Final Report for NC Sea Grant

Minigrant RMG-1513

Quantifying estuarine habitat use by multiple coastal shark species

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Background Information

Though sharks may undergo migrations that cover entire coastlines or ocean basins, many species show fidelity to specific areas within their habitat range. These areas may represent nursery, foraging, or refuging habitat, but in all cases may have a disproportionate influence on the status of shark populations (Chapman et al. 2015). In addition, direct and indirect trophic interactions involving sharks can structure entire marine communities, and fine-scale habitat use patterns by sharks can have observable effects on the behavior and distribution of other species (Heithaus et al. 2012, Burkholder et al. 2013). Therefore knowledge of fine-scale habitat use patterns by sharks is critical to management and conservation of shark populations and the other species within the community.

Passive acoustic telemetry is an effective and rapidly developing method for studying the movements of marine animals. Animals are fitted with transmitters that project an ultrasonic signal that is detected by stationary receivers. Though detection of highly migratory species like sharks depends on receiver location, arrays of acoustic receivers have been effective in recording the movements of sharks in estuarine nursery habitats (Heupel and Heuter 2001). The use of a receiver array with overlapping detection ranges can allow for very fine-scale tracking of tagged fishes, particularly for species with relatively small activity ranges (Espinoza et al. 2011, Fodrie et al. 2015). However, for species that range more widely even within relatively restricted habitats, such fine-scale arrays may not be practical. For this study we assessed the feasibility of using a small-scale acoustic array deployed at different habitat types to identify patterns of habitat use among sharks inhabiting the warm-temperate estuary of Back Sound, North Carolina.

Methods

Sharks were captured using gillnet, longline, and drumline gear during sets deployed between May 15 and October 15, 2015 as part of a shark survey conducted in Back and Core Sounds (Figure 1). Sampling sites were chosen using a stratified-random strategy in which the area from lower Newport River to Jarrett Bay was divided into five major strata based on expected environmental differences, which were then further divided into 6-9 numbered substrata that were randomly chosen before each sampling date. Gillnet gear measured 45 m in length and 2 m in height, and was comprised of five 9-m panels ranging from 2.5- to 14-cm stretched mesh. Longline gear consisted of a 274-m mainline with 20-30 gangions constructed of 1 m of 136 kg-test monofilament line and a 12/0 circle hook. Drumline gear consisted of a single 15-m 408.23 kg-test monofilament leader with a 15/0 circle hook mounted on a 18.14-kg weight. Longline hooks were baited with cut Atlantic mackerel (*Scomber scombrus*) supplemented by locally available baitfish, and the drumline was baited with cut sections of spiny dogfish (*Squalus acanthias*), Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), or striped bass (*Morone saxatilis*). When possible, a combination of multiple gear types was deployed simultaneously within 100 m of each other. Soak time was limited to 30 minutes.

All sharks were identified to species, and total length (TL, mm), fork length (FL, mm), and sex were recorded. Three species were targeted for acoustic tagging: the blacknose shark (*Carcharhinus acronotus*), blacktip shark (*Carcharhinus limbatus*), and bonnethead shark (*Sphyrna tiburo*). Condition was assessed using signs of stress such as coloration and responsiveness to stimuli; sharks in good condition were selected for internal acoustic tagging. Sharks selected for tagging were placed in a state of tonic immobility and gills were irrigated with flowing seawater from a hose inserted into the mouth. Prior to surgery, an incision site was chosen on the left ventral side of the shark approximately 2/3 of the distance between the mouth and pelvic fins. The incision site was disinfected by swabbing with Novalsan and locally anesthetized using a 0.2-mL lidocaine injection, then an approximately 4- to 5.5-cm incision was made through the skin and musculature into the body cavity. A Vemco V16 69 kHz transmitter was inserted into the body cavity through the incision, which was then closed using an interrupted stitching pattern. After surgery, sharks were returned to the water for release and held alongside the boat until normal swimming behavior resumed.

Transmitters were detected on Vemco VR2W 69 kHz receivers deployed in the area surrounding Middle Marsh, an isolated shallow salt marsh habitat in the center of Back Sound, with the goal of determining habitat preferences of the tagged sharks (Figure 1). This site was chosen due to the variety of discrete subtidal habitat types around the perimeter of the marsh and its location between the two main channels running through the estuary, with the assumption that sharks would use these channels to move in and out of Back Sound. Receivers were housed in PVC tubes attached inside half-cinderblocks and connected to the surface by a single polypropylene line tied to a foam crab pot float or "poly ball" buoy. Deployment sites were chosen to ensure that a single subtidal habitat type was spatially dominant within the receiver's detection range.

Four habitat types were represented: deep (> 2 m) channels, shallow sand flats, oyster reefs, and seagrass beds. Receivers were deployed at sites both relatively near and far from Beaufort Inlet, the nearest opening to the Atlantic Ocean. Deployment sites were given a two-letter designation based on the habitat type and distance from the inlet: channel (C), sand flat (S), oyster reef (O), and seagrass (G), followed by near (N) or far (F) from the inlet (e.g. GN would designate the seagrass near inlet site). Four receivers were deployed at seagrass and sand flat sites on May 28, 2015 and an additional four receivers loaned by the Ocean Tracking Network (OTN) were deployed on September 30, 2015 at deep channel and oyster reef sites. Receivers remained in the water until retrieval and data download on November 11-12, 2015. Prior to retrieval, receiver range was tested by lowering a test tag approximately 1 m under the surface for 5 min at 3-4 locations at increasing distances from the receiver. Distances between range test locations and receiver sites were calculated using ArcGIS 10.1 and the percentage of actual tag detections out of expected tag transmissions was plotted against distance.

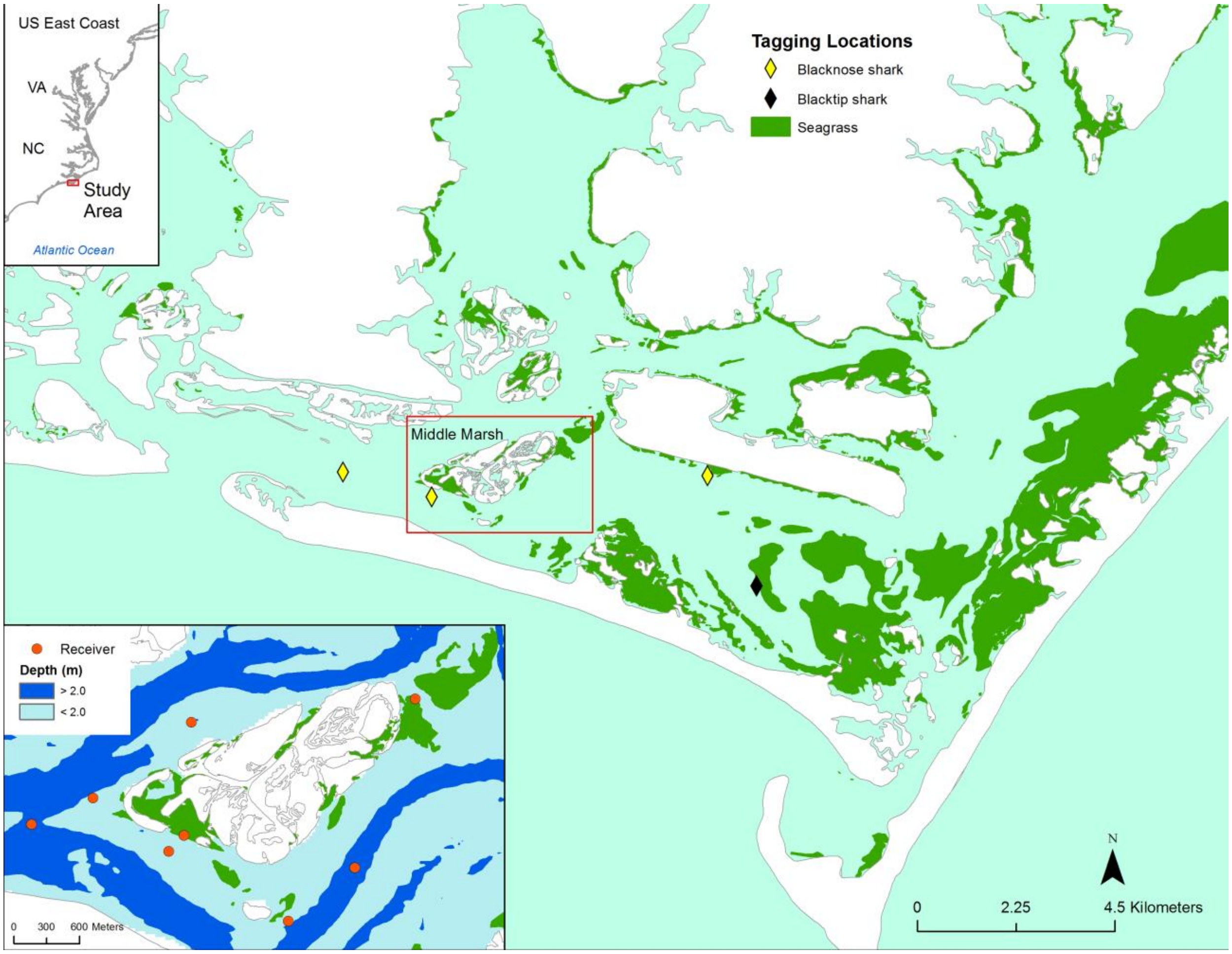

Figure 1. Study area with tagging and acoustic receiver locations.

Transmitter numbers that did not correspond to any of the sharks tagged in this study were identified through the tag database maintained by the Atlantic Cooperative Telemetry (ACT) Network (www.theactnetwork.com) and were included in habitat use analysis with the permission of the researchers responsible for tagging. Habitat preference was assessed for each species by observing the number of detections and number of visits, defined as discrete periods of sustained detection. Temporal patterns of habitat use were also assessed by date and time of day, which was classified by dividing hours of the day into Day (0730-1800), Night (2000-0500) and Twilight (0500-0730 or

1800-2000). For species with a sufficient number of detections, circular statistics were used to calculate the mean hour of presence in the Middle Marsh array and at each receiver. To accomplish this, detection time was converted into numeric values with the hour and proportion of an hour represented by the minute values. These numeric time values were then converted into angles and analyzed using the "circular" package in R. Rayleigh's test of uniformity was used to determine whether detection time showed a statistically significant trend in directedness. A significant result from this test denotes a definite range in detection time, while an insignificant result shows a lack of definitive time preference.

Results

A total of four sharks were acoustically tagged: one blacktip shark and three blacknose sharks (Table 1, Figure 1). All tagged sharks were male. The blacktip shark fell within immature size range for the species, while all tagged blacknose sharks were over the size at maturity. No bonnethead sharks were captured, and available tagging equipment was insufficient to penetrate the skin of one 2.5-m TL bull shark (*Carcharhinus leucas*) caught during the 2015 survey. Inclement weather also forced the release of other blacktip and blacknose sharks without tagging.

Table 1. Information for blacktip and blacknose sharks acousticallytagged and released in Back Sound, NC during 2015 sampling.

Shark ID	Species	Tagging Date	TL (mm)	Sex
1490	Blacktip shark	6/14/15	1295	M
1491	Blacknose shark	6/29/15	1280	M
1488	Blacknose shark	8/9/15	1162	M
1483	Blacknose shark	9/19/15	1005	M

Range testing showed that detection was possible up to 500 m from receivers at deep channel sites, but detection probability dropped sharply in shallow habitat areas, with maximum detection range estimated at 50 m into seagrass, sand flat, or oyster reef habitats. More detailed analysis of detection probability was prevented by a sudden onset of high wind during range testing.

Of the tagged sharks, two blacknose sharks were detected on the array. Blacknose shark 1488 was detected continuously on the GN and ON receivers from August 10, one day after tagging, until November 11 when both receivers were recovered. This suggests that this shark suffered post-release mortality and its transmitter settled on the bottom within detection range of both receivers. Shark 1483 was detected briefly on the SN receiver approximately two hours after tagging and was not detected again for the rest of the study (Figure 2, Figure 3).

Four other transmitters were detected during the study period, corresponding with a bull shark, finetooth shark (*Carcharhinus isodon*), cownose ray (*Rhinoptera bonasus*), and weakfish (*Cynosion regalis*), each tagged by other researchers within the ACT

Network (Table 2). Of these animals, the bull shark, finetooth shark, and weakfish made multiple visits to receiver sites.

Table 2. Species tagged by other researchers during our 2015 sampling, which were detected on receivers placed around Middle Marsh, Back Sound, NC.

Species	Tagging Researcher, Institution
Bull shark	Debra Abercrombie, Stony Brook University
Finetooth shark	Eric Reiyer, Kennedy Space Center Ecological
Cownose ray	Matthew Ogburn, Smithsonian Ecological Research Center
Weakfish	Jacob Krause, North Carolina State University

Most detections were recorded during autumn months, with only the bull and finetooth sharks detected prior to the second round of receiver deployment in September (Figure 2). The bull shark was the only tagged animal to be detected during both summer and autumn months, but was detected more often during autumn, occurring repeatedly during a period from September 30 through October 15.

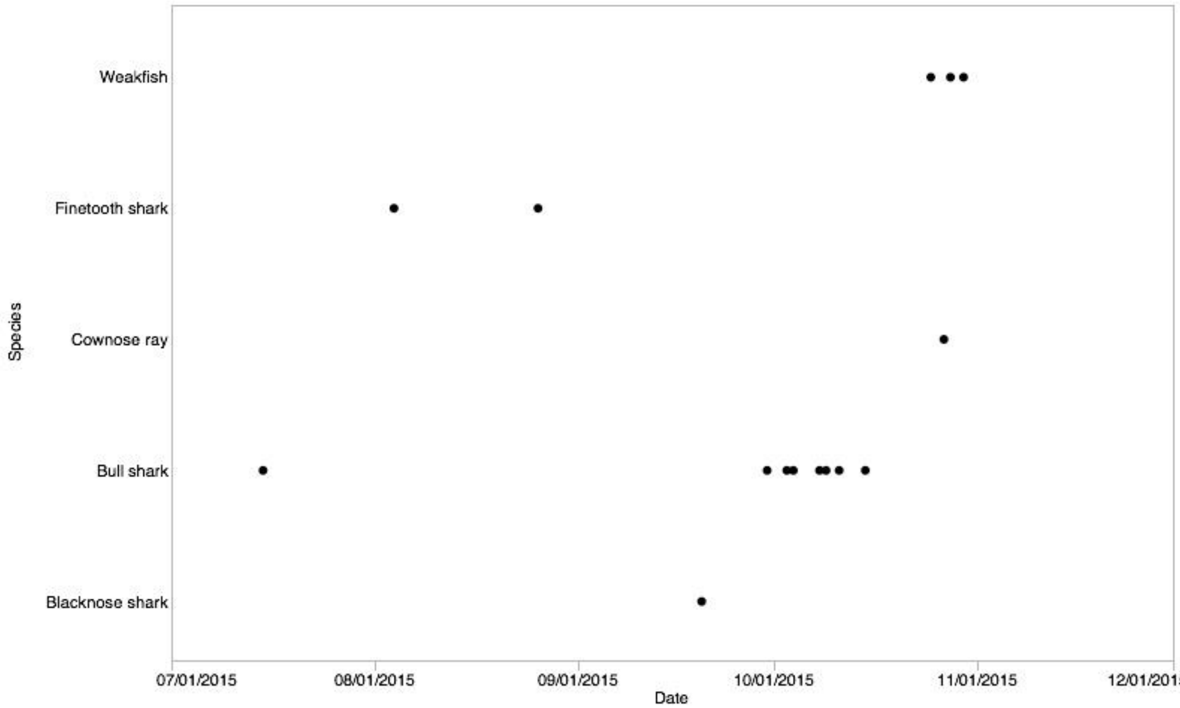

Figure 2. Detection dates for all species detected by receivers deployed around Middle Marsh, Back Sound, NC, during 2015.

Tagged animals were detected by all receivers with the exception of GN, though this receiver did detect the presumed stationary transmitter deployed on blacknose shark 1488 (Figure 3). The bull shark was detected by all receivers except those in seagrass habitats. The SF receiver made up a slight majority of bull shark detections, but was followed closely by the two receivers in oyster reef habitats. An equal number of finetooth shark detections were recorded on the GF and SF receivers. The weakfish and cownose ray were detected exclusively at oyster reef receivers, and the blacknose shark was detected briefly at the SN receiver (Figure 3).

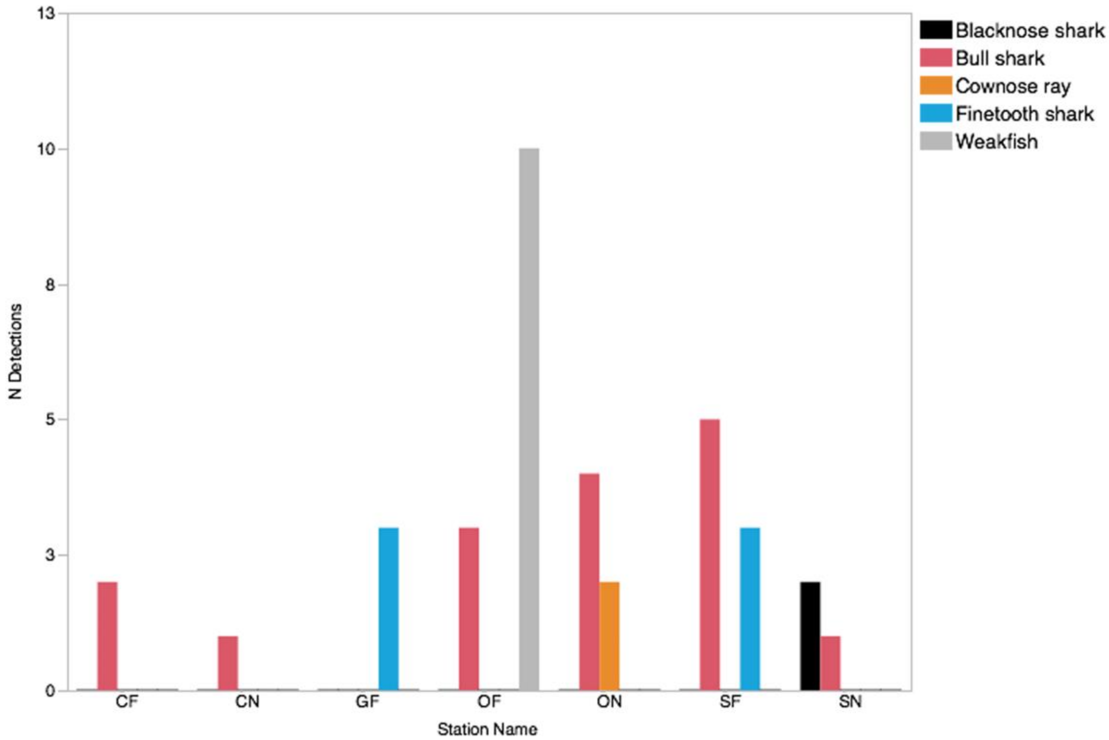

Figure 3. Number of detections of each species by receiver station.

The majority of detections for all species were recorded at night, with the exception of the finetooth shark, which was recorded an equal number of times during day and night hours (Figure 4). The bull shark was the only species detected during twilight hours. The blacknose shark and cownose ray were both only detected at night (Figure 4).

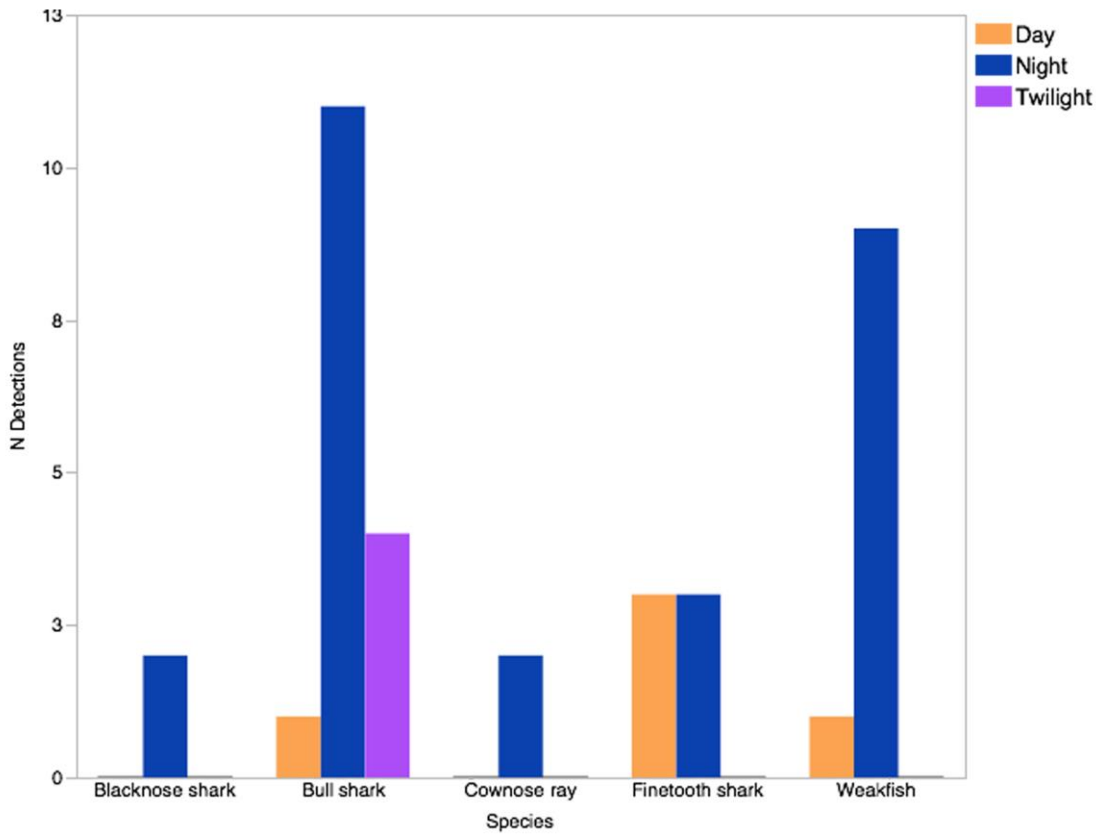

Figure 4. Detections of each species by receivers in Middle Marsh by time of day.

Detections at each receiver station varied by time of day for both the bull and finetooth sharks (Figure 5). The bull shark was detected more often at near-inlet sites during twilight hours than at night, though the only daytime detection of this shark occurred at a site far from the inlet. The majority of nighttime bull shark detections occurred at the sand flat and oyster reef sites far from the inlet. The finetooth shark was only detected at stations far from the inlet, and occurred at a seagrass site during daytime hours and a sand flat at night. All other tagged animals were detected only at one station and strictly occurred at night, with the exception of one weakfish detection during the day (Figure 5).

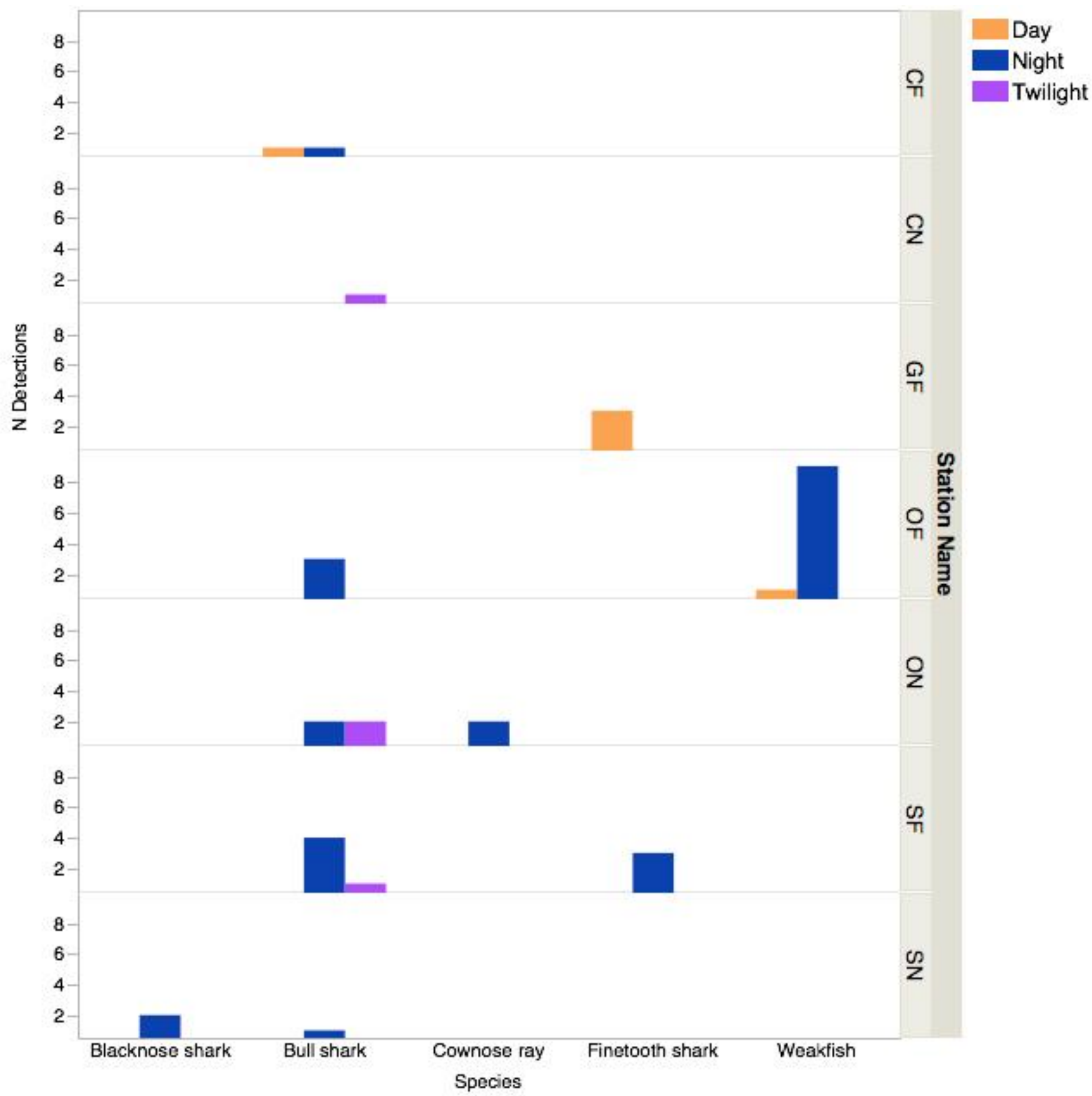

Figure 5. Detections of each species at each Middle Marsh receiver station by time of day.

Of all the tagged animals detected at the Middle Marsh receiver sites, the bull shark was detected the most and was the only species to be detected at multiple receivers in the same day, allowing for more detailed analysis of temporal habitat use patterns. The bull shark appeared to be mostly nocturnal, with time of detection ranging between 20:46 and 7:39 the following morning (Figure 6). The mean hour of detection was 2:36

(± SD 1:02) and Rayleigh's test results showed this time distribution to be significant (Z = 0.5883, $p = 0.003$).

The low sample size of detections precluded statistical analysis of detection time on individual receivers. The CF, ON, OF, and SF receivers were visited on multiple days during the time of receiver deployment, and on October 8 the bull shark was detected over a continuous 20-minute period at receiver SF followed by a 12-minute period at receiver ON. Though receiver SF accounted for the most bull shark detections at a single site, the two oyster reef sites combined had more bull shark detections than the sand flat sites.

Figure 6. Temporal distribution of bull shark detections in the Middle Marsh receiver array, Back Sound, NC during 2015.

Discussion

Though we experienced very limited success in tagging and detecting sharks on our own, detections of other animals tagged by other ACT Network researchers showed that a small acoustic array focused on habitat types can be effective in identifying patterns of habitat use for wide-ranging species. This information can be used to inform further studies on habitat use by highly mobile predators within estuaries.

Every species detected on the array can be considered highly mobile in terms of both long-range migrations and movements within estuaries. Bull sharks are known to be highly migratory and may range widely within estuaries (Curtis et al. 2011, Matich and Heithaus 2014). Cownose rays are well-known for their mass migrations (Smith and Merriner 1987, Goodman et al. 2010) and there is evidence that their high short-term abundance within Back Sound may affect local populations of their prey (Peterson et al. 2001). Weakfish show diel patterns of movement within estuarine habitats, with greater activity ranges at night (Turnure 2010). Though movements of blacknose and finetooth sharks have not been studied in great detail, mark-recapture data show that these species may also travel across large areas of the U.S. southeast coast (Kohler et al. 1998).

Though the number and time distribution of detections were low for all species, some preliminary conclusions can be drawn regarding habitat preferences for the animals detected by the Middle Marsh array. Dates of detection for all species fell within periods of seasonal occurrence in North Carolina waters already documented in the literature (Schwartz 1984, 2012, Goodman et al. 2010). All species appeared to be primarily nocturnal in their occurrence within the Middle Marsh array with the exception of the finetooth shark, for which detections were split evenly between night and daytime hours.

Interestingly, the finetooth shark occurred at a seagrass site during the day and a more-exposed sand flat site at night, though it is impossible to make any definitive conclusions from only two brief occurrences within the array. The blacknose shark and cownose ray were only briefly detected at a single station, while the weakfish made repeated visits to one of the oyster reef sites, primarily at night.

The best set of detections data were recorded from a single bull shark, originally tagged in 2010 off of Jupiter, Florida and measuring 2.13 m TL at the time of tagging (Debra Abercrombie, Stony Brook University, personal communication). This shark showed a significant preference for nighttime hours, but most detections were recorded just after sunset or around the sunrise twilight period, suggesting that this shark passed by Middle Marsh on its way in and out of the estuary, likely using Beaufort Inlet to move between Back Sound and the Atlantic Ocean. Detections during the sunrise twilight period occurred on receivers on the south side of the marsh (sites SF, ON, and CN), while detections on the north side tended to occur during earlier nighttime hours. This may indicate that the bull shark traveled along the channel to the north of Middle Marsh on its way into the estuary and left the estuary by way of the southern channel. Extended visits to the SF and ON sites may represent foraging within these shallow habitat areas, since a shark this size is likely an apex predator in the estuary and would have little need for refuging habitat. Though a single detection of this shark was recorded in July, it made repeated visits to the array area during a period from late September to mid-October. These results show that while this individual bull shark did not appear to show high residency to Middle Marsh, it did make repeated nocturnal or twilight visits to sand flat and oyster reef habitats during the first half of October, possibly related to foraging. The occurrence of a large bull shark in the estuary at night coincides with nocturnal feeding behavior observed across the southeastern U.S. (Driggers et al. 2012), and the seasonal preference for mid-autumn would place this shark in the estuary during the time of peak red drum (*Sciaenops ocellatus*) spawning activity (Luczkovich et al. 2008).

Though detection probability was higher at deep channel sites, few tag detections were recorded at these sites and duration was generally brief. The majority of detections occurred at oyster reef habitats, followed by sand flats, with three species occurring at each. However, detection probability was reduced in seagrass habitats caused by the receiver at the GN site unexpectedly running out of battery in mid-August. Since this receiver and the ON receiver both detected the stationary tag from the blacknose shark mortality, the GN receiver was likely well-positioned to detect the large bull shark if it had entered the seagrass habitat on the southern entrance to Middle Marsh. All receivers in shallow habitats were deployed approximately 50 m or more from the edge of the nearest channel, so the reduced detection range at shallow sites increased the likelihood that detections at those sites actually represented the tagged animal entering the habitat area. Most detections occurred in autumn, which is a time of increased fish abundance on oyster reef habitats in North Carolina estuaries (Pierson and Eggleston 2014), but this may also be an artifact of the oyster reef receivers not being deployed until September 30. Even with this taken into account, our results are suggestive of a greater use of shallow oyster reef and relatively unstructured sand flat habitats than seagrass habitats by large-bodied, highly mobile estuarine predators. However, the tagged bull shark appeared to utilize multiple microhabitat areas, sometimes within the same night, showing that mobile predators may forage across a variety of habitat types. A similar result was found for subadult red drum tracked within Middle Marsh (Fodrie et al. 2015), suggesting that this may be a consistent strategy among high trophic level predators in estuarine environments.

The primary limitation of this study was an insufficient number of tagged sharks, though the presence of other tagged animals in the study area still allowed for a multispecies analysis of habitat use. The sharks tagged as part of this study were captured during a survey designed to determine the habitat preferences of multiple shark species using a stratified-random sampling design, reducing the amount of time spent sampling in optimum habitat for the tagging target species. The results of both the shark survey and this acoustic telemetry project should identify optimum conditions for targeting these species and will make future tagging efforts more efficient. Some tagging opportunities were also lost due to inclement weather, which may be mitigated by a larger-scale project with more sampling days.

Despite its limitations, this study showed that an array of a relatively low number of acoustic receivers placed within discrete habitat types can provide information about fine-scale estuarine habitat preferences for highly mobile predators like coastal sharks. This requires careful choice of deployment sites and a sufficient number of tagged animals in the area, as the highly mobile nature of sharks will reduce detection probability. Middle Marsh proved to be an ideal location, with sharks and fishes tagged by other researchers occurring within the array often enough to draw some preliminary conclusions about habitat use. An expanded tagging effort with a sampling design specifically targeting the species of interest and coordination with other local tagging efforts would improve detection probability while also allowing for true multispecies analysis of habitat use.

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