

Movement and Habitat Selection by Migratory Fishes within the Maryland Wind Energy Area and Adjacent Reference Sites



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List of Abbreviations and Acronyms

ACF	Autocorrelation Function
ACT	Atlantic Cooperative Telemetry Network
ARIMA	Autoregressive Integrated Moving Average
BACI	Before-After-Control-Impact
BAG	Before-After-Gradient
BOEM	Bureau of Ocean Energy Management
CHL-A	Chlorophyll-a
CI	Confidence Interval
D50	Distance at 50% frequency of detection
DE WEA	Delaware Wind Energy Area
DOY	Day-of-Year
DPD	Detection-Positive Day
ERDDAP	Environmental Research Division's Data Access Program
GAM	Generalized Additive Model
GAMM	Generalized Additive Mixed Model
HGAM	Hierarchical Generalized Additive Model
MAB	Middle Atlantic Bight (US)
MD WEA	Maryland Wind Energy Area
PACF	Partial Autocorrelation Function
QI	Quotient Index
RMSE	Root Mean Square Error
SST	Sea Surface Temperature
ΔT	Delta T, Sea Surface Temperature-Bottom Temperature
UMCES	University of Maryland Center for Environmental Science

EXECUTIVE SUMMARY

Wind farms within inner shelf regions of the southern Mid-Atlantic Bight (DelMarVa region) will greatly increase the amount of structured habitat for coastal fishes. Installed wind turbines present permanent (decades) impervious structures, which can alter movement behaviors by fishes and the fisheries associated with impacted species. Fish concentrations surrounding oil rigs are but one example of how artificial structures can influence both fish and fisheries. We hypothesized that many coastal migratory fishes currently use southern Mid-Atlantic Bight shelf waters as a migration corridor, but that fields of wind turbines in this relatively “featureless” region could alter behaviors of migratory fishes causing them to dwell on high relief wind turbine structures.

The objective of this project was to measure seasonal transit and habitat occurrence of striped bass and Atlantic sturgeon in relation to depth, temperature, and other oceanographic and benthic variables in and adjacent to the Maryland Wind Energy Area (MD WEA). We used biotelemetry deployed in a before-after-gradient design centered in the Maryland Wind Energy Area to gather baseline measures of seasonal patterns of migration by Atlantic sturgeon and striped bass and model their incidence against gradients of depth, temperature, and other oceanographic variables. This study leverages recent and concurrent telemetry studies in NW Atlantic shelf regions and the availability of hundreds of acoustically-tagged striped bass and Atlantic sturgeon. Specific objectives included (1) two-year deployment of an extensive telemetry receiver array within the MD WEA and adjacent shelf reference regions; (2) analysis of patterns of incidence, transit, and depth; (3) development of predictive habitat models for the MD WEA shelf region; and (4) extensive data sharing through the Atlantic Cooperative Telemetry Network and the Mid-Atlantic Telemetry Observing System.

In triannual cruises beginning November 2016 and ending December 2018, we deployed, maintained, and retrieved 20 VEMCO VR2AR Acoustic-Release receivers in the test MD WEA array. We deployed additional receivers at two sites to test receiver detection distances for the period December 2017-December 2018 under different oceanographic conditions. To augment tagged coastal striped bass available for detection, 40 large striped bass were surgically implanted with depth-transponding transmitters. Environmental data for the array was compiled from receiver-logged bottom temperature and noise levels and from NOAA buoys, and remote sensing platforms. Patterns of seasonal species incidence and environmental dynamics were analyzed together with transit rates between the MD WEA and DE Wind Energy Area. Incidence data was transformed into relative density based on modelled detection probability across seasons and strata. Generalized Additive Mixed Models were developed to predict the relative density and weekly residence of striped bass and Atlantic sturgeon based on environmental features of the MD WEA. Our main findings were:

- Atlantic sturgeon and striped bass occurred extensively in the MD WEA, with seasonal incidence supporting the hypothesis that the MD WEA occurred within migration corridors for both species. Detections of Atlantic sturgeon occurred throughout autumn and early winter and throughout spring and early summer. Striped bass occurrence was more concentrated during winter months and brief during spring. Within these periods of occurrence:
 - Atlantic sturgeon were at mid-range depths in the MD WEA during autumn, but occurred in shallower regions within and outside the MD WEA in spring.
 - Striped bass broadly utilized the MD WEA cross-shelf region during spring, and were more abundant in deeper areas during winter.

- Hot spots of individual occurrence did not reveal singular areas of intensive use. Detections for both species showed stronger association with cross-shelf depth and environmental gradients rather than specific seabed characteristics.
- Temperature was a strong driver of striped bass incidence patterns. Detections occurred within a narrow range of 5-15°C. Striped bass shifted toward greater depths during winter as shelf temperatures cooled to avoid the colder inshore temperatures. Atlantic sturgeon showed broader temperature tolerance, 4-24°C, selecting warmer temperatures than striped bass.
- Both species were relatively transient in the array, with mean detection durations of 1.6 and 2.5 days respectively for individual Atlantic sturgeon and striped bass. However, striped bass tended to spend more time in the area during winter months (mean= 3.06 days), which could suggest this shelf region functions as overwintering habitat in some years.
- Habitat models were complex owing to concurvity among fitted oceanographic terms, but provided strong explanatory power for species abundance and residency. Model performance was markedly improved through inclusion of changes in daily telemetry detection ranges. Predictions reinforced the importance of depth and temperature variables, and their interactions with season, in determining species distribution.

The cross-shelf telemetry sampling design allowed key inferences in the MD WEA as a key migration corridor habitat pertinent to likely impacts of wind energy development. Summer-time wind turbine construction would minimize interactions with both test species: striped bass and Atlantic sturgeon. During fall, winter and spring striped bass distributions centered within the footprint of the MD WEA, whereas Atlantic sturgeon would overlap with inshore transmission lines. Detections of many other tagged species occurred in the MD WEA throughout the year, which will also need due consideration in Construction and Operation Planning.

The telemetry gradient design is well suited for evaluating impacts of wind farm development across WEAs in the Mid-Atlantic Bight and Southern New England, which together comprises a multispecies “flyway.” Cooperation among researchers, expanded scale of acoustic telemetry arrays, and increased incorporation of oceanographic variables, physiological data, and individual characteristics will all serve to improve understanding of how fishes will respond to wind energy development in the US NW Atlantic Ocean.

1 Introduction

1.1. Statement of Purpose

Recent increases in the reliability, cost-effectiveness, and widespread use of acoustic biotelemetry provides a timely opportunity to evaluate population-level responses by migratory species to wind energy development. At present, limited information is available on the fine-scale seasonal patterns of distribution and abundance of migratory fishes in and around offshore wind energy areas. This information is necessary for BOEM and developers to meet their obligations under the National Environmental Policy Act, the Endangered Species Act, and the Magnuson-Stevens Fishery Conservation and Management Act. These considerations are of particular importance for protected species, such as the Endangered Atlantic sturgeon, and commercially important ones, such as striped bass. Information on the seasonal occurrence of migratory species within wind lease areas will help minimize potential impacts of turbine construction and provide a baseline with which to compare future changes in migration behavior and habitat selection during the decades following construction (Bailey et al. 2014, Petruny-Parker et al. 2015). In this study, we have used acoustic telemetry to characterize the seasonal distribution, habitat selection, and migratory patterns of Atlantic sturgeon and striped bass in the Maryland Wind Energy Area (MD WEA) along gradients of depth, temperature, and other oceanographic variables.

2 Background

2.1 Wind energy development in the Middle Atlantic Bight

Motivated to promote offshore wind energy and thereby reduce carbon emissions (White House 2013), BOEM and state actions have resulted in industrial leases of large Wind Energy Areas (WEAs) in Mid-Atlantic and other federal waters (Figure 1). As an example, US Wind Inc. was competitively awarded two lease areas - since combined into one lease area - comprising the entire Maryland WEA (Figure 1). This area, c. 36,000 ha in extent, could support >100 turbines, and produce sufficient energy to sustain hundreds of thousands of households (DOI 2014). WEAs have been sited to reduce marine use conflicts including shoreline vistas, commercial navigation and fishing, recreational fishing, artificial reefs (e.g., fish havens), historical sites (e.g., wrecks), and restricted military areas (<http://portal.midatlanticocean.org/>). Ecological impacts are another central concern to siting and development of WEAs (McCann 2012; Petruny-Parker et al. 2015).

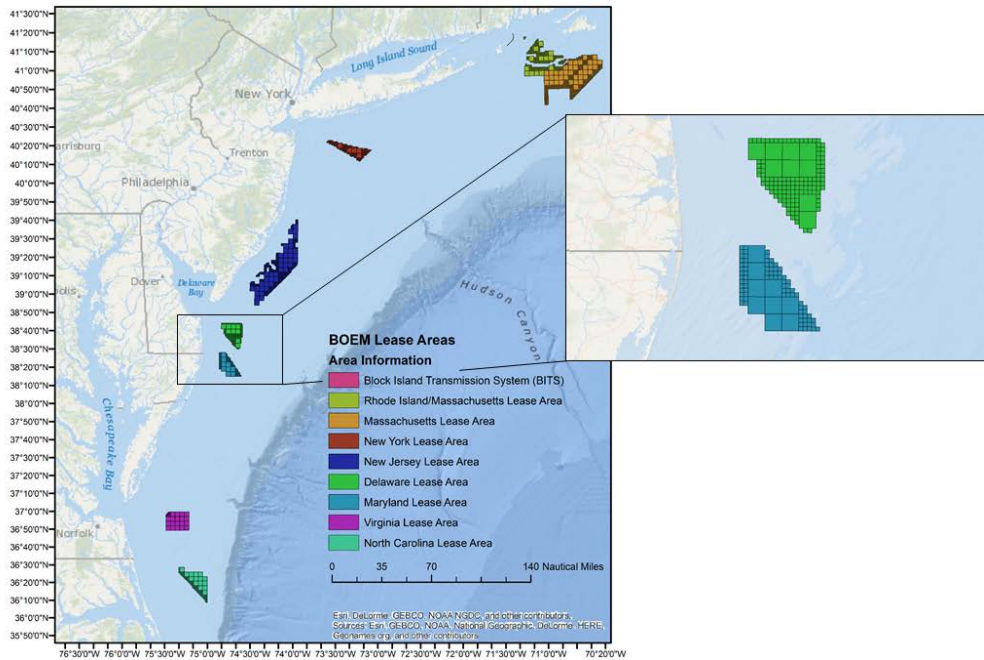


Figure 1. BOEM Lease Areas

WEAs within US Mid-Atlantic and NY Bight federal waters (left; as of 2018), and inset showing the MD WEA (blue) and DE WEA (green). The MD WEA is located 16-46 km offshore in depths ranging 12-35 m. Lease area shape files obtained from BOEM.

2.2 Review of wind energy development impact studies on migratory fishes

The future construction and maintenance of offshore wind energy farms are hypothesized to cause several classes of ecological impacts to migratory fishes in the US Mid-Atlantic Bight (MAB) shelf ecosystem. During the construction of wind turbines, the noise associated with pile driving and vessel traffic could lead to physiological stress, avoidance, or evacuation of the area by fishes (Thomsen et al. 2006; Popper and Hastings 2009; Gill et al. 2012). The operation of wind turbines could also create broader adverse impacts to the MAB through altered electromagnetic fields, pollution from vessel traffic, or release of contaminants from the seabed (Gill 2005; Westberg and Lagenfelt 2008; Boehlert and Gill 2010; Normandeau et al. 2011). Positive impacts may also occur. The shelf region of the MAB is commonly described as a relatively homogenous and flat seabed habitat, composed primarily of soft sediments (Stumpf and Biggs 1988; Poppe et al. 1994). Wind turbines will create novel vertical structure throughout the water column, a feature which has been known to attract fish aggregations. Small fish and invertebrates often school around structures such as submerged oil and gas rigs both to forage on encrusting organisms and to obtain refuge from predators (Boehlert and Gill 2010). Larger fish can be attracted to such aggregations, creating a chain of effects that can alter local foodwebs (Wilhelmsson et al. 2006; Inger et al. 2009; Bergström et al. 2013).

2.3 Rationale for baseline telemetry study and gradient design

We employed an *in-situ* gradient design centered on the MD WEA to measure seasonal patterns of incidence by Atlantic sturgeon, striped bass, and other migratory fishes. The complex spatial and

temporal impacts of planned offshore wind energy farms on mobile fauna can be best understood through the use of a Before-After-Gradient (BAG) study design. BAG designs are an extension of the classical Before-After-Control-Impact (BACI) approach (Green 1979). Although BACI designs are traditionally used in environmental impact studies, these methods can have confounding assumptions related to the scale of effect and selection of reference sites. The gradient-based extension of the BACI approach largely resolves these issues by considering the distance of sampled sites from the area of impact (Bailey et al. 2014). The BAG design still incorporates the before-after elements of BACI to control for temporal confounders, but eliminates the issue of arbitrary control site selection by taking samples along a gradient of distance from the impact stratum. Gradient-based designs incorporate the spatial scale of impacts and have been proven to be more effective for detecting changes due to environmental disturbance than classical randomized Control Impact designs (Ellis and Schnieder 1997). Additionally, in this study, the BAG approach permits collection of data across the environmental gradients likely to influence the movements of striped bass and sturgeon (Cushman et al. 2010, Alvarez-Berastegui et al. 2014). By gathering information across biologically relevant spatiotemporal gradients, the BAG study design lends itself to the development of predictive oceanographic models of species occurrence that can help inform management decisions and assess long-term impacts.

2.4 Introduction to test species: Atlantic sturgeon and striped bass

This baseline study focused on striped bass and Atlantic sturgeon, both of which represent indicator species in evaluating the impact of offshore wind farms on migratory fishes owing to, (1) seasonal migration behaviors, which cause them both to frequently occur in Mid-Atlantic WEAs; (2) public and management priorities related to their recovery from endangered status (Atlantic sturgeon) and importance to commercial/recreational fisheries (striped bass); and (3) the fact that these species comprise the majority of acoustic-tagged fish currently active within US Middle Atlantic Bight (MAB) shelf waters.

Atlantic sturgeon *Acipenser oxyrinchus* are a large, long-lived, anadromous demersal species that range widely in the Northwest Atlantic (Florida to Quebec). Generally, adult Atlantic sturgeon undertake large-scale coastal migrations north in the spring and south in the fall and winter. Recent biotelemetry applications have provided key insights into the coastal migrations of Atlantic sturgeon. Once sturgeon reach maturity, they remain largely in shelf waters and in the mouths of estuaries for foraging until they progress into natal rivers to spawn (Dunton et al. 2012; Breece et al. 2016). Evidence has shown that Atlantic sturgeon tend to remain in areas relatively shallow and close to shore (10-50 m in depth) in the MAB, with a slightly broader shelf distribution in spring compared to autumn (Stein et al. 2004; Laney et al. 2007; Erickson et al. 2011). Some fish have been captured in depths up to 75 m (Colette and Klein-MacPhee 2002). Atlantic sturgeon aggregate at specific coastal features, such as the mouths of major estuaries, and that individual fish are more likely to be found over sand or gravel rather than silt or clay substrates (Bain et al. 2000; Stein et al. 2004; Laney et al. 2007).

Similar to Atlantic sturgeon, the striped bass *Morone saxatilis* spawns in tidal freshwater and undertakes extensive migrations; however, striped bass are highly mobile pelagic and epi-demersal predators that exhibit complex and diverse movement patterns. Striped bass are also known to exhibit high levels of maneuverability around structure and are particularly adept at capturing prey in such environments, which may cause them to be attracted to structured habitat (Buckel et al. 2009). While some individuals remain in estuaries their entire lives, certain population contingents migrate into coastal waters from St. Lawrence, Quebec to Cape Hatteras, North Carolina (Secor 1999; Gahagan et al. 2015). Generally, Mid-Atlantic striped bass >80 cm become oceanic migrants that move northward in the spring and southward in the fall (Waldman et al. 1990, Dorazio et al. 1994; Secor and Piccoli 2007; Kneebone et al. 2014).

Coastal telemetry arrays have confirmed the broad movement of individuals south in the fall and north in the spring, with some evidence for slightly faster northward migrations (Kneebone et al. 2014).

2.5 Introduction to MD WEA physical and ecological setting

The MD WEA occurs within the MAB, a large temperate shelf ecosystem characterized by strong seasonal changes in temperature and related oceanographic dynamics (Bigelow 1933; Bigelow and Sears 1935; Beardsley and Boicourt 1981; Yoder et al. 2002). Physically, the MAB consists of a relatively broad (50-200 km wide) shelf area that stretches from Cape Hatteras, North Carolina to the southern flank of Georges Bank off Massachusetts. However, the MAB also acts as a dynamic boundary between cooler sub-arctic waters and warmer sub-tropical waters. The currents associated with these hydrographic elements, along with seasonal changes in winds, currents, and temperature, and the inputs of several large rivers and estuaries, structure the seasonal changes in thermal conditions, fronts, and other density features (Fong and Geyer 2001; Choi and Wilkin 2007; Chant et al. 2008).

Biological dynamics in the MAB are tied to seasonal changes in stratification and oceanographic regimes. During summer, the cessation of strong winds, combined with the warming of surface waters, creates a persistent thermocline that extends over much of the shelf (Houghton et al. 1982; Lentz 2017). Stratification effectively traps cooler winter waters under warmed surface waters, resulting in a “cold pool” bounded by warmer near-shelf waters and dense, saltier waters at the shelf break (Houghton et al. 1982, Rassmussen et al. 2005). Summer months are therefore characterized by a cross-shelf gradient of decreasing temperature with distance from shore. Cooling, storm events, and wind-driven mixing with the onset of fall break down this stratification regime, leading to relatively homogeneous shelf water temperatures throughout the water column during winter months. (Castelao et al. 2010; Gong et al. 2010; Lentz 2017). However, a cross-shelf gradient still exists with more rapid shelf cooling in shallow waters and comparatively warm waters at the outer shelf. Although seasonal patterns of temperature and stratification have fundamental effects on the MAB ecosystem (Malone et al 1983; Flagg et al. 1994; Shofield et al. 2008), little is known about how the MAB’s thermal regime influences fish migration (Secor et al. 2019).

2.6 Study hypotheses and objectives

The objective of this project was to measure seasonal transit and habitat occurrence of striped bass and Atlantic sturgeon in relation to depth, temperature, and other oceanographic and benthic variables in and around the MD WEA. We hypothesized that addition of wind farm construction in the “featureless” MD WEA could alter baseline behaviors of migratory fishes by causing them to increasingly dwell on high relief turbine structures as they seasonally transit through DelMarVa’s continental shelf waters. Furthermore, based on species biology, we expected that the movements of Atlantic sturgeon and striped bass would differ in terms of transit rate and habitat preference in the MD WEA. Because Atlantic sturgeon principally forage in soft-bottom habitats, they should select habitats similar to those that occur in the MD WEA (Vladykov and Greeley 1963; Savoy 2007; McLean et al. 2013). Sand and organic debris were a major component in the stomachs of sturgeon captured off the MAB, which provides evidence of benthic feeding behavior (Johnson et al. 1997). Other studies suggest that juveniles and non-spawning adults remain in coastal waters in order to increase foraging opportunities (Bain 1997; Stein et al. 2004). We therefore postulated that Atlantic sturgeon would transit more slowly through the shelf region, as they forage within coastal migration corridors. Unlike Atlantic sturgeon, adult striped bass are pelagic predators that frequently rely on mobile prey as a food source and are often associated with structure (Haeseker et al. 1996; Tupper and Able 2000; Harding and Mann 2003). Due to the relatively featureless nature of the MAB, we hypothesized that striped bass would not forage during their seasonal

migrations through the area. In comparison to Atlantic sturgeon, we expected that striped bass would move more rapidly through MD WEA shelf waters.

3 Design and Methods

3.1 MD WEA telemetry array design

Passive acoustic receivers were deployed in a gradient design centered across the MD WEA to observe the seasonal patterns of Atlantic sturgeon and striped bass occurrence. With this design, a central and high-density receiver array was located within the WEA. Inshore and offshore arrays of less densely distributed receivers were adjoined to this central (MD WEA) array (Figure 2). Receivers were thus positioned across a broad width of the shelf environment, which Atlantic sturgeon and striped bass make use of as a migration corridor. The design featured key depth, temperature, and other oceanographic gradients that influence species transit and habitat selection. Additionally, the seasonal and inter-annual variations in migratory behaviors were accommodated by the two-year duration of the study. Thus, the design fulfilled the Before-phase of a BAG impact study, through inclusion of key gradient (e.g., confounding) features.

Atlantic sturgeon and striped bass detections were assessed across gradients ranging from 10-50 km from shore and 10-45 m depth for the period November 2016- December 2018 (Figure 2). The main MD WEA array of 12 receivers were spaced at intervals of 3.2 km East-West and 3.6 km North-South. The Inner and Outer strata were located 8 km inshore and offshore of the MD WEA stratum and each consisted of 4 receivers each at 8 km spacing (East-West and North-South). Receiver spacing allowed for approximately 50% detection in the MD WEA and 20% detection probabilities in the Inner and Outer strata, based on the *a priori* expectations of an 800 m maximum detection radius (but see 3.4. Receiver Range Testing).

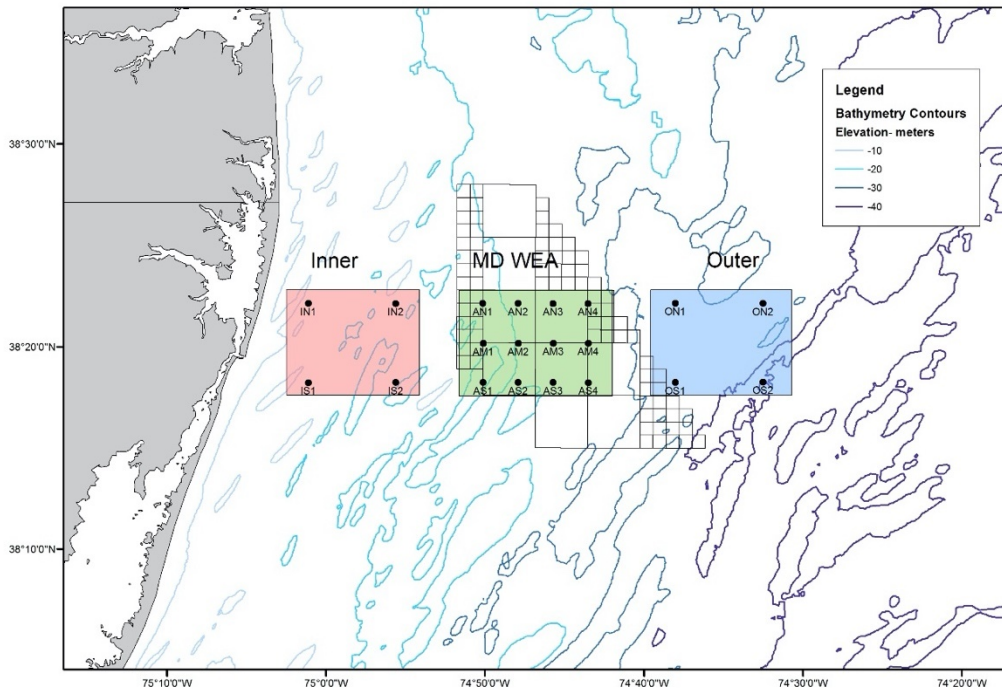


Figure 2. Acoustic receiver array design

Twenty receivers are divided into three strata; Inner (pink), MD WEA (green), and Outer (blue). Bathymetric depth contours are shown at 10-m intervals.

3.2 BOEM consultation and changes to study design

Following discussions with BOEM staff, we augmented the study design to (1) increase the duration of receiver array deployment from November 2016-July 2018 to November 2016-December 2018; and (2) conduct a receiver range-detection test for the period November 2017-December 2018. An additional winter period deployment of the array was deemed important to capture two full years of seasonal patterns of striped bass and sturgeon incidence. Change in duration of the array deployment was implemented through a 1-year no-cost extension. The additional 2018 December cruise was supported by cost savings in vessel steam time by the R/V Carson from its berth in Solomons MD to Ocean City MD. These costs were shared by a separate funding source. Telemetry receiver detection ranges are not well documented, particularly in ocean shelf environments. To support study design assumptions related to array detection probabilities, we designed a 1-year study to evaluate detection ranges in two different shelf environments – the MD WEA, where summer stratification is pervasive and surface noise expected to be moderate, and the Inner Array, where stratification is less pervasive and surface noise is expected to be high (see 3.4. Receiver Range Testing). The design required four additional telemetry receivers, which were available from a separate study. Because these receivers were immediately adjacent to study array receivers, their deployment and retrieval were easily accommodated during array maintenance cruises.

3.3 Telemetry receiver deployments, maintenance, and database management

In triannual cruises beginning November 2016 and ending December 2018, we successfully deployed, maintained, and retrieved 20 VEMCO VR2AR Acoustic Release receivers (Figures 3, 4). We opted for a

low vertical deployment profile (2.0-2.5 m) and a submerged buoy attachment to curtail losses due to vessel collision, theft, and tampering. The VR2AR receivers represent a substantial advance because the release mechanism is built into the receiver housing at a considerably reduced cost and without the need for retrieval lines, which can entangle upon retrieval (Figure 3). A transponding deck-based hydrophone communicates with a release trigger causing the receiver and attached buoy to separate from a sacrificial mooring anchor. The transponder further functions in triangulating the location of the receivers and querying the receiver for temperature, tilt, data memory, and battery life. Receivers were moored onto two 45-lb flat iron weight plates and maintained in the water column by a hard trawl float attached by a 5/16" rope (Figure 4). Receivers detected and logged all telemetered fish on a continuous basis.

All receivers were recovered, cleaned of fouling organisms, had batteries replaced as needed, and were re-deployed during maintenance cruises taking place approximately every 4 months (first year of cruise reports available in Appendix A). Detection and environmental parameter data were downloaded following each cruise and stored in a geospatial database for distribution, quality control, and analysis. Fish detection data were retained in R (R Development Core Team, 2005) and matched to scientists associated with individual transmitter codes using an R package developed from previous telemetry applications (available at <https://github.com/mhpob/TelemetryR>). Where data agreements were in place, detection data were retained for further analysis. Detections were further filtered to include only codes heard more than once to help correct for false detection and code collision (VEMCO guidelines). Metadata on environmental parameters and sent detections were stored in an MS Access database. Data were also archived internally in three-month cycles by archiving Chesapeake Biological Laboratory's file server uploads to a removable drive and by uploading data to an external hard drive. Acoustic receiver detection data will also be provided to MATOS for future study, once the database is fully accessible.



Figure 3. VEMCO VR2AR Acoustic Release receiver, transponder and deck box.

The release mechanism at the bottom of the receiver is a bolt that unscrews and detaches leaving behind a sacrificial weight. The receiver is maintained in the water column through attachment by a short line to a float. Images from <http://vemco.com/products/vr2ar-acoustic-release-and-transceiver/>.



Figure 4. Acoustic Release receiver detection (left) and acoustic release mooring design (right).

3.4 Receiver range testing

Both ambient noise and changes in the speed of sound due to temperature, depth, and salinity can influence the detection range of acoustic transmitters; these ranges have been rarely tested in shelf oceanic ecosystems. Research on black sea bass in the MD WEA (Secor et al. 2019) demonstrated that strong wind events interfered with telemetry detection rates through high ambient noise levels. Thus, we amended the study design to include range testing of the V2AR receivers. We tested our current assumed detection distance (800 m) against two other distances (250 and 550 m). Several acoustic-release receivers containing internal synchronization transmitters were made available at the conclusion of a complementary black sea bass telemetry project funded by the Maryland Department of Natural Resources (October 2017).

On December 20, 2017, we deployed two receivers each at two sites (AN3 and IS2; see Figure 2) to test our current assumed detection distance (800 m) against two other distances (250 and 550 m) in the MD WEA and Inner arrays, respectively (Figure 5). Internal synchronization transmitters are components of our acoustic-release receivers and were programmed to emulate those striped bass and sturgeon transmitters being detected within the present array.

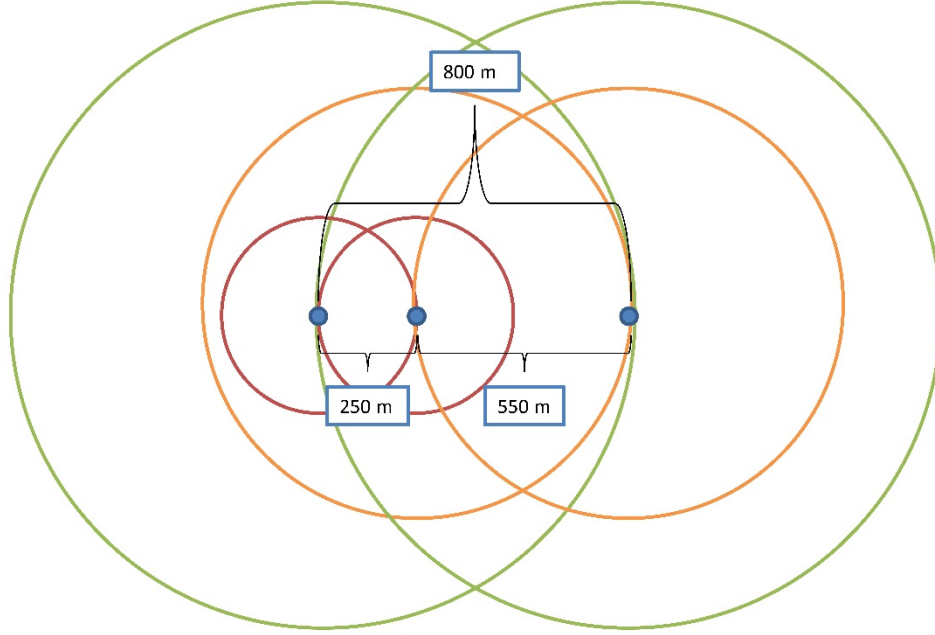


Figure 5. Range test transect schematic.

Synchronization receivers (blue dots) were deployed at 250 and 800 from a reference receiver, allowing for evaluation of detections from 250 (red), 550 (orange), and 800 (green) meter distances. Tests were conducted at sites AN3 and IS2 (see Figure 2).

Data from the range test sites were downloaded on April 11, August 9, and December 5, 2018. Daily frequency of detection was calculated for each distance in each site for a total of two measurements per distance, per site, per day. Proportional daily detection, hereafter referenced as “detections,” was calculated as

$$\frac{transmissions_{ij}}{transmissions_i}$$

where $transmissions_{ij}$ are the transmissions from receiver i detected at distance j and $transmissions_i$ are the total transmissions from receiver i . To visualize changes in detections through time, detections were modeled as a function of distance using nonlinear least squares, binomial regression with a logit link function, and binomial regression with a probit link function. The distance at 50% frequency of detection (D50) was calculated and the best model form was chosen from the fitted models:

Nonlinear Least Squares

$$Dp = D_0 - \frac{\ln\left(\frac{1}{p} - 1\right)}{k}$$

$$D50 = D_0$$

Logit

$$Dp = \frac{\log \frac{p}{1-p} - \beta_0}{\beta_1}$$

$$D50 = -\beta_0/\beta_1$$

Probit

$$Dp = \frac{\text{invnormal}(p) - \beta_0}{\beta_1}$$

$$D50 = -\beta_0/\beta_1$$

As daily modeled D50 contained extreme outliers, the binomial regression modeling process was further refined by imposing covariance through estimating random day-by-site responses and solving the individual coefficients:

$$Dp = \frac{\log \frac{p}{1-p} - \beta_0}{\beta_{km}}$$

$$D50 = -\beta_0/\beta_{km}$$

Where β_{km} is the response at site k on day m .

A dominating feature in the MAB is seasonal stratification; weak salinity-driven stratification dominates in the winter, with strong temperature-driven stratification dominating in the summer (Li et al. 2015). Stratification, especially that associated with the cold pool (Section 2.5), entails large changes seawater density with increasing depth. The change in density affects the speed of sound, and so acoustic detection range will likely vary greatly between periods of cold pool presence or absence. To test for this influence, time series models were fit to the corrected modeled D50 and change point detection was conducted using the PELT algorithm with CROPS penalty to identify changes in mean and variance in the time series of modeled D50 (Killick et al. 2012, Haynes et al. 2014).

As daily D50 varied substantially through time (see Section 4.2), a generalized additive model was developed to scale recorded transmitter detections by a subset of recorded variables. A range of environmental, meteorological, and water quality variables were collected from *in-situ* receivers, the National Data Buoy Center, and remote sensing NOAA Environmental Research Division's Data Access Program (ERDDAP) servers that could be used to create a predictive detection range model (Table 1). Principal component analysis of daily mean records was used for model variable selection; prior to modeling, highly-correlated groups were culled to orthogonal representative variables.

Table 1. Metadata of variables used in the predictive detection range model.

Units, spatiotemporal resolution, and general description are provided. Stations of the National Data Buoy Center (*) are indicated.

Resolution				
Variable	Units	Time	Space	Description
D50	Meters	Hourly	Array	Distance at 50% frequency of detection Modeled aggregate
Average noise	Millivolts	10 minutes	Receiver	Average noise level at 69 kHz Recorded <i>in-situ</i>
Average temperature	Degrees C	Hourly	Receiver	Bottom water temperature Recorded <i>in-situ</i>
Tilt angle	Degrees	Hourly	Receiver	Degrees from vertical of receiver Recorded <i>in-situ</i>
sst	Degrees C	Daily	Array	Multi-scale Ultra-high Resolution Sea Surface Temperature 1 km satellite-derived
dt	Degrees C	Daily	Array	sst - Average temperature
wdir	Degrees	Hourly	Array	Wind direction; degrees from true north OCIM2, 44009*
wspd	Meters/second	Hourly	Array	Wind speed averaged over an eight-minute period OCIM2, 44009*
gst	Meters/second	Hourly	Array	Peak 8 second wind gust speed OCIM2, 44009*
wvht	Meters	Hourly	MD WEA array	Mean of the highest one-third of wave heights during the sampling period 44009*
dpd	Seconds	Hourly	MD WEA array	Dominant wave period: period with the maximum wave energy 44009*
apd	Seconds	Hourly	MD WEA array	Average wave period 44009*
mwd	Degrees	Hourly	MD WEA array	Mean wave direction; degrees from true north 44009*
pres	Hectopascals	Hourly	Array	Atmospheric pressure OCIM2, 44009*

atmp	Degrees C	Hourly	Array	Air temperature OCIM2, 44009*
wtmp	Degrees C	Hourly	Array	Surface water temperature OCIM2, 44009*

The effect of the selected environmental variables on frequency of detection was modeled using a generalized additive model (GAM) with a binomial distribution and log link function. A linear term of distance was used as a predictive variable, along with and additive terms of ΔT , noise (those parameters retained in the variable selection process, Section 4.2), and the interaction between ΔT and noise. Additive components were modeled using 5 knots and a cubic spline basis to control overfitting; the model was trained using the recorded range test data.

3.5 Striped bass transmitters

During the period of receiver deployment, >500 striped bass implanted with active transmitters were at large within the Mid-Atlantic Bight and southern New England (Table 2). The majority of these transmitters were associated with projects by Co-PI Secor; data agreements with other scientists allowed access to information for other tagged striped bass. During this BOEM project, an additional 40 large striped bass were implanted with depth transponders to evaluate depth behaviors in the MD WEA and provide additional incidence data (Table 3). A portion of these fish (n=28) were sampled from a pound net located in the lower Potomac River, Point Lookout State Park, MD during April – May 2017 and 2018 under special permit from the Potomac River Fisheries Commission. An Investigational New Animal Drug permit was attained each year, permitting the use of Aquic-S, an FDA-controlled anesthetic, during acoustic transmitter implantation surgery. Fish were surgically implanted with depth-transponding acoustic transmitters (VEMCO®; model V16P-4H-S256; 67 mm, 10 g, 2.5 year expected battery life) according to tested (Wingate and Secor 2007) and IACUC-approved surgical protocols. Scales were collected for ageing. Additional tagging of a subset of large striped bass occurred off the coast of Massachusetts during August - October 2017 courtesy of the Massachusetts Department of Marine Fisheries. Past telemetry research showed that many coastal migrants from the Chesapeake Bay and other systems enter these waters during summer months (Kneebone et al. 2014). Thus, striped bass tagged in New England waters were expected to exhibit seasonal migrations through the MD WEA.

Table 2. List of active acoustic transmitters associated with large research projects on striped bass and Atlantic sturgeon during the period of the proposed study.

All PIs have agreed to share data with Co-PIs Secor and Bailey. SB=striped bass; AS=Atlantic sturgeon; UMCES=University of Maryland Center for Environmental Science; NYSDEC=NY State Department of Environmental Conservation; MADMF=MA Division of Marine Fisheries; MD DNR= MD Department of Natural Resources; VCU=Virginia Commonwealth University; SUNY=State University of NY. Stipulated period of tag activity is based on VEMCO specifications; transmitter lifespans are typically in excess of these periods.

Species	PI	Institution	N	Tagging Location	Stipulated Period of Tag Activity
SB	D. Secor	UMCES	71	Potomac River	Spring 2014-Winter 2016
SB	D. Secor	UMCES	40	Potomac River	Spring 2017-Winter 2019
SB	D. Secor, A. Higgs	UMCES, NYDEC	100	Hudson River	Spring 2016-Winter 2018
SB	B. Gahagan	MADMF	224	Coastal MA	Summer 2015-Winter 2017
AS	C. Stence	MD DNR	30	Nanticoke	Fall 2015-Fall 2025
AS	D. Fox	DE State Univ.	>500	Delaware	2010-2025
AS	M. Balazik	VCU	155	James River	2010-2025
AS	K. Dunton, M. Frisk	SUNY Stony Brook	495	NY Bight	2010-2025

Table 3. Tagged striped bass information.

Characteristics of the 40 striped bass tagged between 4/21/17 and 5/11/17 in the Lower Potomac River, Point Lookout State Park, MD and off the coast of Massachusetts. All fish were surgically implanted with depth-transponding acoustic transmitters (VEMCO®; model V16P-4H-S256; 67 mm, 10 g, 2.5 year expected battery life).

Tag Date	Transmitter ID	Length (TL, cm)	Weight (kg)	Sex	Tagging Location
5/11/2017	A69-9002-6757	77	5.1	Male	Potomac
9/1/2017	A69-9002-6758	81			Massachusetts
9/1/2017	A69-9002-6759	76			Massachusetts
9/1/2017	A69-9002-6760	82			Massachusetts
9/1/2017	A69-9002-6761	78			Massachusetts
9/1/2017	A69-9002-6762	86			Massachusetts
9/1/2017	A69-9002-6763	77			Massachusetts
9/1/2017	A69-9002-6764	80			Massachusetts
9/1/2017	A69-9002-6765	81			Massachusetts
9/1/2017	A69-9002-6766	114.3	19	Female	Potomac
9/1/2017	A69-9002-6767	107.3		Female	Potomac
9/1/2017	A69-9002-6768	100.3	13	Female	Potomac
9/1/2017	A69-9002-6769	100.3	13.2	Female	Potomac
9/1/2017	A69-9002-6770	107.9	17.7	Female	Potomac
9/1/2017	A69-9002-6771	106.7	16.8	Male	Potomac
9/1/2017	A69-9002-6772	97.8	13	Female	Potomac
9/1/2017	A69-9002-6773	106.7	15.6	Female	Potomac
9/1/2017	A69-9002-6774	104.1	16.8	Female	Potomac
4/21/2017	A69-9002-6775	75.7	5.1	Female	Potomac
4/21/2017	A69-9002-6776	88.6	7.2	Male	Potomac
4/21/2017	A69-9002-6777	99.8	9.8	Female	Potomac
4/21/2017	A69-9002-6778	99.8	10	Female	Potomac
4/21/2017	A69-9002-6779	99.7	11.7	Female	Potomac
4/21/2017	A69-9002-6780	89.1	8.4	Female	Potomac

Tag Date	Transmitter ID	Length (TL, cm)	Weight (kg)	Sex	Tagging Location
5/8/2017	A69-9002-6781	81.4	6.5	Female	Potomac
5/8/2017	A69-9002-6782	80.0	5.6	Female	Potomac
5/8/2017	A69-9002-6783	98.9	10.2	Female	Potomac
5/8/2017	A69-9002-6784	87.1	6.6	Male	Potomac
5/8/2017	A69-9002-6785	81.7	9.4	Female	Potomac
5/8/2017	A69-9002-6786	101.	10.6	Female	Potomac
5/8/2017	A69-9002-6787	81.7	6.2	Male	Potomac
5/11/2017	A69-9002-6788	85.7	7	Male	Potomac
5/11/2017	A69-9002-6789	77.1	5.1	Male	Potomac
5/11/2017	A69-9002-6790	83.0	5.8	Female	Potomac
5/11/2017	A69-9002-6791	77.5	5.7	Female	Potomac
5/11/2017	A69-9002-6792	99.5	11.7	Male	Potomac
9/1/2017	A69-9002-6793	83			Massachusetts
9/1/2017	A69-9002-6794	86			Massachusetts
9/1/2017	A69-9002-6795	84			Massachusetts
9/1/2017	A69-9002-6796	75.5			Massachusetts

3.6 Atlantic sturgeon transmitters

Atlantic sturgeon with active transmitters in the Mid-Atlantic exceed 1000 in number, owing to long-term and intensive research programs on this endangered species and because transmitters are long-duration (~10 years). Through the Atlantic Cooperative Telemetry (ACT) Network, multiple data-sharing agreements have been formed with researchers who have tagged sturgeon in systems ranging from Virginia to New York (Table 2).

3.7 Environmental data sources: temperature, wind, storms, noise, bottom characteristics

Environmental, meteorological, and water quality variables were collected from receivers, the National Data Buoy Center, and remote sensing NOAA ERDDAP servers. Bathymetry (dataset ID usgsCeCrm2), Sea surface temperature (dataset ID jplMURSSST41), and 8-d averaged chlorophyll-a concentration (dataset ID erdMH1chla8day) values were accessed from the CoastWatch West Coast Regional Node

ERDDAP server (<https://coastwatch.pfeg.noaa.gov/erddap/>). Other meteorological variables were downloaded from the National Data Buoy Center. Deployed receivers also recorded tilt, ambient noise, and bottom temperature on an hourly basis, which provided supplementary *in-situ* data. The difference between satellite-observed sea surface temperature and receiver-recorded bottom temperature (ΔT) was calculated and used as an index of water column temperature stratification; higher absolute values of ΔT represent increased stratification strength. Bottom type information was obtained from the Northwest Atlantic Marine Ecoregional Assessment. Bathymetric, sediment grain-size, slope, and Ecological Marine Unit variables were visually assessed for general patterns and notable features in the MD WEA study region

3.8 Data analysis

3.8.1 Seasonal incidence

Presence/absence was calculated at a daily time step to examine striped bass and Atlantic sturgeon incidence. Thus, single or multiple individual incidences over a 24-hr period were summed as a single daily incidence. Daily incidence data (no. individual fish d^{-1}) was summed by stratum (array) and season. For all analyses, seasons were divided equally and defined as winter (Dec, Jan, Feb), spring (Mar, Apr, May), summer (Jun, Jul, Aug), and autumn (Sep, Oct, Nov). Because incidence data was zero-inflated and skewed, non-parametric Kruskal-Wallis tests and post hoc Dunn's test with the Bonferroni method for multiple comparisons were used to determine significant differences in number of individuals detected between seasons and stratum (Inner, MD WEA, Outer).

3.8.2 Transit rates and patterns

Indices of movement and residence were calculated from individual data aggregated into broad autumn/winter and spring/summer periods to facilitate comparisons between northern and southern migrations for each species. The autumn/winter season is referenced by the three years according to the year that the winter season ended: autumn/winter 17, or autumn/winter 18, or autumn/winter 19. We examined patterns of residence and movement across the entire MD WEA receiver array (all strata) for both species within these seasonal periods. Movement was evaluated by examining the number of receivers visited by individuals within migration seasons. Residency was calculated using original VEMCO detections that were run through the "RunResidenceExtraction" function in the R V-Track package (c/o Franklin Ecolab, The University of Queensland, St Lucia, Qld, Australia). In the function, a residence event began when an acoustically-tagged fish was detected at least two times and was terminated when the tag was detected at a different receiver or if no new detections were recorded for 12 hours. Residence events were summed for each fish and each migration season and reported as hours detected. Cumulative unique days detected for each individual per season were also calculated to provide a comparative, coarse measure of residence. Differences in residence periods between species and seasons were compared using Wilcoxon rank sum tests.

Rate of movement calculated within the MD array did not provide sufficient data given the number of sequential detections, cooperative data sharing with University of Delaware colleagues (D. Haulsee and M. Oliver) permitted evaluation of transit rates between the MD WEA and the adjacent DE WEA. Though residence and within-array movements were available for both species, transit rates between MD and DE arrays were only calculated for tagged striped bass. Detailed information on Atlantic sturgeon movement between the two arrays can be found in the complementary report to BOEM by Delaware colleagues (Haulsee et al. 2020; https://espis.boem.gov/final%20reports/BOEM_2020-020.pdf). Striped bass transit events between the MD WEA and DE WEA were evaluated using receiver locations to estimate transit (straight line) distance, time interval of serial detections, and direction of transit (North or

South). To the extent that data were available, we estimated linear transit velocities as body lengths s^{-1} , which is a more ecologically relevant measure. Differences in log-transformed swimming speed between direction (north vs. south) were evaluated using Student's t-tests. Transit rates were further tested for differences according to size and sex using linear mixed effect models (LMMs) in the R package nlme (Pinheiro et al. 2017). Rate of transit was the dependent variable with year, season, and sex as categorical variables and body size at tagging (TL in cm) as a continuous covariate. LMMs for log-transformed transit rate only included fish tagged in the Potomac and Hudson Rivers; tagging region was not investigated as a fixed effect due to limited sample size. Each individual (tag code) was included as a random effect in the models to account for repeated measures. The full model contained all biologically-relevant two-way interactions, including Sex*Season, TL*Season, and TL*Sex.

3.8.3 Distribution and depth of occurrence for tagged striped bass

Striped bass that received depth transponders provided depth of incidence data within the full MD WEA array as well as distributional information when records were received from ACT network participants. Broader migration and depth of occurrence data throughout ACT network sites were visually assessed for trends and patterns. Depth of incidence within the MD WEA region was examined for seasonal and strata differences.

3.8.4 Environmental covariates of MD WEA incidence

Since preliminary results in regional telemetry arrays indicated that some species, particularly Atlantic sturgeon, may select specific habitats that result in disproportionate detections at certain receivers (D. Haulsee, University of Delaware and C. Watterson, US Navy; pers. communication), we sought to evaluate whether high densities of detection corresponded with bottom type characteristics. Spatial patterns of site (receiver) usage within the gradient array were assessed using the Optimized Hot Spot Analysis tool (Getis-Ord G_i^* statistic) in ArcGIS. Separate analyses were conducted based on the number of unique individuals detected daily at each receiver within each season and over all seasons and years combined.

Single Parameter Quotient analysis (Lluch-Belda et al. 1991) was used to quantitatively investigate the average selection behavior of each species for temperature in autumn/winter and spring/summer seasons. Habitat selection was determined by presence over time for regions within the study array. Daily presence of fish was compared to all temperatures when fish were either present or not within seasonal periods. Temperature values were binned so that each interval contained a range of 5°C to reflect regional variability (Bonanno et al. 2014). For each season and temperature interval, a Quotient index (QI) was calculated as

$$QI_i = \frac{\%Observed\ Detections}{Env.\ Var.\ Freq_i \times 100}$$

where i is i -th frequency histogram interval.

The resulting QI values compare the proportion of available habitat to the proportion of habitat in which detections occurred. A value of QI=1 represents even distribution across habitat types, values greater than 1.0 indicate preference, and values lower than 1.0 indicate avoidance. Significant deviation from QI=1.0 was tested using a randomization procedure. Confidence intervals (CI) were calculated based on the null hypothesis of a random association between biological and environmental variables. The calculated CI was then used to infer avoidance or selection of specific temperatures by Atlantic sturgeon and striped bass. QI values lying outside of the CI curve indicate significant selection or avoidance.

3.9 Predictive habitat models

3.9.1 Daily relative abundance model

Dynamic relative abundance models were formulated separately for each species. The response variable, daily individual incidence, was calculated by tallying the total number of unique tag codes (individual fish) detected at each receiver, each day. Since species occurrence was zero-inflated and expected to vary non-linearly with environmental variables, a Generalized Additive Mixed Model (GAMM) framework with a zero-inflated Poisson distribution was used (Table 4). All modeling was conducted in R statistical software (R Development Core Team, 2015) using the *mgcv* package (Wood and Wood 2019). To account for the variable detection range of receivers (see Section 3.4), modeled D50 predictions (site-specific 50% detection range), were added as an offset to the GAMM habitat models. This predicted range represented an index of sampling effort and was used to adjust each day's sum of detections such that abundance recorded on days with lower D50 values were up-weighted and abundance recorded on days with larger detection ranges were down-weighted. The D50 offset thus reduced temporal autocorrelation caused by underlying fluctuations in detectability. Receiver site and study year were added as random effects to limit spatial autocorrelation and to account for inter-annual differences in the number of fish detected.

Previous results and past habitat-selection modeling in the Mid-Atlantic suggested that variables such as temperature, stratification, depth, and oceanographic satellite-derived measures of productivity would be important factors in the daily presence of both species (Manderson et al. 2011; Breece et al. 2017; Haulsee et al. 2018). We therefore selected bottom water temperature, sea surface temperature (SST), stratification (ΔT), bathymetry, and MODIS aqua-derived satellite measurements of chlorophyll a concentration as environmental covariates. Depth was chosen as the most representative bottom characteristic variable since preliminary telemetry results in the MD WEA suggested that species do not select habitats based on sediment type or benthic class in this section of the MAB shelf (PI D Secor, unpubl. data). We also considered magnitude of monthly SST change as a covariate; temperature change was calculated using the difference between current SST on a given day minus the lagged SST value over the previous 1-30 days (SST $\Delta 1-30$).

Preliminary examination of collinearity through pairwise comparison and variance inflation factor calculation showed that SST, ΔT , and bottom temperature were highly correlated ($r > 0.7$, variance inflation factor > 3). SST was selected among these variables because it was most accessible via the ERDDAP server. Similarly, SST $\Delta 1-30$ was strongly correlated with SST; here models included either but not both variables. To account for seasonality in the data, day-of-year (DOY) was included as a predictor variable. The oscillatory nature of DOY was accommodated using cyclic splines (bs= "cs"; gam function, *mgcv* package) (Wood 2017). All other variables were modeled using singular smooth terms (formula= s, gam function, *mgcv* package) and thin plate regression splines (bs= "ts", gam function, *mgcv* package) and were limited to 6 knots to reduce potential over-fitting (Wood, 2003). Interactions between environmental variables and DOY were also systematically included and a tensor product smooth term (formula= t2, gam function, *mgcv* package) was used to accommodate differing units among interaction variables (Wood et al. 2013). Only one interaction was allowed per modeling iteration to limit complexity.

All possible relative abundance model combinations were tested and ranked according to AIC score. Final models were then checked for concurvity, the non-linear equivalent of collinearity using the "concurvity" function in the *mgcv* package. Concurvity occurs when there is similarity between the smooth functions of different variables. Concurvity can thus lead to difficulty in interpreting model effects and in severe cases can bias estimates of residual variance, leading to false confidence in results (Ramsay et al. 2003).

Therefore, if observed values of concurvity were > 0.8 (values range 0-1, with higher values indicating increased concurvity), the model was dismissed from consideration. Because SST and SST $\Delta 24-30$ always resulted in concurvity values exceeding 0.8, only models that included SST $\Delta 1-23$ were used for selection. Final model residuals were visually checked for temporal and spatial correlation using autocorrelation function (ACF), partial autocorrelation function (PACF), and semi-variogram plots. Overall model performance was evaluated with k-fold cross validation in which the data were randomly split into training (75%) and testing (25%) sets over each of 5 folds. The root mean square error (RMSE) and average error between observed abundance in testing data and training model-predicted abundance were then calculated and used to assess model predictive error (Potts & Elith 2006).

Table 4. Summary of intended purpose and modeling approach for each research question.

See Methods for additional explanation. GAMM=Generalized Additive Mixed Model; HGAM=Hierarchical Additive Mixed Model.

Category	Objective	Modeling approach	Response variable	Level of organization	Autocorrelation compensation	Random effects
Relative abundance	Predict fine-scale relative abundance of test species	GAMM	Number of individuals per receiver	Temporal: Daily Spatial: Receiver-based	Range test offset	Receiver site and Year of study
	Determine predictors of individual residence	GAMM	Number of days per week	Temporal: Weekly Spatial: Array-wide	Lagged residency response	Individual ID
	Evaluate residence response by population (tagging origin)	HGAM submodel	Number of days per week	Temporal: Weekly Spatial: Array-wide	Lagged residency response	Tagging origin

3.9.2 Environmental and individual drivers of weekly residency

Environmental drivers of individual residency on the MAB shelf were also assessed using a zero-inflated GAMM approach (Table 4). The response variable for residency models was the total number of days of positive detections within each week. Individual ID (transmitter code) was included as a random effect to account for correlation from repeated measures of the same individual. “Population”-level differences in individual response were tested in the same model by considering tagging region as a fixed effect. Only tagging regions with a sample size > 5 individuals were included in analyses. Differences between tagging regions was evaluated using the *post-hoc* multiple comparison, Wald test (wald_gam function, ‘itsadug’ package; Van Reij et al. 2017).

Week-of-year, CHL-A, and SST were examined for their effect on the weekly residency of individual fish. Thin plate splines with a limit of 6 knots were used to specify all environmental covariate functions with the exception of week-of-year, which was modeled with a cyclic spline. Although models likely suffered from concavity, thus increasing the potential for biased estimates or Type I error (Amodio et al 2014), SST and week-of-year were both retained so that the influence of each term could be evaluated while accounting for individual-level variability.

Preliminary analysis showed that inclusion of individual random effects did not resolve all residual temporal autocorrelation and unlike daily-resolution modeling, the use of a D50 offset did not effectively diminish correlation at the weekly timescale. A state-dependence approach using lagged individual residency was used to model and reduce remaining serial autocorrelation in weekly residence probability. Three state-dependence sub-models were created that corresponded to how many days an individual fish was detected in the previous 1-3 weeks. Each considered submodel added the first- through third-order smoothed autocorrelation terms to find which structure most decreased autocorrelation while limiting complexity. Residual autocorrelation was again checked using ACF and PACF plots.

When significant differences in residency were identified between tagging regions (populations) in the GAMM *post-hoc* tests described in the previous section, hierarchical generalized linear models, or HGAMS, were used to further evaluate the group-level differences in response to environmental and temporal covariates (Table 4). HGAMS are used to allow for varying degrees of non-linear response over different grouping levels (Pedersen et al 2018). For hierarchical modeling, significant predictors of residency were each tested individually. The smoothed functional response in each model was allowed to vary by group (tagging region), but group-level functions were pooled in a common response. The hierarchical relationship between predictor variables and tagging-region groupings was specified using different variable and factor relationships. First, the global response of all groups to the variable of interest (either week-of-year, SST, or CHL-A) was specified using a singular thin plate regression spline. Next, the predictor was modeled according to each tagging group factor using the factor-by-smooth model specification (formula = “by”, gam function, mgcv package). However, a cyclic spline was still used to model the temporal week-of-year variable. Finally, a random effect for tagging group was explicitly included so that model intercepts could differ among the group factor levels (Pedersen et al 2018). Collinearity between the global response and group-level responses was deliberately penalized and reduced using additional model terms (bs= “ts”; m=2, gam function, mgcv package), thereby increasing certainty around the global smoothed predictor (Wieling et al. 2016; Baayen et al. 2018). The best state-dependence correlation structure identified in the full residency model was used in hierarchical models. Model diagnostics and performance were not assessed for HGAMS since their purpose was to support visualization of group-level differences in response to individual environmental covariates and not to predict residency.

4 Results

4.1 Database guidance and total detection summary

Detailed species detection data were shared directly with BOEM project officers and will become publicly available through the MATOS network (the ACT network successor), which is currently still under development. All information necessary to directly reproduce study results are available via the Dryad data repository along with relevant metadata guidance (<https://doi.org/10.5061/dryad.6hdr7sqx3>).

From November 2016- December 2018, the array logged 745,385 detections of 1,286 acoustically-tagged fish, the bulk of which were target species of the current study: striped bass (n=315 individuals) and Atlantic sturgeon (n=352 individuals, Table 5). In addition to target species, 18 additional species were identified through the ACT network and included Atlantic cod, Atlantic bluefin tuna, black sea bass, and miscellaneous elasmobranchs (blacktip, bull, dusky, sand tiger, tiger, and white sharks; cownose ray) belonging to 39 different investigators (Table 5). Sixteen of the detected species were detected within the Wind Energy Area.

The focal species of this study tended to have longer periods of incidence in the array when compared to other identified species (Figure 6). A notable exception was white shark, which were frequently detected within the array throughout the study. However, most elasmobranch species tended to occur for shorter periods of time during summer months or late spring and early fall; Atlantic sturgeon and stiped bass were less common during these same periods (Figure 6).

Table 5. Total species detected and PIs contacted during receiver array deployment period.

Receiver array deployment periods show timing of active deployment between tending of receiver and data downloads. The number of detections logged and number of principle investigators (PIs) represented by detected fish are shown. Number of individual species by array is also shown.

Deployment Period	Species Detected	Number Detected			
		Total	Inner	MD WEA	Outer
11 Nov, 2016 - 29 Mar, 2017 28,003 detections 24 PIs	Sand tiger shark	1	1		
	Atlantic sturgeon	157	57	101	12
	Striped bass	238	19	198	117
	White shark	6	1	5	2
	Black sea bass	4		3	1
	Atlantic cod	2		2	1
	Unidentified	6	3	7	
29 Mar, 2017 - 23 Aug, 2017 6,990 detections 31 PIs	Cownose ray	1	1		
	Sand tiger shark	21	19	2	
	Bull shark	2	1	2	
	Atlantic cod	1	1	1	
	Atlantic sturgeon	115	100	18	1
	White shark	19	8	12	7
	Striped bass	115	7	100	23

	Blacktip shark	10	2	5	4
	Dusky shark	3	1	2	1
	American shad	1		1	
	Black sea bass	4		3	1
	Atlantic bluefin tuna	1		1	1
	Tiger shark	1			1
	Unidentified	14	7	6	3
<hr/>					
23 Aug, 2017 - 20 Dec, 2017	Sand tiger shark	25	22	4	
16,132 detections	Striped bass	55	13	52	
29 PIs	Bull shark	2	2	1	
	Atlantic sturgeon	234	146	108	8
	Dusky shark	19	14	15	2
	Blacktip shark	13	6	9	2
	White shark	20	4	14	4
	Cownose ray	3	2		1
	Smooth dogfish	3		3	
	Atlantic bluefin tuna	1		1	
	Atlantic cod	1		1	
	Shortnose sturgeon	1		1	
	Black sea bass	12		4	10
	Sandbar shark	4		2	3
	Unidentified	22	11	12	3
<hr/>					
20 Dec, 2017 - 12 Apr, 2018	Atlantic sturgeon	90	29	55	9
208,740 detections	Striped bass	199	25	162	85
17 PIs	Winter skate	5	2	2	
	White shark	1		1	
	Atlantic cod	1		1	1
	Black sea bass	1			1

	Spiny dogfish	1			1
	Unidentified	23	17	7	3
<hr/>					
12 Apr, 2018 - 08 Aug, 2018	Sand tiger shark	23	22	1	
226,145 detections	Striped bass	29	2	20	7
	Winter Skate	11	5	4	2
	Atlantic sturgeon	172	144	25	3
	Dusky shark	15	3	12	
	Blacktip shark	17	6	11	
	White shark	23	6	12	5
	Cownose ray	1	1		
	Smooth dogfish	2	2		
	Sandbar shark	5	2	1	2
	Tiger shark	1		1	
	Tarpon	1	1		
	Unidentified	49	30	17	2
<hr/>					
08 Aug, 2018 - 12 Dec, 2018	Sand tiger shark	19	9	9	1
259,375 detections	Striped bass	54	4	50	
25 Pls	Bull shark	1		1	
	Atlantic sturgeon	183	73	101	9
	Dusky shark	23	9	8	6
	Blacktip shark	29	12	12	5
	White shark	17	3	8	6
	Cownose ray	3	1	1	1
	Smooth dogfish	4	1	1	2
	Sandbar shark	3	1	1	1
	Tiger Shark	1			1
	Unidentified	130	47	64	19
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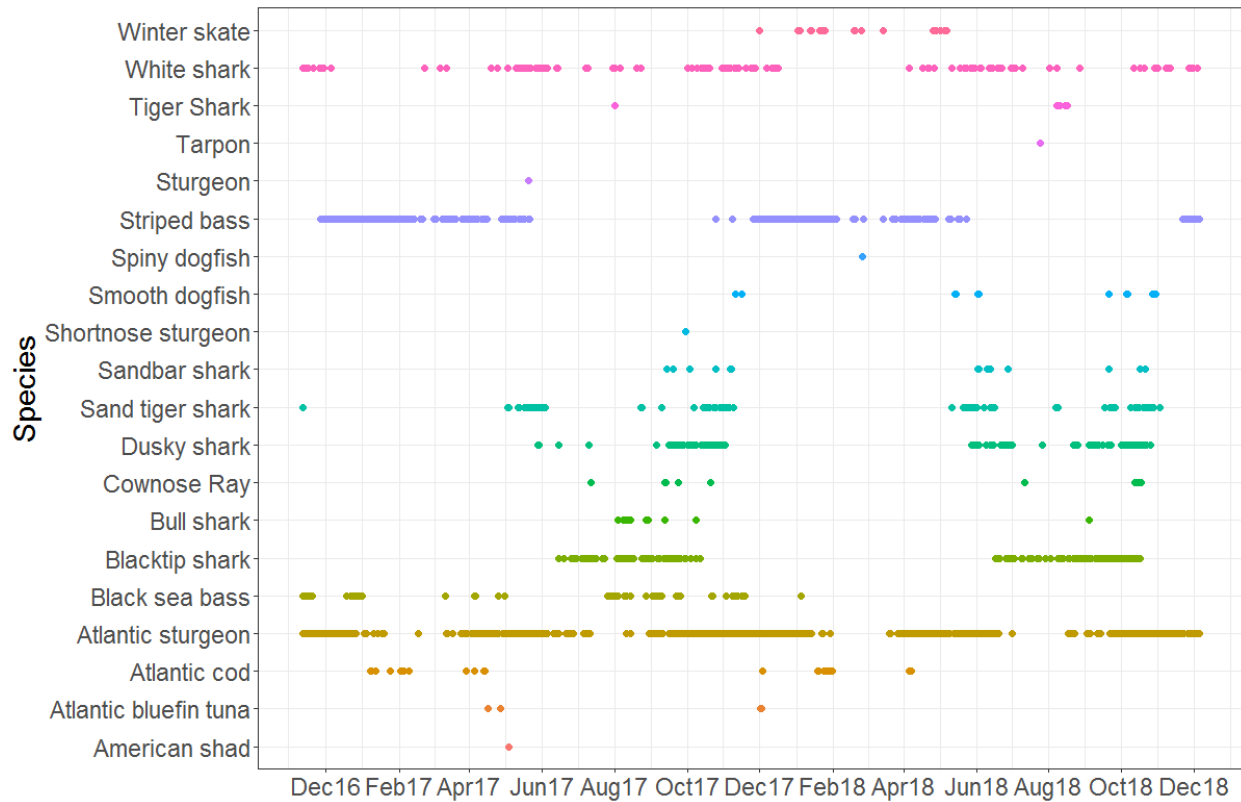


Figure 6. Summary incidence of all species detected in the MD WEA throughout the study. Colored points represent the presence of at least one tagged individual for 20 species detected in the MD WEA.

4.2 Receiver range testing

Range and variation in transmitter detections varied with distance from each receiver, array segment (Inner or MD WEA), and season (Table 6). Detections were higher within the MD WEA than the Inner array (ANOVA, $p < 0.001$), likely due to attenuation of surface noise in the deeper waters of the MD WEA. Detections were also substantially higher during the Spring-Summer 2018 season in both arrays (ANOVA, $p < 0.001$).

Table 6. Summary of proportional detection within the deployed range test arrays.

Array (Depth)	Distance	Autumn-Winter 2018			Spring-Summer 2018			Autumn-Winter 2019		
		Minimum	Mean \pm SD	Maximum	Minimum	Mean \pm SD	Maximum	Minimum	Mean \pm SD	Maximum
Inner	0	1	1 \pm 0	1	1	1 \pm 0	1	1	1 \pm 0	1
16.5 – 19.5 m	250	0.08	0.88 \pm 0.19	1	0	0.87 \pm 0.24	1	0.16	0.89 \pm 0.17	1
	550	0	0.43 \pm 0.33	1	0	0.68 \pm 0.34	1	0	0.38 \pm 0.32	1
	800	0	0.12 \pm 0.18	0.85	0	0.42 \pm 0.30	0.93	0	0.17 \pm 0.26	0.94
	Overall	0	0.48 \pm 0.40	1	0	0.66 \pm 0.35	1	0	0.48 \pm 0.40	1
MD WEA	0	1	1 \pm 0	1	1	1 \pm 0	1	1	1 \pm 0	1
26.5 – 27.5 m	250	0.87	0.98 \pm 0.02	1	0.42	0.97 \pm 0.06	1	0.75	0.97 \pm 0.03	1
	550	0.01	0.71 \pm 0.24	1	0	0.77 \pm 0.28	1	0	0.63 \pm 0.30	1
	800	0	0.15 \pm 0.16	0.83	0	0.52 \pm 0.37	1	0	0.33 \pm 0.34	1
	Overall	0	0.61 \pm 0.38	1	0	0.78 \pm 0.31	1	0	0.64 \pm 0.37	1

The three modeling approaches (nonlinear least squares, binomial regression with logit link, and binomial regression with probit link) yielded similar estimates of D50 for each array in the Winter – Early Spring deployment period ($D50_{\text{Inner}} = 464, 478, 478$ m and $D50_{\text{MD WEA}} = 609, 607, 603$ m respectively; Figure 7). The binomial regression with a logit link function was chosen for further analysis due to its comparative generality and ease of use. Similar to the individual proportional detections (Table 6), the modeled frequency curve showed significantly higher detection range (i.e., greater D50 values) at the deeper MD WEA site in all seasons than the Inner site, and across sites in Spring-Summer 2018 when compared with the Autumn-Winter seasons (Chi-square, $p < 0.001$; Figure 7).

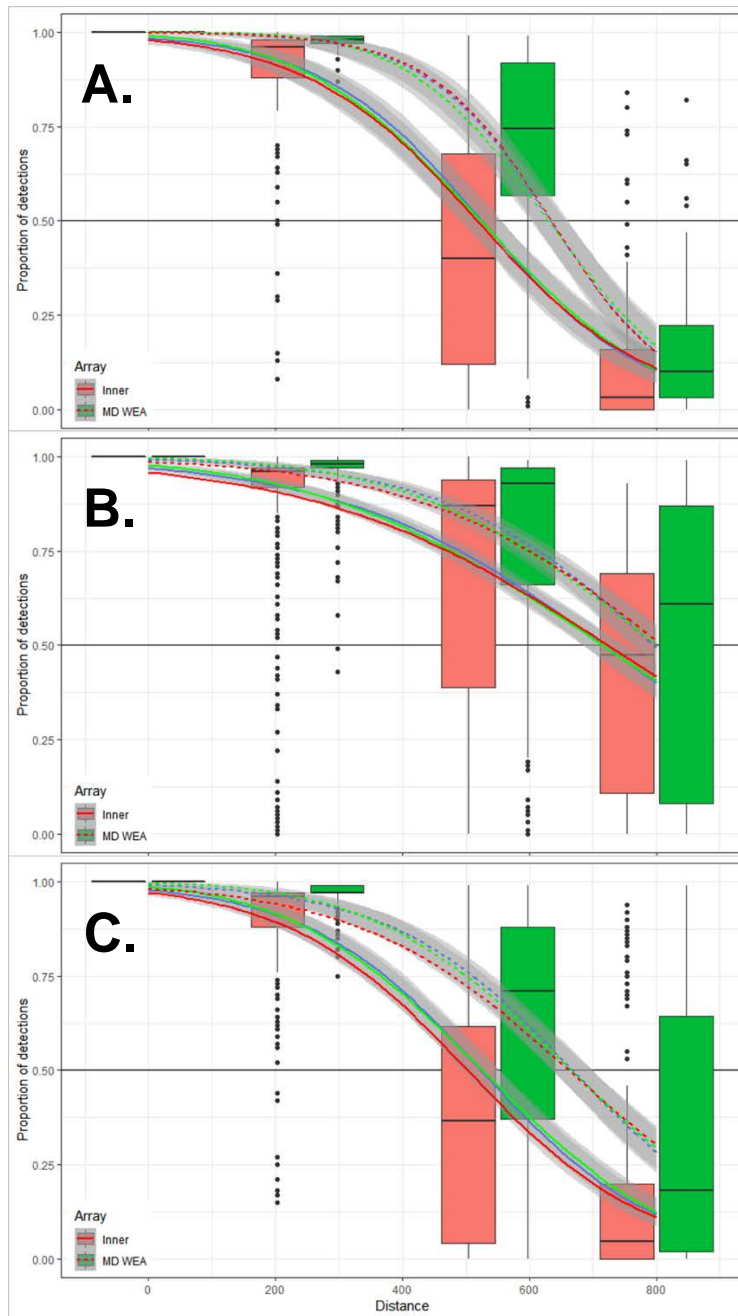


Figure 7. Box-whisker plots of the frequency of detection for Inner and MD WEA arrays in the Autumn-Winter 2018 (A), Spring-Summer 2018 (B), and Autumn-Winter 2019 (C) seasons.

Logit (blue), probit (green), and nonlinear least squares (red) detection frequency fits are shown for both Inner (solid) and MD WEA (dashed) arrays. Gray envelopes represent the standard error of the logit and probit regressions. Error was not calculated for the nonlinear least squares solution.

Modeled D50 varied between sites and across seasons (Figure 8), ranging from 130 to 1657 m in the Inner and 260 to 2221 m in the MD WEA array. A more-conservative estimate of D95 (95% proportional

detection) ranged from 97 to 1189 m in the Inner and 168 to 1578 m in the MD WEA. Detection probability was notably reduced in 2018 during March due to the winds of four nor'easters impacting the region on March 1-3, 6-8, 12-14, and 20-22. Following this, D50 increased in mid-April, reaching its maximum on September 7, after which it rapidly fell to levels similar to winter-spring 2018.

Both the MD WEA and Inner site D50 time series were best-fit by a ARIMA(2, 1, 2) model; that the model contains a differencing term along with autoregressive and moving averages suggests at least one abrupt shift in the series. Change point detection showed that time series for both sites had increases in the mean and variance D50 from winter to summer, followed by a decrease in early autumn. The Inner site increased from 488 ± 183 m to 890 ± 184 on April 27, while the MD WEA site similarly increased from 639 ± 137 m to 1204 ± 250 m on May 20. Both sites experienced a large reduction in D50 on September 8, falling back to levels similar to those early in the year (660 ± 195 m at the MD WEA site and 495 ± 156 m at the Inner site). These dates broadly correspond to the period of cold pool development and destruction (Section 4.3).

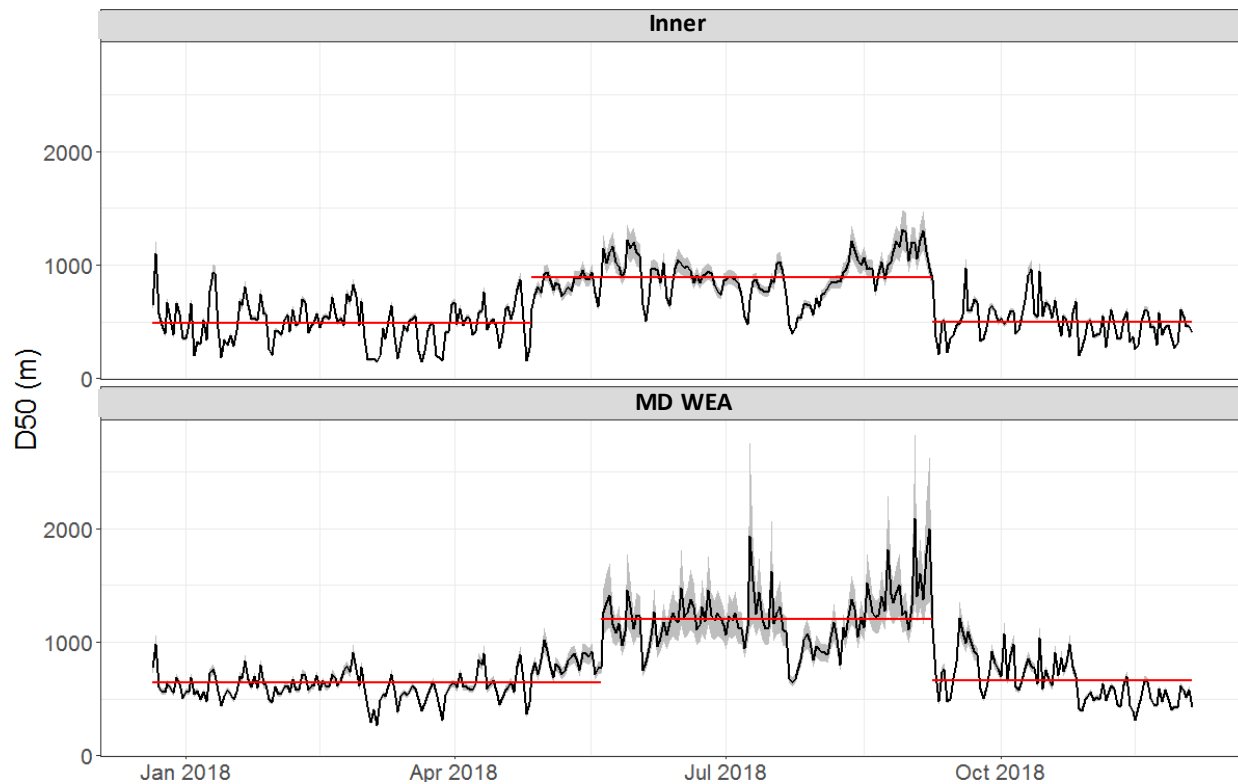


Figure 8. Modeled 50% detection distance (black line) and 95% population prediction interval (gray band) at the Inner and MD WEA study sites.

Change points in the mean and variance of the time series are shown by breaks in mean (red line).

Of the variables investigated, D50 had a negative correlation with wind speed metrics, wave height, and 69 kHz noise (Figure 9). Conversely, D50 showed positive correlations with temperature-derived variables, while receiver tilt, atmospheric pressure, wind and wave direction, and wave period showed

little correlation. The roughly-orthogonal variables of ΔT (dt in Figure 9), an index of stratification, and noise at 69 kHz were retained for predictive modeling of frequency of detection and D50.

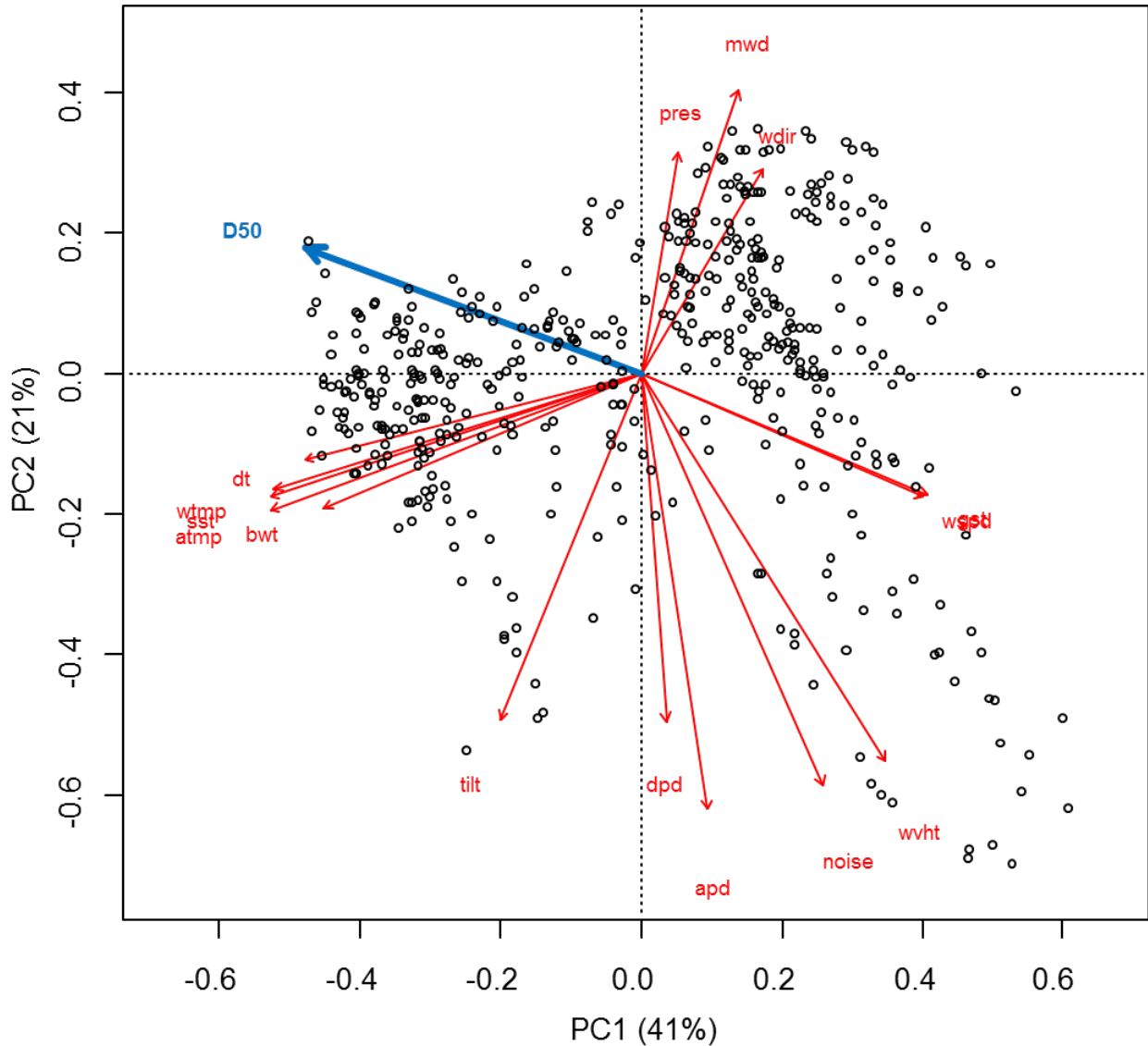


Figure 9. Principal component analysis of daily mean records (points) of environmental variables (arrows) to be used in a predictive detection range model.

The first two axes explain 62% of variance. Variables include distance at 50% detection (D50), average noise, average temperature, tilt angle, sea surface temperature (sst), sea surface temperature -average temperature (dt), wind direction (wdir), wind speed (wspd), wind gust speed (gst), wave height (wvht), dominant wave period (dpd), average wave period (apd), mean wave direction (mwd), atmospheric pressure (pres), air temperature (atmp), surface water temperature (wtmp); see Table 1 for variable descriptions.

4.2.1 Modeled frequency of detection

Frequency of detection modeled as a function of distance, ΔT , noise, and ΔT -noise interaction explained 82.6% of deviance with an adjusted R^2 of 0.847. Generally, the proportion of possible transmissions detected decreased as ΔT approached 0 or as ambient noise and distance from source increased. Near-0 values of ΔT , which correspond to a well-mixed, homogeneous water column, had a negative effect on the proportion of possible transmissions detected; higher indices of stratification (larger ΔT values, cold pool present) were found to increase the proportion of transmissions detected (Figure 10). The interaction between ΔT and noise revealed that when the water column was homogeneous, proportion of transmissions detected, and thus detection distance, declined with increased noise over 200 mV. However, detection distance was comparatively greater at higher ambient noise levels when the water column was stratified and decreased rapidly when noise levels exceeded 300-400 (mV) (Figure 10).

GAM predictions for the period of investigation (November 2016 – December 2018) were converted to D50 as outlined in Section 3.4. D50 for the entire telemetry dataset exhibited the expected patterns of larger detection range values during warmer, stratified months that increased with greater depth ($D50_{Inner} < D50_{MD\ WEA} < D50_{Outer}$; Figure 11). There was noticeable daily variability in estimated D50 that likely occurred due to fluctuating ambient noise levels (Section 4.5). Larger decreases in detection range were also apparent and were likely tied to increases and noise and decreases in stratification associated with anomalous wind events.

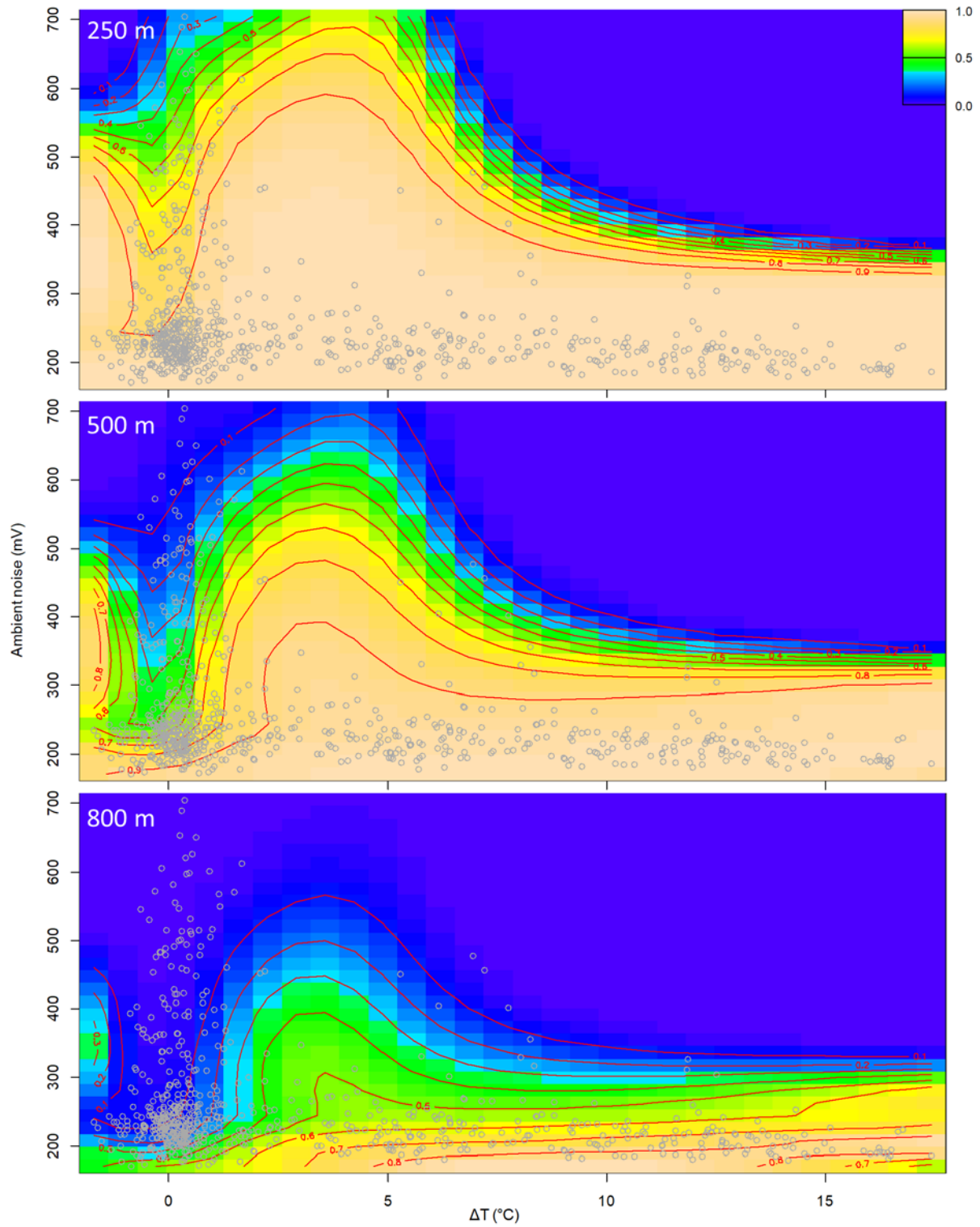


Figure 10. GAM-predicted proportional daily detections (contours) for combinations of 69 kHz ambient noise and ΔT at 250, 500, and 800 meters from source. Observed noise- ΔT combinations are shown as gray points.

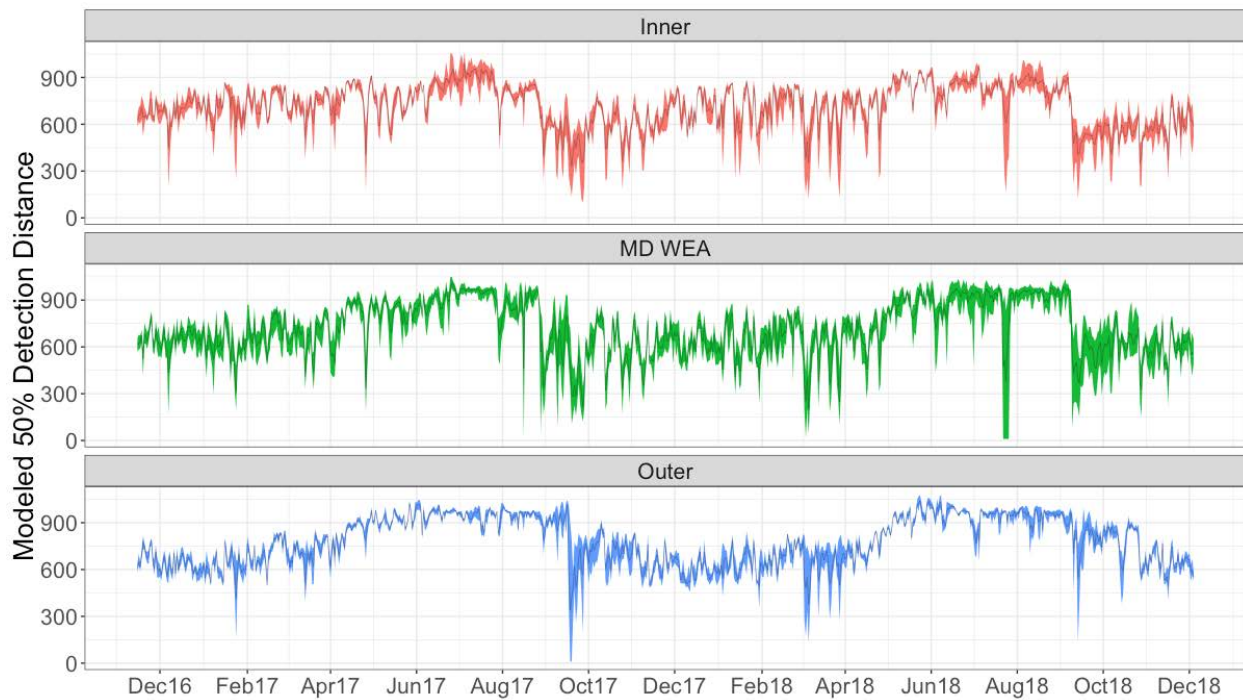
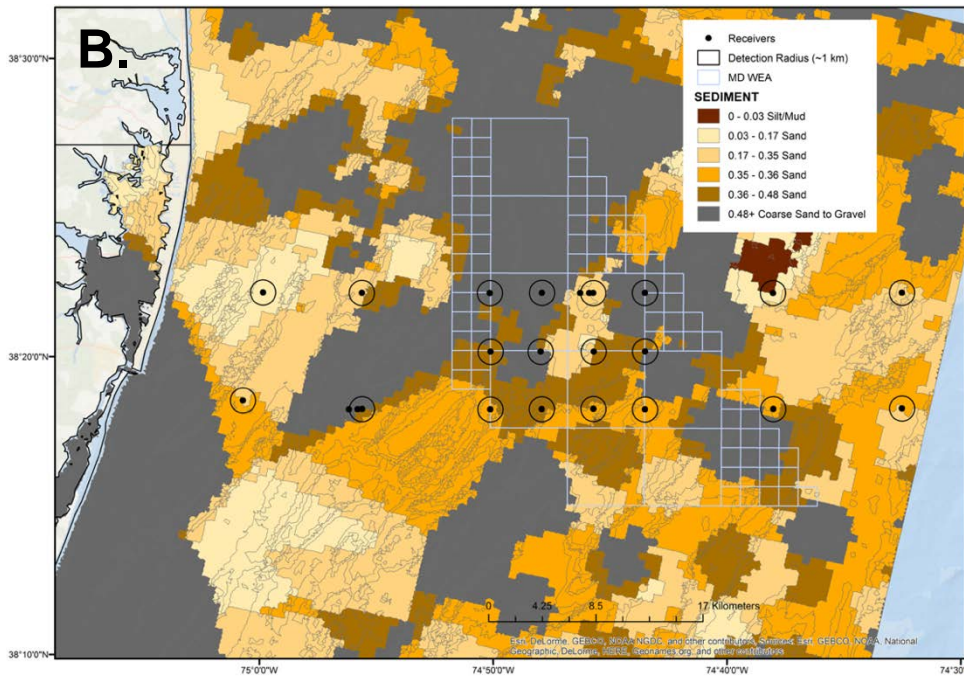
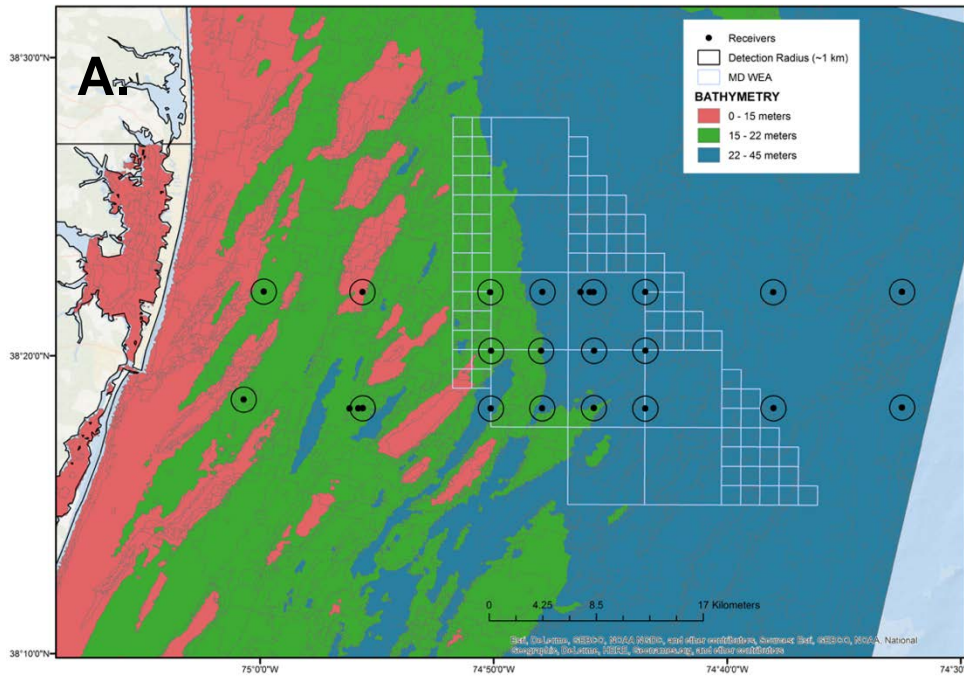


Figure 11. Results of modeled range test predictions for the entire time series of the study (November 2016 - December 2018), ordered by stratum.

Black lines show the mean predicted detection range across the array while shaded ribbons represent the range (minimum – maximum) of predicted values.

4.3 Study site benthic characteristics and bottom type

The shelf habitat off Maryland had the expected pattern of relatively homogenous sandy habitat, but some topographic complexity was revealed from assessment data visualization (Figure 12). Although depth generally increased with distance from shore, there were notable higher-relief ridges located directly West of the MD WEA (Figure 12; A). Most sediments were classified as sand bottom types, but certain study site patches contained regions of finer muddy substrates or more coarse gravel substrate (Figure 12; B). There was relatively little topographic complexity in terms of slope (Figure 12; C), but combined Ecological Marine Units did vary over the effective area surveyed by receivers; inshore sites tended to encompass shallow depression or high flat habitats while deeper MD WEA and Outer stratum sites corresponded with moderate depressions and moderate flats (Figure 12; D).



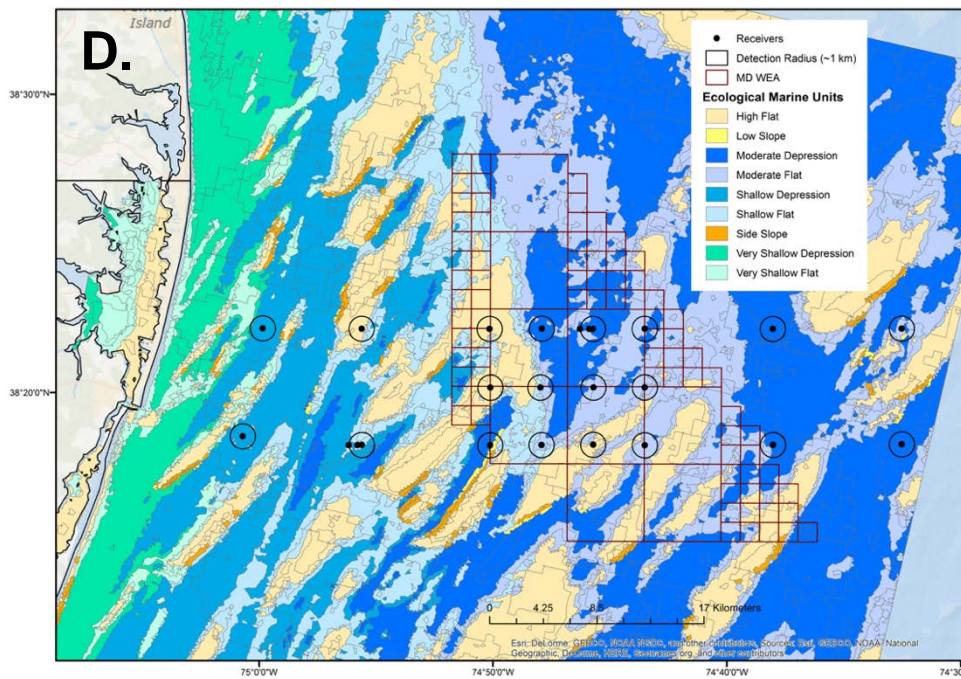
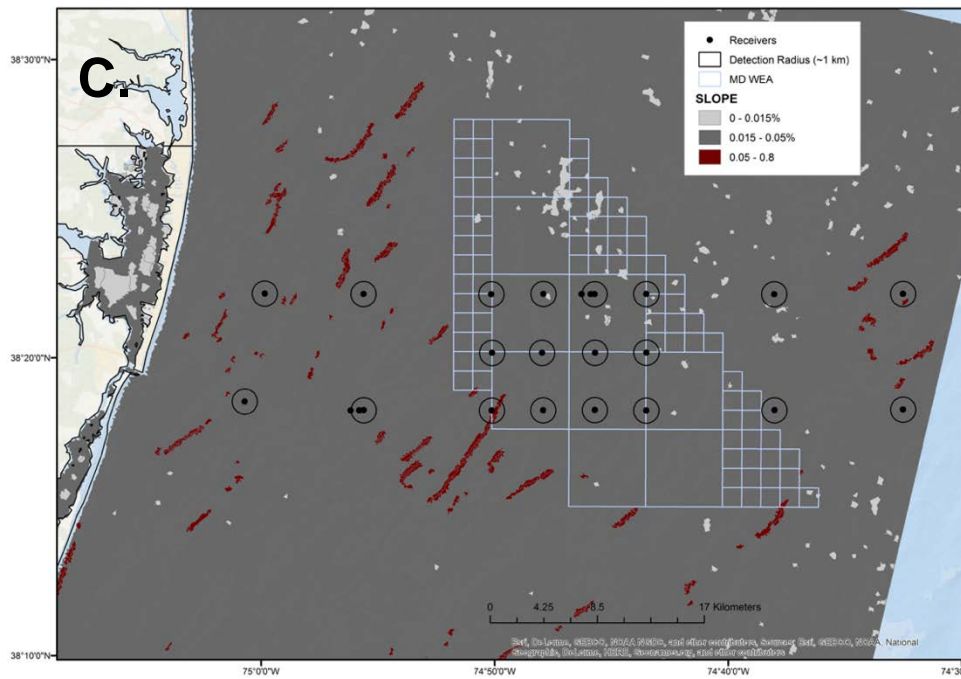


Figure 12. Bathymetry and benthic characteristics surrounding acoustic telemetry array receiver sites.

Maps depict the study site region off the coast of Ocean City, MD along with the MD WEA footprint. The anticipated maximum detection radius of each receiver is also shown. Bottom type summaries include general depth gradients (A), sediment grain-size classifications (B), bathymetric slope calculations (C), and Ecological Marine Units (D). Ecological Marine Units represent a three-way combination of depth, sediment grain-size, and seabed forms that were found to influence ecological relationships of surveyed organism communities (Source: Northwest Atlantic Marine Ecoregional Assessment, The Nature Conservancy).

4.4 Study site seasonal temperature changes

Mean daily bottom temperature in the study array ranged from 2.6 to 24.3°C through the study period, with trends reflecting a seasonal gradient of shelf warming and cooling characteristic of the Mid-Atlantic Bight. During spring and summer months (March 1 – August 31), bottom waters had a mean daily temperature of 10.9°C and 10.1°C in 2017 and 2018, respectively, with cooler temperatures associated with increasing distance from shore (Figure 13). During the fall and winter, inshore bottom waters both cooled more-rapidly than offshore waters and displayed comparatively greater variation. This is likely due to the more-rapid cooling of shallow inshore water, leading to cooler bottom waters inshore and warmer waters offshore during winter months. Bottom temperatures did not differ noticeably between Northern, Middle, and Southern transects of the entire array.

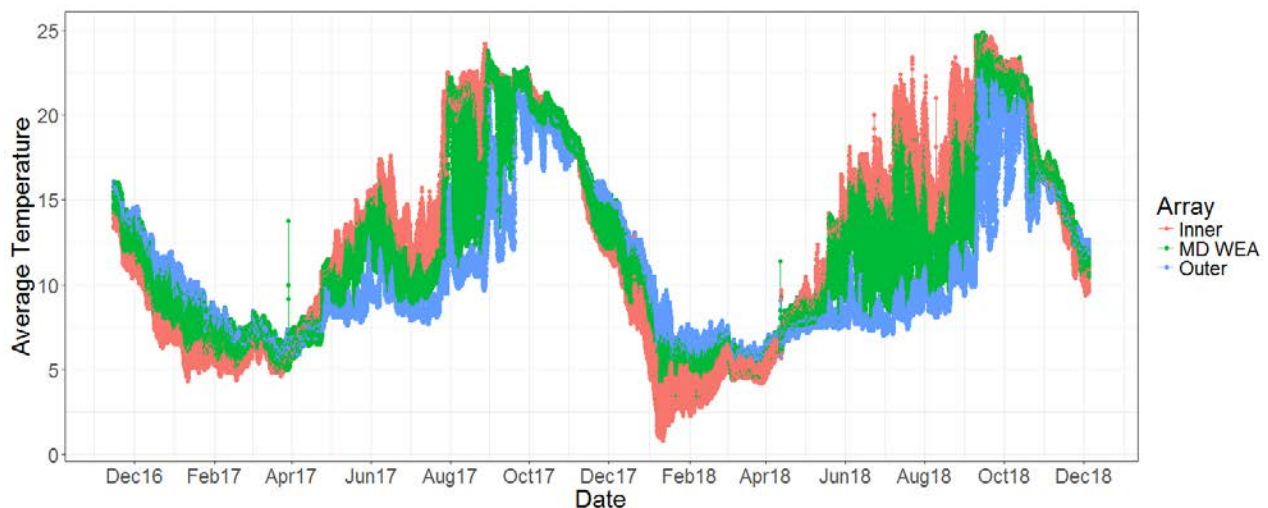


Figure 13. Mean hourly bottom temperature (°C) for each receiver in the Inner (pink), MD WEA (green), and Outer (blue) strata of the current array.

Data shown for all receiver records within each stratum.

Stratification, measured as ΔT , varied among season and arrays, with the range of values increasing with depth and distance from shore; Inner sites ranged from -1.84° to $13.07^\circ \Delta T$, MD WEA sites from -2.14° to $18.22^\circ \Delta T$, and Outer sites from -1.92° to $19.63^\circ \Delta T$. As indicated by near-0 $^\circ C^\circ \Delta T$ values, the water column in the fall/winter season of both years was mixed in all array segments (Figure 14). In 2017, stratification developed at a moderate rate through early-June with ΔT increasing rapidly through mid-July following a brief mixing event. After reaching maximum ΔT , the MD WEA and Inner arrays rapidly destratified to near-0 values in late July. Stratification developed again at all sites, but not to the same extent with the Outer sites regaining ΔT values similar to those observed pre-destratification. This process repeated twice more during summer 2017; destratification broke down and all sites became mixed by mid-September. A similar pattern occurred in 2018, although there were higher overall ΔT values and more frequent destratification events during the summer period. These dynamics reflect the expected seasonal progression of the Mid-Atlantic cold pool, which develops during the spring months, persists during summer and breaks down during fall (Houghton et al. 1982; Lentz 2017).

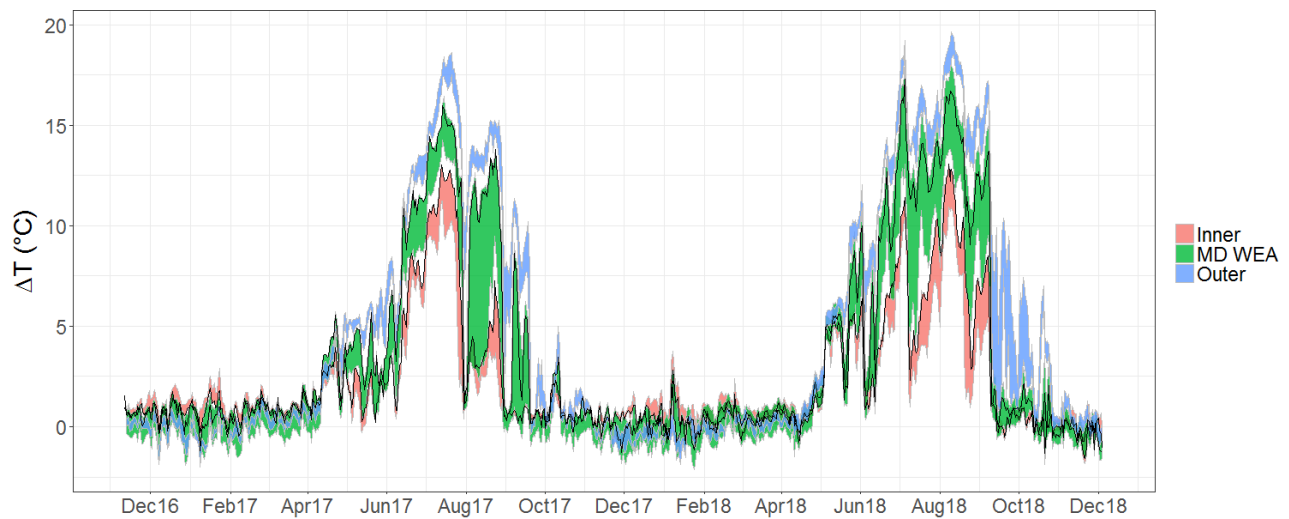


Figure 14. Daily ΔT in the Inner, MD WEA, and Outer arrays from November 11, 2016 through December 5, 2018.

Ribbon thickness shows the daily range of ΔT .

4.5 Study site ambient noise levels

Mean daily 69 kHz noise in the array ranged from 163 to 691 mV (note mV levels at 69 kHz correspond positively but coarsely with decibel levels; D. Secor, unpubl. data), with an average value of 234 mV. The number of days with “loud” (>300 mV) maximum noise levels decreased with increasing distance from shore, recorded on 567, 452, and 178 days across the Inner, MD WEA, and Outer strata, respectively. Similarly, the Inner and MD WEA strata had more days with average noise levels that exceeded 300 mV (121 and 94, respectively) than the Outer stratum (24; Figure 15). There was no apparent difference in daily noise patterns across the Northern, Middle, and Southern transects.

Protracted noise events were often concurrent with rapid increases in bottom temperature (Figure 11) and decreases in stratification (Figure 14). This concurrence, in conjunction with the fewer recorded noise events in the deeper Outer stratum when compared to the two inshore strata, suggests that large, extended increases in bottom noise are caused by surface conditions during large wind events. Notably, four large pulses of noise across strata during March 2018 align with four recorded nor’easters during that time period. As previously mentioned (see Section 4.2. Receiver Range Testing), these storms can cause intense surface noise that likely impact receiver detection distance.

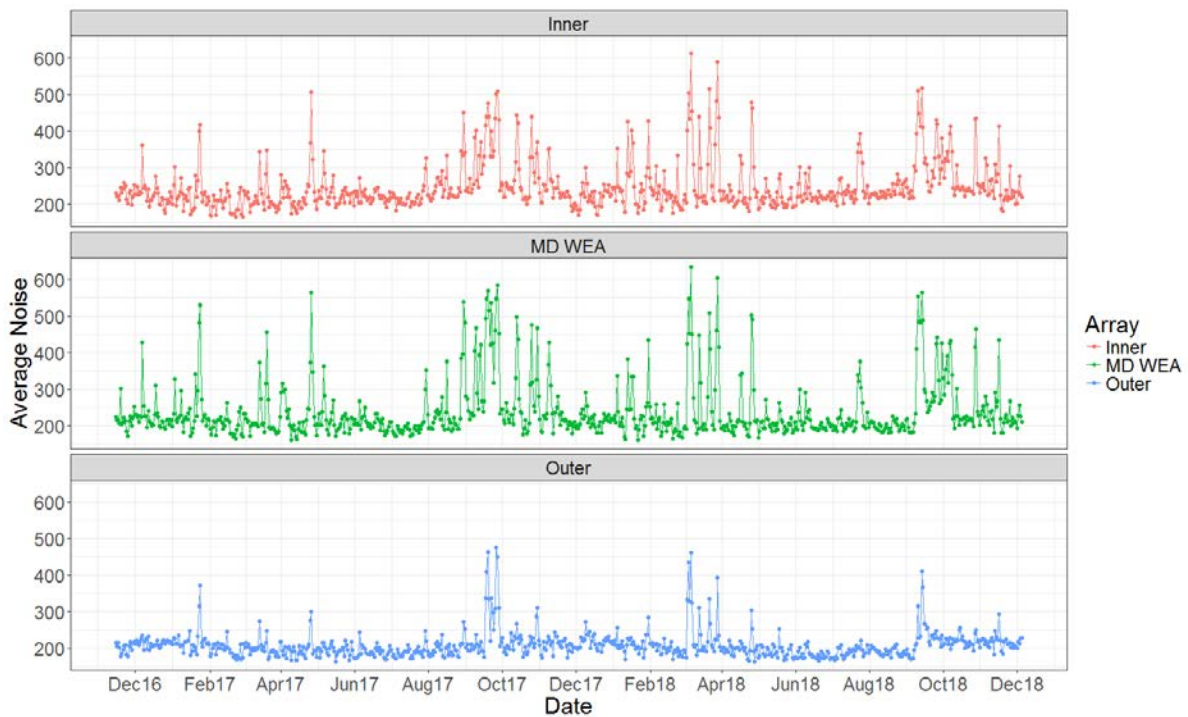


Figure 15. Average daily noise level (mV) for the Inner (pink), MD WEA (green), and Outer (blue) strata.

Spikes above 300 mV indicate protracted noise events associated with wind events, which likely interfered with receiver detection efficiency.

4.6 Seasonal incidence

Recovered telemetry data indicate that both Atlantic sturgeon and striped bass were detected extensively within the MD WEA but patterns of incidence were highly seasonal. Atlantic sturgeon occurred over broad periods during early spring-early summer and early autumn-early winter each year (Figure 16), with very few detections during later summer or winter months. There were significant differences in the number of individuals detected seasonally for each species (Table 7). Pairwise comparisons using Dunn's post hoc test showed that more Atlantic sturgeon were detected during autumn compared to all other seasons and that individual incidence was greater during the winter than the summer. Incidence did not significantly differ between spring and summer or winter and spring. Cross-shelf strata differences were evident across all seasons (Table 8). Pairwise comparisons of number of individual Atlantic sturgeon were significant for all strata with the Inner stratum exhibiting nearly 3-fold higher average incidence than the MD WEA and Outer regions, and the MD WEA stratum having higher individual incidence than the Outer stratum. These patterns were relatively consistent across years with sturgeon having a broader distribution in autumn and winter months than in spring and summer (Figure 17). However, Atlantic sturgeon had somewhat higher individual incidence throughout 2018.

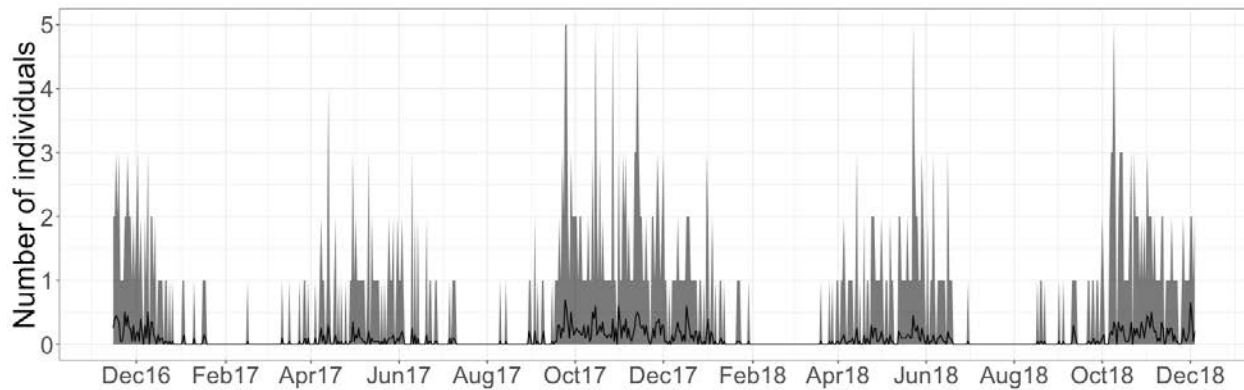


Figure 16. Seasonal occurrence of Atlantic sturgeon.

Number of unique individual Atlantic sturgeon recorded per receiver, summed per day. Gray shading represents the minimum and maximum values of incidence across the array. Black lines show the mean number of individuals detected across the array.

Table 7. Seasonal and spatial differences in Atlantic sturgeon incidence.

Statistical results from Kruskal-Wallis (K-W) and Dunn's post-hoc tests on how number of individuals detected vary between seasons and strata. Asterisks indicate statistical significance.

	K-W		Dunn's test	
	χ^2	<i>p</i>	<i>z</i>	<i>p</i>
Season	42.85	<0.001*		
Autumn-Spring			4.257	<0.001*
Autumn-Summer			6.253	<0.001*
Autumn-Winter			3.120	0.006*
Spring-Summer			1.822	0.205
Spring-Winter			-1.473	0.420
Summer-Winter			-3.471	0.002*
Stratum	52.27	<0.001*		
Inner-MD WEA			3.234	0.002*
Inner-Outer			7.092	<0.001*
MD WEA-Outer			5.452	<0.001*

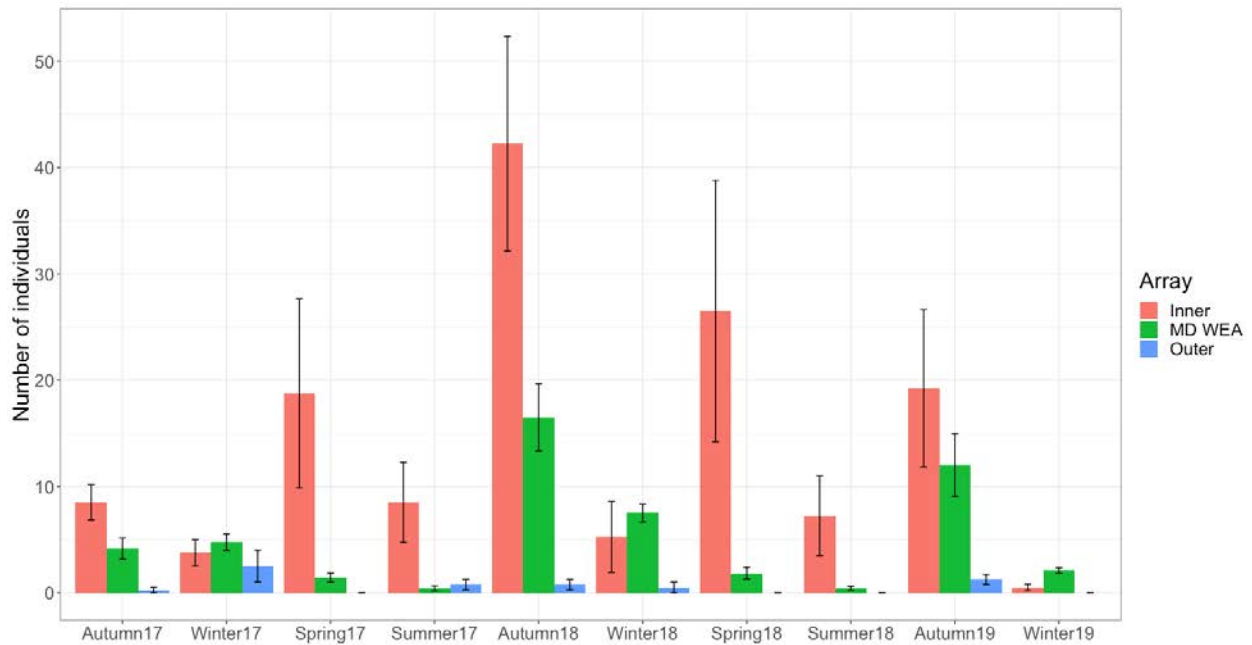


Figure 17. Patterns of Atlantic sturgeon incidence throughout the study period. Figure shows mean number of individuals detected by receivers within each stratum and each season/year.

Compared to Atlantic sturgeon, striped bass had a higher mean number of individuals detected on each receiver per day (Figure 18). Additionally, striped bass exhibited more sporadic but concentrated seasonal incidence; greater numbers of individuals occurred December-February and early April both years. Striped bass were consistently absent from the array across summer and autumn months. Pairwise comparisons showed significant differences in striped bass incidence between all seasons except between spring and winter (Table 8). Individual striped bass incidence was highest in the winter and lowest in the summer. In terms of cross-strata differences in occurrence, striped bass incidence only varied significantly between the MD WEA and Inner strata; in this case, more individuals were detected in the MD WEA region over the study period. Across years, there was a consistent pattern in which striped bass displayed a higher concentration in the MD WEA stratum during winter that shifted toward the Outer region during spring (Figure 19). During 2018, there appeared to be reduced presence of striped bass in the MD WEA stratum and more detection occurred at Outer stratum sites compared to the preceding year.

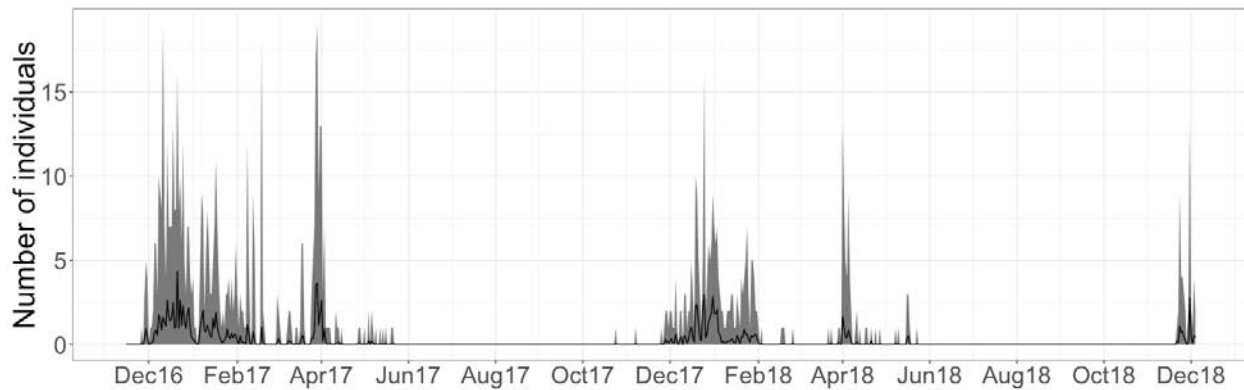


Figure 18. Seasonal occurrence of striped bass.

Number of unique individual Atlantic sturgeon recorded per receiver, summed per day. Gray shading represents the minimum and maximum values of incidence across the array. Black lines show the mean number of individuals detected across the array.

Table 8. Seasonal and spatial differences in striped bass incidence.

Statistical results from Kruskal-Wallis (K-W) and Dunn's post-hoc tests on how number of individuals detected vary between seasons and strata. Asterisks indicate statistical significance.

	K-W		Dunn's test	
	χ^2	<i>p</i>	<i>z</i>	<i>p</i>
Season	86.20	<0.001*		
Autumn-Spring			-3.689	<0.001*
Autumn-Summer			3.266	0.003*
Autumn-Winter			-5.856	<0.001*
Spring-Summer			6.349	<0.001*
Spring-Winter			-1.549	0.364
Summer-Winter			-8.504	<0.001*
Stratum	8.949	0.01*		
Inner-MD WEA			-2.863	0.006*
Inner-Outer			-1.068	0.429
MD WEA-Outer			1.555	0.198

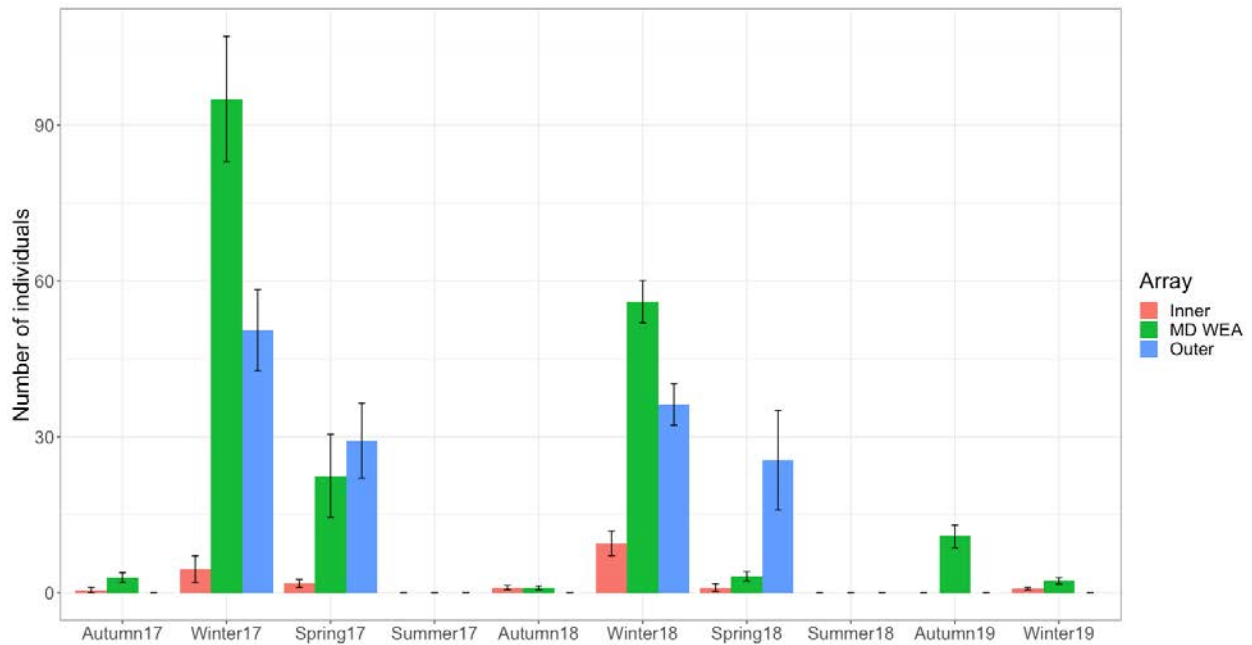


Figure 19. Patterns of striped bass incidence throughout the study period. Figure shows mean number of individuals detected by receivers within each stratum and each season/year.

4.7 Transit rates and patterns

Analysis of the number of unique strata visited by each individual fish revealed that yearly patterns of cross-shelf connectivity differed across species and seasons. Although their inshore-offshore movement was relatively limited, striped bass were more likely than sturgeon to transit between multiple strata, especially during their autumn/winter migration (Table 9). Striped bass showed comparatively less cross-shelf movement during the spring/summer period, reflecting faster spring transit rates. Although sturgeon showed extended presence in the fall and winter during both years, they exhibited little movement between strata, suggesting a directed north/south movement in both seasons

Table 9. Number of Strata visited by each individual striped bass and Atlantic sturgeon during each season and year.

Season/Year	# Strata visited by each individual		
Atlantic Sturgeon			
	1	2	3
Autumn/Winter			
2017	97	11	N/A
2018	152	30	N/A
2019	125	8	1
Spring/Summer			
2017	88	5	N/A
2018	121	5	N/A
Striped Bass			
	1	2	3
Autumn/Winter			
2017	167	60	4
2018	165	47	1
2019	48	3	N/A
Spring/Summer			
2017	123	38	N/A
2018	90	5	N/A

Degree of residency tended to be low for both Atlantic sturgeon and striped bass; average cumulative time spent in the detection radius of receivers per migration season was less than 4 hr for both species (Figure 20; Atlantic sturgeon: mean \pm SE = 3.04 \pm 0.26 hr; striped bass: 3.25 \pm 0.13 hr). Total number of unique days detected for each species were also relatively low across migration seasons (Figure 21; Atlantic sturgeon: mean \pm SE = 1.6 \pm 0.04 d; striped bass: 2.55 \pm 0.05 d). Differences in residency were statistically significant, with striped bass occurring for more hours and days than sturgeon (Wilcoxon rank sum test, hours: $p < 0.001$; days: $p < 0.001$). Striped bass were also detected for more hours and days during autumn/winter months compared to spring/summer months (hours: $p < 0.001$; days: $p < 0.001$). Like striped bass, sturgeon were detected for more days on average during autumn/winter months ($p < 0.001$) but hourly presence did not differ between migration seasons ($p = 0.09$).

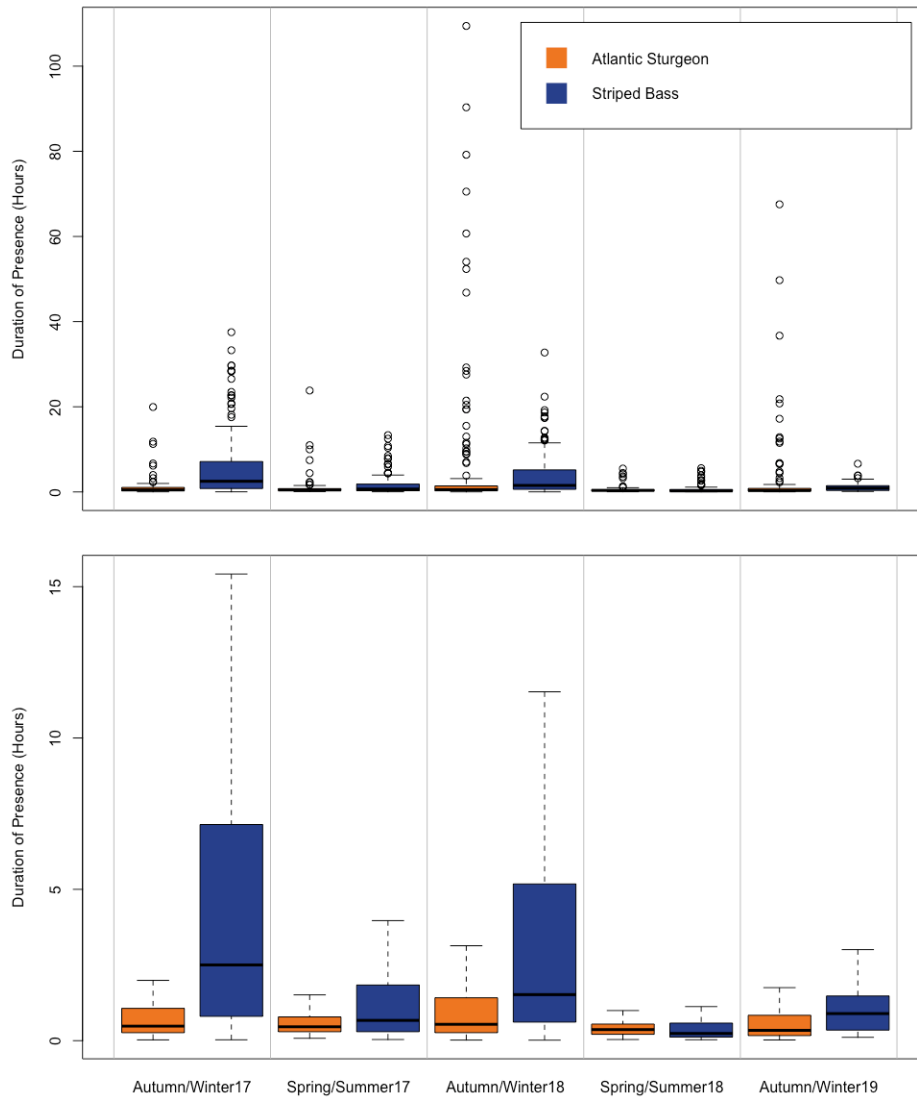


Figure 20. Boxplot of total hours present in the array.

Average number of hours each individual Atlantic sturgeon and striped bass was detected in the study array by season and year depicted normally (top) and with outliers removed to better visualize average duration of presence patterns (bottom).

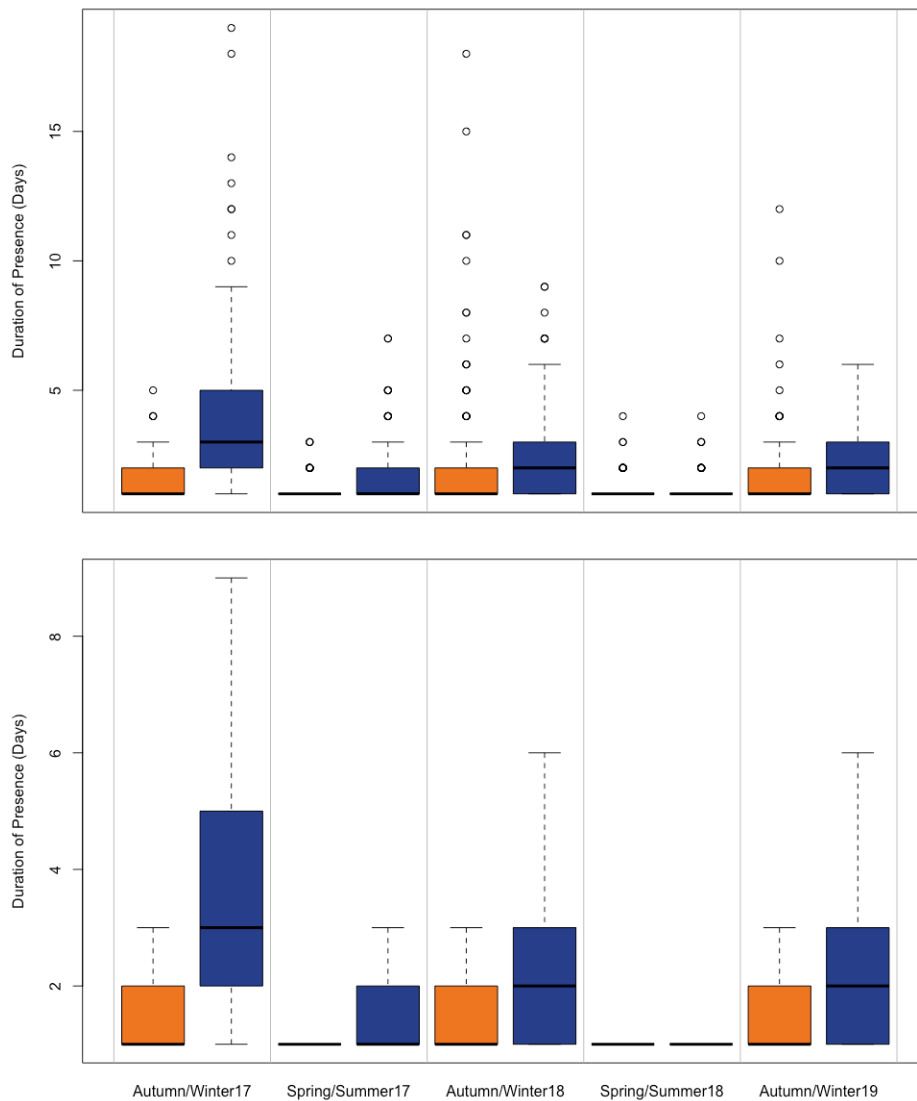


Figure 21. Boxplot of total days present in the array.

Average number of days each individual Atlantic sturgeon and striped bass was detected in the study array by season and year depicted normally (top) and with outliers removed to better visualize average duration of presence patterns (bottom).

Serial detections of striped bass between the coastal MD and DE arrays mostly occurred in the expected direction of movement: south in autumn/winter and north in spring/summer (Figure 22). There were occasional instances where individuals made both north and south transits within a migration season (spring 2017: 3 of 38 individuals; autumn 2017: 3 of 33 individuals; autumn 2018: 8 of 23 individuals). Sequential detections between arrays were noticeably reduced during spring of 2018, in which telemetered fish were detected more often in the MD array than the DE array (Figure 22). During autumn/winter, mean transit rate in the southerly direction was $0.99 \text{ km hr}^{-1} \pm 0.11 \text{ SE}$ and during spring/summer, mean transit rate in the northerly direction was $1.13 \text{ km hr}^{-1} \pm 0.2 \text{ SE}$. Although the fastest observed transit rates ($> 2 \text{ km hr}^{-1}$) tended to occur in the northern direction during spring, speed was

similar between the two directions of movement ($t = -0.106$, $df = 108.43$, $p = 0.92$). The maximum observed transit rates of 6 km hr^{-1} would translate to 1.7 m s^{-1} , or about two body lengths per second. Each of the best performing models ($< 2 \Delta \text{AICc}$) predicting transit rates contained TL at tagging as a covariate and all models that included interactions were ranked lower than the null model (Table 10). Only TL was found to significantly affect transit rate with larger fish being more likely to transit faster between arrays (Table 10; Sex $p = 0.41$, Season $p = 0.15$, Year $p = 0.29$, TL $p = 0.02$).

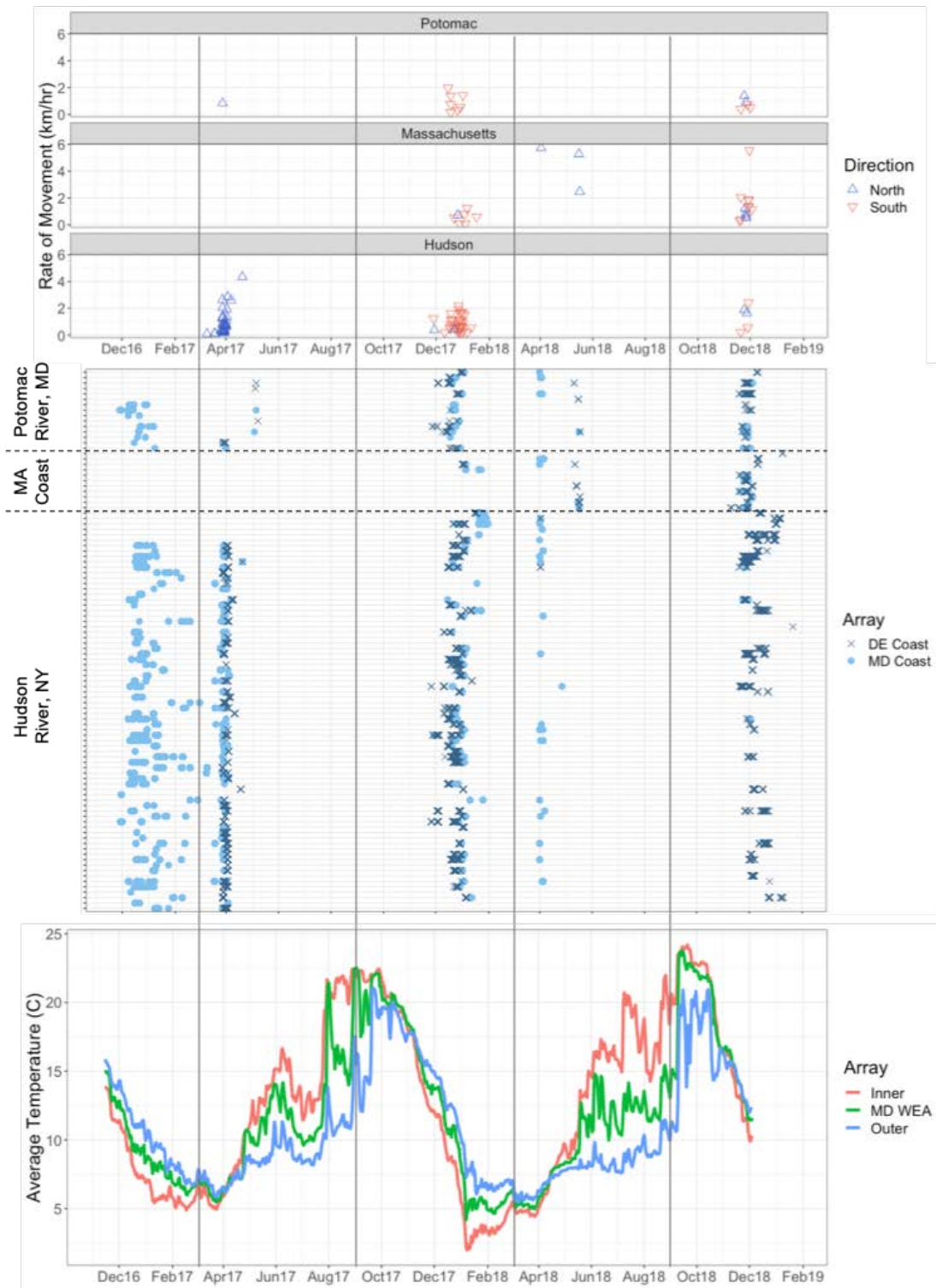


Figure 22. Summary of transit information for striped bass

Transit rate of movement by tagging region (top panel), timing of detection for acoustically-tagged individuals by region of tagging (middle panel), and average bottom temperature recorded by receivers (bottom panel) are shown.

Table 10. Striped bass transit rate linear mixed model results

Parameters and factors for the top 5 models for log-transformed striped bass transit rate (Log km hr⁻¹) including Tag ID as a random effect (1 | Tag) to account for repeated measures. TL= Total length in cm. AICc = corrected Akaike's Information Criterion; LogLik = Log Likelihood.

Model	df	AICc	Δ AICc	LogLik
Log km hr ⁻¹ ~ TL + (1 Tag)	4	230.5	0.00	-110.992
Log km hr ⁻¹ ~ Season + TL + (1 Tag)	5	231.5	1.07	-110.403
Log km hr ⁻¹ ~ Year + TL + (1 Tag)	5	232.0	1.57	-110.654
Log km hr ⁻¹ ~ Sex+ TL + (1 Tag)	5	232.5	2.02	-110.882
Log km hr ⁻¹ ~ 1 + (1 Tag)	3	233.5	3.03	-113.600

4.8 Distribution and depth of occurrence for tagged striped bass

The vast majority (95%: 38 of the 40) of striped bass implanted with depth-transponding acoustic transmitters were subsequently detected in the ACT network of telemetry arrays (Figure 23) between April 24, 2017 and March 27, 2019, but less than half (19) were detected in the MD WEA array and were recorded during either December 2017 – January 2018 (n=11), April 2018 – May 2018 (n=12), or December 2018 (n=8). Other detections were provided to us through the ACT Network arrays in: Chesapeake and Delaware Bays; Merrimack, Hudson, Potomac, and James Rivers; coastal Massachusetts, New York, New Jersey, Delaware, Maryland, and Virginia (Figure 23). The greatest number of detections occurred in the Merrimack River (n=11,349), which was likely the result of prolonged residence and close proximity to receivers by four Massachusetts-tagged individuals (Figure 24). With the exception of these high-density return records from the Merrimack River, most detections occurred along the Massachusetts coastline (n=8,151) and in the upper Chesapeake Bay (n = 4,936). Depictions of detection returns should not be interpreted as absolute presence or absence, as they do not indicate when receivers were deployed or removed and some data may not have been shared with project PIs as of the date of this report (February 2020).

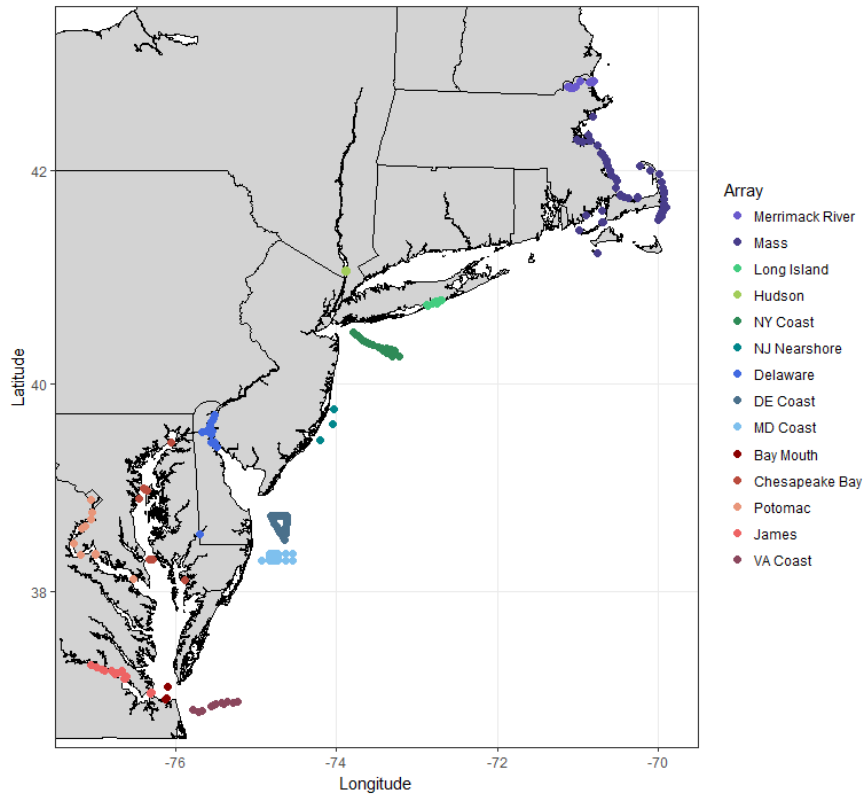


Figure 23. Locations of depth-transponding striped bass tag detections.

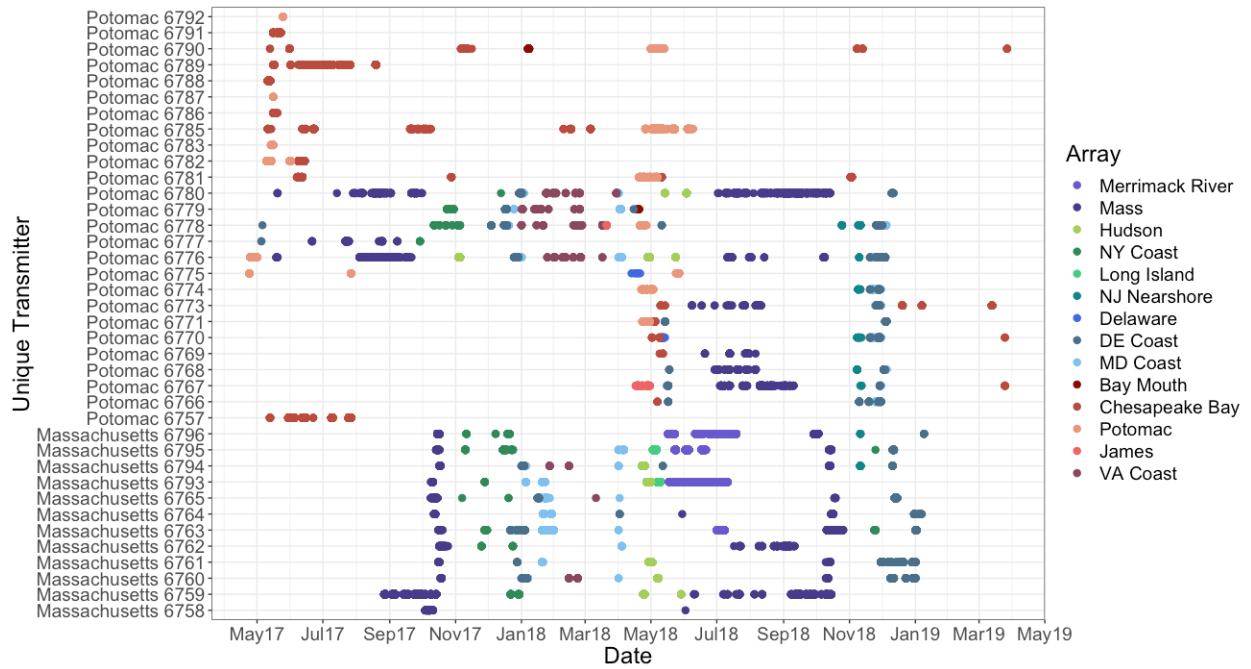


Figure 24. Summary of depth-transponding striped bass returns. Timing of detection for individual striped bass tagged in the Potomac River, MD (n = 26, upper panel) and Coastal Massachusetts (n = 12, lower panel). Colors indicate the array of detection.

Fish tagged in the Potomac River showed two distinct movement patterns: 1) directed movement to, and residency in, the upper Chesapeake Bay and 2) migration into shelf waters, summer residency in Massachusetts, and gradual southerly movement from fall through and early spring with some fish eventually residing in waters off Virginia for a protracted period of time (Figure 24). All striped bass tagged in coastal Massachusetts departed from the area by November and gradually moved south through coastal New York, Delaware, and Maryland after the first year of tagging. This movement mirrors that of the late-April-tagged migratory-Potomac group, although Potomac fish appear to depart Massachusetts waters earlier (Figure 24). Detection histories were noticeably less complete during late 2018 (due to removal of receivers or lack of data-sharing), but migration trends appeared to be similar for the two-year duration of the study. Still, there were individuals and small groups of tagged striped bass that exhibited extended stopovers in areas like the Hudson, James, and Merrimack Rivers that deviated somewhat from mean group behavior (Figure 24).

Depths of tagged striped bass ranged from 0 to 36 m over the study period, with no noticeable differences in depth preference between fish or tagging groups (Figure 25). General depth of occurrence instead appeared to align with observed migration patterns; shallow detection depths were observed when striped bass occurred in nearshore and estuarine habitats while deeper detections corresponded with known periods of movement through coastal waters (Figure 25). Densities of detection depth by region confirmed that striped bass occurred at greater depths across coastal arrays compared to other sites (Figure 26). Among coastal arrays, mode of depth selection was slightly deeper in the Maryland and Virginia arrays than in Delaware or New York. Detection depths were the most shallow in the Merrimack River, Coastal Massachusetts, near Long Island, and in the Delaware River, while deeper modes were found in nearshore New Jersey and in tributaries of the Chesapeake Bay. Striped bass in the Hudson River strongly preferred depths just above 5 meters. High detection densities away from the surface occurred in the Upper Chesapeake Bay (~ 5 m depth) and was especially noticeable at the mouth of the Chesapeake Bay (~ 15 m depth).

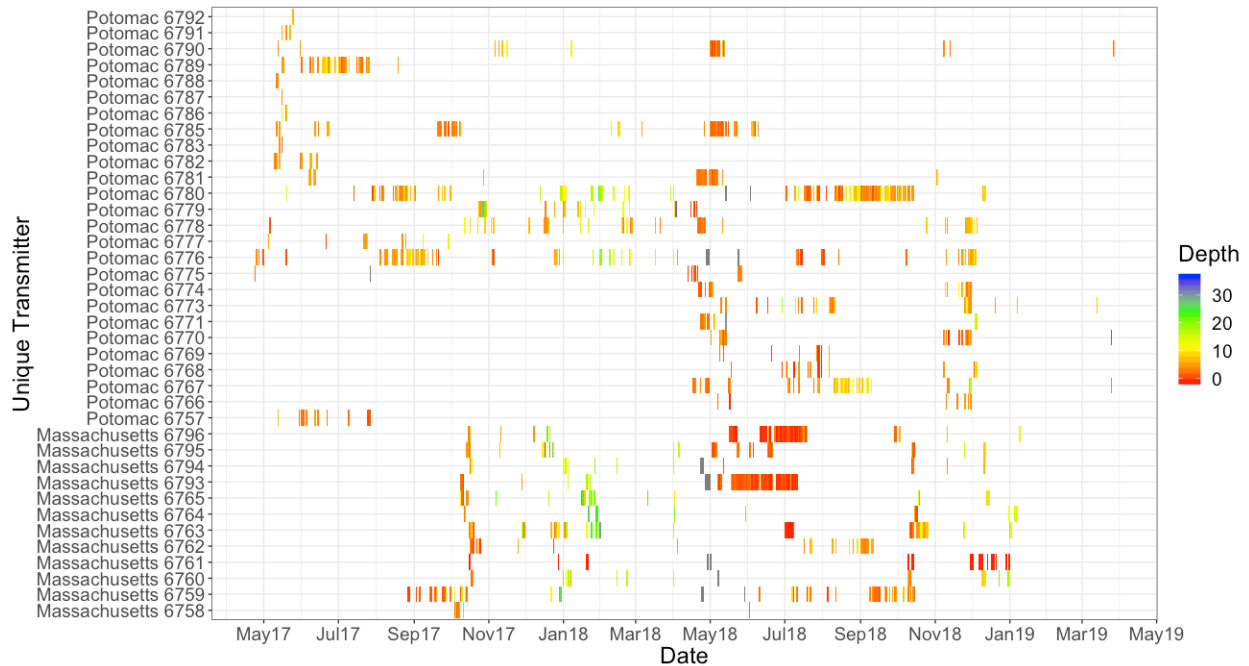


Figure 25. Depth of detection (meters) of individually-tagged striped bass through time.

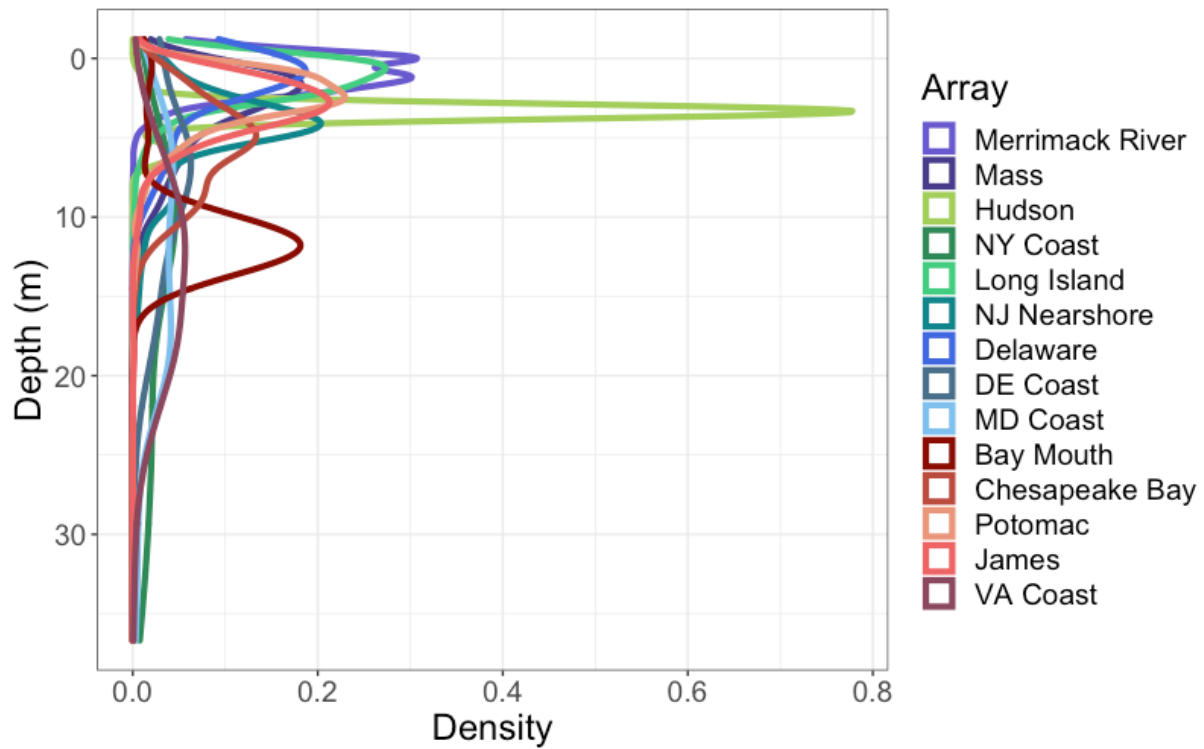


Figure 26. Density of tagged striped bass depths (in meters) by telemetry array.

Within the MD WEA array, 19 depth-transponding striped bass were detected from December 2017 through December 2018. During the autumn/winter 18 period, striped bass were initially detected at shallower depths in the WEA array before shifting to deeper water in the Outer array through January (Figure 27). In autumn/winter 19, striped bass occurred at more shallow WEA locations. In April and May 2018, striped bass were detected throughout the water column in the Outer array during an early spring migration interval and near the surface in the WEA during a later migration interval, respectively.

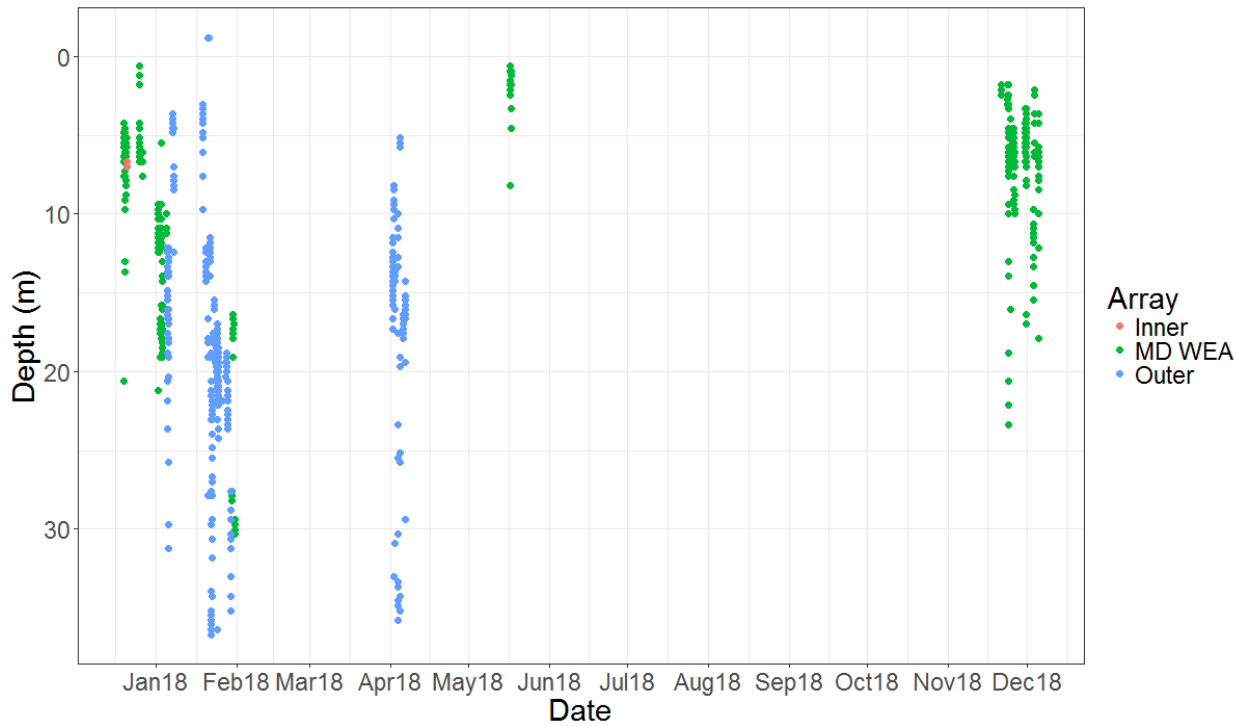


Figure 27. Depth of striped bass detection by transect within the MD WEA receiver array.

4.9 Environmental covariates of MD WEA incidence

The two shallowest receivers were a hot spot for Atlantic sturgeon within the array, especially during spring and summer seasons (Figure 28). This hot spot diminished during the autumn, with simultaneous evidence for a cold spot (90% confidence, $p < 0.1$) at the deepest Outer stratum receivers in the same season. During winter, there was an area of increased clustering for Atlantic sturgeon in the deeper section of the MD WEA stratum and a significant cold spot (99% confidence, $p < 0.01$) at the deepest sites. Striped bass detection hot spots were only identified within the Middle region. However, clustering occurred at shallower depths during the autumn compared to winter and spring. No striped bass were detected during summer months.

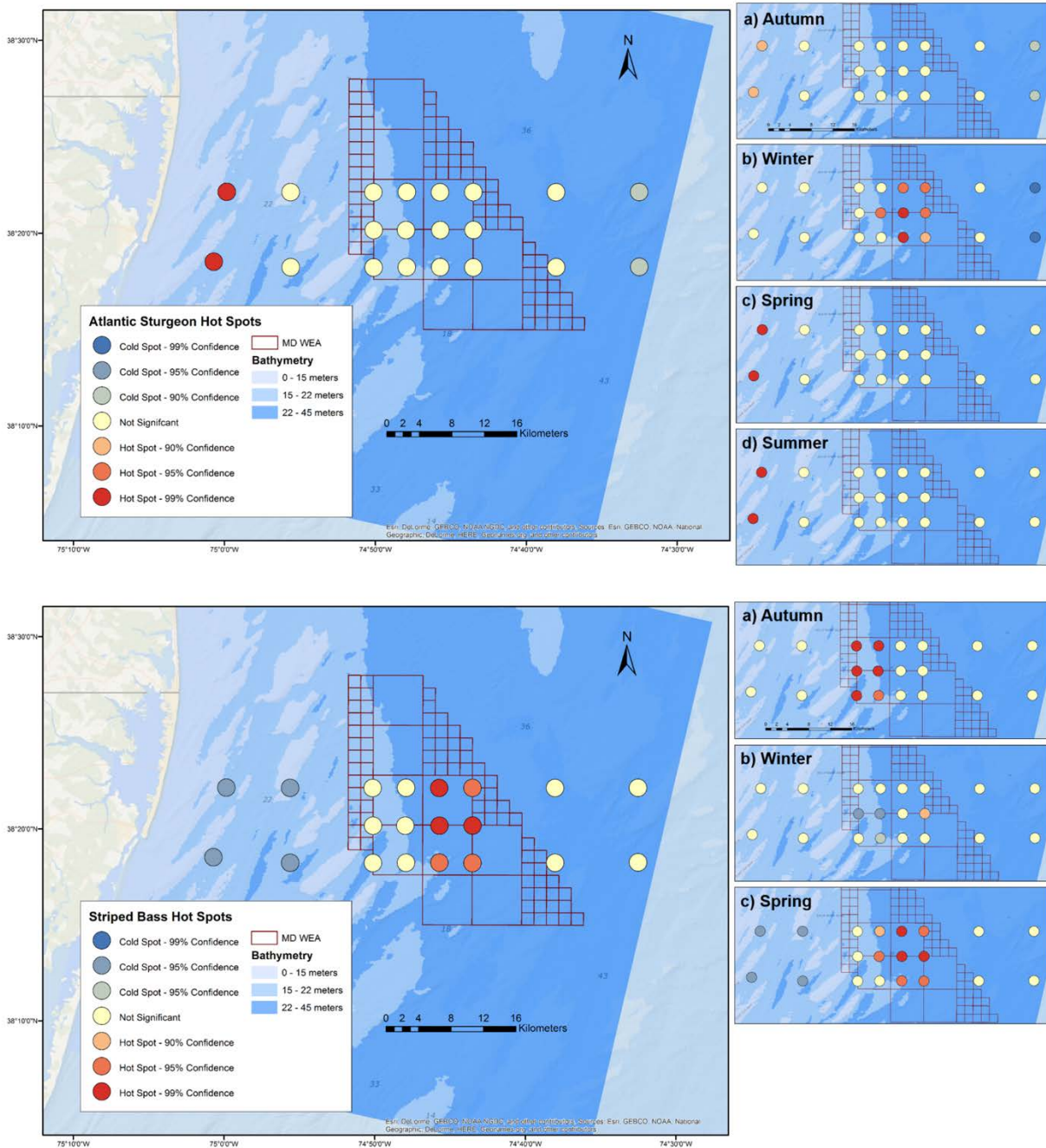


Figure 28. Hot spots of species occurrence across the acoustic receiver array.

Results reflect annual (left) and seasonal (insets, right) numbers of individual Atlantic sturgeon (top) and striped bass (bottom) detected per receiver.

Atlantic sturgeon were detected over nearly the entire range of bottom temperatures recorded by receivers (4.3 – 24.2°C), suggesting little to no temperature limits in this region (Figure 29). This is reflected in large pulses of detections in both the warm- (April – July) and cold-water (September – January) periods (Figure 16).

In comparison to Atlantic sturgeon, striped bass were detected over a relatively narrow temperature band (5°C - 15°C), completely absent during the highest temperatures occurring in the summer (Figure 29). In both autumn/winter 17 and 18, number of individual striped bass day⁻¹ increased at offshore strata, departing more shoal strata as temperatures were cooling in winter (Figure 19).

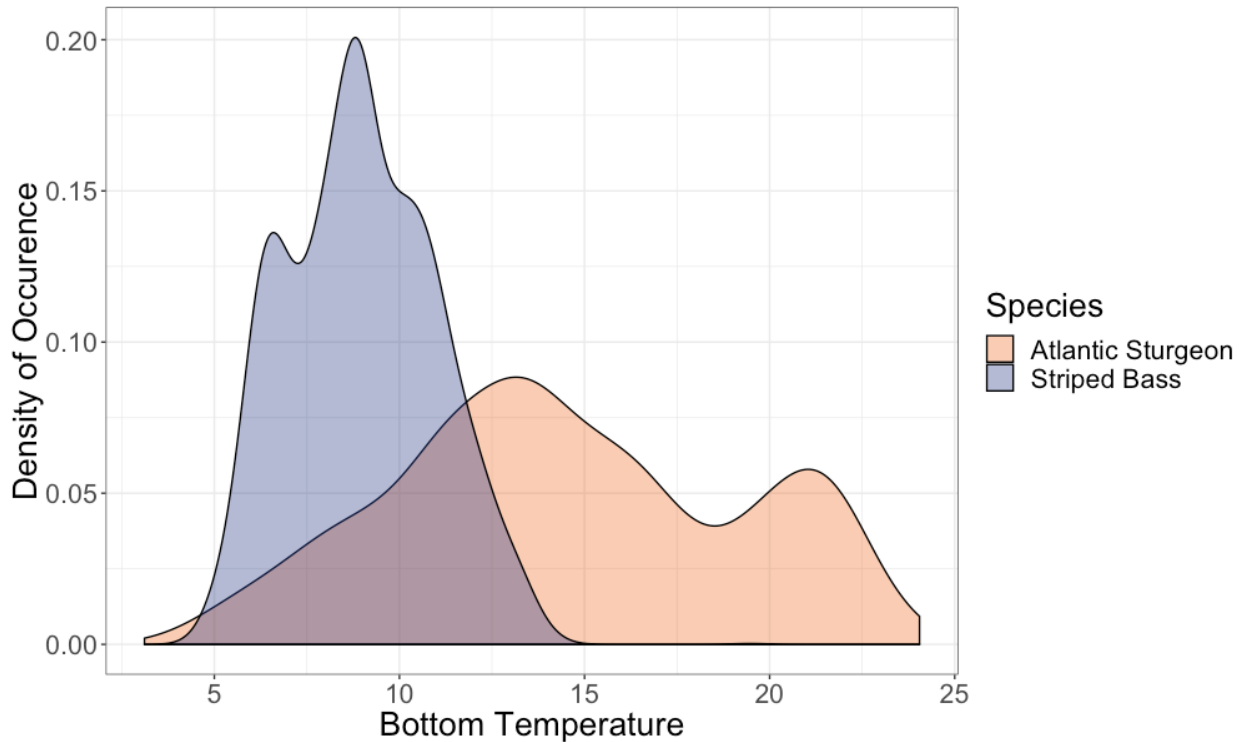


Figure 29. Density of detections by receiver-recorded temperature.

Kernel density estimate of the bottom temperature distribution for detections for Atlantic sturgeon and striped bass.

Single Parameter Quotient analysis showed that in all seasons, sturgeon preferred relatively warm bottom temperatures between 9-22°C (Figure 30). Warmer seasonal conditions were only avoided by Atlantic sturgeon when temperatures exceeded 22°C in autumn. During autumn months, sturgeon actively selected relatively cool temperatures between 10-14°C but were still broadly tolerant of temperatures between 14-22°C. Otherwise, across winter, spring, and summer, sturgeon avoided cooler seasonal temperatures.

As anticipated from incidence data (Figures 18-19), striped bass significantly avoided temperatures higher than 15°C and were not present at all during the warm summer months (Figure 31). During autumn, striped bass selected the coolest available temperatures < 14°C and during winter, they preferred temperatures between 9-12°C. Similar to autumn months, striped bass avoided warmer seasonal conditions during winter, but the coolest regional temperatures, <6°C, were also significantly avoided. Temperature selection by striped bass occurred within a narrow window during spring months, between 4-12°C, with preference occurring within the 6-7 °C temperature bin. Temperatures higher than 12°C were avoided by striped bass during this season, but wider confidence bands (as a result of low sample size) limit this inference.

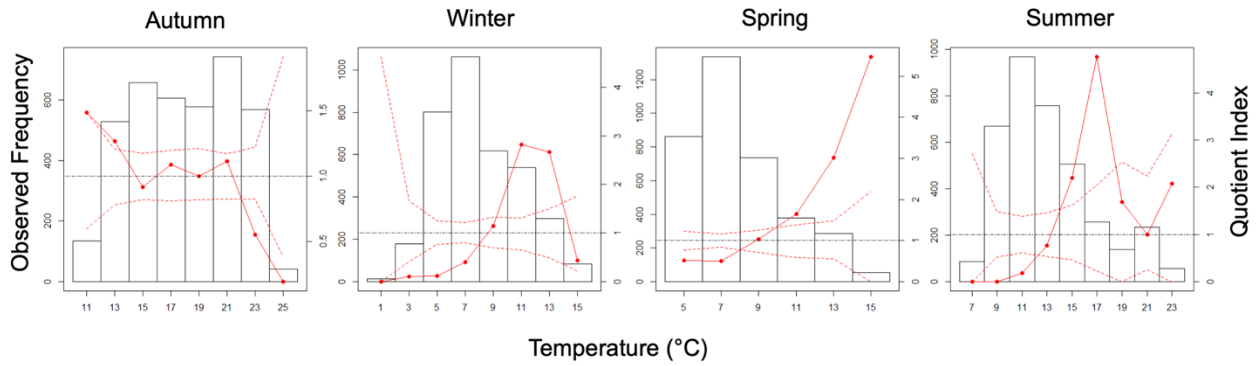


Figure 30. QI plots for Atlantic sturgeon during each season. Each plot shows the observed QI curve (solid red line), its CI (dashed red lines), and the frequency histogram of temperature. The dotted black line in each plot indicates the value QI=1.

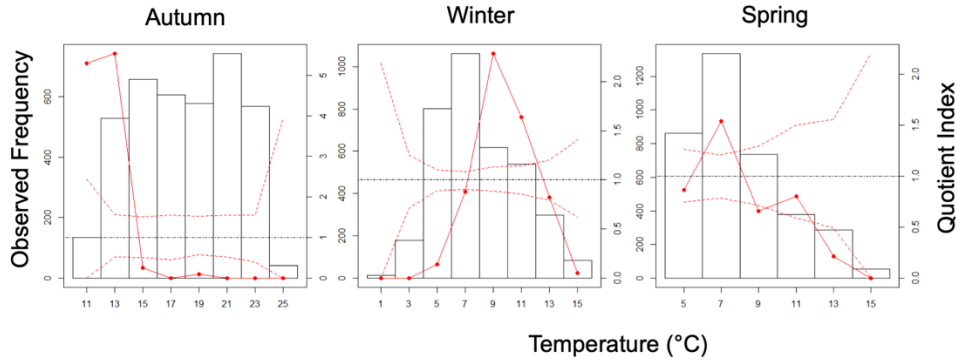


Figure 31. QI plots for striped bass during each season Each plot shows the observed QI curve (solid red line), its CI (dashed red lines), and the frequency histogram of temperature. The dotted black line in each plot indicates the value QI=1.

4.10 Predictive habitat models

4.10.1 Daily relative abundance model

A total of 753 potential predictive models were considered for each species. For Atlantic sturgeon, the top 10 models all contained an interaction between depth and DOY (Table 11). The top three ranked models all included significant effects of CHL-A, the interaction between DOY and depth, and the magnitude of SST change over the previous 3-4 days. AIC scores and deviance explained were similar among these three models ($<\Delta 2$ AIC; $<\Delta 1\%$ deviance explained), but the model containing a smooth for SST $\Delta 4$ d had the best overall performance and was selected as the best fitted GAMM.

For striped bass, the interaction between depth and DOY was also retained in the 10 best models (Table 11). However, in contrast to the importance of SST change on the 3-4 day timescale identified in Atlantic sturgeon models, the top ranked models for striped bass showed that abundance was more influenced by the magnitude of SST change over the previous 15-20 days. Though top-ranked striped bass GAMs explained a similar amount of deviance ($<\Delta 2\%$ deviance explained), the best model, which contained a significant effect of SST $\Delta 17$, resulted in an AIC score that was substantially lower than the next best model ($>\Delta 10$ AIC).

Table 11. Summary of GAMM model formulas for the top ten predictive models for each species.

Degrees of freedom (df), Akaike information criterion (AIC), and percent deviance explained are shown for models, ordered by AIC score. Considered predictors are chlorophyll-a concentration (CHL-A), magnitude of SST change (SST $\Delta 1-13$), day-of-year (DOY), and depth. Model term “s” represents singular smooth terms (single factors) and “t2” represents tensor-product smooth interactions (interaction between factors with different scales). Selected models are at the top of the table for each species.

Model terms	df	AIC	Deviance explained
Atlantic Sturgeon			
s(CHL-A) + s(SST $\Delta 4$) + t2(DOY, Depth)	51.99133	5042.376	79.9%
s(CHL-A) + s(SST $\Delta 2$) + t2(DOY, Depth)	53.02093	5043.901	79.9%
s(CHL-A) + s(SST $\Delta 3$) + t2(DOY, Depth)	52.58188	5044.783	80%
s(CHL-A) + s(SST $\Delta 23$) + t2(DOY, Depth)	53.71414	5045.779	79.7%
s(SST $\Delta 4$) + t2(DOY, Depth)	45.59794	5047.142	79.5%
s(SST $\Delta 2$) + t2(DOY, Depth)	46.97376	5047.626	79.4%
s(CHL-A) + s(SST $\Delta 9$) + t2(DOY, Depth)	52.24633	5047.696	79.5%
s(SST $\Delta 3$) + t2(DOY, Depth)	46.65425	5049.766	79.5%
s(CHL-A) + s(SST $\Delta 5$) + t2(DOY, Depth)	50.25464	5050.407	79.7%
s(CHL-A) + s(SST $\Delta 22$) + t2(DOY, Depth)	52.45791	5050.455	79.5%

Striped Bass			
s(CHL-A) + s(SST Δ17) + t2(DOY, Depth)	57.19528	7090.493	60.1%
s(CHL-A) + s(SST Δ16) + t2(DOY, Depth)	56.85801	7103.559	60.1%
s(CHL-A) + s(SST Δ19) + t2(DOY, Depth)	57.85631	7112.665	59.6%
s(SST Δ17) + t2(DOY, Depth)	52.41223	7116.058	59.9%
s(CHL-A) + s(SST Δ18) + t2(DOY, Depth)	57.08371	7123.809	59.5%
s(SST Δ16) + t2(DOY, Depth)	52.65560	7125.717	59.9%
s(SST Δ19) + t2(DOY, Depth)	52.26835	7141.836	59.4%
s(SST Δ18) + t2(DOY, Depth)	52.31685	7147.398	59.3%
s(CHL-A) + s(SST Δ20) + t2(DOY, Depth)	58.17577	7159.898	58.6%
s(CHL-A) + s(SST Δ15) + t2(DOY, Depth)	56.28915	7161.697	58.9%

The best predictive model for Atlantic sturgeon revealed a bimodal response to the magnitude of SST change over the previous 4 days; individuals were most likely to occur when surface temperature had decreased $\sim 2.5^{\circ}\text{C}$ or when it had increased more rapidly, by up to 4°C (Figure 32). Greater abundance of Atlantic sturgeon was also more likely at lower CHL-A concentrations with a peak in predicted occurrence just above a concentration of 5 mg m^{-3} . Atlantic sturgeon exhibited a complex response to depth in which individuals were more likely to occur at shallow depths ($< 20 \text{ m}$) during the spring but were more broadly distributed across mid-range and shallow depths ($\sim 15\text{-}35 \text{ m}$) during autumn and winter (Figure 33). The 5-fold cross-validation RMSE of the model was 0.29 ± 0.01 and average error was -0.001 ± 0.004 , meaning the model-predicted abundance was 0.06 of the maximum number of sturgeon per receiver deployed (maximum =5) with an error < 0.01 of the maximum and thus error was small compared to the units of individual incidence. Model diagnostics did not show spatial or temporal autocorrelation in residuals (Figures 34 and 35).

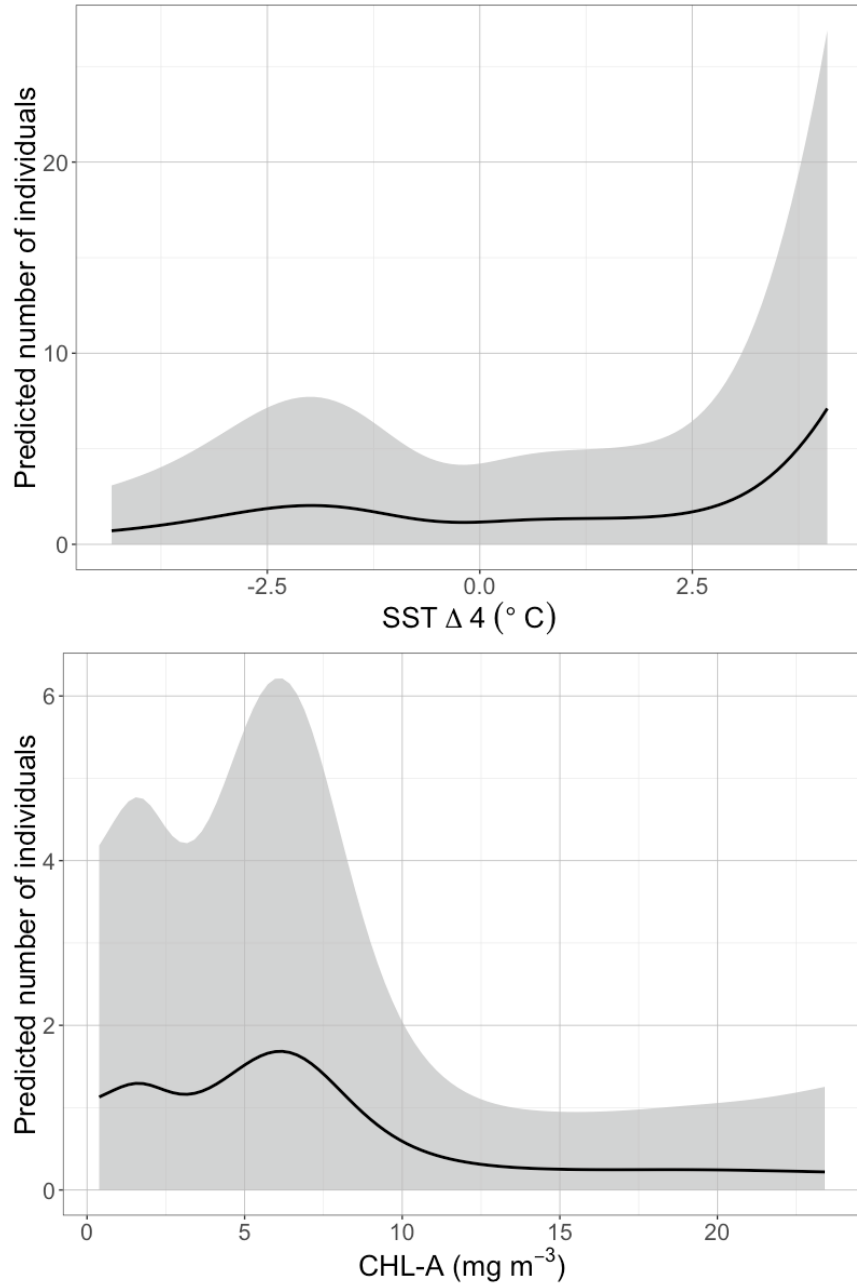


Figure 32. GAMM Summed effects of the magnitude of sea surface temperature change over the previous 4 days (SST $\Delta 4$; top) and chlorophyll-a concentration (CHL-A; bottom) on the relative abundance of Atlantic sturgeon.

Shading represents ± 2 standard error. Both predictions are made on day-of-year =300 and depth=15 m to represent conditions when sturgeon are expected to occur. Mean SST $\Delta 4$ and CHL-A were set as the conditions in each corresponding prediction. Random effects were excluded to allow for interpretability across all sites and years.

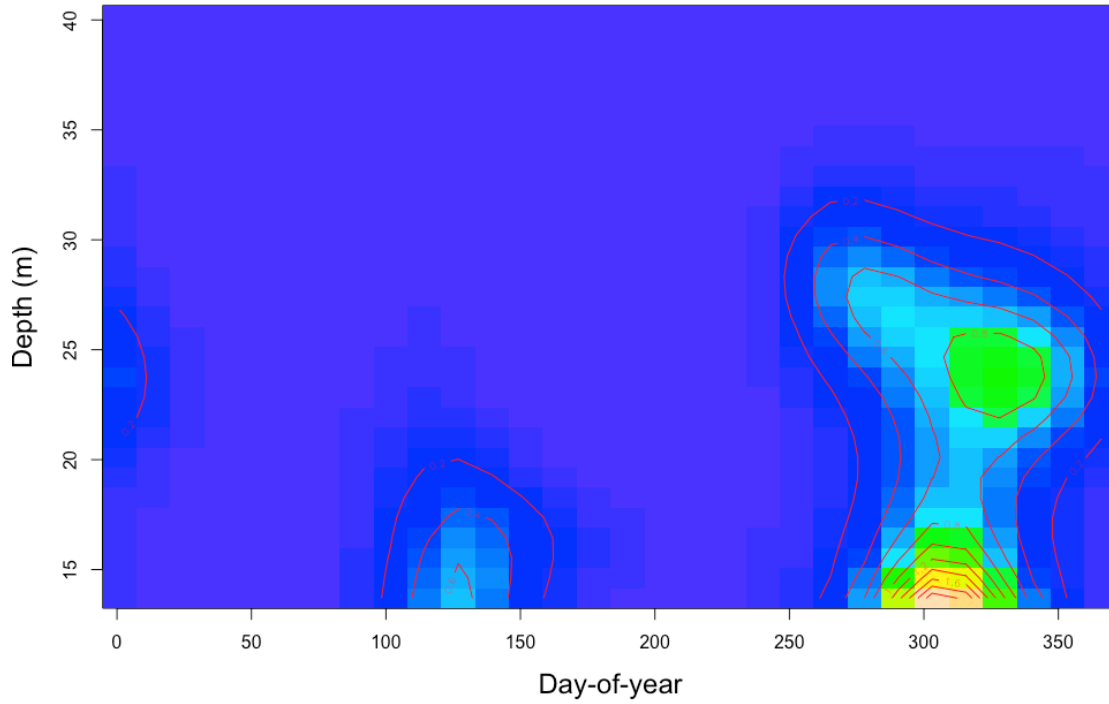


Figure 33. GAMM response function for the interaction between day-of-year and depth from the best model of Atlantic sturgeon relative abundance. Visualizations are on the response scale and warmer colors indicate a higher predicted number of individuals.

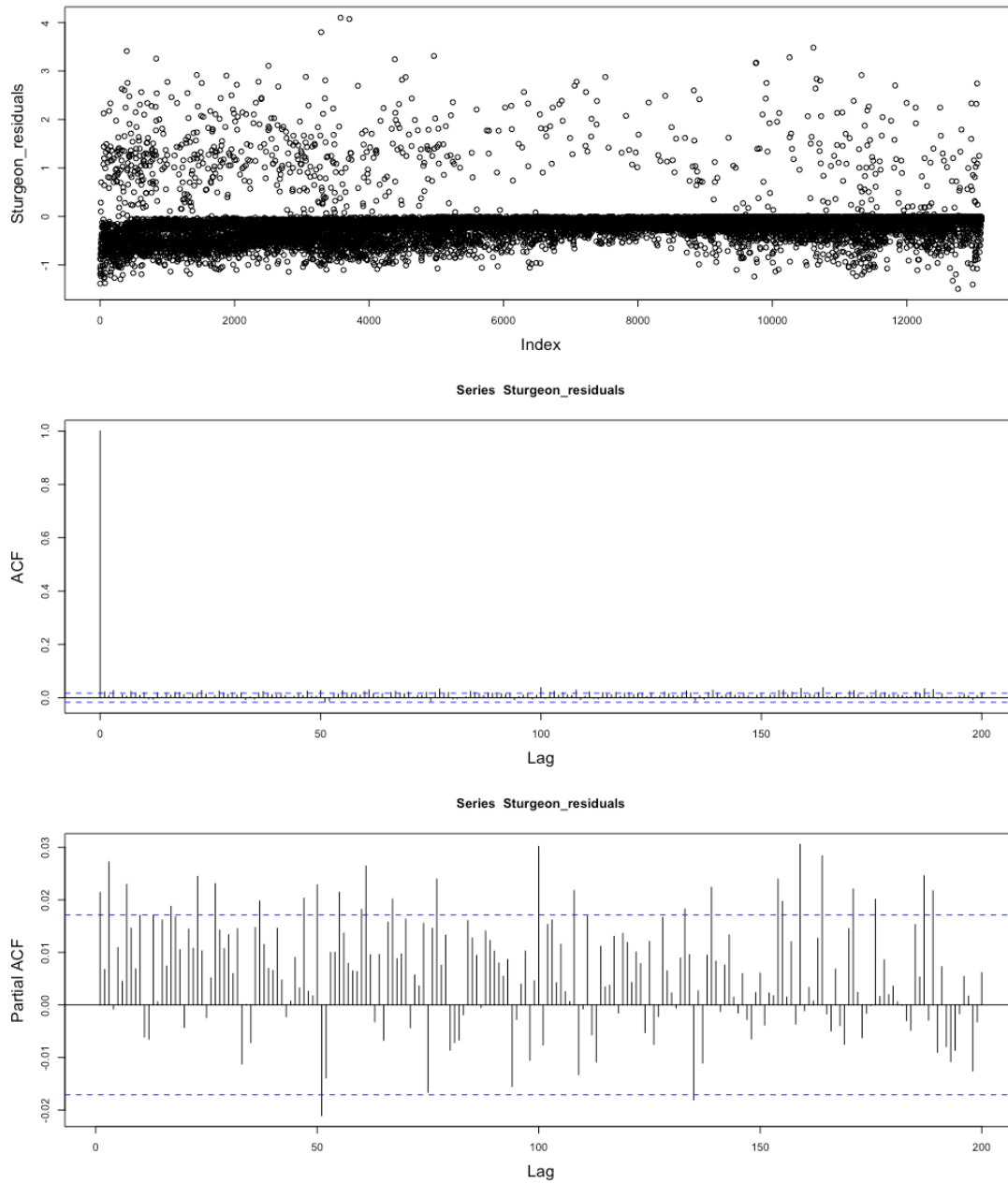


Figure 34. Summary plots for Atlantic sturgeon relative abundance model temporal residuals
 Distribution of residuals over time (top panel), autocorrelation function plot of residuals (ACF, middle panel), and partial autocorrelation plot of residuals (Partial ACF, bottom panel).

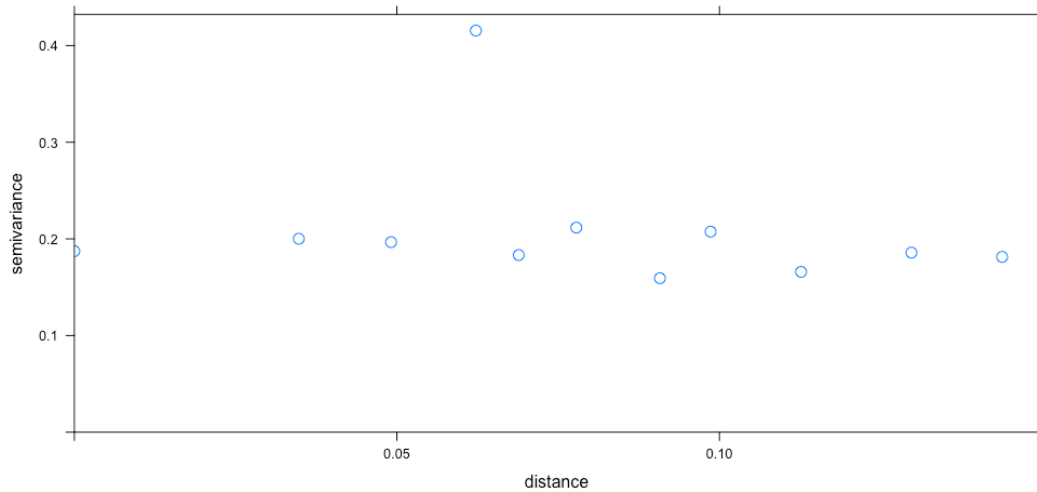


Figure 35. Semi-variogram of residuals from best Atlantic sturgeon relative abundance model using latitude and longitude to calculate distance between sites.

The selected GAMM for striped bass predicted the highest number of individuals when SST had decreased $\sim 4^{\circ}\text{C}$ or increased more than 4°C over the preceding 17 days (Figure 36). Higher striped bass abundance was also likely when SST had remained relatively constant ($\Delta 0$) over 17 days. Striped bass had increased likelihood of occurrence as CHL-A concentration increased. Like Atlantic sturgeon, striped bass abundance varied spatially over the DOY. During early winter, relative abundance was highest at mid-range depths (20-30 m) but shifted toward greater depths (> 35 m) during later winter months (Figure 37). Striped bass were likely to occur over a broader range of depths during spring, but were predicted to have the highest abundance at depths between 25 and 30 m. The optimal model had a 0.05 error rate compared to the maximum (maximum=15; RMSE 0.84 ± 0.07) with an average error < 0.01 (average error 0.003 ± 0.022) calculated by k-fold cv score. There was no residual spatial or temporal autocorrelation patterns apparent in ACF, PACF, of semi-variogram plots (Figures 38 and 39).

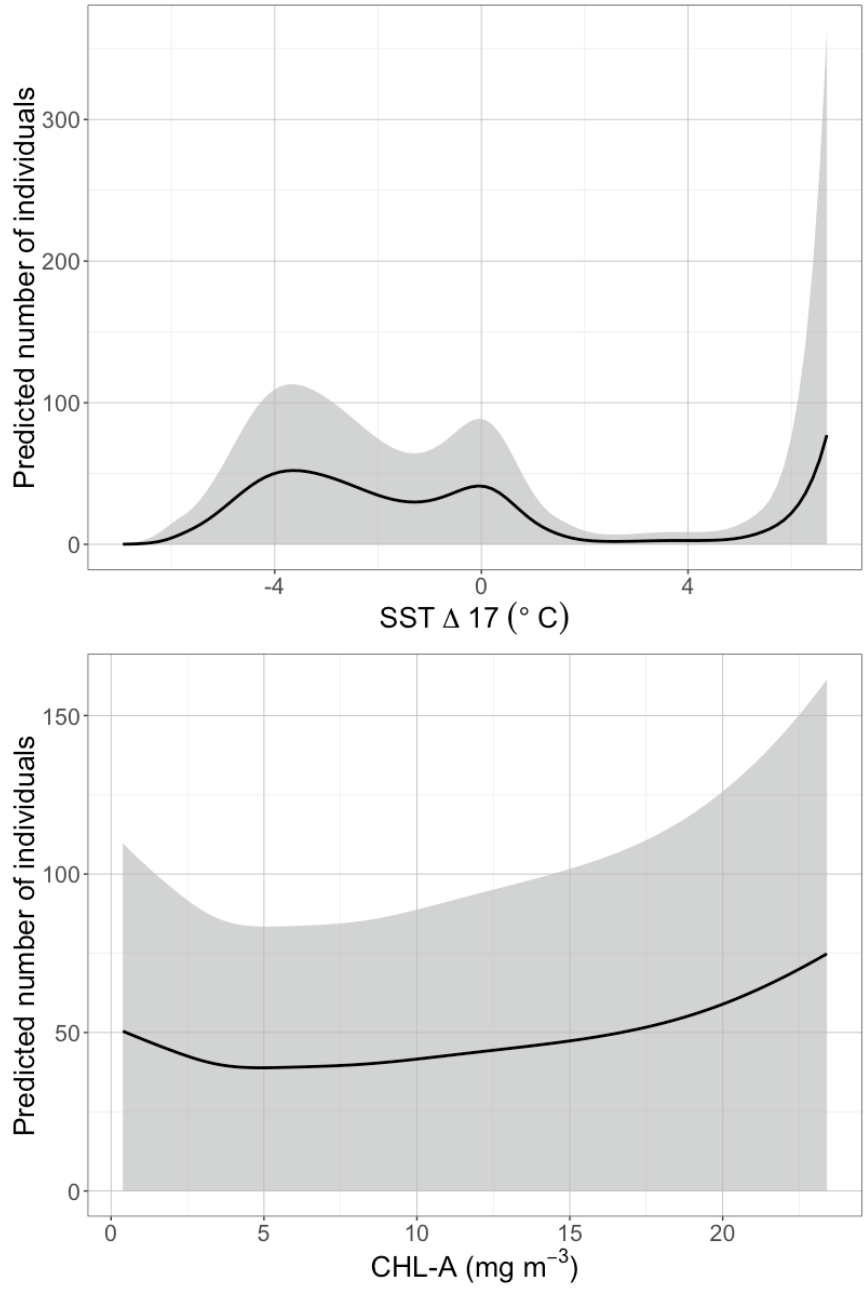


Figure 36. GAMM Summed effects of magnitude of sea surface temperature change over the previous 17 days (SST Δ17; top) and chlorophyll-a concentration (CHL-A; bottom) on the relative abundance of striped bass.

Shading represents ± 2 standard error. Both predictions are made on day-of-year =350 and depth=25 m to represent conditions when striped bass are expected to occur. Mean SST Δ17 and CHL-A were set as the conditions in each corresponding prediction. Random effects were excluded to allow for interpretability across all sites and years.

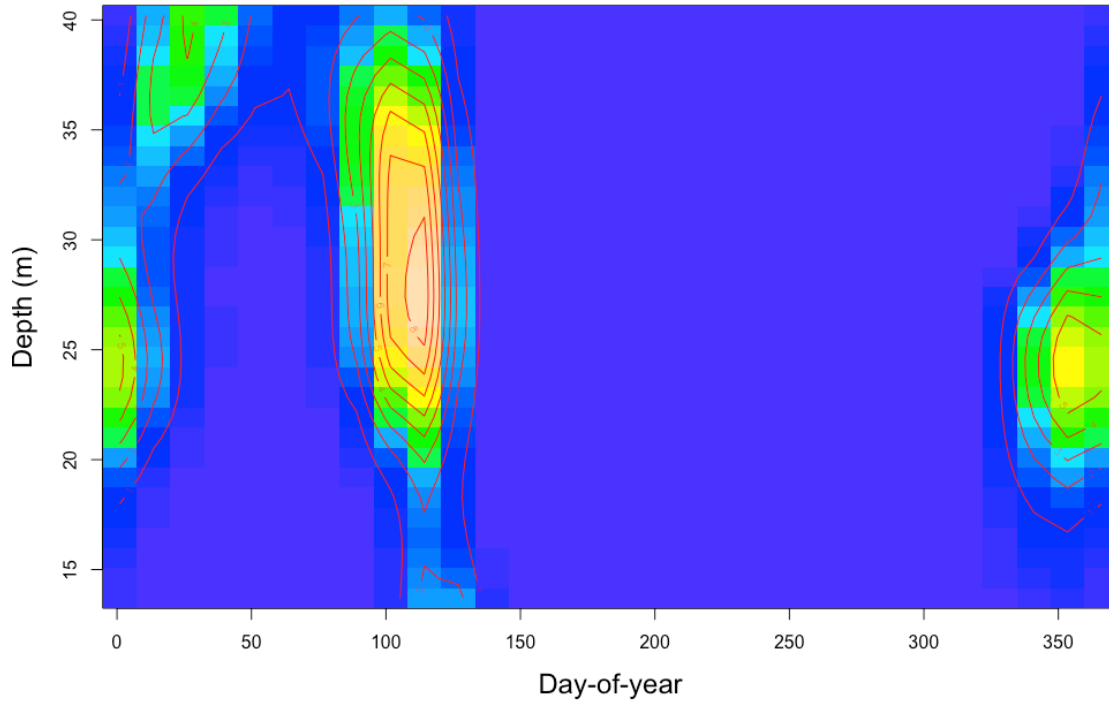


Figure 37. GAMM response function for the interaction between day-of-year and depth from the best model of striped bass relative abundance. Visualizations are on the response scale and warmer colors indicate a higher predicted number of individuals.

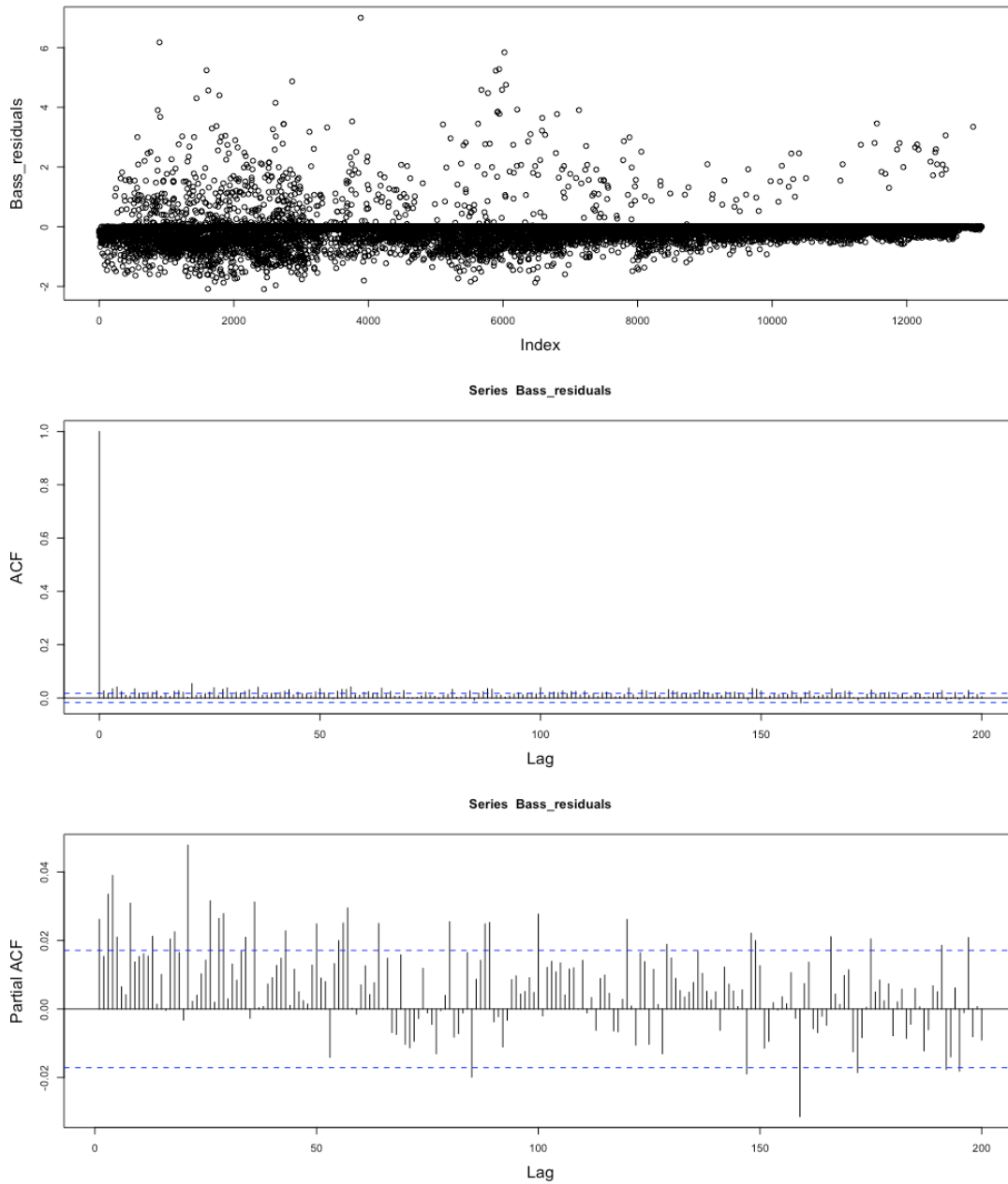


Figure 38. Summary plots for striped bass relative abundance model temporal residuals Distribution of residuals over time (top panel), autocorrelation function plot of residuals (ACF, middle panel), and partial autocorrelation plot of residuals (Partial ACF, bottom panel).

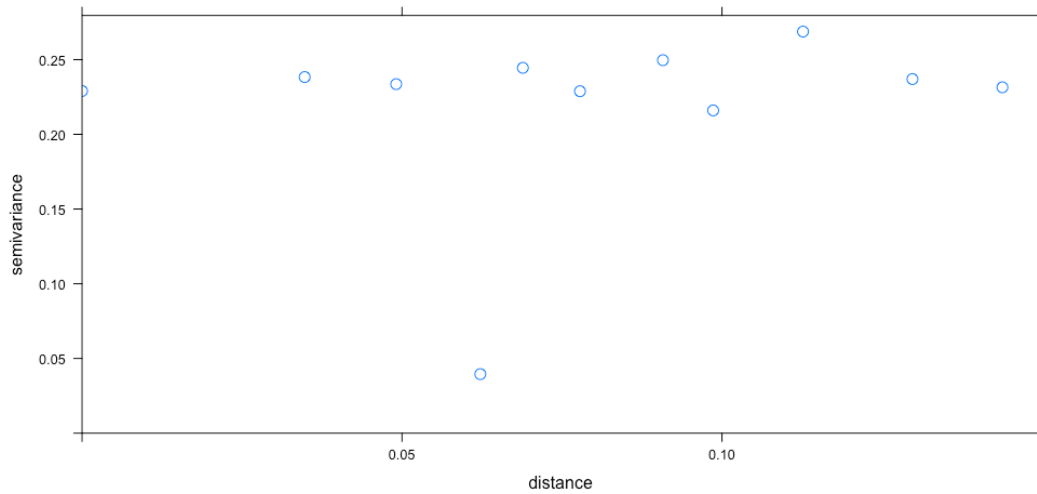


Figure 39. Semi-variogram of residuals from best striped bass relative abundance model using latitude and longitude to calculate distance between sites.

4.10.2 Environmental and individual drivers of weekly residency

Inclusion of the first-order lagged weekly occurrence markedly improved residual temporal autocorrelation in all individual residency models for both species. Although addition of second and third order correlation terms increased the explained deviance, these terms added excess complexity and did not considerably improve ACF and PACF-visualized autocorrelation. Analysis thus proceeded with the use of a first-order autocorrelation structure, or 1-day state-dependence residency lag only.

The weekly residency models for Atlantic sturgeon and striped bass showed that SST and week-of-year were significant predictors of the number of days individuals were present in the array (Table 12). However, unlike predictive habitat models, CHL-A concentration was not a significant predictor of Atlantic sturgeon occupancy at the $\alpha = 0.05$ level. The residency model for Atlantic sturgeon showed that the individual random effect was important and that response differed between Chesapeake Bay vs. South Carolina Rivers, Chesapeake Bay vs. Virginia Rivers, and Coastal Delaware vs. Virginia River tagging regions (Table 12: Wald test, $p < 0.05$). For striped bass, the effect of CHL-A concentration on residency was significant; however, the random effect of transmitter was not significant. Pairwise comparison between tagging regions revealed differences in response between the Delaware River vs. Coastal Massachusetts and Delaware River vs. Hudson River origins (Table 12: Wald test, $p < 0.05$).

Table 12. Parameter and pairwise factor comparison significance for weekly species residency GAMMs.

Significance of model parameters and pairwise tagging region factors (Origin) are indicated by asterisks (<0.001= ***; 0.001-0.009 =**; 0.01-0.009=*; 0.05-0.1=.). For Atlantic sturgeon, tagging regions are CB = Chesapeake Bay; SC = South Carolina Rivers; DE Coast = Atlantic Coast of Delaware; VA = Virginia Rivers. Striped bass tagging regions are: Hudson = Hudson River, New York; Potomac = Potomac River, Maryland; MA = Coastal Massachusetts; Kennebec = Kennebec River, Maine.

Species	Term	p-value	df	AIC	Deviance explained
Atlantic Sturgeon					
	s(SST)	0.017 *	85.20	7453.49	68.6%
	s(Week)	<0.001 ***			
	s(CHL-A)	0.112			
	s(Lag 1 Residency)	<0.001 ***			
	s(Transmitter)	0.012 *			
	Origin: CB with SC	0.039 *			
	Origin: DE Coast with SC	0.058 .			
	Origin: CB with VA	0.033 *			
	Origin: DE Coast with VA	0.028 *			
	Origin: DE Coast with CB	0.503			
	Origin: SC with VA	0.542			
Striped Bass					
	s(SST)	<0.001 ***	25.83	9899.17	56.2%
	s(Week)	<0.001 ***			
	s(CHL-A)	<0.001 ***			
	s(Lag 1 Residency)	<0.001 ***			
	s(Transmitter)	0.593			
	Origin: Hudson with Potomac	0.200			
	Origin: Hudson with Kennebec	0.417			

Origin: MA with Potomac	0.255
Origin: Hudson with MA	0.674
Origin: Kennebec with Potomac	0.789
Origin: DE River with Potomac	0.967
Origin: DE River with Kennebec	0.767
Origin: Kennebec with MA	0.507
Origin: DE River with MA	0.025 *
Origin: DE River with Hudson	0.025 *

Partial effects of environmental and temporal variables in species residency GAMMs were largely consistent with the responses observed in relative abundance modeling, but revealed variation in how these factors affected the amount of time individuals spent in the area. Additionally, contrasts between species were apparent. Atlantic sturgeon had a bimodal response to SST in which individuals were more likely to occupy the region when weekly, array-wide surface temperatures were around 10°C or 20°C (Figure 40). Temperatures between and outside these general ranges had a negative effect on sturgeon residency. Week-of-year was the most significant term in the model and showed that Atlantic sturgeon occupancy was highest during spring and autumn, with peaks in the number of days present around week 20 (mid-May) and week 45 (mid-November), respectively. In contrast to Atlantic sturgeon, partial effects showed that temperatures <15°C were associated with higher striped bass residency while temperatures higher than this threshold negatively affected residency duration (Figure 41). Similar to the GAMM abundance model, striped bass were likely to occur for more days per week during winter and spring months and were unlikely to reside in the area during summer. Though CHL-A observations were skewed, striped bass occupancy was highest when concentrations were either just above 0 mg m⁻³ or very high between 10-20 mg m⁻³.

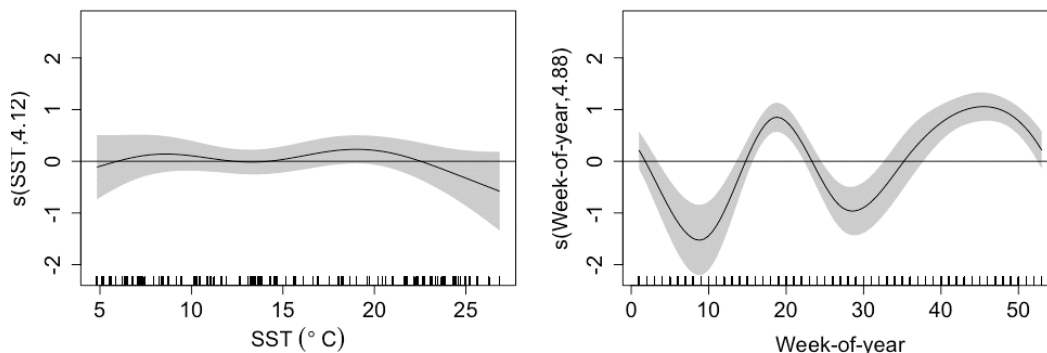


Figure 40. Atlantic sturgeon: GAMM partial effects for sea surface temperature (SST, left), week-of-year (right).

Chlorophyll-a concentration not plotted due to lack of significance. Rugs along the x-axis represent the distribution of observations.

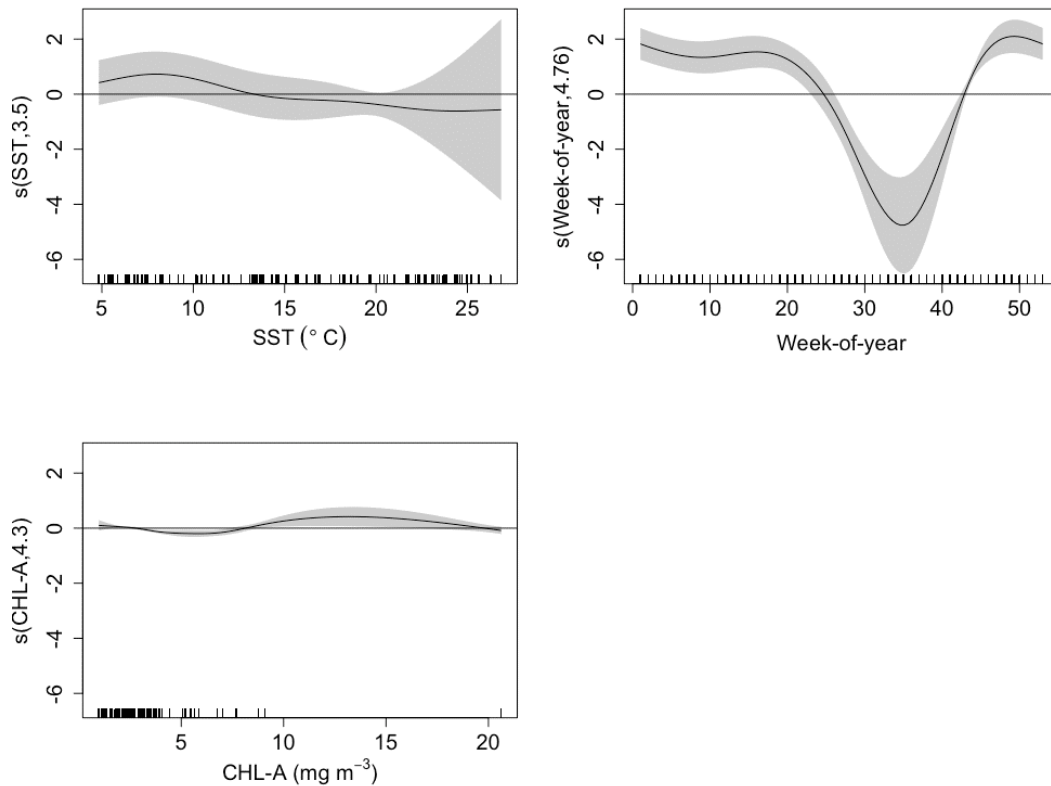


Figure 41. Striped bass: GAMM partial effects for sea surface temperature (SST, top left), week-of-year (top right), and chlorophyll-a concentration (CHL-A, bottom left).

Rugs along the x-axis represent the distribution of observations.

HGAM-predicted residency revealed that Atlantic sturgeon responded differently to SST and week-of-year depending on their tagging origin. For sturgeon tagged in the Chesapeake Bay, Santee River, and Virginia Rivers, longer residency was most likely when SST was between 15-20°C (Figure 42). The group tagged off the Atlantic coast of Delaware differed in that individual residency was more likely at lower surface temperatures between 10-15°C. The highest predicted increases in residency in response to SST occurred for the Chesapeake Bay and South Carolina River groups. Individuals tagged in coastal Delaware and Virginia Rivers did not show the same magnitude of response to SST and were predicted to reside in the array for less time. There were also group-level differences in timing of arrival and amount of seasonal residency for Atlantic sturgeon in response to week-of-year. The week-of-year hierarchical model showed that degree of residency was fairly similar between spring and fall for sturgeon tagged in the South Carolina and Virginia Rivers (Figure 43). In contrast, individuals tagged on the Atlantic Coast of Delaware and in the Chesapeake Bay were more likely to reside longer in the area during autumn compared to spring. Sturgeon tagged off Delaware were predicted to arrive slightly earlier in the MD WEA array over both migration seasons compared to relatively later arrivals and peaks in residency for the Chesapeake Bay and Virginia tagging regions.

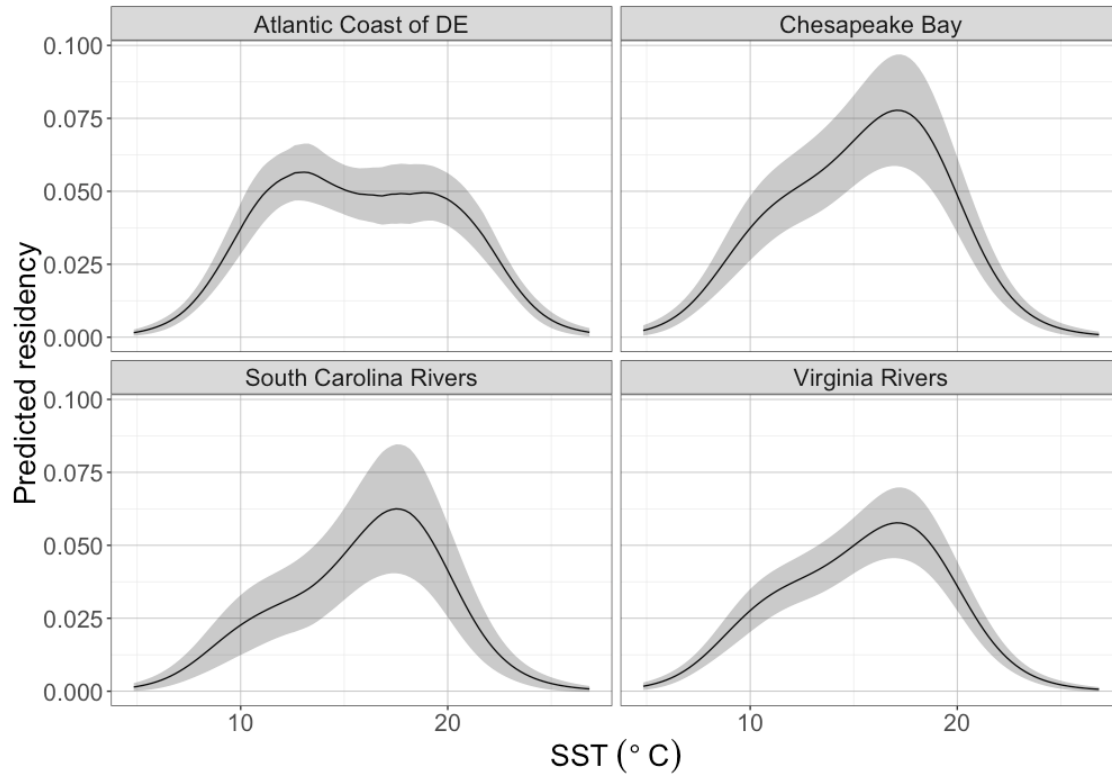


Figure 42. Predicted residency function (days per week \pm 2 se) of Atlantic sturgeon for each tagging region based on the sea surface temperature (SST) across the MD WEA.

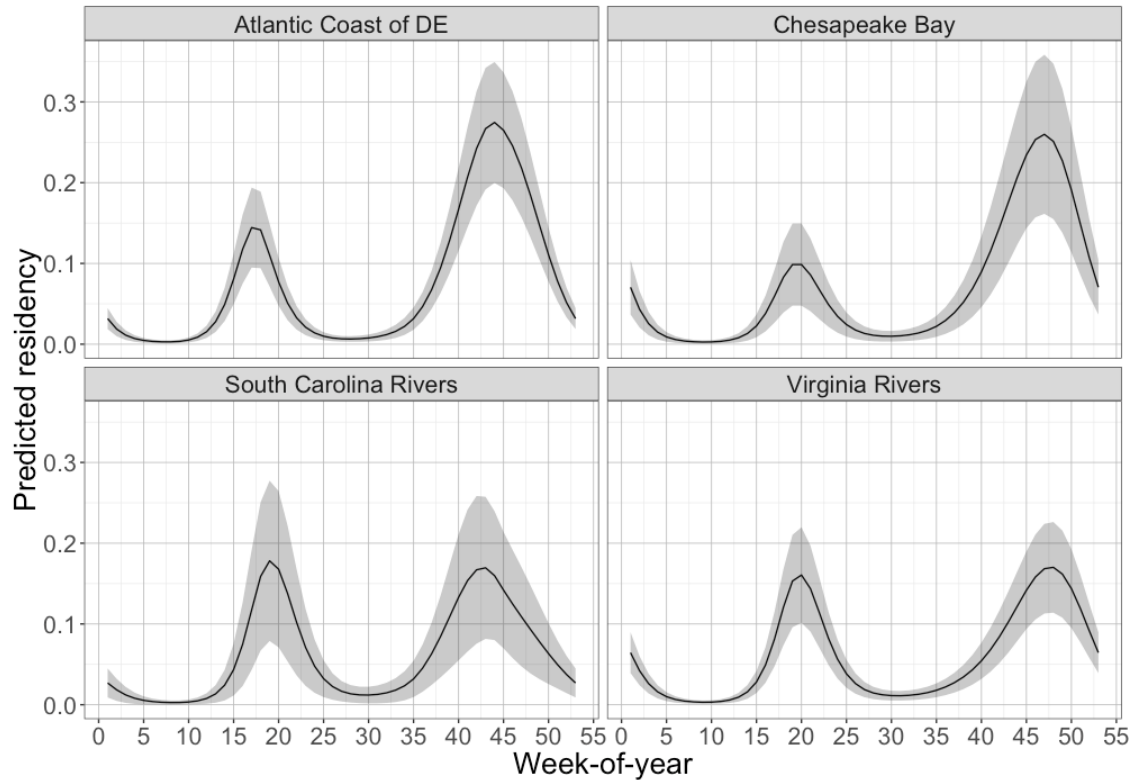


Figure 43. Predicted residency function (days per week \pm 2 se) of Atlantic sturgeon in the MD WEA array for each tagging region based on week-of-year.

Group-level differences occurred in how striped bass responded to SST and week-of-year, but variation in response to CHL-A concentration was less apparent. Residency predictions were highest when SST was $< 15^{\circ}\text{C}$, with striped bass tagged in the Delaware and Potomac Rivers showing peaks in the number of days detected at 10°C (Figure 44). Individuals tagged in coastal Massachusetts and the Kennebec River had a slightly flatter response to SST and were predicted to reside for less time over a broader range of temperatures ($5\text{-}10^{\circ}\text{C}$) compared to the other groups. All tagging regions showed a similar pattern of lower residency in the spring and higher residency in the winter, but individuals tagged in the Hudson River were predicted to occupy the region for the greatest amount of time in both seasons (Figure 45). The peak in spring residency also appeared to occur slightly earlier in the spring for Hudson fish compared to other groups. Group-level heterogeneity was not obvious in the response of striped bass to chlorophyll-a concentration (Figure 46).

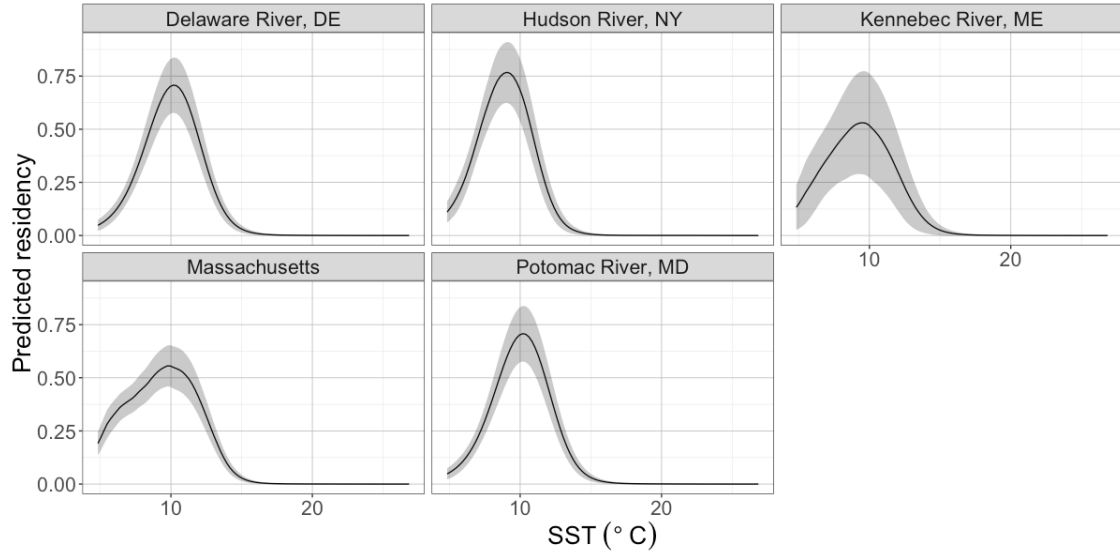


Figure 44. Predicted residency function (days per week \pm 2 se) of striped bass for each tagging region based on the sea surface temperature (SST) across the MD WEA.

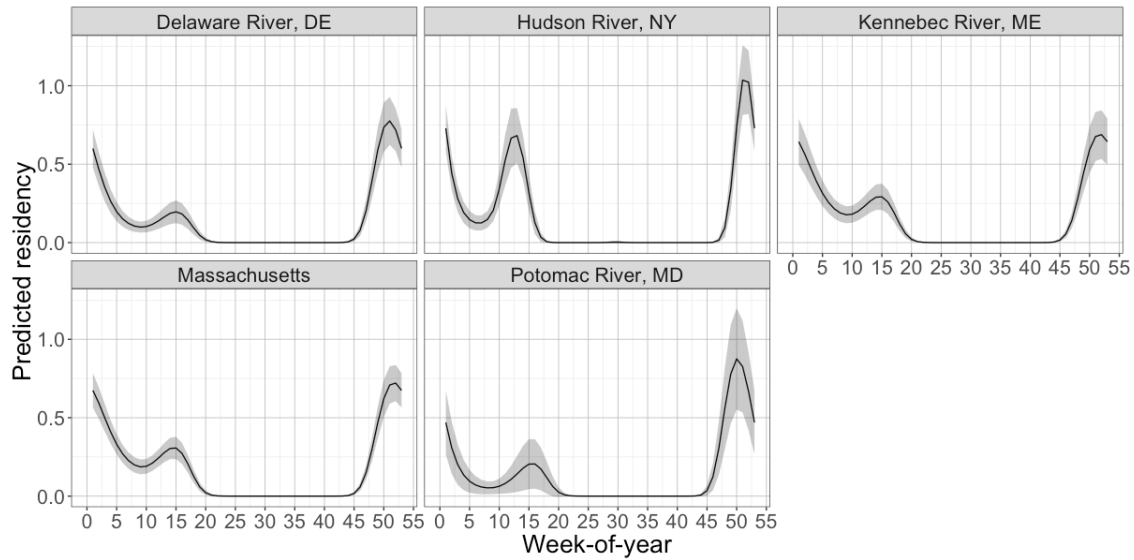


Figure 45. Predicted residency function (days per week \pm 2 se) of striped bass in the MD WEA array for each tagging region based on week-of-year.

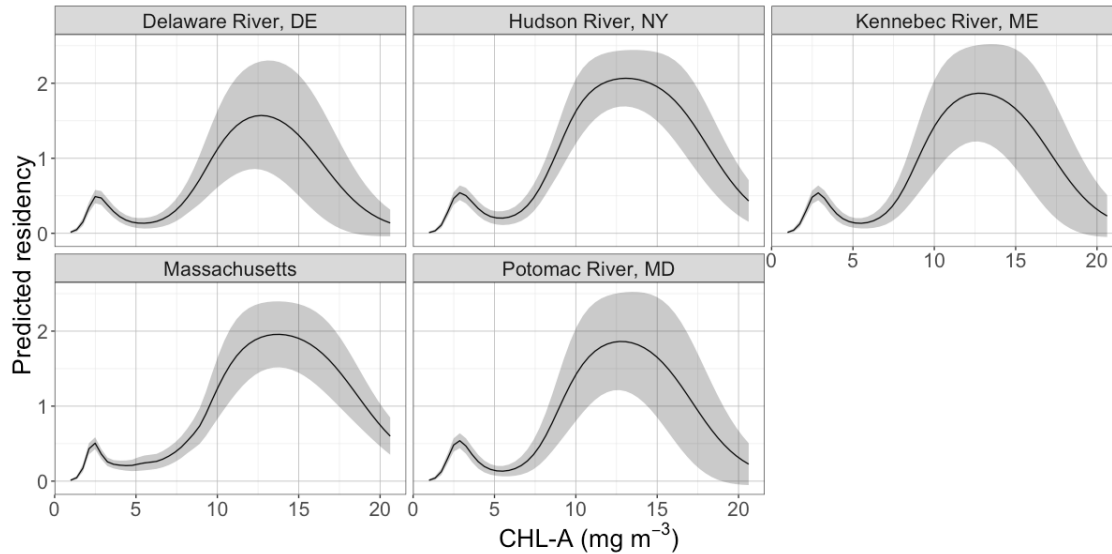


Figure 46. Predicted residency function (days per week \pm 2 se) of striped bass in the MD WEA array for each tagging region based on chlorophyll-a concentration (CHL-A).

5 Discussion

5.1 Migration through the MD WEA

Biotelemetry of striped bass and Atlantic sturgeon in the MD WEA confirm that this region is occupied extensively and used by the two species as a migration corridor. Large numbers of both species were detected during the two-year study – 378 tagged Atlantic sturgeon and 316 tagged striped bass – with most of the returns within the footprint of the MD WEA, but movement metrics and analyses indicated that this MAB shelf region mainly functions as a transient migration corridor for these species. Few individuals were detected in the array for longer than two days, which implies relatively rapid movement through the study area. However, there were notable differences in migration patterns between seasons and species. Both species were more likely to reside for multiple days during the autumn and winter months and cross-shelf movements were also more common during these months. Although some individual sturgeon exhibited multiple-day residency in the array, those that transited through within a day did so more rapidly than striped bass.

In contrast to our original hypothesis, Atlantic sturgeon appeared to migrate through the MAB shelf region relatively quickly, with only a few instances ($n=15$) of seasonal residence ≥ 24 hr. These transit rates may indicate a lack of favorable conditions available for Atlantic sturgeon in the MD WEA. Species like sturgeons are known to exhibit reduced movement rates in habitats with favorable conditions, while faster movement rates are more likely to occur where conditions are less suitable or physically taxing (Avgar et al. 2013). The lack of residency by Atlantic sturgeon may also relate to this shelf region serving as a transit route between northern spawning and nearshore summer feeding grounds and southern winter habitat (Figure 47). Atlantic sturgeon in the coastal ocean are known to concentrate around the mouths of inlets and estuaries in spring, summer, and fall (Dunton et al. 2010; Erickson et al. 2011). Within these regions, sturgeon have been found to associate with river plumes or sandy and muddy substrates that may offer increased foraging opportunities (Savoy and Pacileo, 2003; Laney et al. 2007; Oliver et al. 2013; Breece et al. 2016). Catches and returns of Atlantic sturgeon in southern overwintering areas in Virginia and North Carolina similarly reflect an association with specific benthic types that support food resources

(Laney et al. 2007; Erickson et al. 2011). The telemetered sturgeon detected in this study may be moving relatively quickly through Maryland's shelf waters in order to reach spawning grounds or more favorable nearshore (estuarine outlet) foraging habitats. Relevant detailed information on Atlantic sturgeon migration behaviors (in terms of transit and occupancy) can be found in the final report produced by University of Delaware colleagues responsible for the complementary DE WEA acoustic array (Haulsee et al. 2020; https://epis.boem.gov/final%20reports/BOEM_2020-020.pdf).

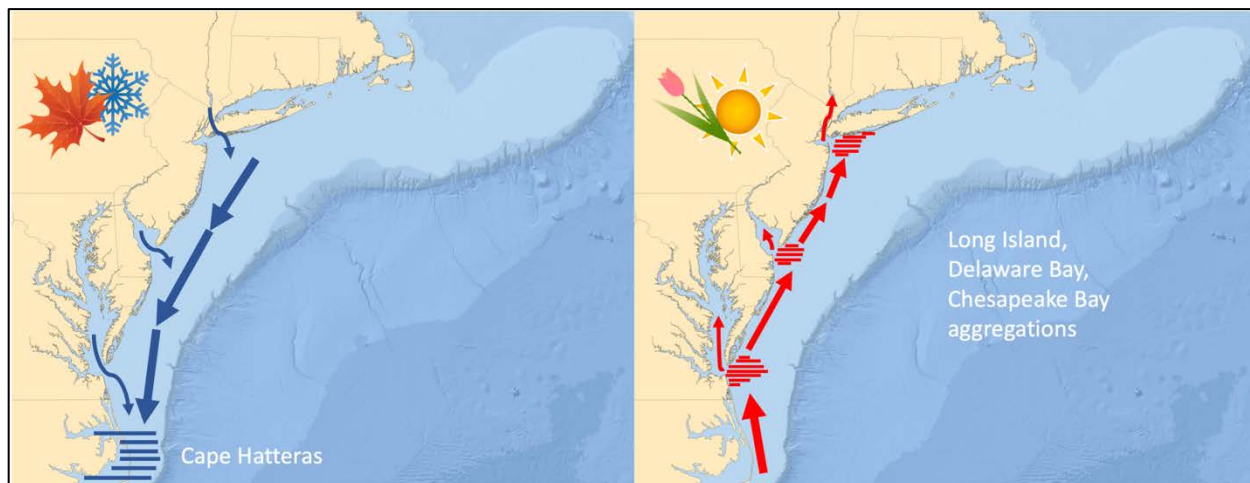


Figure 47. Conceptual diagram of seasonal MAB distribution for Atlantic sturgeon.

Distribution during autumn/winter months is shown on the left; spring/summer on the right. Horizontal shading indicates recognized aggregation areas, which are also labeled. Arrows show general movement patterns with line thickness corresponding to the shelf-scale spatial distribution of individuals (wide for broad distribution, narrow for more limited distribution).

Striped bass showed greater relative residency than Atlantic sturgeon during fall and winter and very rapid spring time migration through the MD WEA. Further, residency and transit results revealed previously undocumented occupancy of striped bass in outer shelf waters during winter months. Rapid movement through the study area was common for striped bass, with larger fish showing faster transit rates than smaller individuals. Striped bass movement behavior during spring supported our original hypothesis of rapid transit through the MAB shelf region associated with post-spawning migrations. The highest rates of transit tended to occur in a northerly direction in the spring, corresponding with northward movement toward Delaware and Hudson River spawning areas or summer foraging grounds located off the coast of Massachusetts (Figure 48; Koo 1970; Collette and Klein-MacPhee 2002; Welsh et al. 2007). Spring transits $> 4 \text{ km hr}^{-1}$ would translate to 1.1 m s^{-1} , or roughly 1-1.5 body lengths s^{-1} for an 80 cm TL striped bass. Although these speeds are well below maximum sustained swimming speeds of 2.9–3.3 body lengths s^{-1} for striped bass (Freadman 1979), they are greater than mean southern transits, which were closer to 0.3 m s^{-1} , or $1/3$ body lengths s^{-1} . Still, uniform directionality was not always observed and sequential detections were not consistent during spring 2018, leading to equivalent northern vs. southern transit rates. Although striped bass appeared to move through the region between the MD and DE WEAs relatively rapidly in our study, this does not preclude extended stopovers in other areas such as New Jersey estuaries or Long Island Sound during the spring, which have been recorded in the past (Able and Grothues 2007; Grothues et al. 2009; Kneebone et al. 2014). Other telemetry studies have found highly variable rates of transit among individual striped bass during spring, but together with this study suggest that striped bass emigrate relatively quickly from overwintering and spawning regions, likely motivated by warming temperatures (Kneebone et al. 2014; Callihan et al. 2015).

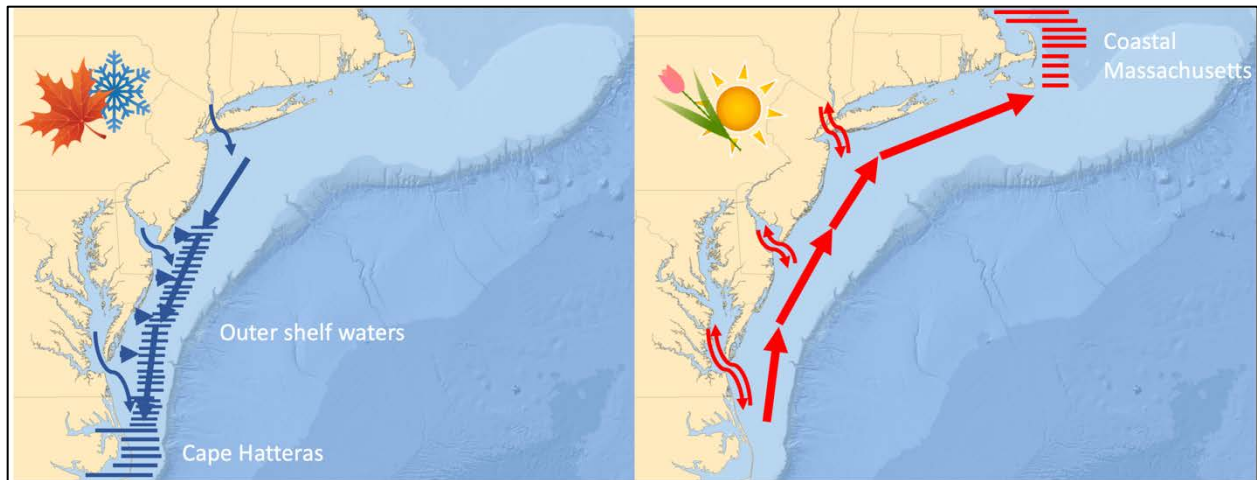


Figure 48. Conceptual diagram of seasonal MAB distribution for striped bass.

Distribution during autumn/winter months is shown on the left; spring/summer on the right. Horizontal shading indicates recognized aggregation areas, which are also labeled. Arrows show general movement patterns with line thickness corresponding to the shelf-scale spatial distribution of individuals (wide for broad distribution, narrow for more limited distribution).

The current function of the MD WEA as a migration corridor could be altered with the addition of wind turbine structures, causing increased stop-over behavior during seasonal migrations owing to alterations in local food webs. As a possible analogous example, oil and gas production rigs in the Gulf of Mexico and off California provide habitat and promote increased abundance of numerous fish species (Wilson et al. 2003; Lindquist et al. 2005; Claisse et al. 2014). Though production of biomass versus attraction of individuals as the source of such observations is debated (Bohnsack 1989), platform structures lead to demonstrable behavioral changes in demersal reef fishes and transient pelagic top-order predators alike (Keenan et al. 2007; Szedlmayer 2007; Todd et al. 2009). Like other large predators, striped bass may be attracted to smaller fish schooling around turbine structures and could dwell longer in the region as they forage on these prey species. Fish aggregations patterns have been noted around wind turbine foundations (Reubens et al. 2013) and inactive tidal turbines (Viehman et al. 2018). Beyond fish assemblages, petroleum or wind energy platforms influence entire food webs, often promoting increased benthic biomass that may have spillover effects to the larger area surrounding the structures themselves (Lindeboom et al. 2011; Macreadie et al. 2011; Coolen 2017). Changes in benthic resources may thus alter local Atlantic sturgeon movement as well; sturgeons are known to exhibit fidelity to regions with substrates that support infaunal prey availability (Lepage et al. 2005; Parsley et al. 2008). Depending on the type of benthic organisms that benefit from spillover effects of turbine installations, Atlantic sturgeon may, like striped bass, dwell longer in the MD WEA to forage during their migration through the area.

5.2 Functional habitat attributes of the MD WEA

Analysis of benthic, *in-situ*, and satellite-derived variables highlighted the heterogeneous and dynamic nature of the MD WEA habitat. Although the broader shelf region has been historically characterized as a relatively homogenous soft-bottom habitat, categorical descriptors of sediment and topography varied at a fine resolution over the MD WEA. Similar subtle complexity has been noted in previous shelf habitat assessments as factors that could affect the movement and behavior of fishes (Guida et al. 2017). Temperature, both at the surface and bottom of the water column, was seasonally dynamic in this study. Indeed, the MAB shelf is characterized by large changes in seasonal temperature ($\Delta 18^{\circ}\text{C}$ sea surface temperature; He et al. 2010; Richaud et al. 2016), which shape regional shelf ecosystems. In our array,

temperature preference and differential distributions suggest that Atlantic sturgeon and striped bass select distinct depth and temperature gradients rather than specific benthic characteristics.

Our results are consistent with past studies, in which adult and sub-adult Atlantic sturgeon in the Atlantic Ocean were frequently found over sand or mud substrates that are favorable for foraging. (Savoy and Pacileo 2003; Stein et al. 2004; Laney et al. 2007). Nearshore regions of the MAB are hypothesized to support benthic prey resources for Atlantic sturgeon (Bain 1997; Stein et al. 2004) and individuals captured along the shelf have shown evidence of feeding (Dovel and Berggren 1983; Johnson et al. 1997). A spatial shift in occurrence between spring/summer and autumn/winter has also been observed previously; Atlantic sturgeon are thought to utilize a broader range of depths during their autumn occupancy in the coastal ocean compared to a relatively shallow distribution during the spring (Stein et al. 2004; Laney et al. 2007; Erickson et al. 2011; Breece et al. 2017). In our array, Atlantic sturgeon were in fact most likely to occur at the two receiver sites closest to shore, particularly during spring and summer. These inshore sites are associated with mostly fine sandy substrates and shallow flats with some NE-SW trending crests (Figure 12). Clustering at shallow sites was less apparent during autumn and winter, with a hot spot of sturgeon occurrence within a deeper portion of the MD WEA stratum. This area has relatively higher muddy sediment concentrations and more topography compared to the rest of the MD WEA sites. Although we were unable to detect fine scale use of different substrate types, that may have been associated with varying prey densities, broad spatial clustering rather than intensive use of specific sites in our study indicates the MD WEA serves more as a migration corridor than exclusive foraging habitat. Combined with rapid transit through the MD WEA (see previous section), results suggest that this portion of the shelf off Maryland does not currently provide optimal foraging conditions for Atlantic sturgeon.

Throughout our study, striped bass clustered at receiver sites within the MD WEA stratum, but their distribution shifted seasonally. During spring, striped bass were more concentrated at deeper sites in the MD WEA stratum and in autumn, distribution shifted to the shallower portion of the MD WEA, which is near a known angler reef zone characterized by prominent cobble and gravel substrates (Guida et al. 2017, Figure 12). This area may provide increased structure or foraging opportunities compared to the rest of the Maryland MAB shelf since striped bass are known to be structure-oriented (Haeseker et al. 1996; Tupper and Able 2000; Harding and Mann 2003). Though there was little clustering in winter, striped bass did show some preference for a deeper site while avoiding more shallow sites. In general, striped bass were distributed over the deeper sites of the array, including the Outer stratum. Striped bass, like Atlantic sturgeon, likely utilize different migration corridors seasonally and prefer broader depth and temperature gradients rather than specific benthic characteristics. This inference is also supported by the fact that striped bass tended to utilize the entire water column during their incidence in the area. Given their pelagic distribution, individuals are likely not responding to benthic characteristics.

Temperature conditions had a stronger apparent influence on the habitat selection of both species compared to substrate type. While Atlantic sturgeon were broadly tolerant of a wide range of temperatures, they were more likely to select the warmest available conditions. The temperature preferences identified here are supported by previous bioenergetic studies in which sturgeon metabolic rates (albeit those of juveniles < 1 m total length) increased with temperature but leveled off at warmer extremes of 24-28°C (Niklitschek and Secor 2009; 2010). Other work has suggested that temperature is key in structuring Atlantic sturgeon movement behavior. In the Delaware Bay, adult Atlantic sturgeon are known to transition from resident to active movement behaviors when sea surface temperatures decrease below 18-19°C (Breece et al. 2018). Lower temperature may therefore cause Atlantic sturgeon to move through the region more quickly in order to reach spawning destinations or more favorable foraging habitats along their migratory route. Striped bass differed from Atlantic sturgeon in that they preferred a relatively narrow range of cool bottom temperatures. Preferred temperatures between ~ 6-15°C are considerably lower than thermal niches reported for striped bass in landlocked environments, which are thought to range between 18-25°C (Coutant 1985) with a hypothesized fundamental niche between 19-

23°C (Coutant 1990). However, striped bass are known to acclimate to a remarkably wide range of temperatures; the species may tolerate temperatures up to 30°C to avoid hypoxic conditions (Jackson and Hightower 2001; Thomson et al. 2010; Kraus et al. 2015) and remain active as low as 1.0°C (Clark 1968; Tagatz 1961). Notably, striped bass avoided the coolest temperatures that occurred during winter months in our study and likely shifted distribution toward regionally warmer deeper sites to maintain favorable habitat conditions.

5.3 Spatial and temporal patterns of habitat use by test species

The observed spatial and temporal patterns of Atlantic sturgeon presence were consistent with those previously described for this species along the US East Coast. Atlantic sturgeon were most abundant during the fall and spring months, when they are known to undertake coastal migrations (Smith, 1985; Erickson et al. 2011). Like our findings, tagging and bycatch records in the MAB shelf region have reported the highest numbers of sturgeon captures occurring in the spring and fall (Collins et al. 2000; Stein et al. 2004). The timing of this seasonal presence is likely dependent on movements between spawning rivers and coastal habitat during those same periods. Atlantic sturgeon from regions in the Chesapeake Bay and south are known to spawn during fall and may also have spring spawning runs while Atlantic sturgeon in regions north are known to have only a spring run (Balazik and Musick 2015; Hilton et al. 2016; ASMFC 2017). Atlantic sturgeon tended to be absent in our array when they were occupying riverine spawning and nearshore foraging habitats from the late spring through early fall (Borodin 1925; Stein et al. 2004). During the winter, sturgeon may be inhabiting relatively warmer habitats to the south, near Virginia and Cape Hatteras, where they have been shown to aggregate (Moser et al. 1998; Laney et al. 2007; Stein et al. 2004; Dunton et al. 2010, Figure X1). Similar to our results, past studies have recorded higher abundance of Atlantic sturgeon in shallow, near-shelf areas compared to deeper waters in the coastal region (Stein et al. 2004; Erickson et al. 2011; Ingram et al. 2019). Although there have been occasional instances of sturgeon occurring at greater depths (110 m, Timoshkin 1968), the species has been thought to remain relatively close to shore during its seasonal occupancy in oceanic waters.

Patterns of striped bass occurrence also aligned with established seasonal migrations south in the fall and north in the spring, but revealed patterns of oceanic abundance that have not been documented in the past. Evidence for striped bass overwintering in the nearshore waters off Cape Hatteras has existed for some time (Chapoton and Sykes 1961; Benton 1992; Laney and Cole 1994, Figure X2), but other findings have suggested that a portion of the migratory contingent may winter in the shelf region as far north as Cape Cod, Massachusetts (Clark 1968; Wirgin et al. 1997). Although it has been postulated that striped bass may overwinter in areas along the MAB shelf, ours is the first to measure striped bass presence in the offshore Maryland region using acoustic telemetry. Further, a previous view was that striped bass seldom occur more than 6 to 8 km offshore (Bain and Bain 1982), however, our results show that individuals move to areas > 40 km from the coast. For autumn and winter, our results contradicted the original hypothesis that the coastal stock of striped bass would rapidly transit through the MD WEA. Instead, detections occurred throughout winter months and shifted toward the outer shelf as temperatures began to cool more rapidly near shore.

Striped bass showed a winter-time cross-shelf distribution pattern that was likely related to nearshore cooling; as winter progressed individuals selected deeper waters. A variety of other fish species in the Northwest Atlantic are known to undertake similar cross-shelf distributional shifts, including black sea bass, fluke (*Paralichthys dentatus*), and scup (*Stenotomus chrysops*) (Nesbit and Neville, 1935; Colvocoresses and Musick, 1984). Like these species, striped bass may select warmer shelf waters over the cooler winter waters of the inshore region to maintain preferred temperature conditions. Temperature data from receivers supported the persistence of warmer temperatures at outer shelf sites compared to cooler MD WEA and inshore sites during autumn/winter 2017. The diminished presence of striped bass during autumn/winter 2018 may be due to the cooler winter temperatures that occurred in 2018

throughout all shelf strata. These relatively cooler temperatures may have caused striped bass to move faster or farther offshore, leading to fewer overall detections during the second autumn/winter season.

5.4 Study design limiting assumptions

Here we used biotelemetry to sample rather than entirely census regions for tagged fish incidence. One of the key assumptions of our original study was an assumed maximum detection distance of 800 m, which would have permitted approximately 50% detection in the MD WEA and 20% detection in the Inner and Outer strata. To better evaluate the probability of acoustic tag detection over the dynamic spatial and temporal gradients in the study area, we conducted a 12-month range test. Detection distance (measured as 50% detection recovery) was noticeably reduced during loud wind and storm events, but increased during warmer summer months with the onset of stratification. Understanding and quantifying detection efficiency is key to drawing robust inferences in acoustic telemetry studies; underlying detection range dynamics have been known to lead to false conclusions regarding species biology (Payne et al. 2010). Here, the weighted adjustment based on detection range significantly reduced temporal autocorrelation in predictive models, which suggests that raw counts of individuals were influenced by underlying patterns in tag detectability. These findings indicate that future biotelemetry offshore studies will benefit from range test incorporation.

The gradient telemetry array allowed us to evaluate species habitat selection on relevant spatiotemporal scales (Cushman et al. 2010, Alvarez-Berastegui et al. 2014). However, other study designs may be more useful for evaluating specific questions. Originally, we had expected to be able to track latitudinal movements through the array. However, early analysis showed that receiver spacing did not provide sufficient coverage to resolve the direction of movement; there was no strong pattern of directionality within sequences of individual detections. Thus, we sought out additional data from the DE WEA to evaluate transit rates, data provided by colleagues at University of Delaware from a separate BOEM study.

The vast majority of focal species were within the detection range of receivers for < 24 hr, which suggests that the shelf waters surrounding the MD WEA function primarily as a migration corridor for Atlantic sturgeon and striped bass. Though residency, as recorded here, is conservative due to the limited spatial detection range of receivers. Further, the occupancy of these species in the region may ultimately be related to seasonal migration cues more than physical habitat conditions. For example, though interannual differences in the wintertime occurrence and cross-shelf distribution for striped bass could be related to measured habitat variables within the study site, the timing and speed of migration probably depends on conditions and seasonal cues occurring in other shelf regions or spawning tributaries such as the Hudson River and Chesapeake Bay. Migratory behavior is often considered preemptive in that individuals will depart areas before they become unfavorable (Dingle and Drake 2007). In the case of estuaries like the Chesapeake Bay, striped bass will emigrate before temperatures become too warm and metabolically demanding, particularly for large individuals > 90 cm TL (Coutant 1985; Hartman and Brandt 1995). However, local habitat attributes still likely influenced patterns of occurrence; striped bass may have transited through the area using deeper offshore waters during winter and spring of 2018 because they were avoiding excessively cold nearshore temperatures.

5.5 Prediction of migratory habitat use in the MD WEA

As expected from previous habitat selection modeling (Manderson et al. 2011; Breece et al. 2017; Haulsee et al. 2018) and preceding results, relative abundance of test species was highly dependent on shelf environmental gradients, especially depth and temperature. However, response to dynamic factors was also seasonally variable: Atlantic sturgeon were more broadly distributed during autumn compared to

spring while striped bass shifted to deeper waters as winter months progressed. Temperature and season (DOY) were key predictors of weekly species residency in the region for both species, with Atlantic sturgeon exhibiting the highest degree of residency during autumn and spring when SSTs were generally warm, between 10-20°C, and striped bass residing for more days during winter compared to spring when surface temperatures were cooler, near 10°C. Although CHL-A was retained and significant in all of the best-performing models besides the sturgeon residency model, this variable appeared to have less predictive value compared to DOY, depth, and SST. Although the interaction between DOY and depth was most influential in explaining relative abundance, other important unmeasured factors include mesoscale oceanographic features, physiological constraints, prey availability, and broader migration cues were influencing the distribution and behavior of test species. Lagged SST values were also deemed significant for both species suggesting that temperatures occurring outside the MD WEA were influencing (cueing) shelf movements through the study area.

Weekly residency modeling also revealed potential variation in migration behavior between distinct tagging regions for each species. Still, these differences were subtle and eclipsed by principal environmental variables and week-of-year. Our results may indicate that individuals originating from diverse locations ultimately utilize the shelf migration corridor in a similar manner. However, the key assumption that tagging region indexed different populations could not be substantiated. The statistical modeling approach nevertheless shows a way forward should future telemetry studies incorporate genetic assays for population-origin.

6 Conclusions and Recommendations

A broad cross-shelf biotelemetry survey through the MD WEA confirmed year-round presence of Atlantic sturgeon and striped bass with the noticeable absence of striped bass during summer months. Atlantic sturgeon were distributed inshore, inclusive of the MD WEA, with incidence peaks during fall and spring. Striped bass incidence data was more squarely centered in the MD WEA as they migrated north during spring and south during fall. Incidence and transit data supported short-term residence (<2 d) and rapid movement (~1 body length s⁻¹) through the MD WEA for striped bass. Still, the extended period of incidence among individual striped bass suggested that the MD WEA might in some years function as an overwintering habitat. Habitat models selected SST, depth, proxies of seasonality, and interaction terms as most influential in predicting incidence, while sediment type or benthic class were weak predictors of occurrence in this section of the MAB.

6.1 Overview findings related to functional habitat attributes of the MD WEA

- Both species occur frequently in the MD WEA with seasonal incidence showing that the MD WEA occurs within the MAB migration corridor for both species.
- Striped bass tended to occur in deeper and more distant mid-shelf waters while Atlantic sturgeon were biased toward shallow nearshore waters
- Striped bass were associated with a relatively narrow range of bottom temperatures (5-15°C) and preferred cooler sea surface temperatures
- Atlantic sturgeon were more likely to coincide with warmer bottom and sea surface temperatures than striped bass
- Atlantic sturgeon may respond to temperature changes on shorter time scales than striped bass

- Differences in MD WEA habitat use between tagging origins was subtle at the scale of concern to management

6.2 Considerations related to timing and location of potential impacts and benefits of wind facility construction within the MD WEA

- Based on study results of animal occurrence, ideal timing for activities that may negatively impact both species is summer
- The installation and maintenance of renewable energy export cables may cause interactions with inshore sturgeon distributions
- Turbine structures may alter behaviors, especially for striped bass – a structure-oriented forager - leading to longer residency within the shelf region off Maryland seasonally, when environmental conditions are favorable

6.3 Recommendation for future studies to build on the current baseline study

- Increased incorporation of oceanographic variables, physiological data, and multi-species information is feasible with new observing system capabilities and could greatly improve dynamic habitat models for Atlantic sturgeon, striped bass, and other migratory species
- Large offshore telemetry studies are feasible here and in other WEAs and should be deployed and coordinated in baseline, impact, and post-impact phases of wind energy development
- Sampling biotelemetry survey designs (here, a Before After Gradient design) hold advantage in coverage of larger cross-shelf ecosystems and seminal environmental variables
- Opportunities for aligned biotelemetry survey design and data sharing should be encouraged across WEA regions

7 Research Products

7.1 Presentations

Secor, DH. 2017. Before-after-gradient designs in monitoring the ecological impacts of offshore wind development. National Academy of Sciences Workshop. New Bedford MA.

Rothermel, E, MHP O'Brien and DH Secor. 2018. Seasonal migrations of striped bass and Atlantic sturgeon through the Maryland Wind Energy Area. American Fisheries Society, Tidewater Chapter Annual Meeting, Beaufort, NC, January 25-27.

Secor, DH, Rothermel E, MHP O'Brien and H Bailey. 2018. Movement and Habitat Selection by Migratory Fishes within the Maryland Wind Energy Area and Adjacent Reference Sites. Environmental Studies Program Science Exchange, BOEM Sterling VA, February 14.

- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2018. Seasonal migrations of Atlantic Sturgeon and Striped Bass through the Maryland Wind Energy Area. National American Fisheries Society Annual Meeting, Atlantic City, NJ, August 19-23.
- Rothermel, E, MHP O'Brien and DH Secor. 2018. Understanding the seasonal movements of Striped Bass and Atlantic Sturgeon in Maryland's coastal waters. MEES Colloquium, Frostburg MD, October 5-6.
- Secor, DH. 2018. Designing research and monitoring studies to effectively detect impacts. State of the Science Workshop on Wildlife and Offshore Wind Energy Development, Woodbury NY, November 13-14.
- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2018. Understanding the Seasonal Movements of Atlantic Sturgeon and Striped Bass in the Maryland Wind Energy Area. State of the Science Workshop on Wildlife and Offshore Wind Energy Development, Woodbury NY, November 13-14.
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- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2019. Seasonal and environmental predictors of Atlantic Sturgeon and Striped Bass occurrence in the Maryland Wind Energy Area. Oral presentation for the Chesapeake Biological Laboratory Brown Bag Series. Solomons, MD, March 1.
- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2019. Science Updates: Atlantic Sturgeon and Striped Bass in the Maryland Wind Energy Area. Oral presentation at the Mid-Atlantic Telemetry Workshop. Newark, DE, April 18-19.
- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2019. Seasonal and environmental predictors of Atlantic Sturgeon and Striped Bass occurrence in the Maryland Wind Energy Area. Oral presentation at the 5th International Conference on Fish Telemetry. Arendal, Norway, June 24-28.
- Rothermel, E, MHP O'Brien, D Fox, B Gahagan, I Park, M Balazik, and DH Secor. 2019. Seasonal incidence of Atlantic Sturgeon and Striped Bass in the Maryland Wind Energy Area. Oral presentation at the 25th Biennial Coastal and Estuarine Research Federation Conference. Mobile, AL, Nov. 3-7.
- Rothermel, E. 2019. Seasonal migrations of Atlantic Sturgeon and Striped Bass through the Maryland Wind Energy Area. Thesis defense presentation for the Chesapeake Biological Laboratory Solomons, MD, Dec. 6.
- Secor, D.H. E. Rothermel, C. Wiernicki, and M.O'Brien. 2019. Before after gradient (BAG) designs to evaluate coastal and wind farm impacts to migratory and sedentary fishes. Oral presentation at the 25th Biennial Coastal and Estuarine Research Federation Conference. Mobile, AL, Nov. 3-7.

7.2 Outreach

PI Secor served on expert panel discussions at National Academy of Sciences Workshop on Offshore Wind. New Bedford MA, 2017 and at the State of the Science Workshop on Wildlife and Offshore Wind Energy Development, Woodbury NY, 2018.

PI Secor served on the Organizing Committee, 2018 Coastal Fisheries and Offshore Energy Development: Managing a Multi-Use Ocean. AFS Annual Conference, August 2018, Atlantic City, NJ.

BOEM-funded student Ella Rothermel worked with UMCES outreach coordinator, Sarah Brzezinski, to produce an outreach video summarizing her research for a general public audience, sent to BOEM winter 2019. The URL is available at <https://www.umces.edu/news/next-generation-ellie-rothermel>

PIs Secor and Bailey and E. Rothermel visited US Wind (T. Sumner) in Baltimore during early 2020 to discuss BOEM research findings and provide input on COP and Fishery Communication planning.

7.3 Theses

The research presented in this report directly contributed to the BOEM-funded Masters of Science thesis, successfully defended Dec. 6, 2019:

Rothermel, ER. 2019. Seasonal migrations of Atlantic Sturgeon and Striped Bass through the Maryland Wind Energy Area. Marine, Estuarine, and Environmental Sciences Program, University of Maryland Center for Environmental Science and the Graduate School of the University of Maryland, College Park, MS thesis. 153 p.

7.4 Publications

Data and analyses from this report have contributed to a submitted paper to Plos One and two manuscripts in preparation.

Rothermel, ER, MT Balazik, JE Best, MW Breece, DA Fox, BI Gahagan, DE Haulsee, AL Higgs, MHP O'Brien, MJ Oliver, IA Park, and DH Secor. In Review. Comparative migration ecology of Striped Bass and Atlantic Sturgeon in the US Southern Mid-Atlantic Bight flyway. Plos One.

In Preparation: Increased ultrasonic transmitter detection range in bottom waters due to thermal stratification in the Mid-Atlantic Bight.

In Preparation: Seasonal and environmental predictors of migratory species occurrence in a Wind Energy Lease area of the Mid-Atlantic Bight.

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Appendix A: Cruise Reports

10-11 November 2016

MD Wind Energy Area Fish Movement Cruise Report

Cruise Participants

Dave Secor (Chesapeake Biological Laboratory, Chief Scientist)

Mike O'Brien (Chesapeake Biological Laboratory)

Michael Hulme (*R/V Rachel Carson*, Captain)

Rob Nilsen (*R/V Rachel Carson*, Mate)

Thursday, 10 November, 2016

Conditions

NNW winds: 15 – 20 kts, gusts to 30 kts. Waves 4-6 ft. Air temperature 43 - 55° F.

Summary

0700 Scheduled departure delayed due to weather.

0900 Depart Sunset Marina, Ocean City, MD aboard the *R/V Rachel Carson*.

0930 Abort cruise due to wind/sea state. Return to Ocean City, MD.

1000 Arrive in Ocean City, MD

Friday, 11 November, 2016

Conditions

NW winds, 15 – 20 kts. Waves 5-7 ft, decreasing to 3-4 ft. Air temperature 45 – 64° F.

Summary

0815 Depart Sunset Marina, Ocean City, MD aboard the *R/V Rachel Carson*.

0944 Arrive at ON2 and deploy mooring.

0945 Communicate with deployed receiver to gather depth and tilt data.

0947 Depart ON2, proceed to next site.

0947 –

Repeat process for all 20 sites. Refer to **Deployment Summary** for complete deployment data.

– 1450

1450 Break cruise. Depart for Ocean City, MD.

1320 Arrive at Sunset Marina, Ocean City, MD.

Deployment Technique

- Rope was passed through hole in weight plates. One end was held by hand with the other cleated to the vessel.
- Mooring was pushed by hand off the stern.
- The rope was slowly released until weights were below the surface of the water. At this point, the rope was completely released to complete deployment.



Deployment Summary

Site	Latitude	Longitude	Depth (m)	Tilt (°)	Arrive	Deploy	Depart
ON2	38.36898	-74.54183	36	3	9:44	9:44	9:47
OS2	38.30435	-74.54175	40	0	10:04	10:05	10:08
OS1	38.30395	-74.63365	32	2	10:39	10:39	10:43
ON1	38.36907	-74.63370	32	3	11:02	11:02	11:04
AN4	38.36893	-74.72530	28	1	11:25	11:26	11:30
AN3	38.36893	-74.76205	24	3	11:38	11:38	11:45
AN2	38.36897	-74.79857	24	2	11:50	11:52	11:55
AN1	38.36895	-74.83567	14	1	12:01	12:02	12:05
AM1	38.33612	-74.83513	18	1	12:12	12:13	12:15
AM2	38.33608	-74.79850	20	2	12:22	12:24	12:32

AM3	38.33620	-74.76170	24	4	12:37	12:38	12:42
AM4	38.33618	-74.72507	26	2	12:48	12:49	12:52
AS4	38.30385	-74.72512	26	1	13:00	13:01	13:03
AS3	38.30395	-74.76187	20	0	13:09	13:10	13:13
AS2	38.30388	-74.79867	20	4	13:20	13:20	13:24
AS1	38.30390	-74.83538	26	2	13:31	13:32	13:35
IS2	38.30387	-74.92695	16	3	13:50	13:51	13:55
IN2	38.36890	-74.92688	14	0	14:08	14:10	14:12
IN1	38.36900	-75.01862	12	2	14:27	14:31	14:33
IS1	38.30382	-75.01858	14	2	14:47	14:47	14:50

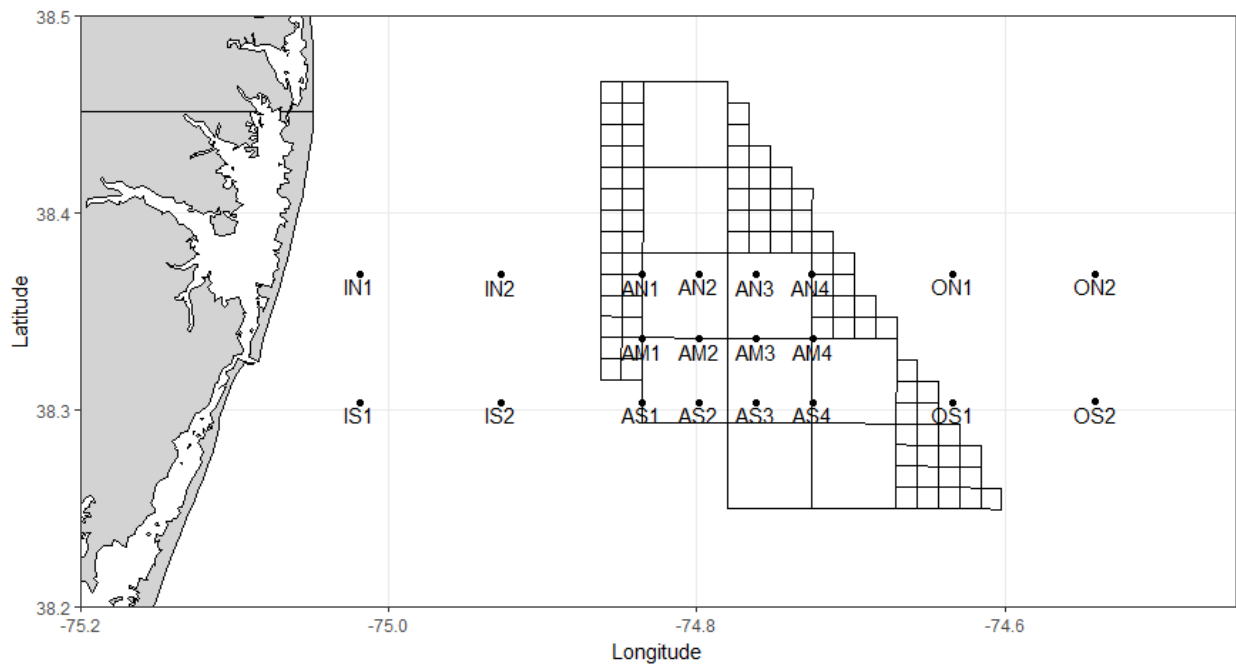


Figure 1. Maryland coastline and wind energy area. Location of deployed receivers (points) and site names are displayed.

28-29 March 2017

MD Wind Energy Area Fish Movement

Cruise Report

Cruise Participants

Dave Secor (Chesapeake Biological Laboratory, Chief Scientist)

Mike O'Brien (Chesapeake Biological Laboratory)

Caroline Wiernicki (Chesapeake Biological Laboratory)

Cory Harrington (*F/V Sea Born*)

Tuesday, 28 March, 2017

Conditions

S winds: 5 - 10 kts, Waves 3 ft. Air temperature 51 - 64° F.

Summary

0600 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.

0757 Arrive at AS1.

0801 Communicate with, release, download, and reset receiver.

0819 Depart AS1 for AS2.

0819 –

Repeat process for AS2, AS3, AS4, OS1, OS2, ON2, ON1, AN4, AM4, AM3, AN3, and AN2.

- 1606

1622 Arrive at AM2. Attempt communication with release.

1700 Communication unsuccessful. Return to Ocean City, MD.

1820 Arrive in Ocean City, MD

Wednesday, 29, March, 2017

Conditions

N winds, 10 - 15 kts. Waves 4 ft. Air temperature 39 – 57° F.

Summary

0630 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.

0815 Arrive 0.25 miles west of AM2. Attempt communication with receiver.

0840 Communication failed. Proceed to AM2.

0845 Arrive at AM2. Attempt communication with receiver.

0915 Communication failed. Deploy replacement VR2AR. Move 0.25 miles south of AM2.

0925 Arrive 0.25 miles south of AM2. Attempt communication with original receiver.

0930 Communication failed. Proceed to location 0.25 east of AM2.

0933 Arrive 0.25 miles east of AM2. Attempt communication with original receiver.

0937 Communication failed. Proceed to location 0.25 north of AM2.

0940 Arrive 0.25 miles north of AM2. Attempt communication with original receiver.

0945 Communication failed. Proceed to AM1.

1004 Arrive at AM1.

1007 Communicate with, release, download, and reset receiver.

1023 Depart AM1 for AN1.

1045 –

Repeat process for AN1, IN2, and IS2.

- 1316

1316 Arrive at IS1.

1318 Communicate with, release, and download receiver.

1329 Deploy receiver 0.25 to the north to avoid trawling.

1333 Depart IS1 for IN1.

1408 Arrive at IN1.

1409 Communicate with, release, and download receiver.

1423 Deploy receiver offshore, outside the 3-mile line, to avoid trawling.

1426 Return to Ocean City, MD.

1530 Arrive in Ocean City, MD.

Deployment Technique

- Rope was passed through hole in weight plates. One end was held by hand with the other cleated to the vessel.
- Mooring was released into the water, by hand, over the starboard-side gunwale.

Recovery and Deployment Summary

Date	Site	Latitude	Longitude	Depth (m)	Tilt (°)	Arrive	Recover	Deploy	Depart
20170328	AS1	38.3039	-74.8363	28	0-11	7:57	8:03	8:15	8:19
20170328	AS2	38.3037	-74.7985	23.8	0-11	8:35	8:42	8:56	8:53
20170328	AS3	38.3041	-74.7617	21.9	0-11	9:06	9:15	9:22	9:25
20170328	AS4	38.304	-74.7252	29.9	2	9:40	9:48	9:54	9:58

20170328	OS1	38.3039	-74.6336	35.4	2	10:32	10:37	11:29	10:46
20170328	OS2	38.3042	-74.5416	41.1	4	11:19	11:24	11:29	11:33
20170328	ON2	38.369	-74.5418	36	3	12:06	12:12	12:16	12:19
20170328	ON1	38.3691	-74.6336	36.6	1	13:00	13:04	13:09	13:13
20170328	AN4	38.3688	-74.7252	29.1	0-11	13:53	13:58	14:02	14:06
20170328	AM4	38.3362	-74.725	25.8	2	14:22	14:28	14:31	14:38
20170328	AM3	38.3361	-74.7617	24.1	4	14:54	14:59	15:02	15:08
20170328	AN3	38.3689	-74.762	26.5	1	15:25	15:30	15:35	15:39
20170328	AN2	38.369	-74.7985	24.7	4	15:54	15:58	16:02	16:06
20170329	AM2	38.3361	-74.7985	22.9	2	8:45		9:17	9:22
20170329	AM1	38.336	-74.8351	19.5	1	10:04	10:10	10:18	10:23
20170329	AN1	38.3689	-74.8356	16.8	4	10:45	10:49	10:55	11:07
20170329	IN2	38.3688	-74.9268	14	4	11:44	11:48	11:56	11:59
20170329	IS2	38.3038	-74.9271	17.8	1	12:27	12:33	12:39	12:42
20170329	IS1	38.3089	-75.0117	15.2	2	13:16	13:20	13:29	13:33
20170329	IN1	38.3693	-74.9975	14	3	14:08	14:12	14:23	14:26

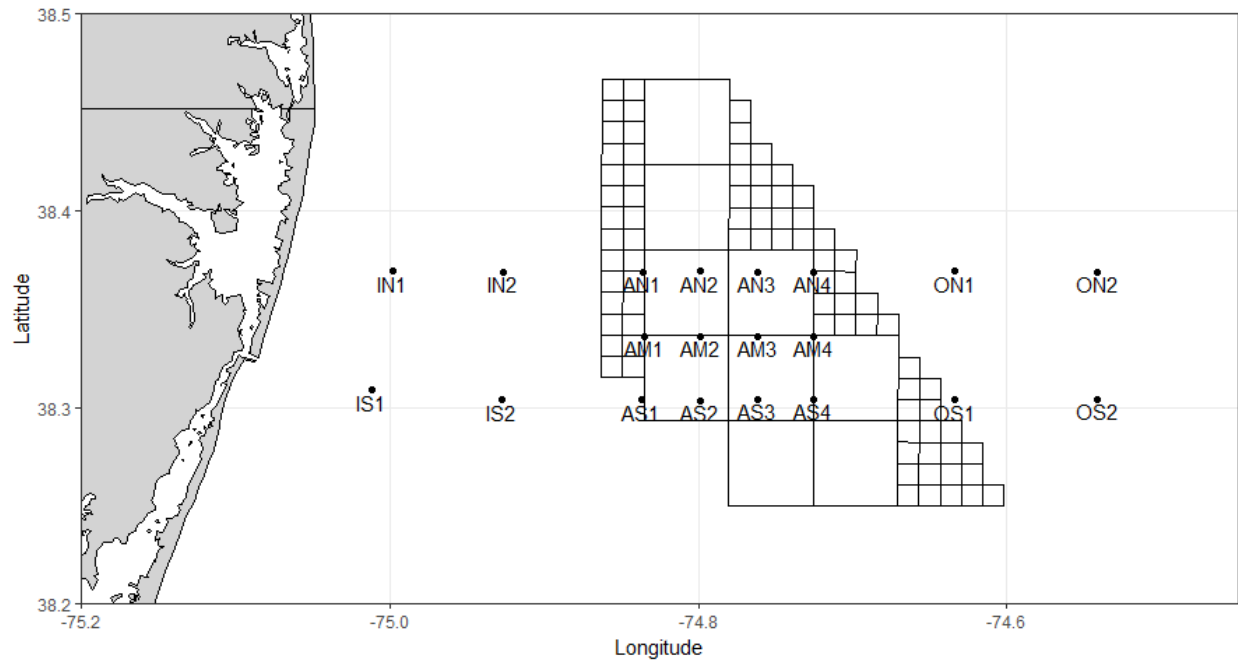
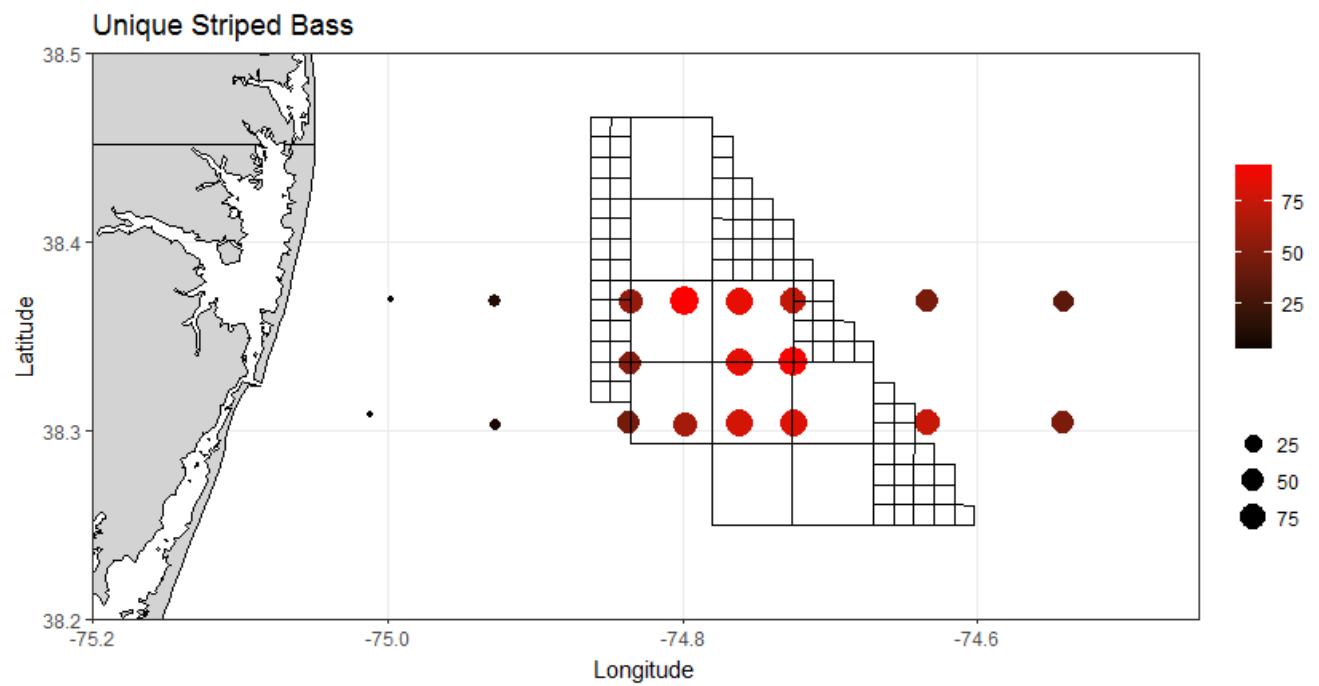


Figure 1. Maryland coastline and wind energy area. Location of deployed receivers (points) and site names are displayed.



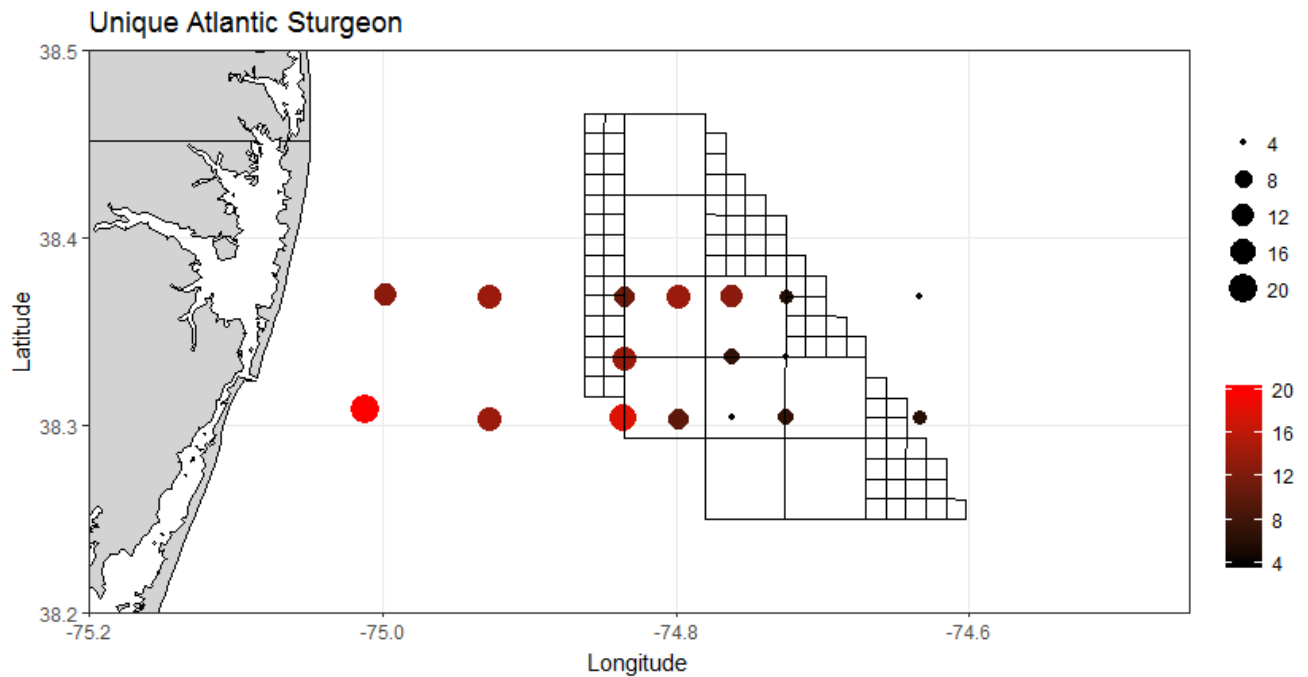


Figure 2. Detections of unique, individually-tagged striped bass and Atlantic sturgeon during the period of deployment (11/9/2016 – 3/28/2017).

11-12 April 2018

MD Wind Energy Area Fish Movement

Cruise Report

Cruise Participants

Mike O'Brien (Chesapeake Biological Laboratory)

Ellie Rothermel (Chesapeake Biological Laboratory)

Aimee Hoover (Chesapeake Biological Laboratory)

Cory Harrington and mate (*F/V Sea Born*)

Wednesday, 11 April, 2018

Conditions

E winds: 0 - 10 kts, Flat seas. Air temperature 28 - 48° F.

Summary

- 0524 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.
- 0716 Arrive at AS1.
- 0719 Communicate with and release receiver. Immediate data download failed, hot swap with spare receiver.
- 0725 Depart AS1 for AS2. Clean, download, and reset receiver in transit.
- 1053 –
Repeat process for AS3, AS4, OS1, OS2 using the previous site's receiver to hot swap.
- 1030
- 1030 Arrive at T-2C (Bailey site, pickup only).
- 1037 Retrieve CPOD.
- 1039 Anchor on deck.
- 1041 Depart T-2C for T-3C.
- 1144 Arrive at T-3C (Bailey site, pickup only).
- 1147 Retrieve CPOD.
- 1150 Anchor on deck.
- 1152 Depart T-3C for ON2.
- 1305 Arrive at ON2.
- 1308 Communicate with, release, hot swap using the previous site's receiver.
- 1310 Depart ON2 for ON1. Clean, download, and reset receiver in transit.
- 1343 Arrive at ON1.
- 1346 Communicate with, release, hot swap using the previous site's receiver.
- 1348 Depart ON1 for AN4. Clean, download, and reset receiver in transit.
- 1421 Arrive at AN4.
- 1424 Communicate with, release, hot swap using the previous site's receiver.

1425 Depart AN4 for A-5C. Clean, download, and reset receiver in transit.

1441 Arrive at A-5C (Bailey site, tending)

1535 Depart A-5C for AM4

1536 Arrive at AM4

1540 Communicate with, release, hot swap using the previous site's receiver.

1542 Depart AM4 for new1. Clean, download, and reset receiver in transit.

1553 Arrive at new1 (Bailey site, tending)

1633 Depart new1

1641 Arrive at AN3.

1647 Communicate with, release AN3 and AN3_250 simultaneously.

1648 Recover AN3.

1649 Recover AN3_250.

1649 Depart for AN3_800. Clean, download, and reset both receivers in transit.

1650 Arrive at AN3_800

1653 Communicate with, release, hot swap using the previous site's receiver. Clean, download, and reset AN3_800 receiver in transit back to AN3.

1702 Hot swap AN3_250.

1706 Hot swap AN3.

1706 Depart AN3 for new2.

1710 Arrive at new2 (Bailey site, tending).

1730 Depart new2 for IS2_800.

1905 Arrive at IS2_800.

- 1911 Communicate with, release receiver.
- 1913 Depart for IS2_250. Clean, download, and reset receiver in transit.
- 1918 Arrive at IS2_250.
- 1920 Communicate with, release IS2_250 and IS2 simultaneously. Clean, download, and reset both receivers in transit back to IS2.
- 1929 Hot swap IS2_800.
- 1932 Hot swap IS2_250.
- 1936 Hot swap IS2.
- 1936 Depart IS2 for T-1C.
-
- 1950 Arrive at T-1C (Bailey site, deployment).
- 1958 Redeploy T-1C.
-
- 2000 Return to Ocean City, MD.
- 2126 Arrive in Ocean City, MD.

Thursday, 12 April, 2018

Conditions

SW winds, 10 - 15 kts. Waves 2-3 ft. Air temperature 45 - 64° F.

Summary

- 0510 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.
- 0730 Arrive at BSB site "InnerSW".
- 0730 **No communications after multiple attempts.**
- 0735 Depart InnerSW for new4.
- 0737 Arrive at new4 (Bailey site, pickup only).
- 0740 Retrieve CPOD.
- 0744 Anchor on deck.

0747 Depart new4 for C5-1.

0800 Arrive at C5-1 (Bailey site, pickup only).

0802 Retrieve CPOD.

0805 Anchor on deck.

0807 Depart C5-1 for AN2.

0825 Arrive at AN2.

0829 Communicate with, release, hot swap using the previous day's final site receiver.

0830 Depart AN2 for AM3. Clean, download, and reset receiver in transit.

0830 –

Repeat process for AM2, AM1, AN1, IN2 using the previous site's receiver to hot swap.

- 1050

1119 Arrive at IN1

1126 Communicate with receiver, establish communication with presumed lost IN1 receiver (deployed August 2017). Successfully release, recover both IN1 receivers. Hot swap with prepared receiver.

1130 Depart IN1 for IS1. Clean, download, and reset receiver deployed in December 2017 in transit.

1202 Arrive at IS1.

1206 Communicate with, release, hot swap receiver.

1208 Return to Ocean City, MD.

1256 Arrive in Ocean City, MD.

Recovery and Deployment Details

Date	Site	Latitude	Longitude	Depth (m)	Arrive	Recover	Deploy	Depart
20180411	AS1	38 18.230	-74 50.125	28.3	7:16	7:19	7:25	7:25
20180411	AS2	38 18.231	-74 47.917	22.8	7:46	7:50	7:52	7:52
20180411	AS3	38 18.238	-74 45.712	20.7	8:07	8:12	8:13	8:14
20180411	AS4	38 18.226	-74 43.507	29.1	8:28	8:32	8:35	8:35
20180411	OS1	38 18.240	-74 38.020	35.4	9:10	9:22	9:24	9:24
20180411	OS2	38 18.255	-74 32.499	40.5	10:01	10:05	10:08	10:08

20180411	ON2	38 22.141	-74 32.519	36.9	13:05	13:08	13:10	13:10
20180411	ON1	38 22.146	-74 38.033	37.2	13:43	13:46	13:48	13:48
20180411	AN4	38 22.134	-74 43.519	29.8	14:21	14:24	14:25	14:25
20180411	AM4	38 20.177	-74 43.508	26.8	15:36	15:40	15:41	15:42
20180411	AN3	38 22.139	-74 45.722	27.4	16:41	16:48	17:06	17:06
20180411	AN3_250	38 22.132	-74 45.899	27.2	16:49	16:49	17:02	17:02
20180411	AN3_800	38 22.133	-74 46.286	26.7	16:50	16:53	16:55	16:55
20180411	IS2_800	38 18.236	-74 56.166	19.5	19:05	19:13	19:29	19:29
20180411	IS2_250	38 18.236	-74 55.792	16.9	19:18	19:21	19:32	19:32
20180411	IS2	38 18.236	-74 55.612	18	19:23	19:23	19:36	19:36
20180412	AN2	38 22.135	-74 47.909	25.2	8:25	8:29	8:30	8:30
20180412	AM3	38 20.164	-74 45.702	25	8:53	8:55	8:56	8:57
20180412	AM2	38 20.166	-74 47.914	22.3	9:13	9:17	9:19	9:20
20180412	AM1	38 20.166	-74 50.100	18.9	9:35	9:42	9:43	9:43
20180412	AN1	38 22.131	-74 50.141	16.5	10:00	10:03	10:04	10:04
20180412	IN2	38 22.135	-74 55.602	13.1	10:43	10:49	10:50	10:50
20180412	IN1				11:19	11:26		
20180412	IN1	38 22.160	-74 59.846	15.2	11:19	11:26	11:29	11:30
20180412	IS1	38 18.531	-75 00.701	17.4	12:02	12:06	12:08	12:08

19-20 December 2017

MD Wind Energy Area Fish Movement

Cruise Report

Cruise Participants

Mike O'Brien (Chesapeake Biological Laboratory)

Ellie Rothermel (Chesapeake Biological Laboratory)

Cory Harrington and mate (*F/V Sea Born*)

Tuesday, 19 December, 2017

Conditions

W winds: 5 - 10 kts, Waves 1 ft. Air temperature 33 - 57° F.

Summary

0645 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.

0953 Arrive at OS1.

1000 Communicate with, release, download, and reset receiver. Update firmware.

1013 Re-deploy mooring. Depart OS1 for OS2.

1053 –

Repeat process for OS2, ON2, ON1, AN4, and AM4.

- 1417

1417 Return to Ocean City, MD.

1650 Arrive in Ocean City, MD

Wednesday, 20 December, 2017

Conditions

NW winds, 10 - 15 kts. Waves 2-3 ft. Air temperature 28 - 54° F.

Summary

0600 Depart Fisherman's Marina, Ocean City, MD aboard the *F/V Sea Born*.

0707 Arrive at IS2_800 (new range test site). Deploy synchronization receiver.

0712 Arrive at IS2_250 (second range test site) and deploy synchronization receiver.

0715 Arrive at IS2.

0717 Communicate with and release receiver. Hot swap with new receiver.

0721 Depart IS2 for AS1. Clean, download, update firmware, and reset receiver in transit.

0756 –

Repeat process for AS1, AS2, AS3, AS4, and AM3 using the previous site’s receiver to hot swap.

- 0928

0945 Arrive at AN3. Communicate with and release receiver. Hot swap with synchronization receiver.

0955 –

Deploy range test receivers at AN3_250 and AN3_800.

- 0959

1010 –

Repeat hot-swap and maintenance-in-transit procedures for AN2, AM2, AM1, AN1, and IN2.

1206

1238 Arrive at IN1 and attempt communication with receiver. Pings are heard on the first attempt (5 of the 7 needed to connect), but **no communication occurs after multiple attempts**.

1328 **Abandon IN1 recovery attempts** and deploy new receiver.

1409 Arrive at IS1. Communicate with, release, download, and reset receiver. Update firmware and redeploy.

1430 Return to Ocean City, MD.

1530 Arrive in Ocean City, MD.

Recovery and Deployment Details

Date	Site	Latitude	Longitude	Depth (m)	Arrive	Recover	Deploy	Depart
20171219	OS1	38 18.240	-74 38.021	35.1	9:53	10:00	10:13	10:13
20171219	OS2	38 18.262	-74 32.512	40.2	10:53	10:56	11:09	11:09
20171219	ON2	38 22.143	-74 32.514	36	11:42	11:46	11:58	11:58
20171219	ON1	38 22.133	-74 38.029	36	12:35	12:37	12:51	12:51
20171219	AN4	38 22.139	-74 43.510	29	13:27	13:31	13:47	13:47
20171219	AM4	38 20.173	-74 43.505	26.1	14:03	14:06	14:17	14:17
20171220	IS2_800	38 18.231	-74 56.168	19.8	7:07		7:10	7:10
20171220	IS2_250	38 18.235	-74 55.795	17.4	7:12		7:13	7:13

20171220	IS2	38 18.241	-74 55.605	18	7:15	7:18	7:21	7:21
20171220	AS1	38 18.230	-74 50.119	26.5	7:56	7:59	8:02	8:02
20171220	AS2	38 18.239	-74 47.921	23.2	8:15	8:18	8:21	8:21
20171220	AS3	38 18.247	-74 45.710	21.3	8:34	8:38	8:40	8:41
20171220	AS4	38 18.230	-74 43.508	29.6	8:54	8:57	8:59	9:00
20171220	AM3	38 20.169	-74 45.701	25.3	9:02	9:26	9:28	9:28
20171220	AN3	38 22.134	-74 45.720	26.8	9:45	9:49	9:53	9:53
20171220	AN3_250	38 22.134	-74 45.889	26.8	9:55		9:55	9:55
20171220	AN3_800	38 22.136	-74 46.275	26.5	9:58		9:58	9:59
20171220	AN2	38 22.142	-74 47.910	25.3	10:10	10:13	10:15	10:16
20171220	AM2	38 20.167	-74 47.970	22.3	10:31	10:36	10:39	10:39
20171220	AM1	38 20.165	-74 50.109	18.9	10:54	10:57	10:59	10:59
20171220	AN1	38 22.133	-74 50.141	15.8	11:16	11:19	11:23	11:23
20171220	IN2	38 22.139	-74 55.615	14	11:59	12:03	12:06	12:06
20171220	IN1	38 22.154	-74 59.844	15.2	12:38		13:28	13:28
20171220	IS1	38 18.531	-75 00.700	17.4	14:09	14:14	14:30	14:30

Individual fish detected: Sept – Dec 2017

<u>Species</u>	<u>Inner</u>	<u>WEA</u>	<u>Outer</u>
Atl. sturgeon	98	106	8
Dusky shark	11	14	2
White shark	4	14	4
Blacktip shark	3	8	2
Winter skate	1		
Striped bass	13	52	
Sand tiger shark	8	4	
Bull shark	2	1	

Smooth dogfish	3	
Atl. bluefin tuna	1	
Atl. Cod	1	
Shortnose sturgeon	1	
Black sea bass	4	10
Cownose ray		1
Sandbar shark		1



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The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

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