuna were observed over varying degrees of thermal stratification (Figure 11).

Table 8. Environmental conditions in which tagged HMS were detected/observed during the study period. SST = sea surface temperature, T = temperature, Chl_a = chlorophyll a

Species	SST (°C)	Bottom T (°C)	ΔT (°C)	Chl_a (mg/mL)
Blue shark	19.5–25.2	8.0–17.7	3.0–15.4	0.37–1.29
Bluefin tuna	14.4–24.0	9.2–17.8	-0.8–12.8	0.41–1.72
Shortfin mako	16.6–22.7	10.1–17.5	0.3–10.6	0.41–1.13

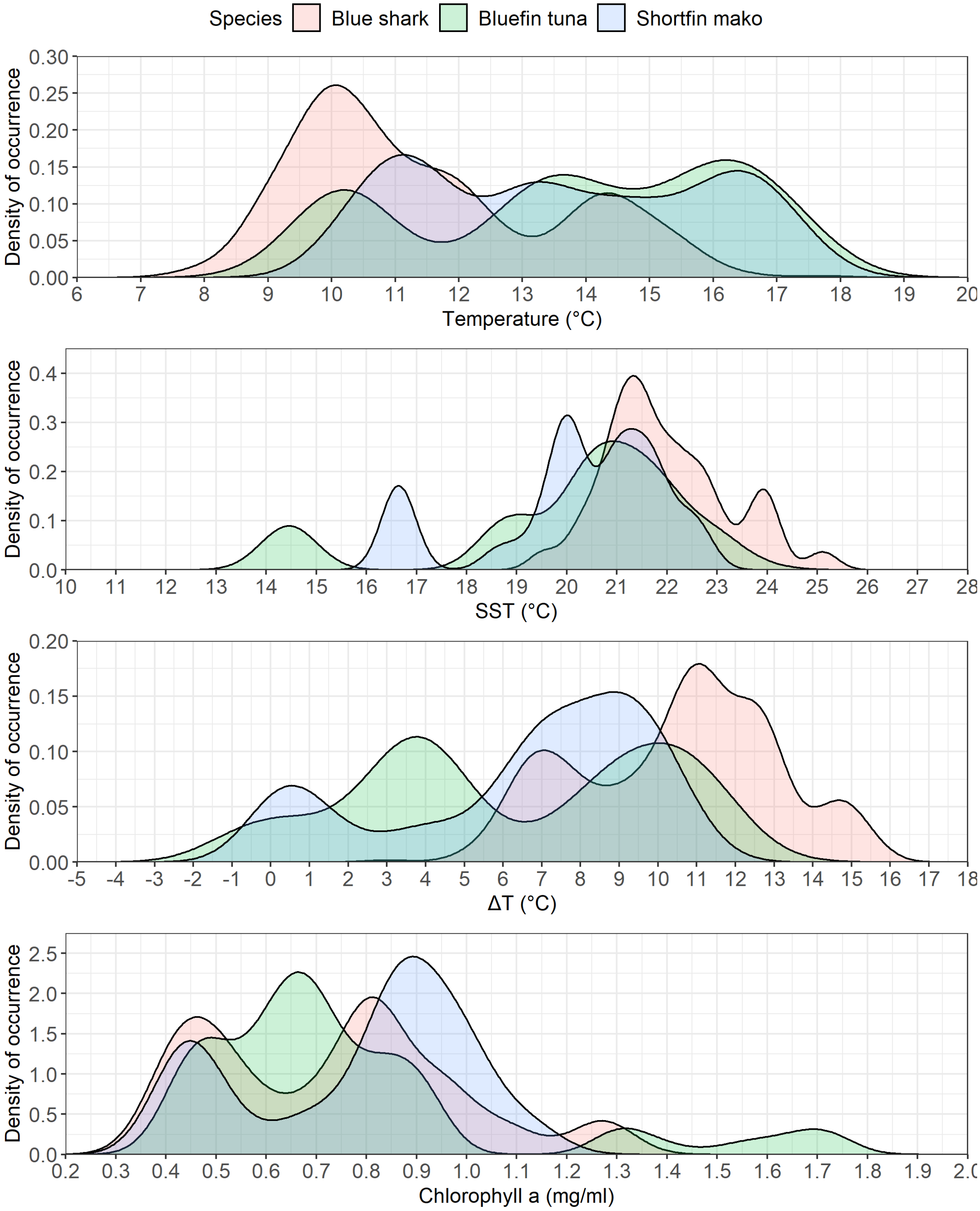


Figure 11. Kernel density plots demonstrating the range of environmental conditions in which blue sharks, shortfin mako sharks, and bluefin tuna were detected/observed during the study period. Higher density values correspond to increased numbers of observations in those conditions. SST = sea surface temperature, T = temperature

Bottom water temperature recorded hourly at each receiver station demonstrated typical seasonal trends evident in southern New England (Table 9; Figure 12). Interestingly, bottom temperature increased relatively rapidly and by nearly 1.5X during the last week of August in 2020 and the third week of August in 2021. The highest bottom temperatures in each year occurred from September to December. Thermal stratification was highest in the late-spring/early-summer and was positive (i.e., surface water warmer than the bottom) at all stations until September, after which reverse stratification (i.e., bottom warmer than the surface) became evident in some of the stations in deeper water (e.g., Stations 10 to 15) (Figure 13). Average noise (mV) was variable throughout each year of the study, with average noise being fairly consistent across all stations (Figure 14).

Table 9. Summary of hourly (bottom) temperature and average noise (mV) measured by acoustic receivers deployed at each station in each year of the study.

Year >	2020			2021		
Station	**Dates**	**Temperature (°C)**	**Noise (mV)**	**Dates**	**Temperature (°C)**	**Noise (mV)**
1	7/7 – 12/21	8.2 – 17.1 (12.7 ± 2.6)	151.2 – 651.9 (214.1 ± 49.7)	5/17 – 12/4	5.5 – 17.5 (12.4 ± 3.3)	151.7 – 634.3 (206.1 ± 40.1)
2	7/7 – 12/21	9.7 – 18.7 (14 ± 2.7)	146.5 – 925.9 (210 ± 71.4)	5/17 – 12/4	6.7 – 18.9 (13.6 ± 3.2)	148.6 – 640.3 (202.3 ± 41.9)
3	7/7 – 12/21	9.5 – 18.1 (13.6 ± 2.6)	148.4 – 808.3 (211.8 ± 59.8)	5/17 – 12/8	6.4 – 18.8 (13.3 ± 3.3)	147 – 689.9 (200.6 ± 42.3)
4	7/7 – 12/21	9.2 – 18.3 (13.9 ± 2.6)	147.6 – 519.6 (192.7 ± 35.9)	5/17 – 12/4	6.5 – 20.4 (13.5 ± 3.2)	145.7 – 633.4 (180.8 ± 28.8)
5	7/7 – 12/12	10.8 – 19.4 (14.5 ± 2.4)	153.3 – 816.7 (231.7 ± 86.8)	5/17 – 12/4	6.9 – 19 (13.8 ± 3.2)	154.8 – 801.3 (222.5 ± 64)
6	7/7 – 12/12	9.4 – 18.6 (13.5 ± 2.4)	151.7 – 723.7 (231.6 ± 77.6)	5/17 – 12/4	5.7 – 18.2 (12.9 ± 3.1)	149.8 – 696.1 (217.1 ± 58.4)
7	7/7 – 12/12	10.1 – 19.1 (14.6 ± 2.3)	151.5 – 630.6 (216 ± 50.7)	5/17 – 12/4	6.9 – 19.1 (14.1 ± 3)	150.1 – 741.2 (210.3 ± 46.2)
8	7/7 – 12/7	8.2 – 19.1 (13.3 ± 3)	155 – 571.6 (212.8 ± 45.6)	6/18 – 12/8	8.4 – 20.4 (13.7 ± 2.9)	157.1 – 735.3 (212 ± 44.4)
9	7/7 – 12/21	8.5 – 17.4 (13.3 ± 2.8)	146.2 – 680.7 (205.3 ± 41.7)	5/17 – 12/4	6.9 – 18.8 (12.4 ± 3.2)	145.4 – 527.9 (195.2 ± 36.3)
10	7/7 – 12/12	8.3 – 16.9 (13 ± 2.7)	152.2 – 675 (217.1 ± 58.1)	7/1 – 12/8	9.5 – 19.6 (13.9 ± 2.5)	158 – 641.5 (222.9 ± 50.5)
11	7/7 – 12/21	8.7 – 17.3 (13.1 ± 2.7)	155.9 – 564.3 (211 ± 44.8)	7/1 – 12/8	9.7 – 19.6 (13.9 ± 2.4)	160.3 – 601.2 (208.5 ± 40.7)
12	7/7 – 12/12	8.1 – 20.5 (12.7 ± 2.9)	150.8 – 656 (211 ± 51.6)	6/23 – 12/4	8.3 – 17.7 (12.7 ± 2.5)	157.9 – 613.7 (209.1 ± 40.1)
13	7/7 – 12/12	8.5 – 17 (13.1 ± 2.9)	146.5 – 554.9 (192.8 ± 34.8)	-	-	-
14	7/7 – 12/12	8.1 – 16.5 (12.8 ± 2.9)	145.8 – 579.2 (194.1 ± 36.8)	6/23 – 12/4	8.2 – 18.1 (12.7 ± 2.5)	149.7 – 644.6 (194.1 ± 35.6)
15	7/7 – 12/12	7.7 – 17.7 (12.4 ± 3)	150.5 – 620.4 (203 ± 38.4)	-	-	-

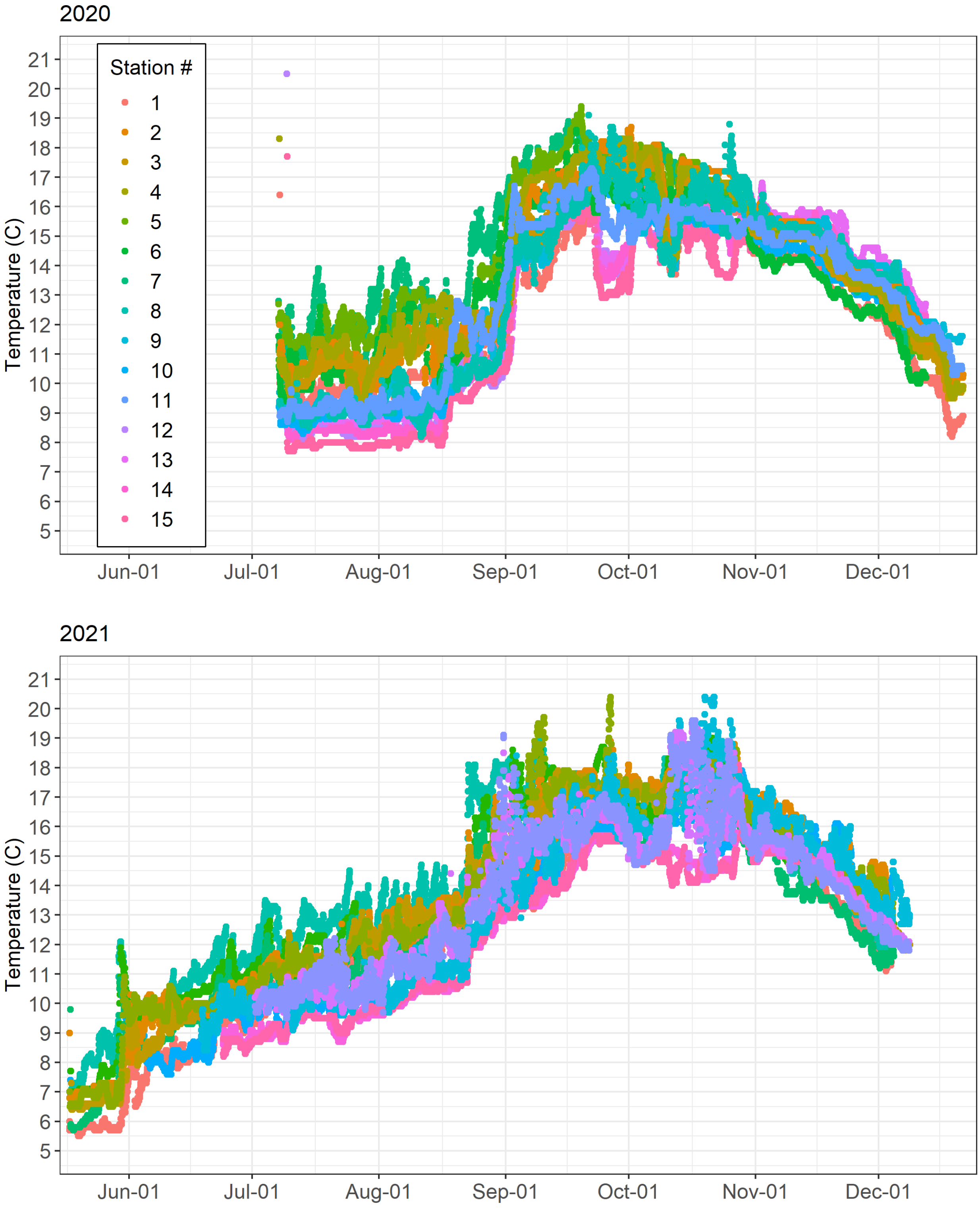


Figure 12. Bottom water temperature measured hourly for all receiver stations in each year of the study.

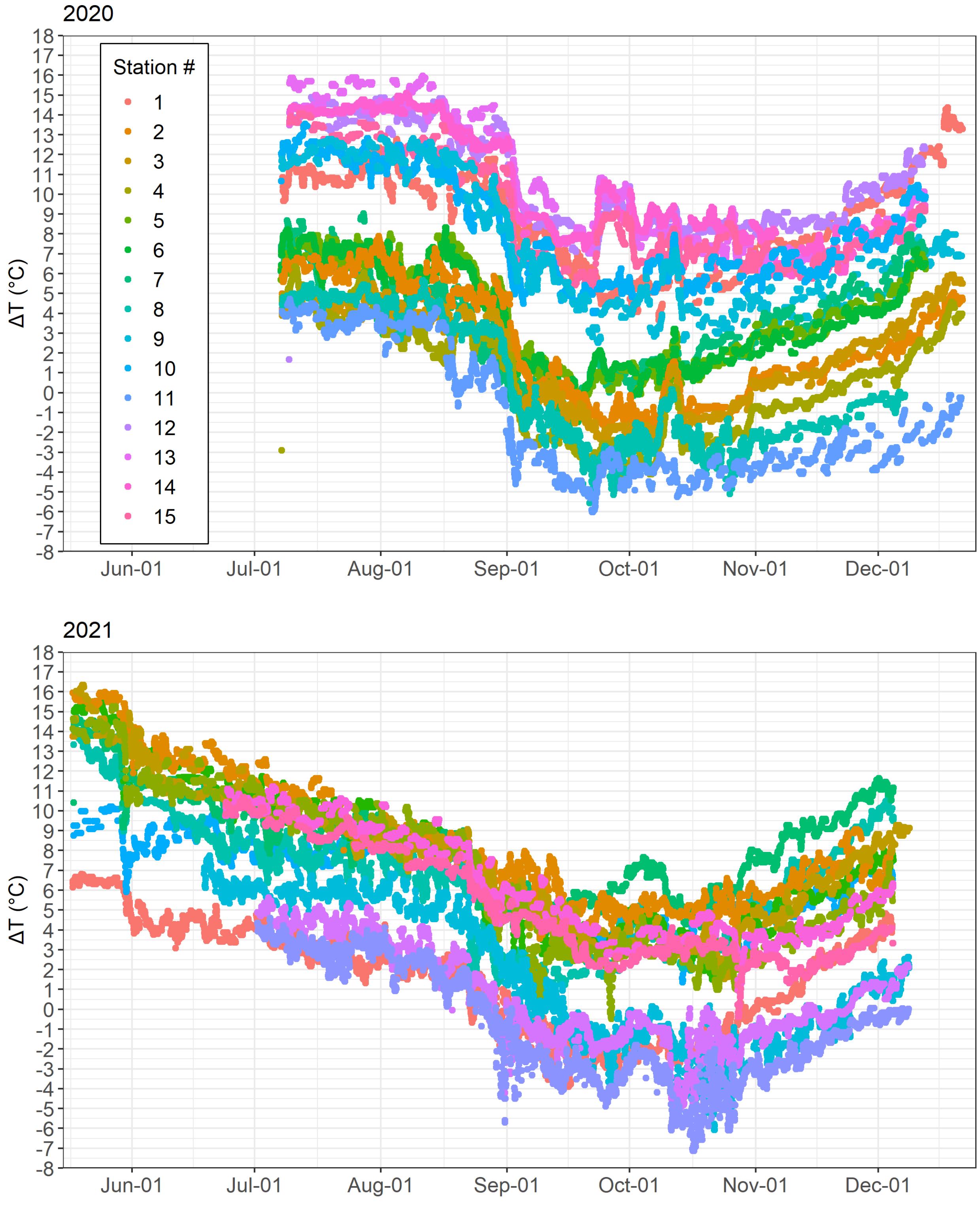


Figure 13. Thermal stratification calculated hourly at each receiver station in each year of the study.

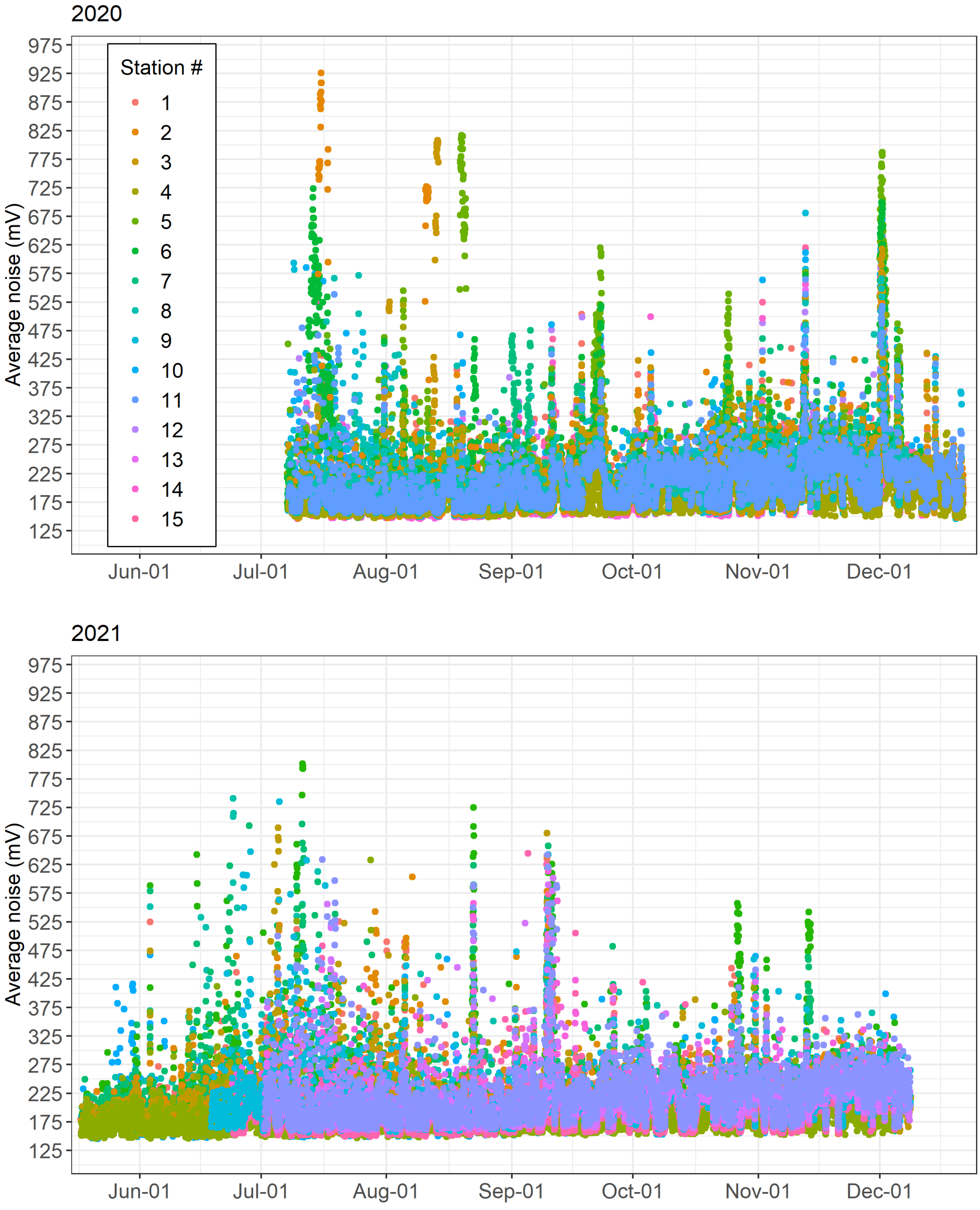


Figure 14. Hourly average ambient noise (in 69 kHz) recorded at each receiver station in each year of the study.

3.6 Detection of Other Transmitters/Species

A total of 4,931 detections were recorded for 206 unique transmitters not deployed by this project, including 66 in 2020 (1,162 detections) and 157 in 2021 (3,769 detections); 17 transmitters were detected in both 2020 and 2021 (Table 10). Communication with transmitter owners via MATOS revealed that at least 17 species were detected; the identity of 15 transmitters could not be determined. Sandbar and white sharks were the most commonly observed species in each year. Detections occurred consistently throughout the period during which receivers were deployed (Figure 15).

Table 10. Summary of the number of unique transmitters (Tx) and detections (Dtx) logged for each species in each year of the study. The number of researchers who own transmitters deployed in a given species are noted. Note that 17 transmitters were detected in both 2020 and 2021.

Year >	2020		2021		Total		
Species	**Tx**	**Dtx**	**Tx**	**Dtx**	**Tx**	**Dtx**	**Researchers**
Atlantic cod	1	2	3	198	4	200	1
Atlantic sturgeon	3	54	8	95	11	149	4
Blue shark	1	2	18	1,139	20	1,141	3
Blueback herring	-	-	21	318	21	318	1
Bluefin tuna	5	213	11	363	13	576	2
Bluefish	-	-	2	45	2	45	1
Common thresher	-	-	1	45	1	45	1
Dusky shark	6	107	14	208	15	315	4
Loggerhead turtle	-	-	2	6	2	6	1
Sand tiger shark	-	-	1	22	1	22	1
Sandbar shark	20	558	22	682	31	1,240	5
Shortfin mako shark	-	-	7	287	7	287	1
Spiny dogfish	2	58	-	-	2	58	1
Striped bass	1	3	-	-	1	3	1
White shark	19	112	33	211	54	323	4
Winter flounder	-	-	5	88	5	88	2
Winter skate	-	-	1	29	1	29	1
Unknown species	8	53	8	33	15	86	-
Total	66	1,162	157	3,769	206	4,931	25

Figure 15. Detection histories of transmitters not deployed by this project in the study site by year. The vertical green line represents the date when receivers were first deployed, and the red line represents when receivers were removed from the study site.

4 Conclusions and Future Directions

The results of this study demonstrate the capabilities of passive acoustic telemetry to effectively collect baseline data on the presence, persistence, movements, and habitat use of HMS within the southern New England WEA. Deployment of acoustic receivers at fixed locations at or adjacent to popular fishing locations in the southern New England region also permitted an evaluation of species presence and availability to the large, directed recreational fishery for HMS that occurs seasonally in the region. Beyond permitting the monitoring of HMS, the detection of large numbers of individual transmitters from a wide range of tagged species further demonstrates the utility of passive acoustic telemetry as a multi-species monitoring system in WEAs (e.g., Frisk et al. 2019, Haulsee et al. 2020, Secor et al. 2020) and underscores the need for coordination and data sharing between acoustic telemetry monitoring studies being conducted in WEAs along the U.S. East Coast. The baseline data obtained in this study will serve as the foundation for examining potential impacts to HMS from the build-out of offshore wind facilities off southern New England and long the U.S. East Coast. However, the relatively low number of detections (and residences) logged over all receiver stations precluded predictive modeling of animal presence (e.g., Haulsee et al. 2020; Secor et al. 2020), and indicates that larger, longer, finer-scale, and more coordinated efforts are required to effectively monitor HMS and other species' response to offshore wind development throughout the vast, ~2,600 km^2 area that has been leased for offshore wind development in southern New England.

Presence of HMS within the study site followed typical seasonal trends for the target species in southern New England (Kohler and Turner 2019, Kneebone and Capizzano 2020), with animals observed from mid-June to late-November. In general, blue shark, shortfin mako shark, and bluefin tuna were observed most frequently and most consistently from July through September, with bluefin tuna being collectively observed over the longest period during the study period (e.g., Figures 4 and 5). Tagged individuals of each target species were detected on every receiver station (with the exception of shortfin mako sharks, which were not detected on stations 10 or 14) demonstrating use of the entire study site; each species was also present at each popular fishing area. However, tagged individuals generally exhibited continuous movements throughout the receiver array with overall low residency duration at particular stations or fishing locations. Several individuals, including multiple bluefin tuna and shortfin mako sharks, tagged within or immediately adjacent to the receiver array were not detected until several weeks or months after release, suggesting they utilized space outside of the study site in the broader southern New England region during the season. Similarly, multiple bluefin tuna and shortfin mako sharks tagged 50 – 80 km away from the closest receiver in the study site exhibited movements into the receiver array in the weeks to months post-tagging, thereby demonstrating the connectivity between distant areas and broad-scale use of area throughout the southern New England region. Lastly, eight individuals tagged in 2020 returned to the array/study site in 2021, demonstrating the use of habitat within the WEA over multiple years.

Wide-ranging movements and low residencies of tagged HMS align with typical movements and behaviors of large marine predators (Block et al. 2011), but the variability in the location of occurrence, residency durations, and movement patterns between years and species indicates that two years of baseline monitoring is insufficient to fully characterize the habits, behaviors, and environmental correlations linked to HMS baseline presence in the southern New England WEA. For example, in 2020 we had to venture 50 – 80 km away from the study site to capture bluefin tuna and their presence in the receiver array was sparse and sporadic throughout the season. In contrast, large aggregations of juvenile bluefin tuna were present within and immediately adjacent to the study site in 2021, and tagged individuals exhibited longer, more continuous, and more spatially-extensive use of the study site throughout this season. Interestingly, environmental conditions in the study site were comparable between 2020 and 2021 (Figures 12 to 14), suggesting that other exogenous factors (e.g., prey availability, oceanographic conditions outside the study area that affected the species' migration) influenced the differential spatial and temporal use of the study site by bluefin tuna during 2020 and 2021. Given this inter-annual difference, it will be difficult to evaluate the effect of offshore wind development with only two years of highly variable data. Accordingly, 3 to 5 years of baseline monitoring seems more appropriate to adequately quantify the factors that dictate HMS presence in a given WEA, particularly one as large as the southern New England WEA.

Deployment of additional transmitters and receivers that permit more complete monitoring of the southern New England (by area) will allow for better observation of localized presence and movement patterns of highly mobile species and enhance the ability to document baseline presence of HMS in the southern New England WEA. Throughout our study, only 35 of 60 tagged individuals (58%) were detected by receivers in the study site. However, eight individuals (two blue shark, one shortfin mako shark, and five bluefin tuna; two tagged in 2020 and six tagged in 2021) that were not detected by our receivers were observed by acoustic receivers maintained within the southern New England WEA by other researchers/research projects, including several near our receiver stations (Figure 10). Similarly, several HMS tagged in various locations outside of our study site, but within the southern New England WEA, as part of ongoing monitoring efforts led by offshore wind developers were detected by our acoustic array (J. Kneebone, personal communication). These results illustrate the need to expand both the spatial and temporal extent of receiver monitoring efforts to better understand the presence, movements, and connectivity that occur/exist over the vast extent of the southern New England WEA. Positioning additional acoustic receivers outside of the southern New England WEA would also greatly assist with the documentation of baseline HMS presence in the broader southern New England region and the evaluation of future impacts from wind project construction and operation. Additional monitoring will also allow for improved evaluation and documentation of the environmental factors that dictate HMS presence and persistence in the southern New England region. HMS are heavily influenced by environmental factors (Casey and Kohler 1992, Vaudo et al. 2017, Bangley et al. 2020) and environmental effects on species presence, residency, and movements in the WEA must be accounted for when evaluating potential impacts of offshore wind development, particularly given the ongoing effects of climate change.

The large number of detections of transmitters deployed by other researchers further demonstrates that passive acoustic telemetry is an effective tool for multi-species regional monitoring. Data sharing efforts and agreements between projects have the potential to bolster sample sizes and expand the scope of regional monitoring efforts to include new species or taxonomic groups (e.g., sea turtles), particularly between monitoring projects occurring within other WEAs. Individuals tagged by this study were detected well outside the study site, including within and in the vicinity of other WEAs along the U.S. East Coast. Examining the interconnectivity between WEAs at various stages of build-out and operation and tracking fish throughout the year (as opposed to seasonally) could aid in identifying areas of attraction or avoidance or other potential impacts. Entities supporting offshore wind telemetry monitoring, particularly offshore wind development companies, should be strongly encouraged to participate in regional data sharing networks and allow contracted researchers to explore opportunities that will bolster monitoring efforts and the ability to detect impacts to species from offshore wind development.

Receiver losses incurred in this study underscore the need to design acoustic telemetry monitoring studies in collaboration with other ocean users, particularly the commercial fishing industry. Efforts were made to deploy acoustic receivers in locations that minimized the chance of interaction with commercial fishing gear, particularly mobile fishing gear. However, receiver losses still occurred in 2021. Beyond leading to the loss of valuable data and expensive monitoring equipment, such interactions can exacerbate or create contentious relationships between the offshore wind and commercial fishing industries and hamper outreach about scientific monitoring efforts and results. Extensive, *a priori* efforts should be made to communicate the intent, scale (both spatial and temporal), and scope of monitoring efforts with users of the study area and to place receivers in locations that will minimize conflict and gear interactions while still allowing study objectives to be met. Effective communication with stakeholders is essential for long-term success of monitoring projects and the preservation of fishing opportunities in WEAs, particularly during and after construction of wind turbine arrays.

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