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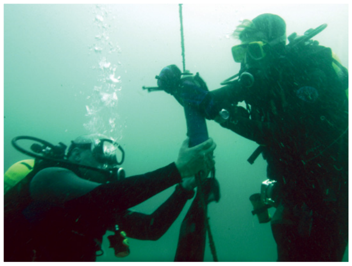
Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean

Authors
Bethany L. Williams
Kimberly Roberson
Joy Young
Matthew S. Kendall

September 2019



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Or direct questions and comments to:

Bethany L. Williams
CSS Inc. under contract to NOAA/NOS/National Centers for Coastal Ocean Science/Biogeography Branch
1305 East West Highway, SSMC4, #9224
Silver Spring, MD 20910
240-533-0359
bethany.williams@noaa.gov

or

Matthew S. Kendall, Ph.D.
matt.kendall@noaa.gov

Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean

Prepared by:
Biogeography Branch
NOAA National Centers for Coastal Ocean Science (NCCOS)
Silver Spring, MD
USA

September 2019

Authors

Bethany L. Williams[1,2], Kimberly Roberson[3], Joy Young[4], Matthew S. Kendall[1]

[1] NOAA National Ocean Service/National Centers for Coastal Ocean Science, Biogeography Branch, Silver Spring, MD, U.S.A.
[2] CSS Inc.
[3] NOAA NOS Office of National Marine Sanctuaries, Gray's Reef National Marine Sanctuary
[4] Florida Fish and Wildlife Conservation Commission

NOAA Technical Memorandum NOS NCCOS 259

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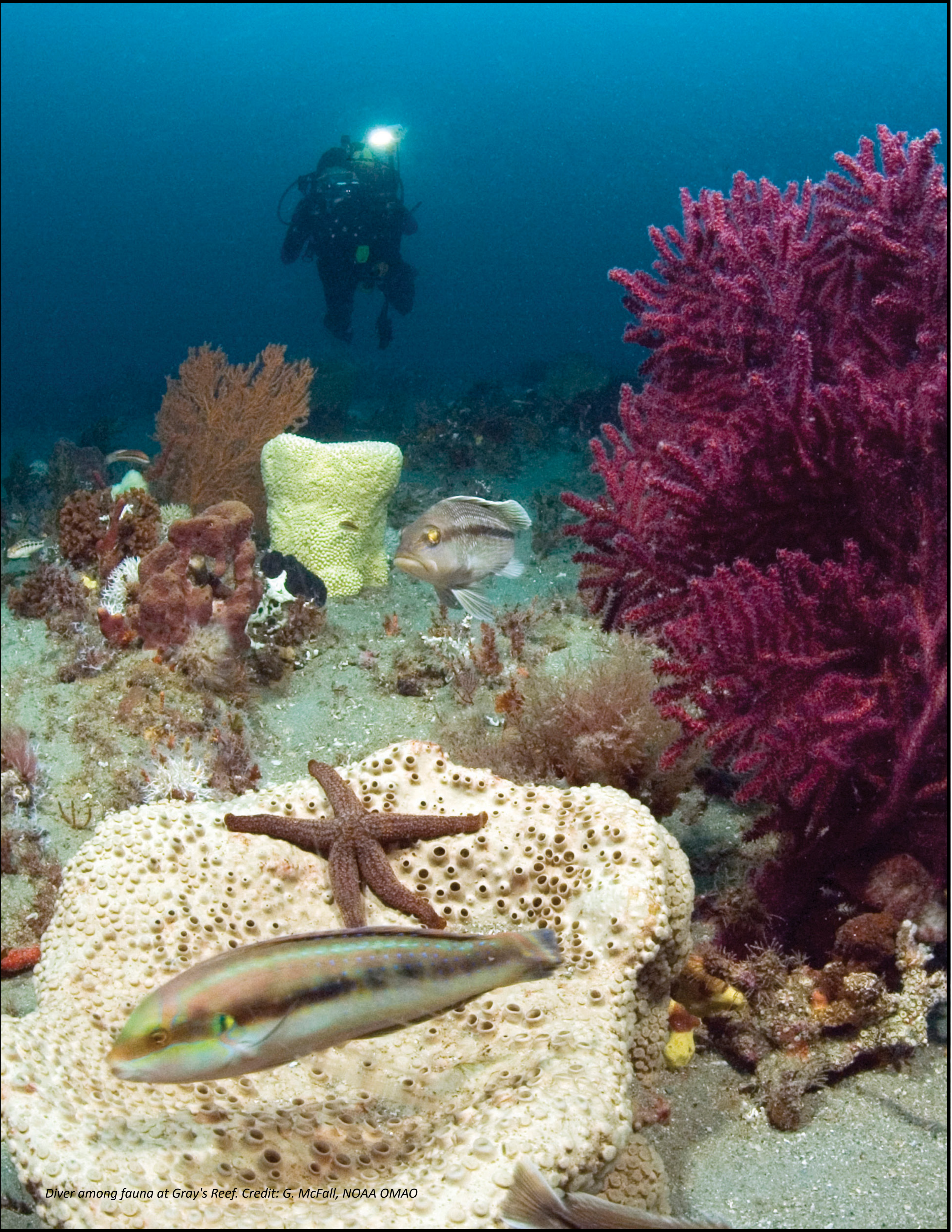
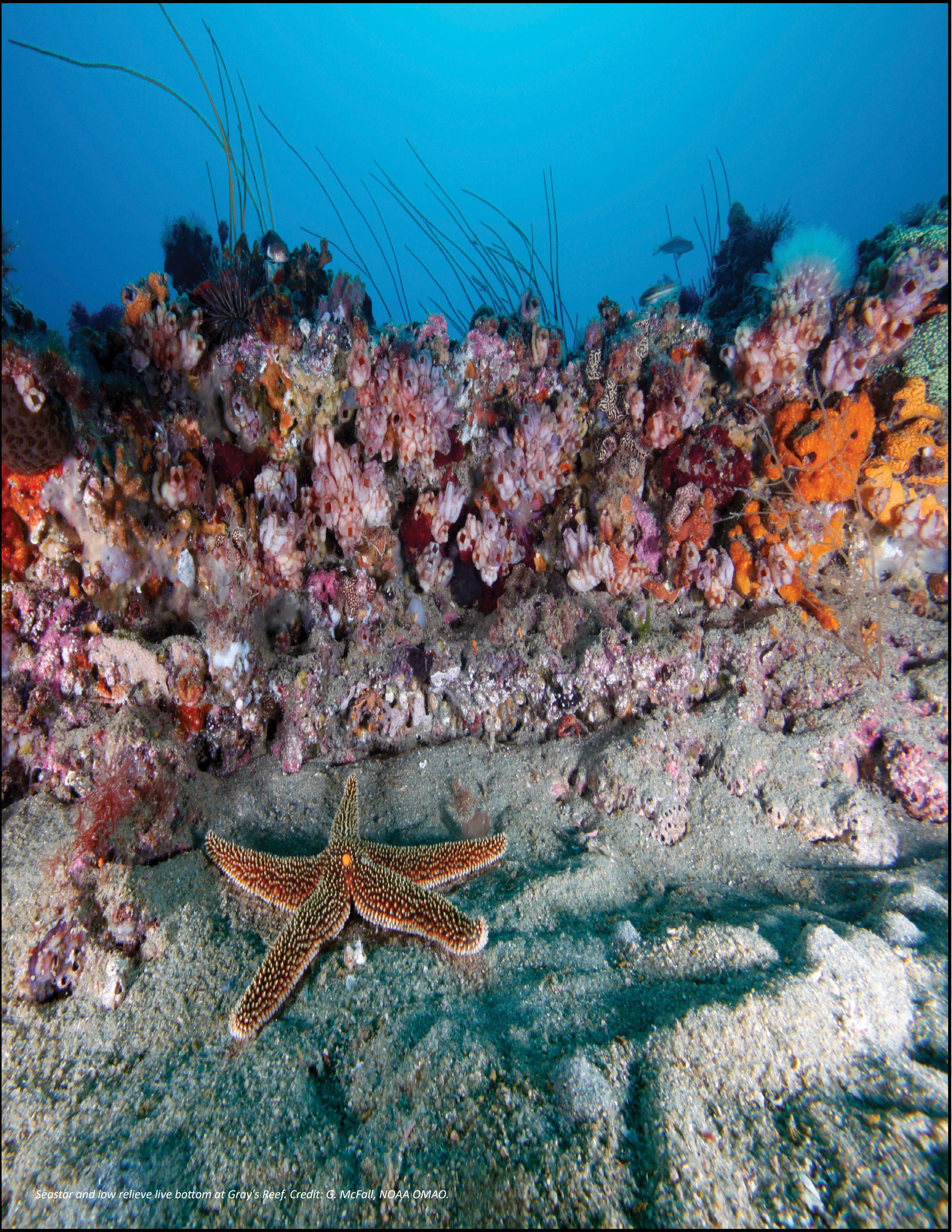


Diver among fauna at Gray's Reef. Credit: G. McFall, NOAA OMAO

TABLE OF CONTENTS

List of Tables

List of Figures



Seastar and low relieve live bottom at Gray's Reef. Credit: G. McFall, NOAA OMAO.

Executive Summary

This study analyzed nearly ten years of acoustic telemetry monitoring at Gray's Reef National Marine Sanctuary, to understand its role in fish movements along the U.S. Atlantic coast. Designated in 1981, Gray's Reef lies 19 miles off the coast of Georgia where water depths are ~60-70 feet and the habitat is comprised of a mosaic of ledges, flat live-bottom, and unconsolidated sediments. Biotic communities there are seasonally influenced by warm waters from the south and cooler temperate waters from the north. The unique geographic location and complex habitat provided by Gray's Reef attracts many transient fish species, however a quantitative understanding of the timing and frequency of their presence is lacking. Here, we identify all transient species that were detected by telemetry receivers at the sanctuary from 2008 to 2017, summarize the timing and seasonality of their visits, and discuss their connectivity to the broader coastal Atlantic ecosystem.

This study relied upon collaboration with the growing community of researchers who implant or attach acoustic transmitters to fish and other animals in order to understand their movement patterns. Presence of tagged fish is recorded when the unique acoustic code that is transmitted by a tagged fish is within the detection range of a receiver. These studies often rely on a broad network of receivers independently owned and deployed by a community of researchers. Since 2008, scientists at Gray's Reef have maintained an array of four to twenty-one receivers at various sites in the sanctuary to study local fish behavior.

We contacted over 32 researchers through the Florida Atlantic Coast Telemetry Network and the Atlantic Cooperative Telemetry Network to identify over 160 transient individuals of eighteen species detected at the sanctuary from 2008-2017. Individual tag owners granted permission to use the data, reviewed draft analyses and interpretations, and in many cases coauthored different sections of the report. Species detected at the sanctuary included a variety of sharks, fish, and sea turtles, two of which are Endangered Species Act listed (Atlantic sturgeon and loggerhead sea turtles). For each species, we provide basic life history information, a summary of detections at Gray's Reef, the location of tagging as well as known positions before arrival and after departure from the sanctuary, and an interpretation of the significance of the observed detection patterns for regional connectivity.

The detection data directly demonstrate a diversity of ways that Gray's Reef is connected to rivers, estuaries, continental shelf, open ocean, and island habitats from Canada to the Bahamas. Individuals traveled to Gray's Reef from as far as 2,400 km away, however the majority were tagged in coastal Georgia and South Carolina. Within the sanctuary, transient species were most commonly detected on receivers deployed at the southeastern and western ledges which line the core of live bottom habitat in the center of the sanctuary. Most fish passed through the sanctuary quickly, with only a few detections on each visit.

Detections of transient species suggest that Gray's Reef may be a hub of migratory activity or a known landmark on the migratory pathway of some individuals. The majority of species were detected at the sanctuary seasonally, suggesting usage of Gray's Reef during annual migrations. These include white sharks, blacktip sharks, Atlantic sturgeon, sandbar sharks (all present in winter/spring), and bull sharks (present in summer/fall). Locations before and after leaving the sanctuary correspond well with known migratory behaviors and indicate usage of the sanctuary on multiple migration legs. Also of note, many individuals made repeated visits to the sanctuary across multiple years, further suggesting Gray's Reef is a known stop-over for some species. For example, Atlantic bluefin tuna, white sharks, bull sharks, blacktip sharks, and Atlantic sturgeon passed through the sanctuary in the same season for up to five years. In contrast, some species, such as tiger sharks and red drum, were present at the sanctuary year round and lacked a clear seasonal pattern.

Continued monitoring via acoustic telemetry at Gray's Reef is critical to enhanced understanding of the role the sanctuary plays in connectivity. The number of transient species and individuals detected at the sanctuary has increased from 0 species in 2008 to 14 in 2016 and 0 individuals in 2008 to 66 in 2016, as the usage of this technology has increased. Also of note, the acoustic receiver array at Gray's Reef is one of the furthest offshore in this region, and fills an important role in cooperative telemetry networks investigating fish migrations along the continental shelf. In order to place Gray's Reef into regional context and better understand its potential function as a migratory hub, it is recommended that acoustic receivers be deployed on nearby live bottom habitats to measure how Gray's Reef compares to other locations.

Diver and reef fauna at Gray's Reef. Credit: G. McFall, NOAA OMAO.

1.0 INTRODUCTION

1.1 CONNECTIVITY AND GRAY'S REEF

Gray's Reef was designated as a National Marine Sanctuary (GRNMS) in 1981. This small sanctuary encompasses 58 km^2 of seafloor at a depth of 18-21 m, and is located 30 km off the coast of Georgia, roughly one-third of the way from the shore to the edge of the continental shelf (Figure 1.1). The sanctuary is centrally located in the Carolinian Atlantic marine-ecoregion (Wilkinson et al., 2009) roughly halfway between the biogeographic breakpoints of Cape Hatteras, North Carolina and Cape Canaveral, Florida (Figure 1.1). This position gives the sanctuary characteristics from warm tropical waters from the south, cooler, more temperate waters from the north, and occasional influence from the Gulf Stream. Gray's Reef is a mosaic of sandy and complex live-bottom habitats that represents one of the largest rocky-outcrops in this region of the continental shelf (Figure 1.2; Kendall et al., 2005). Live-bottom at Gray's Reef is comprised of a carbonate-cemented sandstone foundation comprised of complex ledges and overhangs that are densely colonized by a diversity of sessile invertebrate species (Figure 1.3; Riggs et al., 1996; Freeman et al., 2007). These structural features in turn provide habitat for over 200 species of fish (Kendall et al., 2009; NOAA, 2014). The presence of game fish, such as cobia, black sea bass, grouper species, and king mackerel, make Gray's Reef a popular site for recreational fishing (Kendall et al., 2008; Ehler, 2010; NOAA, 2014).

Mobile fauna, such as bony fish, sharks, and turtles, are commonly found at Gray's Reef (NOAA, 2014). These

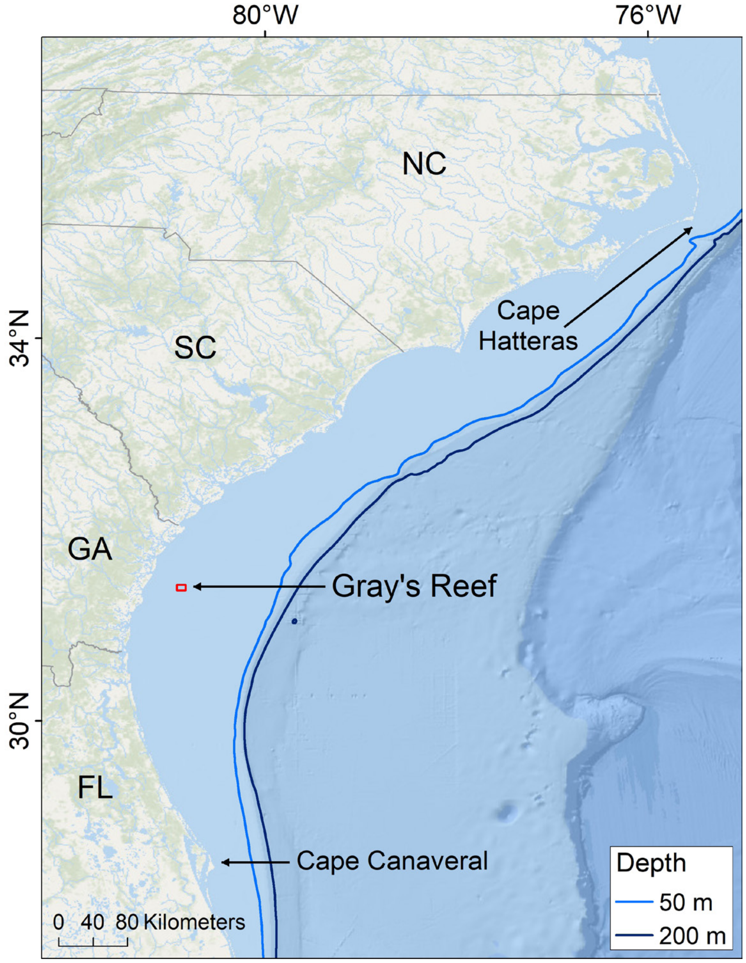


Figure 1.1. Geographic location of Gray's Reef National Marine Sanctuary. Isobath lines applied from Winship et al., 2018.

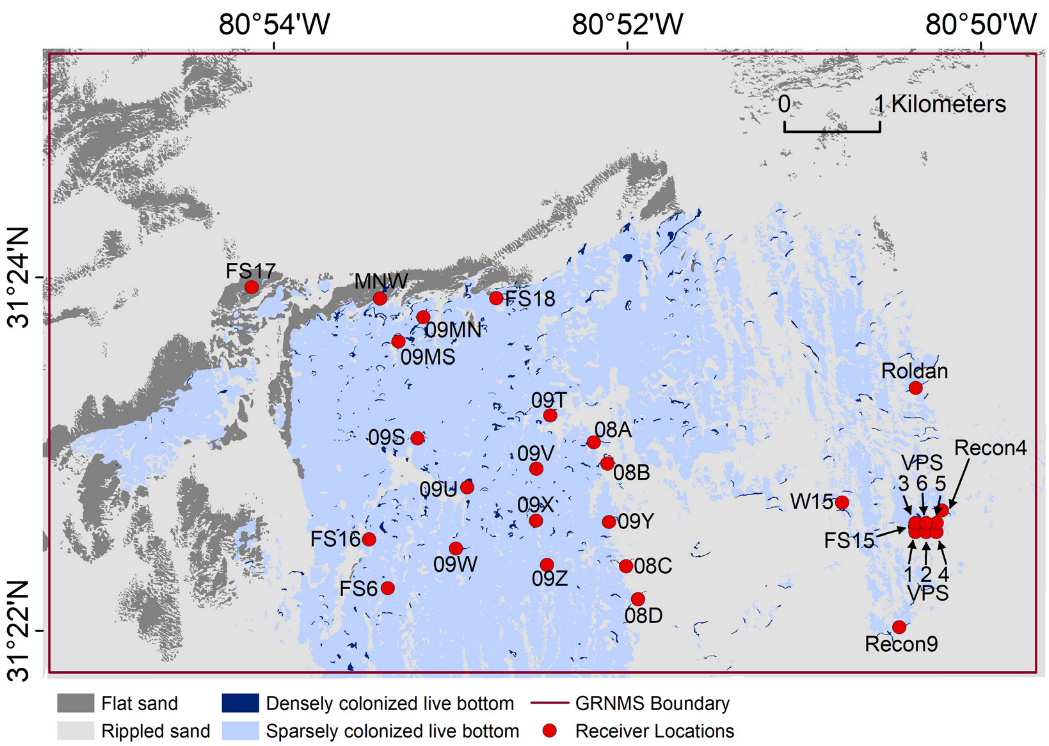


Figure 1.2. Map of substrates and acoustic receiver locations at Gray's Reef. Substrates originally mapped by Kendall et al., 2005.

animals move between habitats for a variety reasons including pursuit of foraging or reproductive opportunities (Quinn and Dittman, 1990; Plotkin, 2003; Block et al., 2011; Hammerschlag et al., 2011; Jessopp et al., 2013; Sequeira et al., 2018). Movements can occur across local, regional, and international scales (Block et al., 2011; Heupel et al., 2015; Harrison et al., 2018), and often take place on a seasonal basis. A common pattern occurring among migrating taxa is poleward movements with increasing springtime temperatures, and equator-ward movement in the fall as temperatures decline. This can be a result of direct physiological tolerances or indirectly due to prey's physiological tolerances or concentrations (Speed et al., 2010; Block et al., 2011). Another common pattern in movements is homing behavior to a particular location or landmark, often along a repeated pathway (Quinn and Dittman, 1990; Speed et al., 2010; Guttridge et al., 2017). While the presence of various transient and migratory species at Gray's Reef has been noted (NOAA, 2014), the role of this protected area in supporting connectivity of these species to the rest of the western Atlantic is not well understood. Because of its geographic location and complex habitat, Gray's Reef attracts a wide variety of transient species and may be an important stopping point or landmark for many during their seasonal migrations or regional movements.

Figure 1.3. Ledge and live-bottom habitat at Gray's Reef. Credit: G. McFall, NOAA OMAO

Understanding patterns of animal movements provides knowledge of their habitat preferences and ecological impacts, and ultimately supports management decisions for these natural resources (Lascelles et al., 2014; Heupel et al., 2015). For example, closure of the permit fishery in Florida was extended after research revealed spawning aggregations during spring and summer (Fla. Admin. Code r. 68B-44.008, 2012). Lemon shark harvest was prohibited in Florida after concentrated aggregations off the east coast were recognized (Fla. Admin. Code r. 68B-44.008, 2012; Reyier et al., 2008; Reyier et al., 2014). At Gray's Reef, knowing the timing and seasonality of sanctuary use by threatened (e.g. loggerhead sea turtles, Atlantic sturgeon) or fisheries species (e.g. cobia, king mackerel), can help managers educate visitors about sanctuary resources and promote sustainable use. Because Gray's Reef is only accessible by boat, educational programs are also critical to communicating the sanctuary's importance to those unable to visit it directly. Showcasing animals that move through Gray's Reef, and thus, the sanctuary's broader role in the regional ecosystem, could be a valued component of the sanctuary's educational programs.

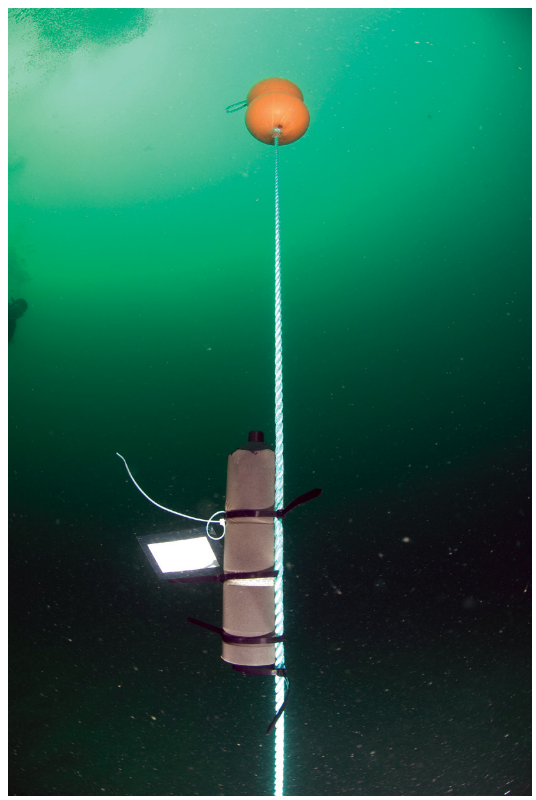


Figure 1.4. Acoustic receiver listening for transmitters implanted in fish at Gray's Reef. Credit: NOAA, GRNMS

1.2 ACOUSTIC TELEMETRY

Acoustic telemetry is a common tool used to passively track mobile aquatic animals (Hussey et al., 2015). With this technology, acoustic receivers (Figure 1.4) are strategically placed underwater throughout a region of interest where they record signals from acoustic transmitters. These acoustic transmitters, or "tags", are placed internally or externally on individual animals (Figure 1.5) and emit unique IDs that the receivers can detect and record. When a receiver detects a tag, it records the presence of the individual in time at the location of the receiver.

*Figure 1.5. Surgical implantation of acoustic transmitter in a grouper (*Mycteroperca sp.*) at Gray's Reef. Credit: D. Dumont, UGA MAREX*

At Gray's Reef, acoustic telemetry monitoring began in spring 2008. Since then, receivers (manufactured by VEMCO, models VR2 and VR2W) (https://www.vemco.com) have been deployed at 30 sites at various times throughout the sanctuary (Figure 1.2). Initially, resident fish (i.e., snappers, groupers, and black sea bass) were tagged to examine their habitat use within the sanctuary (Carroll 2010). Since 2013, fish have not been tagged within the sanctuary, however, receivers have been maintained at several stations within Gray's Reef to facilitate the tracking projects of other researchers working in the region (Figure 1.6). These have been continuously detecting and recording the presence of any organisms tagged by others resulting in a long-term monitoring dataset of animal presences in this protected area. Over the last 9 years (2008-2017) over 1,142 tags have been detected.

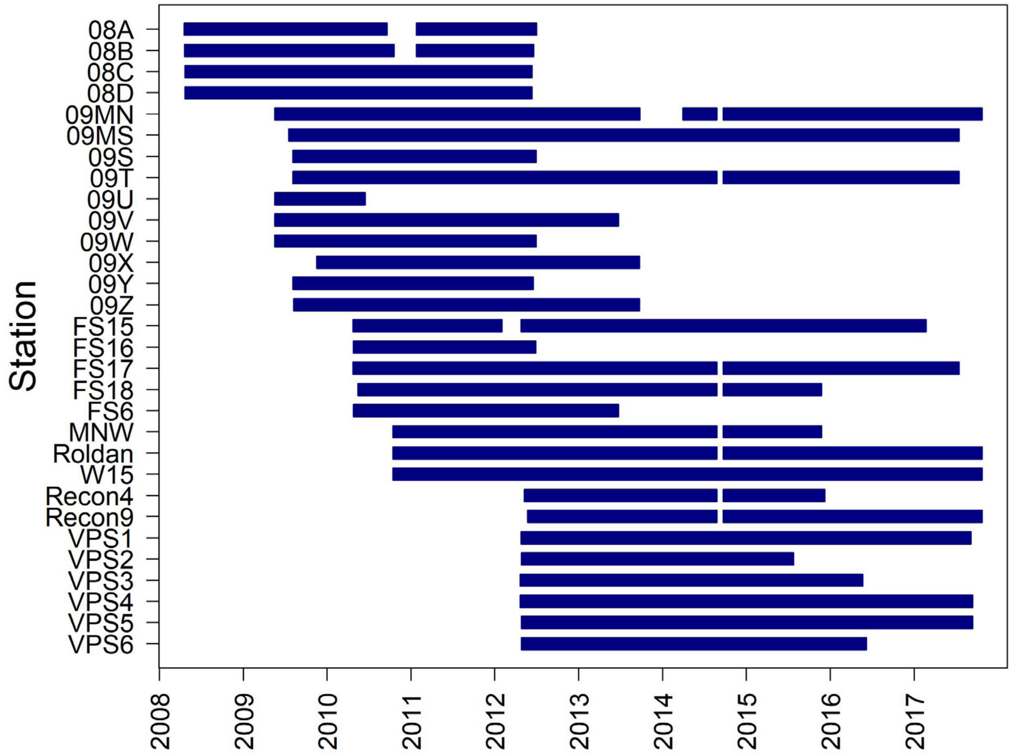


Figure 1.6. Station coverage by acoustic receivers throughout the study period.

By capitalizing on the coverage of a larger geographic space by the members of the network as a whole, a much broader understanding of animal movements and connectivity, such as in this study, can be captured. Researchers have formed collaborative networks for sharing acoustic telemetry detection data for these highly migratory species. These networks enable a much broader understanding of animal movements than can be accomplished by researchers working alone, by capitalizing on the coverage of a larger geographic space by members of the network as a whole. One key to the function of these networks is the common usage of acoustic telemetry technology and equipment developed by VEMCO (https://vemco.com/). Equipment including transmitters, receivers, and underlying software, makes data easily shared among research groups. Gray's Reef lies in the core of the geographic region encompassed by the Florida Atlantic Coast Telemetry Network (FACT; https://secoora.org/fact/) and the southern edge of the region covered by the Atlantic Cooperative Telemetry Network (ACT; http://www.theactnetwork.com/). As of 2018, there were 41 organizations in FACT operating over 900 acoustic receivers and over 120 researchers in ACT. FACT and ACT have been key nodes for the sharing of telemetry data and collaborations among researchers along the Atlantic coast and play a critical role in the effort to understand how Gray's Reef connects to the broader U.S. Atlantic coastal ocean ecosystem.

1.3 OBJECTIVES

Our over arching goal was to summarize the role of Gray's Reef in the movements of a variety of biota along the U.S. Atlantic coast using the acoustic telemetry dataset from 2008-2017. Specifically, our goals were to 1) identify all the species detected at Gray's Reef; 2) quantify the duration of their visits to Gray's Reef; and 3) understand the spatial and temporal properties of their arrival and departure from Gray's Reef. Ultimately, we summarize the importance of Gray's Reef for a wide variety of biota, their seasonal migrations, and connectivity to other areas along the east coast of the U.S.

It is also important to note what this report does not include. Our objective was not to generate a complete track of all the movements of individual animals that have passed through the sanctuary. Instead, we sought to focus more narrowly on the sanctuary's role in connectivity throughout the U.S. Atlantic coastal ocean. Additionally, we focus on the individuals' presence at Gray's Reef, rather than their movements within the sanctuary. We leave it to others to extensively report the movements of the individual species that are the focus of their research.

Introduction

Black Sea Bass at Gray's Reef. Credit: G. McFall, NOAA OMAO

Diver deploying acoustic receiver. Credit: NOAA GRNMS

2.0 METHODS

2.1 TAG IDENTIFICATION

To identify all the tagged species that utilize Gray's Reef, all acoustic telemetry detection data from 2008-2017 were compiled. Individual tag ID codes detected at Gray's Reef were matched with those found in the FACT and ACT Networks. Once tags were matched to a research group and transmitter type, we compared detection dates to tag deployment and tag expiration dates. Any detections of tag IDs that occurred prior to records of tag deployment were deemed false detections and therefore excluded. Detections that occurred well beyond expected dates of tag expiration were also excluded (defined as manufacturer's estimated maximum days of battery life plus 1/3 of battery life). Tags that were not found within FACT or ACT databases were sent to VEMCO for possible matching to owners.

Prior to contacting tag owners, we solicited input and conducted initial outreach with potential collaborators at the 2018 Summer FACT meeting and the 148th annual meeting of the American Fisheries Society. At those meetings, we discussed the goals of this project and best practices to collaborate with various researchers, including their specific needs and data embargoes. Then, researchers whose tags were detected at Gray's Reef were invited to collaborate on the summaries of those species. Tag owner databases were queried for the following data for each individual fish: 1) tagging location, 2) location prior to arrival at Gray's Reef, 3) location after departure from Gray's Reef, 4) body length at the time of tagging, 5) sex, and 6) life stage.

2.2 ANALYSIS

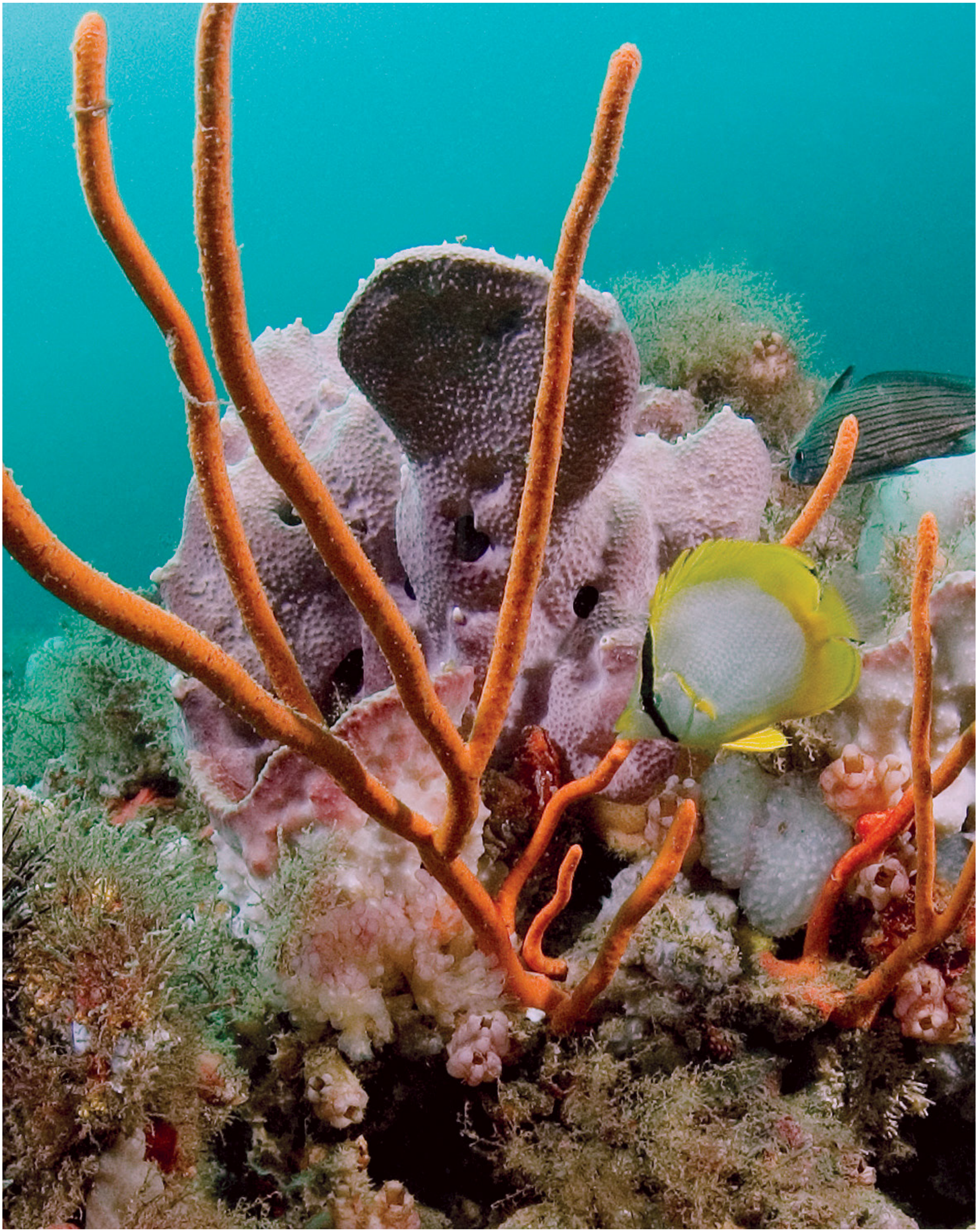
False detections of a tag commonly occur in acoustic telemetry (Pincock, 2012). For this project, we worked directly with tag owners to determine if a detection was potentially false and should therefore be removed from the analysis. This decision was based on the ping rate of each tag, number of detections, duration in between each detection, and basic species ecology (e.g. typical behaviors and swimming speed). In addition, any tags that could not be matched to a researcher were also removed from analysis.

All summary statistics and analyses were conducted in R Version 3.4.3 (R Core Team, 2017). To summarize the timing and seasonality of each individual's visitation to Gray's Reef, we based seasons on meteorological partitioning (spring: Mar. 1 – May 31, summer: June 1 – August 31, fall: Sept. 1 – Nov. 30, and winter: Dec. 1 – Feb. 28). To understand scale and directionality of individuals' movements through Gray's Reef, we compared their geographic location prior to their arrival and after their departure to the coordinates of their first (or last) detection at the sanctuary. Distances between these locations and Gray's Reef were calculated as straight line distances using the pointDistance function in the raster package (Hijmans, 2017). We also compared the distance between each individual's tagging location and Gray's Reef, using the same calculation. To understand timing of their movements to and from Gray's Reef, we calculated the difference in days between detections outside and within the sanctuary.

Summary statistics were calculated at the species level, and if warranted, separately for each life stage and/or sex represented by the species. A completely uniform approach for analysis and summarizing detection patterns was not suitable among all taxa for several reasons. Many species differed dramatically in the timing, number, and duration of their detections not only at Gray's Reef, but also in their dates of arrival and departure. Instead, the summary of detection patterns was optimized separately for each species to best depict their spatial and seasonal movements based on available data. In some cases, we included their locations before and after their visit to Gray's Reef. In others, we were unable to include this information due to data embargo or it was unknown. For some species, duration of a visit by an individual to the sanctuary was calculated as the number of consecutive days the individual was present, whereas for other taxa visit duration was not calculated because they were detected across many days at the sanctuary, but not consistently. The number of individuals of each species that were detected at Gray's Reef also varied widely. These differences in sample size also limited the analytical possibilities for many species. Furthermore, researchers contributing data to this project were in various stages of compilation and publication of their detection data. Network agreements typically entitle tag owners with control over how their data are used when detected on network receivers. With respect to those policies and due to the varying stages and partial embargoes of information, we do not share an entirely consistent level of information for each species. Consequently, not all collected information for every species (e.g. detections directly before or after visits to the sanctuary) can be included until data owners have completed their own analyses and publication.

In addition to species-specific summaries, we conducted similar analyses to understand how transient species, as a whole, use Gray's Reef. To understand overall temporal patterns in transient species' use of Gray's Reef, we summed the number of individuals and detections at the sanctuary both annually and seasonally. Because the number of receivers deployed at the sanctuary varied through time (Figure 1.6) and impacts the potential for detections (i.e. more receivers results in more detections), we standardized the summed number of individuals and detections by the maximum number of receivers deployed in the sanctuary during the corresponding year or season. To understand overall spatial patterns of transient species' detections within Gray's Reef and which receivers may be more important for continued monitoring, the number of detections, individuals, and species were summed for each receiver station. These values were standardized by the number of months a receiver was deployed at that specific station and plotted.

Methods



Spotfin Butterfly fish and live bottom at Gray's Reef. Credit: G. McFall, NOAA OMAO

Divers deplying acoustic receiver. Credit: NOAA GRNMS

3.0 RESULTS

3.1 OVERVIEW

From May 2008 to September 2017, 11,354,341 detections were recorded on the acoustic receiver array at Gray's Reef. The vast majority of these detections (99.95%) were matched to tags deployed in sanctuary studies or found within the FACT and ACT tag databases (hereafter referred to as "matched detections"). The remaining 5,409 detections from 774 tagged individuals (0.048% of total detections collected) were not matched to any tags identified in FACT and ACT databases, could not be linked to owners by VEMCO because they were false detections or due to privacy constraints, and were therefore removed from analysis as their owners could not be identified. The majority (62.3%) of matched detections were from resident fish species tagged at the sanctuary (e.g. gag grouper, scamp grouper, black sea bass), and range test tags (37.6%) which are not the focus for this study (Carroll, 2010; Mathies et al., 2014). The remaining 16,244 detections (0.14% of matched detections) were matched to individuals not tagged in the sanctuary. Of these, 9,149 were removed from analysis because they were deemed false or not applicable to this study. For example, some detections were from a transmitter deployed on an AUV, others were from individuals that were tagged with multiple transmitters. After unusable and false detections were removed, 7,095 detections

Table 3.1. Species detected at Gray's Reef.

Species	Number of Individuals	Number of Detections
Sharks	95	3,749
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	1	3
Blacknose shark (*Carcharhinus acronotus*)	4	97
Blacktip shark (*Carcharhinus limbatus*)	6	72
Bonnethead (*Sphyrna tiburo*)	4	448
Bull shark (*Carcharhinus leucas*)	17	832
Great hammerhead shark (*Sphyrna mokarran*)	3	104
Lemon shark (*Negaprion brevirostris*)	3	59
Sand tiger shark (*Carcharias taurus*)	6	336
Sandbar shark (*Carcharhinus plumbeus*)	4	85
Tiger shark (*Galeocerdo cuvier*)	25	982
White shark (*Carcharodon carcharias*)	22	731
Bony Fishes and Sturgeon	67	3,282
Atlantic Bluefin tuna (*Thunnus thynnus*)	2	4
Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*)	37	976
Cobia (*Rachycentron canadum*)	22	603
Red drum (*Sciaenops ocellatus*)	4	1,690
Southern flounder (*Paralichthys lethostigma*)	1	5
Striped bass (*Morone saxatilis*)	1	4
Other		
Loggerhead sea turtle (*Caretta caretta*)	2	64
Total	**164**	**7,095**

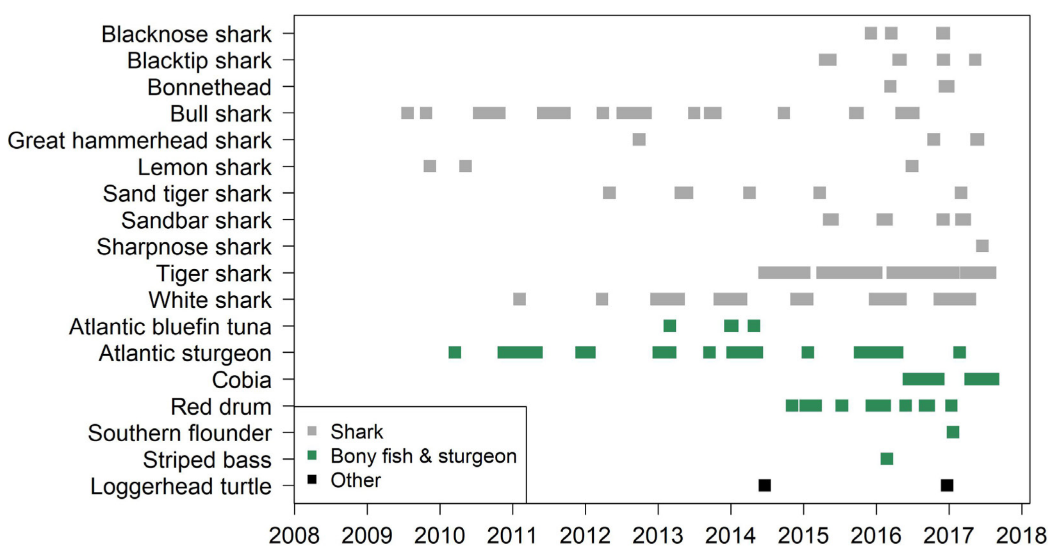


Figure 3.1. Detections of all tagged individuals of each species throughout acoustic receiver deployment at Gray's Reef. Receivers were deployed from May 2008 - September 2017.

were left in the dataset, making up 0.062% of the matched detections. These detections comprised the final dataset analyzed in this study.

Eighteen different transient/non-resident species, totaling 164 individuals, were detected at Gray's Reef, including eleven species of sharks, six species of bony fishes and sturgeon, and one species of turtle (Table 3.1; Figure 3.1). The majority of these individuals (57.9%) were sharks. Bony fish and sturgeon comprised 40.8% of the individuals. For all but three species, multiple individuals were detected. Two Endangered Species Act listed species were detected: Atlantic sturgeon and loggerhead sea turtles (76 FR 58868, October 24, 2011; 77 FR 5879 April 6, 2012; 77 FR 5913 April 6, 2012). Individuals were tagged as far away as 2,341 km (Canadian waters) from Gray's Reef and as close as 16.4 km (Figure 3.2). Mean (± S.E.) distance from tagging location to the sanctuary was 510 ± 41.5 km.

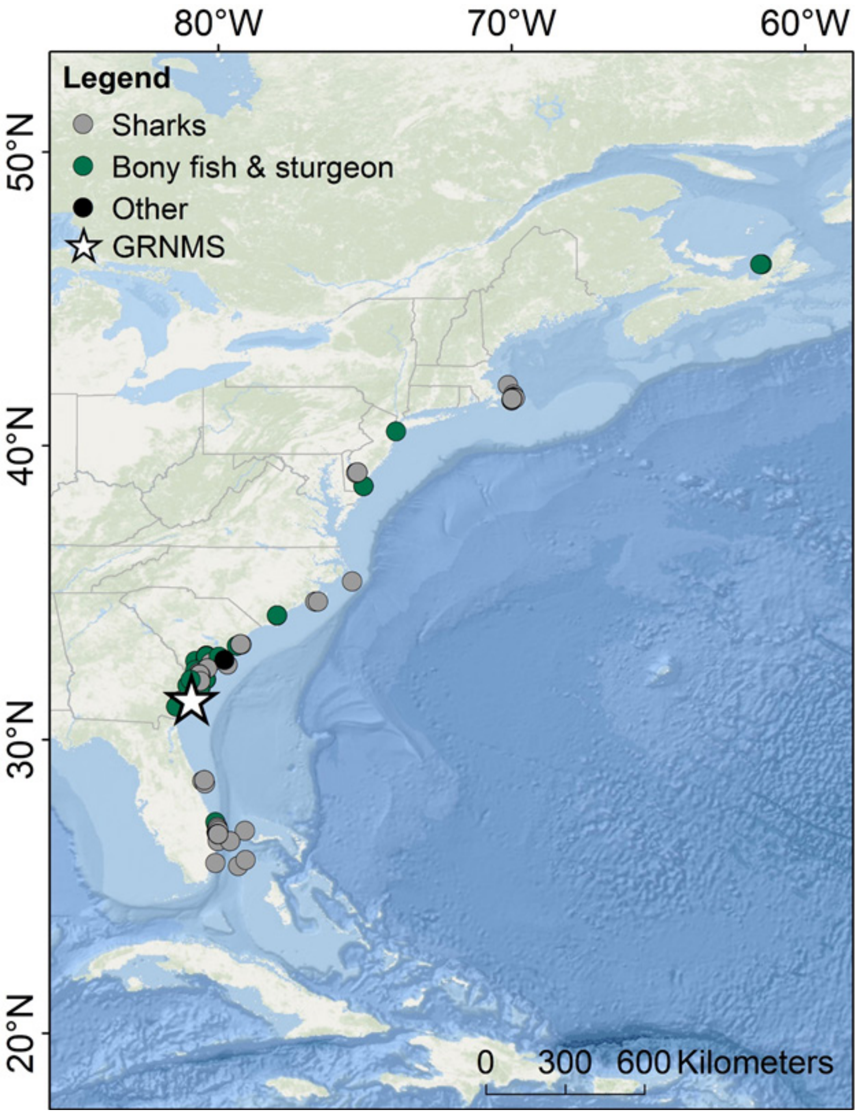


Figure 3.2. Tagging locations of individuals detected at Gray's Reef between 2008 and 2017.

Lemon sharks. Credit: Tanya Houppermans

3.2 ELASMOBRANCHS

3.2.1 Atlantic Sharpnose Shark

(Rhizoprionodon terraenovae)

*Figure 3.3. Adult Atlantic sharpnose shark (*Rhizoprionodon terraenovae*). Credit: NOAA*

Species Description

The Atlantic sharpnose shark (*Rhizoprionodon terraenovae*; Figure 3.3) is a small coastal mesopredator that feeds on small fishes, mollusks, and turtle hatchlings. Maximum size is 83 cm pre-caudal length (PCL) (Loefer and Sedberry, 2003; Delorenzo et al., 2014). They occur from southern Canada to Mexico, but are most common along the southeast U.S. and Gulf coasts (Castro, 1983). This species reaches maturity at 2.2-2.6 years (0.59-0.61 m PCL) and reproduces annually with a mean litter size of four pups (Loefer and Sedberry, 2003). On the southeast U.S. coast, this species migrates inshore to mate and pup from May-June and moves offshore into deeper waters to overwinter (Castro, 1983; Castro, 1993). Atlantic sharpnose sharks are fished commercially and recreationally throughout their range and are considered not overfished (SEDAR, 2014).

Table 3.2. Atlantic sharpnose shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Eric Reyier	Kennedy Space Center Ecological Program	1	3	June 2017

Movements Through GRNMS

One adult male Atlantic sharpnose shark (65 cm PCL), originally tagged off Cape Canaveral, Florida in August 2016, was detected once at Gray's Reef in June 2017 (Figure 3.4; Table 3.2). Twelve days prior to arriving at Gray's Reef, this individual was detected 56.3 km northeast near the mouth of the Ogeechee River, Georgia (Figure 3.4). Nine days after leaving the sanctuary it was detected 56.9 km southeast of Gray's Reef (Figure 3.4).

Significance of Connectivity

While it is not possible to make generalizations about the role of Gray's Reef for Atlantic sharpnose sharks based on the detections of one individual, it is interesting to note the presence of this species. As detections occurred in the summer, this individual could have been moving throughout coastal Georgia for reproductive purposes. While this species is one of the most common small coastal sharks in the southeastern U.S. region (Castro, 1983; Branstetter, 1990), within the FACT and ACT networks, they have only been tagged off Cape Canaveral, Florida, which may be a reason only one was detected at Gray's Reef.

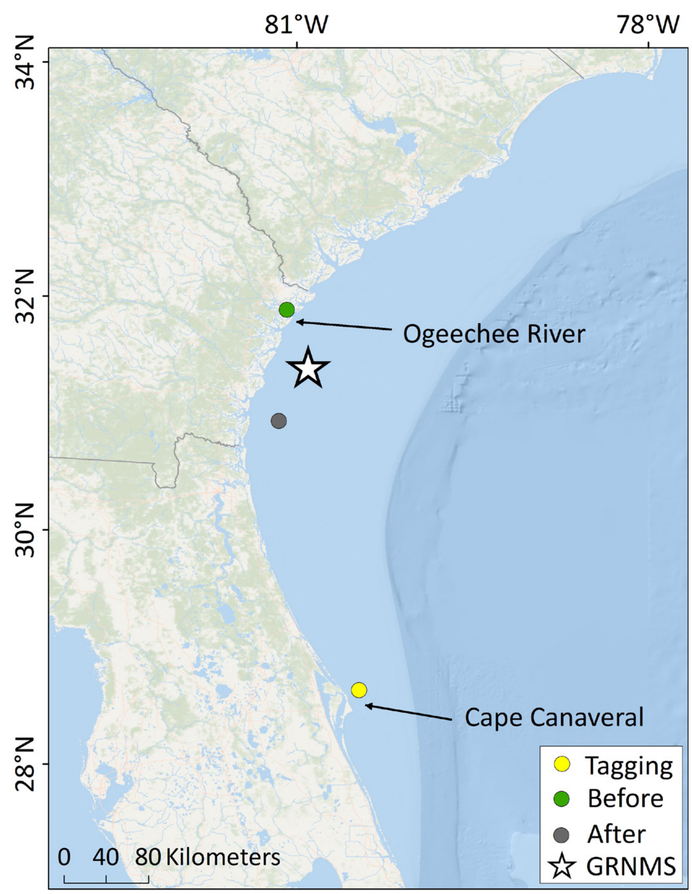


*Figure 3.4. Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) locations of tagging, before, and after its visit to Gray's Reef.*

Acknowledgements
We thank Dr. Eric Reyier and the Kennedy Space Center Ecological Program for contributing detections and individual metadata to this study.

Juvenile sharpnose shark. Credit C. Collatos, Coastal Carolina University

3.2.2 Blacknose Shark *(Carcharhinus acronotus)*

*Figure 3.5. Adult blacknose shark (*Carcharhinus acronotus*). Credit: E. Hoffmayer, S. Iglesias, and R. McAuley, NOAA NMFS.*

Species Description

Blacknose sharks (*Carcharhinus acronotus*; Figure 3.5) are small coastal mesopredators that feed on small fishes and grow to a maximum size of 177 cm fork length (FL) (Compagno, 1984). They occur in the western Atlantic Ocean from North Carolina to Brazil and in the Gulf of Mexico and Caribbean (Compagno, 1984). Reaching maturity at 89-90 cm FL (4.3-4.5 years), blacknose sharks reproduce every two years, pupping in the late spring-early summer with litters ranging from 1-5 pups (Driggers et al., 2004a; Driggers et al., 2004b; SEDAR, 2007). Many individuals migrate northward to North Carolina in the summer and return to Florida or offshore to overwinter, however some remain off the coast of Florida year-round (Schwartz, 1984; Ulrich et al., 2007; SEDAR 2011). Commonly caught as bycatch or by recreational anglers, this species is now considered overfished in the southeast U.S. (Cortes, 2002; SEDAR, 2011).

Table 3.3. Blacknose shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Eric Reyier	Kennedy Space Center Ecological Program	4	97	Dec. 2015-Dec. 2016

Movements Through GRNMS

Three adult (mean ± S.E. = 94.0 ± 3.2 cm FL) and one sub-adult (86.0 cm FL) blacknose sharks have been detected at Gray's Reef, each on one unique day, from 2015-2016 (Figure 3.6, Table 3.3). All individuals were tagged off Cape Canaveral, Florida in 2015, a mean of 312.5 (± 3.2) km from Gray's Reef (Figure 3.7A). Three of four individuals (all male) visited the sanctuary during the late fall-early winter months (Figure 3.6). Two of these males were detected 72.5 and 165.3 km north 11 and 10 days prior to their arrival at Gray's Reef, respectively (Figure 3.6; Figure 3.7C). The third male was detected 46.6 km south of the sanctuary 7 months before its arrival, likely during a separate migration cycle (Figure 3.6; Figure 3.7C). After their departure, one was detected 30.8 km south of the sanctuary 10 days later (Figure 3.6; Figure 3.7C). The remaining two males were not re-detected along the Atlantic coast until the following spring (Figure 3.6; Figure 3.7C). One individual (female) visited Gray's Reef in the spring, and was detected off coastal Georgia, south of Gray's Reef 2 days before arriving at the sanctuary and 12 days after leaving (Figure 3.6, Figure 3.7B).

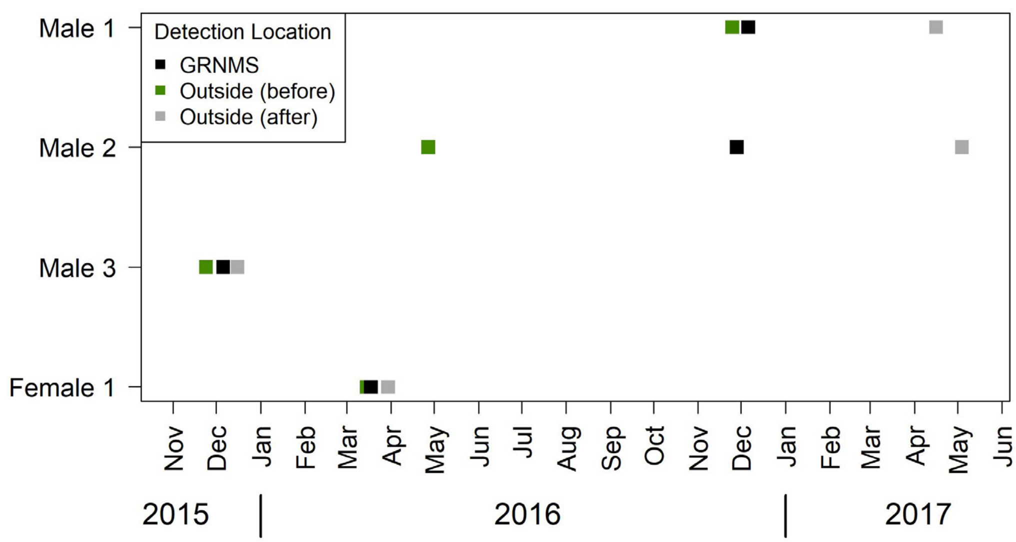


*Figure 3.6. Detections of individual blacknose sharks (*Carcharhinus acronotus*). Black points indicate detections at Gray's Reef. Green points indicate the last detection outside of Gray's Reef, directly before their detection at the sanctuary. Grey points indicate the next detection outside of Gray's Reef, directly after their detection at the sanctuary.*

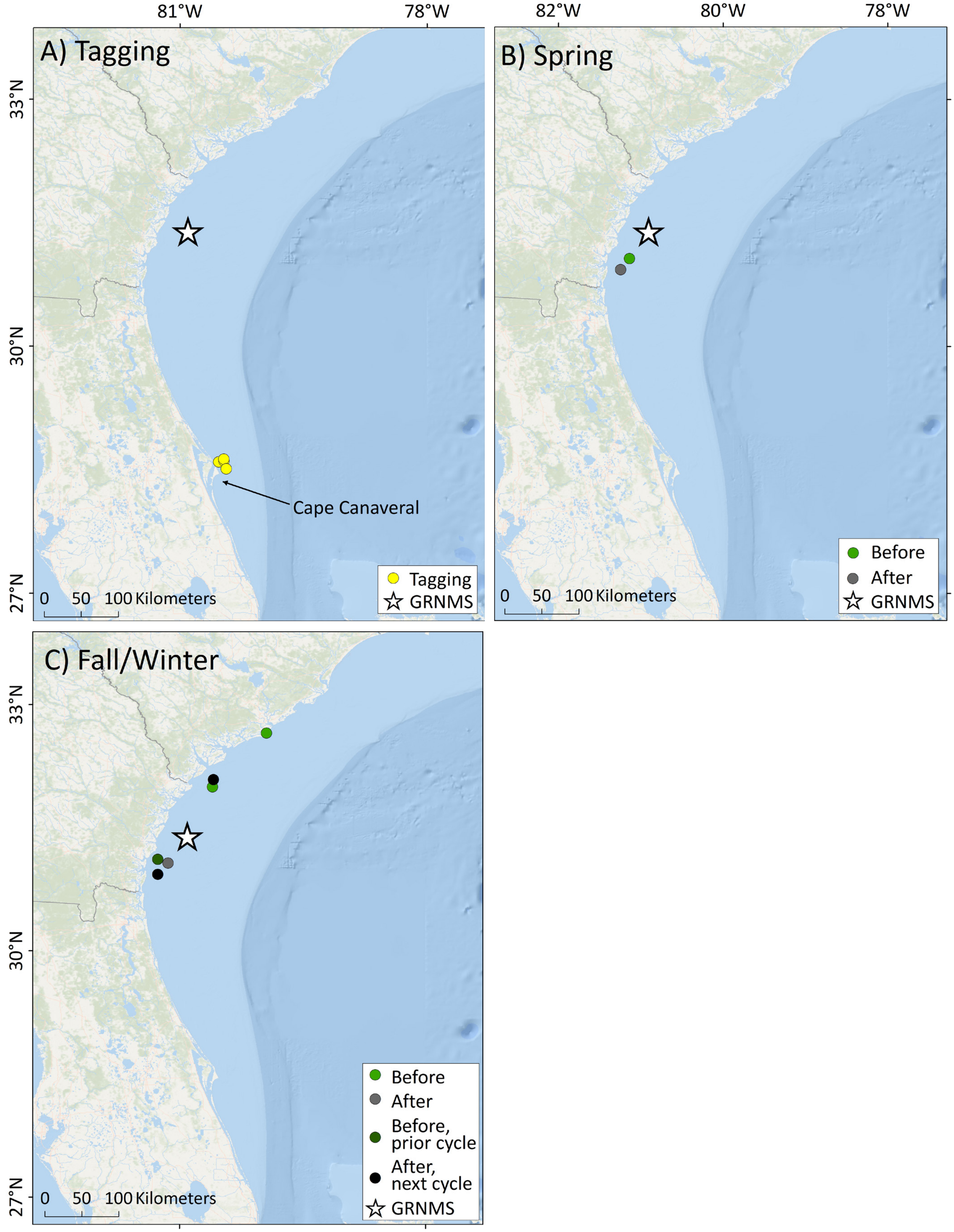


*Figure 3.7. Blacknose shark (*Carcharhinus acronotus*) A) tagging locations, and locations before and after detections at Gray's Reef in the B) spring and C) fall/ winter. Darker shaded points indicate the detection was part of a separate migration cycle (e.g. months apart from their detection at the sanctuary).*

Results

Significance of Connectivity

Blacknose sharks are present seasonally at Gray's Reef, detecting in the spring and late fall/early winter only. Seasonality of their detections at the sanctuary corresponds with the timing of their migrations to and from North Carolina (Schwartz, 1984; Ulrich et al., 2007). However, their locations prior to and after their visit to the sanctuary do not clearly indicate a trend of their use of the sanctuary during migrations. Only one individual exhibited clear southward directionality based on their detections, which is consistent with their return migrations to Florida (Schwartz, 1984; Ulrich et al., 2007). However, gaps in detections spread over months (Figure 3.4) make it difficult to determine the use of the sanctuary during their seasonal migrations. All individuals spent less than one day at the sanctuary indicating they pass through quickly as they move throughout the region.

Acknowledgements

We thank Dr. Eric Reyier and the Kennedy Space Center Ecological Program for contributing detections and individual metadata to this study.

Blacknose shark. Credit C. Collatos, Coastal Carolina University

3.2.3 Blacktip Shark *(Carcharhinus limbatus)*

Citation: Williams, B.L., B. Bowers[1] and M.S. Kendall. 2019. Blacktip shark (*Carcharhinus limbatus*) use of Gray's Reef National Marine Sanctuary. pp. 20-22. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

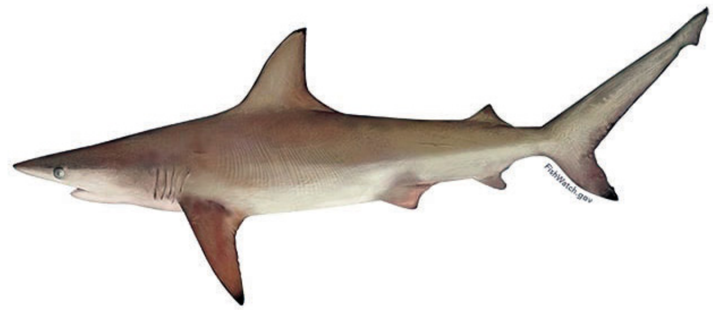


*Figure 3.8. Adult blacktip shark (*Carcharhinus limbatus*). Credit: NOAA NMFS.*

Species Description

Blacktip sharks (*Carcharhinus limbatus*; Figure 3.8) are large coastal predators that feed on small fishes, small elasmobranchs, cephalopods, and crustaceans. Maximum size is 200 cm total length (TL) (Compagno, 1984; Castro, 1996; Kajiura and Tellman, 2016). They occur globally in tropical and subtropical waters, and in the western Atlantic Ocean from Massachusetts to Florida, but are uncommon north of North Carolina (Compagno, 1984; Kajiura and Tellman, 2016). Blacktip sharks pup every two years in May-June inshore off the Carolinas and Georgia, after reaching maturity at 131-143 cm TL and 5-7 years of age (Castro, 1996; Carlson et al., 2006). Temperature and prey driven seasonal migrations occur between North Carolina and southeast Florida, where they form dense aggregations while overwintering (Kajiura and Tellman, 2016). This species supports both a commercial and recreational fishery in the southeast U.S. (SEDAR, 2006).

Table 3.4. Blacktip shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Stephen Kajiura	Florida Atlantic University[1]	6	72	Apr. 2015-May 2017

Movements Through GRNMS

Six adult male blacktip sharks (141.1 ± 2.5 cm TL) have been detected at Gray's Reef from 2015-2017 (Figure 3.9; Table 3.4). Blacktip sharks were only detected in April-May and December, each detected on a single day , within a season, at the sanctuary (Figure 3.9). In spring 2016, two individuals were detected on the same day (Figure 3.9). In winter 2016, three individuals were detected within 1-2 days of each other (Figure 3.9). All individuals were tagged off Palm Beach, Florida, ~510 km from Gray's Reef (Figure 3.10A). Four of the six individuals made repeat visits to Gray's Reef, two individuals in the same year, and two individuals in different years (Figure 3.9). In the spring, individuals were 145.3 ± 56.6 km south of Gray's Reef 4.6 ± 2.6 days before their arrival at the sanctuary (Figure 3.10B). After leaving in the spring, all but one individual were found north of the sanctuary, one even as far north as Maryland (Figure 3.10B). In the winter, three individuals were found 147 ± 31.9 km north of Gray's Reef prior to their arrival 1.7 ± 0.4 days later (Figure 3.10C). After leaving the sanctuary, these same individuals were found 240.2 ± 91.2 km south 10.4 ± 6.3 days later (Figure 3.10C).

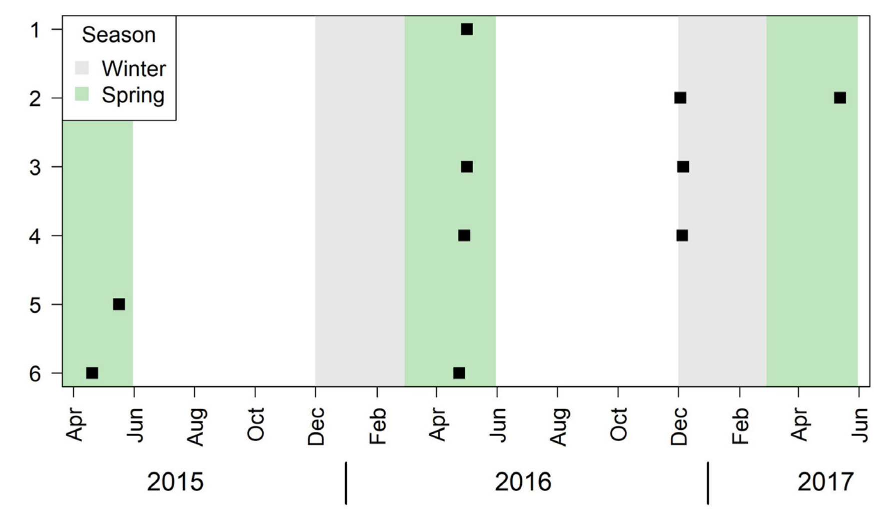


*Figure 3.9. Detections of individual blacktip sharks (*Carcharhinus limbatus*) at Gray's Reef.*

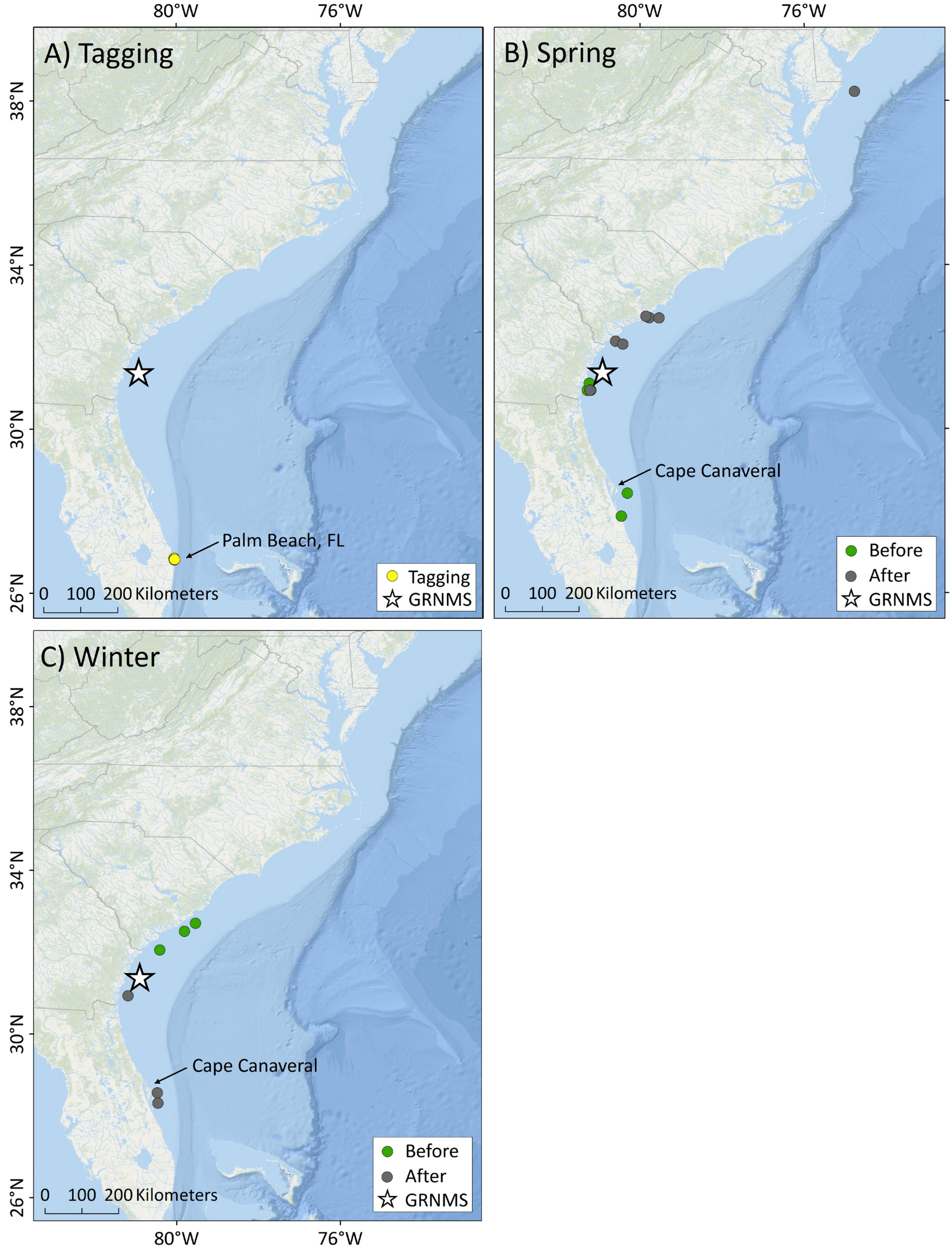


*Figure 3.10. Blacktip shark (*Carcharhinus limbatus*) A) tagging locations before and after their visits to Gray's Reef in B) spring, and C) winter. In B, northernmost point occurs in summer.*

Results

Significance of Connectivity

Detections of blacktip sharks at Gray's Reef indicate that they move through the sanctuary along their seasonal migrations. In the spring, individuals generally arrived at the sanctuary from the south, and continued north after their departure, which is consistent with their northward migration (Kajiura and Tellman, 2016). In the winter, individuals moved southward through the sanctuary, along their return migration to their Florida overwintering grounds (Kajiura and Tellman, 2016). Further, they were only detected at Gray's Reef during spring and winter, which agrees with the hypothesized timing of their migrations through this region (Kajiura and Tellman, 2016). Only male blacktip sharks were detected at Gray's Reef, however, this is likely due to the fact that females (within the FACT network) were tagged with acoustic transmitters after the most recent detection data were collected from acoustic receivers at the sanctuary, as opposed to the sanctuary serving as habitat for males only. Some individuals were detected at the sanctuary on the same day or within a few days of each other, which suggests that they may be migrating through the sanctuary together. The consistent detection and directionality of blacktip sharks at Gray's Reef indicates that it serves as a migratory corridor for this species during their seasonal migrations.

Acknowledgements

We thank Dr. Stephen Kajiura for contribution of tag and individual metadata for this species.

Blacktip shark. Credit: Tanya Houppermans

3.2.4 Bonnethead *(Sphyrna tiburo)*

Citation: Williams, B.L., B. Keller, M. Benavides, and M.S. Kendall. 2019. Bonnethead (*Sphyrna tiburo*) use of Gray's Reef National Marine Sanctuary. pp. 24-26. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.11. Bonnethead (*Sphyrna tiburo*). Credit: T. Hisgett, licensed under CC BY 2.0.*

Species Description

Bonnetheads (*Sphyrna tiburo*; Figure 3.11) are small coastal sharks that feed primarily on crustaceans, specializing on portunid crabs (Kroetz et al., 2017, Ulrich et al., 2007). They typically occur in tropical and sub-tropical waters of the western Atlantic Ocean, occupying insular and coastal habitats (Compagno, 1984; Ulrich et al., 2007; Cortés et al., 2016). Bonnetheads are one of the smallest sharks in the Sphyrnidae family and mature quickly. The length at 50% maturity is 81.9 cm and 61.8 cm FL for females and males, respectively; the maximum size for this species is usually below 130 cm TL (Frazier et al., 2013; Frazier et al., 2014; Cortés et al., 2016). Mating occurs after parturition in early to mid-fall, delayed ovulation and fertilization takes place in spring, gestation is rapid (4-5 months), and birth of 2-14 pups occurs in late summer to early fall (Lombardi-Carlson et al., 2003; Driggers et al., 2014; Frazier et al., 2013; Frazier et al., 2014). When temperatures undergo dramatic shifts in subtropical estuaries in mid to late fall, bonnetheads initiate a climatic migration to warmer waters (Ulrich et al., 2007), however their exact overwintering destination and migration route is currently being investigated (Kenworthy et al., 2018). Recent stock assessments suggest the Atlantic stock may be overfished, when it is considered independently from the Gulf of Mexico stock (SEDAR, 2013b).

Table 3.5. Bonnethead data contributors.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Bryan Keller	Florida State University	2	237	Mar. 2016, Dec. 2016
Martin Benavides	University of North Carolina	2	211	May 2015-Apr. 2016

Movements Through GRNMS

Four female bonnetheads, three adults (849.4 ± 21.6 mm FL) and one juvenile (710 mm FL) visited Gray's reef during 2016 (Figure 3.12; Table 3.5). The adults were each

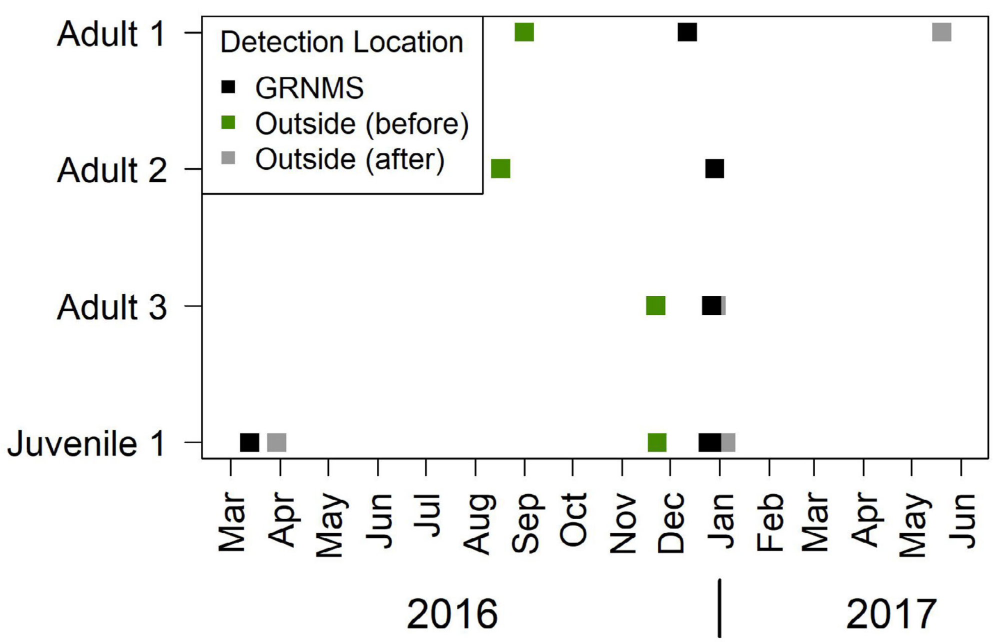


*Figure 3.12. Detection of individual bonnetheads (*Sphyrna tiburo*). Green points indicate the last detection outside of Gray's Reef directly before their detection at the sanctuary. Grey points indicate the next detection outside of Gray's Reef, directly after their detection at the sanctuary.*

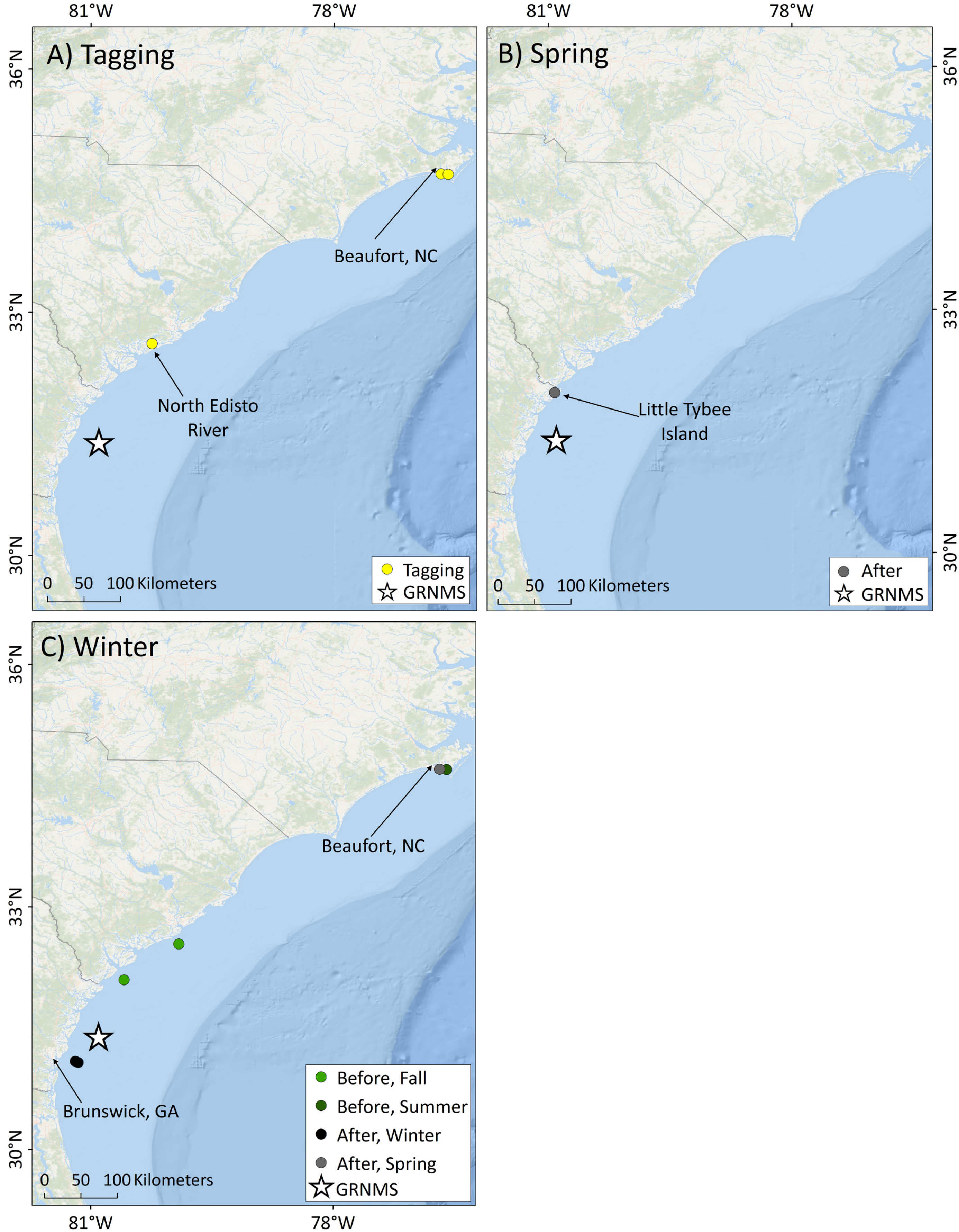


*Figure 3.13. Bonnethead shark (*Sphyrna tiburo*) A) tagging locations, and before, and after their visits to Gray's Reef in B) late winter/spring, and C) fall/early winter. Darker shaded points indicate the detection did not occur in the same season as their visits to the sanctuary.*

detected for an individual visit to the sanctuary, whereas the juvenile made two treks through Gray's Reef in the same year (Figure 3.12). Adults were detected only on one day, whereas the juvenile was detected on three consecutive days during one of its visits to the sanctuary. Two individuals were tagged (a juvenile in September 2015, and adult in October 2016) in the North Edisto River, South Carolina approximately 148 km north of Gray's Reef (Figure 3.13A). They were detected at Gray's Reef at the same receiver on the same day in December 2016, fourteen hours apart (Figure 3.12). The other individuals, both adults, were tagged near Beaufort, NC approximately 539 km north of Gray's Reef (Figure 3.13A). All four individuals were detected at the sanctuary in the winter (Figure 3.12). All were detected north of the sanctuary throughout the late summer and fall, prior to their winter arrival at the sanctuary 32-167 days later (Figure 3.12; Figure 3.13C). Only two individuals, an adult and a juvenile, were detected off Jekyll Island, Georgia, ~44 km southwest, 2-9 days later (Figure 3.12; Figure 3.13C), suggesting a southward movement through the sanctuary. One individual was not detected after departing Gray's Reef, while the fourth was detected off Beaufort, NC, 536 km north, the following May (Figure 3.12; Figure 3.13C). Only one individual, a juvenile, was detected at the sanctuary in the spring, and after its departure was detected 66.5 km northwest of the sanctuary off Little Tybee Island 16.7 days later (Figure 3.12; Figure 3.13B).

Significance of Connectivity

Bonnetheads were only detected at Gray's Reef during the spring and winter, suggesting seasonal use of the sanctuary. In the Southeast U.S., bonnetheads exhibit climatic migrations when falling temperatures approach their physiological tolerances (Ulrich et al., 2007). The southward directionality of their movements through the sanctuary from fall to winter and brevity of visits, suggest the sanctuary is part of the migratory pathway for some individuals. Multiple life stages were detected at the sanctuary suggesting use by a range of ages. However, with only four individuals, it is difficult to generalize the role of the sanctuary for bonnetheads.

Sparsely colonized live bottom habitat at Gray's Reef. Credit: NOAA GRNMS

Results

3.2.5 Bull Shark *(Carcharhinus leucas)*

Citation: Williams, B.L., D. Abercrombie, and M.S. Kendall. 2019. Bull shark (*Carcharhinus leucas*) use of Gray's Reef National Marine Sanctuary. pp. 28-29. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.14. Bull shark (*Carcharhinus leucas*). Credit: Amanderson2, CC BY 2.0.*

Species Description

Bull sharks (*Carcharhinus leucas*; Figure 3.14) are large coastal predators that feed primarily on fish and other elasmobranchs but also have a diverse diet that includes turtles, birds, dolphins, and invertebrates (Snelson et al., 1984; Last and Stevens, 1994). Bull sharks occur globally in tropical and warm temperate waters (Compagno, 1984; Last and Stevens, 1994). They are primarily an inhabitant of continental shelf waters less than 30 m deep, but commonly move into estuaries and even rivers (Thorson, 1971). Maturity is reached at ~160-230 cm and maximum size is ~340 cm TL (Compagno, 1984). Mating is thought to occur bi-annually, with birth of typically 6-8 pups in early summer in estuarine or freshwater nurseries (Branstetter, 1981; Snelson et al., 1984). A seasonal migration along the eastern U.S. coast has been documented, with northwards movement during the summer as water temperatures rise and then southwards as temperatures cool (Castro, 1983). Recreational and commercial harvest coupled with frequent use of estuarine habitat makes the population in the southeastern U.S. more susceptible to deleterious human impacts (e.g. habitat loss) than sharks offshore (Simpfendorfer and Burgess, 2009).

Table 3.6. Bull shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Debra Abercrombie	University of Miami-CIMAS	17	832	Jul. 2009-Jul. 2016

Movements Through GRNMS

Seventeen bull sharks were detected at Gray's Reef from 2009-2016 (Figure 3.15; Table 3.6). Eight mature individuals comprised of six females and two males were detected (241 ± 7.6 cm TL). Nine immature (at time of tagging) individuals comprised of six females and two males were detected (212 ± 1.9 cm TL). Individual bull sharks were typically detected at Gray's Reef for less than 1 day, but four were detected for up to 4 days, although not continuously during that time. Nine bull sharks, both immature and mature individuals, made repeat visits to Gray's Reef, with one even visiting five times over three years (Figure 3.15). Five of the individuals recurring across years made repeat visits in the same month separated by a few days to a few weeks (Figure 3.15). On two occasions, two different bull sharks were detected at the sanctuary

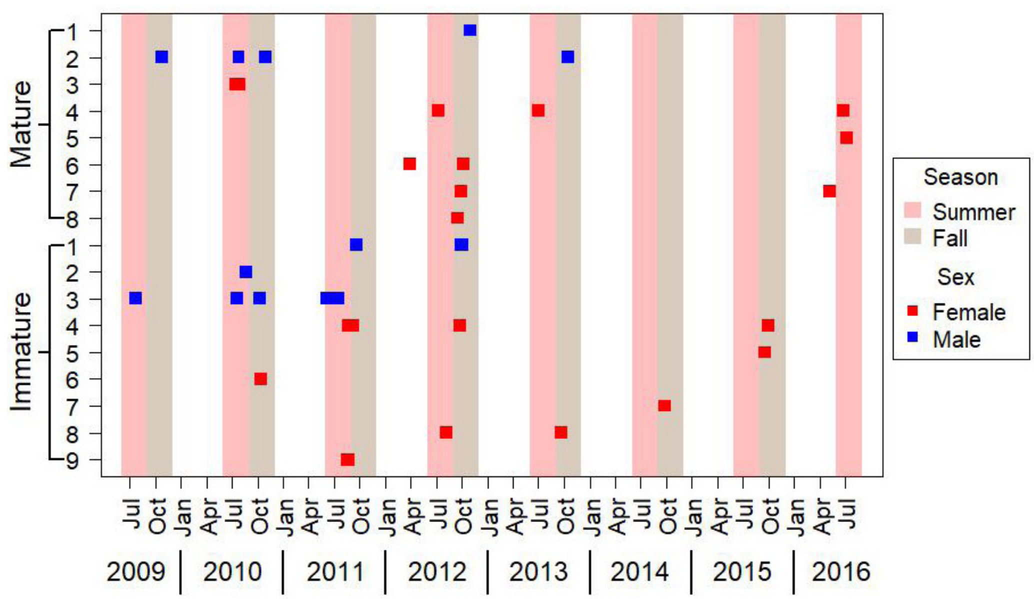


*Figure 3.15. Detections of individual bull sharks (*Carcharhinus leucas*) at Gray's Reef.*

on the same day, once on the same receiver (Figure 3.15). All bull sharks were tagged off the coast of south Florida, approximately 508 km south of Gray's Reef (Figure 3.16) in winter/spring months in 2009 and 2010. Detections prior to and directly after their visits to the sanctuary were not available for this study. Bull sharks were almost exclusively detected at the sanctuary during the summer and fall, however two individuals visited during spring months (Figure 3.15).

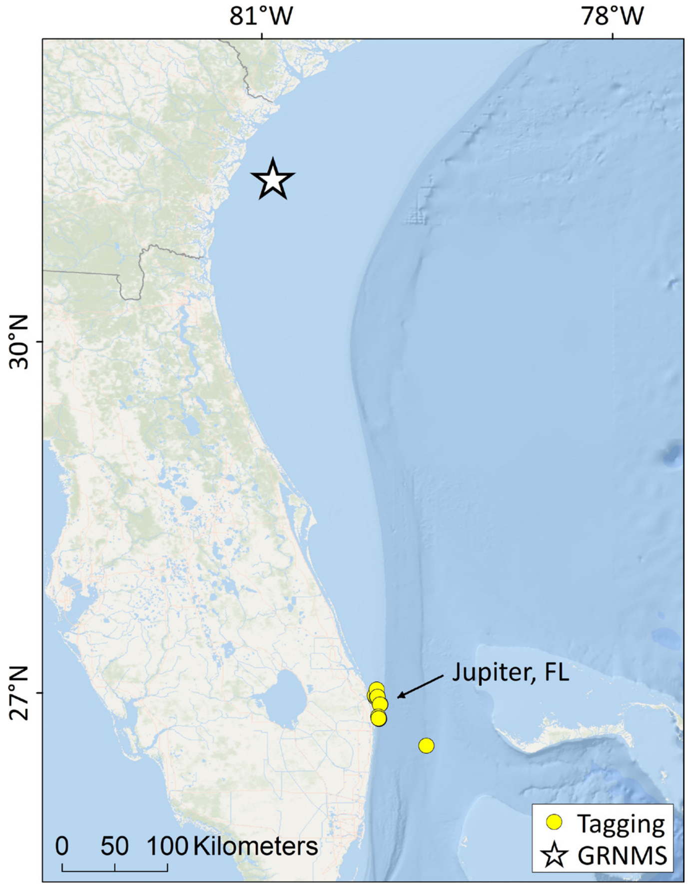


*Figure 3.16. Bull shark (*Carcharhinus leucas*) tagging locations.*

Significance of Connectivity

Based on their detections, Gray's Reef is a seasonal habitat for bull sharks, likely during their annual migrations. Bull sharks were generally detected at the sanctuary during the summer and fall, which matches the timing of their movements along the U.S. Atlantic coast (Castro, 1983; Simpfendorfer and Burgess, 2009). Bull sharks return to Gray's Reef annually, suggesting the sanctuary may be a known point on their migratory pathway. Further, bull sharks were detected briefly (less than 1 day) at Gray's Reef, suggesting they pass through quickly. However, bull sharks have been tagged in other areas along the Atlantic coast, including coastal Florida and North Carolina, but only those tagged off Jupiter, Florida were detected at the sanctuary. The sanctuary is also a habitat for mature and immature bull sharks, both of which made repeat visits across multiple years. However, immature sharks may have reached maturity during later visits to Gray's Reef that occurred up to 5.5 years after initial tagging. The sanctuary is also a habitat for both male and female bull sharks, with females making up 70.6% of the individuals detected. Ultimately, this apex predator passes through Gray's Reef quickly and seasonally across multiple years.

Results

3.2.6 Great Hammerhead Shark

(Sphyrna mokarran)

Citation: Williams, B.L., N. Hammerschlag, V. Heim, M. Van Zinnicq Bergmann, T. Guttridge, K. Parsons, and M.S. Kendall. 2019. Great hammerhead shark (*Sphyrna mokarran*) use of Gray's Reef National Marine Sanctuary. pp. 30-31. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.17. Adult great hammerhead shark (*Sphyrna mokarran*). Credit: A. Kok, licensed under CC BY-SA 3.0*

Table 3.7. Great hammerhead shark data contributors.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Steven Kessel	Shedd Aquarium	1	9	Sep. 2012
Bimini Biological Field Station	-	1	7	Oct. 2016
Dr. Neil Hammerschlag	University of Miami	1	88	May 2017

Species Description

Great hammerhead sharks (*Sphyrna mokarran*; Figure 3.17) are typically solitary coastal-pelagic and semi-oceanic predators, feeding mostly on other elasmobranchs, but also teleosts, cephalopods, and crustaceans (Cliff, 1995). The largest great hammerhead shark recorded reached 600 cm TL (Compagno, 1984). They occur globally in tropical and sub-tropical waters (Compagno, 2005; Guttridge et al., 2017). With a declining population due to bycatch and shark finning, this species is listed as endangered by the IUCN (Clarke et al., 2006; Denham et al., 2007). Great hammerhead sharks reach maturity at 5-6 years of age (~300-327 cm TL; Cliff, 1995; Piercy et al., 2010), reproducing every two years, with large litters of 15-23 pups (Piercy et al., 2010). Recent work by Guttridge et al. (2017) suggests philopatry of this species to Jupiter, Florida, and Bimini, Bahamas. Some individuals make repeated migrations as far north as New Jersey during the spring, returning back to Jupiter or Bimini for the winter, indicating partial migration (i.e. only a portion of the population migrates) (Hammerschlag et al., 2011; Guttridge et al., 2017).

Movements Through GRNMS

Three adult female great hammerhead sharks (3.2 ± 0.03 m TL) have been detected at Gray's Reef, one each in 2012, 2016, and 2017 (Figure 3.18; Table 3.7). Two visited during the fall months, and one in late spring. They spent 3-9 days at Gray's Reef but were not detected continuously within the sanctuary during that time. Individuals were tagged in the winter–spring months off the coast of Jupiter, Florida (n=2)

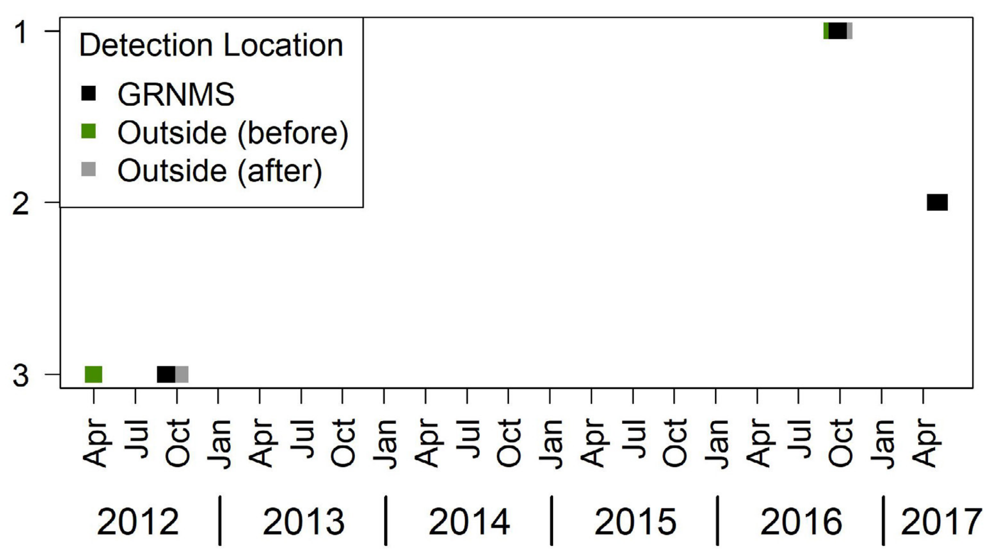


*Figure 3.18. Detections of individual great hammerhead sharks (*Sphyrna mokarran*). Black points indicate detections at Gray's Reef. Green points indicate the last detection outside of Gray's Reef, directly before their detection at the sanctuary. Grey points indicate the next detection outside of Gray's Reef, directly after their detection at the sanctuary.*

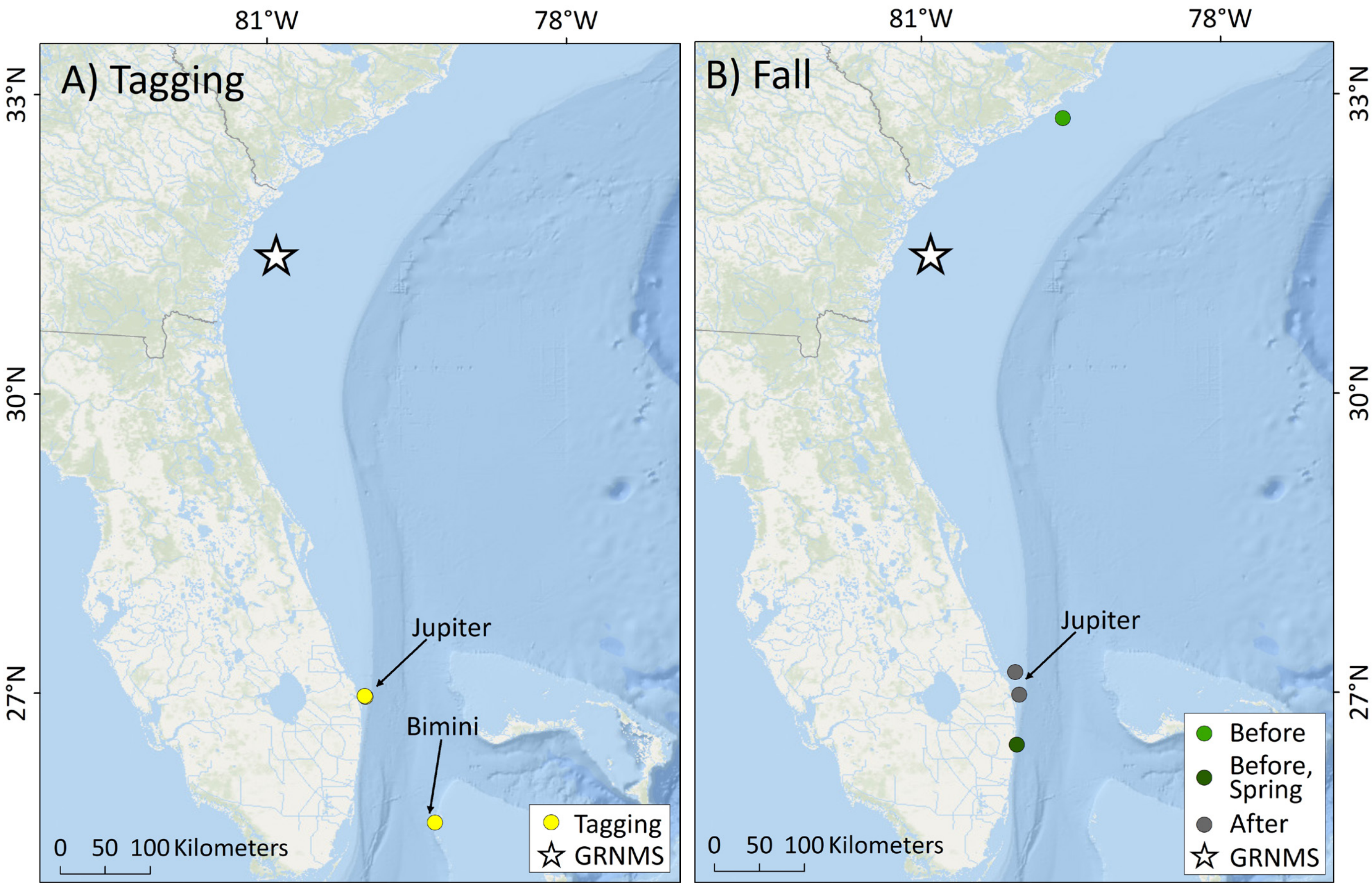


*Figure 3.19. Great hammerhead shark (*Sphyrna mokarran*) A) tagging locations and B) locations before arriving and after departing Gray's Reef in fall months.*

and Bimini, Bahamas (n=1), 498 and 648 km from Gray's Reef, respectively (Figure 3.19A). One individual was detected off Jupiter, Florida in early spring, 158 days before its arrival at Gray's Reef in the fall (Figure 3.18; Figure 3.19B). Another was detected off Charleston, South Carolina in the fall just 12 days before its arrival at Gray's Reef (Figure 3.18; Figure 3.19B). Two individuals were detected off Jupiter, Florida in the fall 21.1 (± 8.2) days after departing from Gray's Reef (Figure 3.18; Figure 3.19B). All individuals only visited the sanctuary once.

Significance of Connectivity

Detections of great hammerhead sharks at Gray's Reef indicate some of the migrating population passes through the sanctuary briefly during its annual migrations. Approximately 20% of individuals tagged by Guttridge et al. (2017) made seasonal long distance migration. The timing of these migrations matches their timing of visits to Gray's Reef. One individual migrated from Jupiter, Florida to Gray's Reef and back between April and October, while another stopped at Gray's Reef in the fall during its southern migration from Charleston, South Carolina to Jupiter, Florida. While the northern migration spanned a longer period (158 days), the duration of the southern migration was much faster (~21 days). All tagged individuals that visited Gray's Reef were female. Habitat suitability models for this species predict low probability of their occurrence at Gray's Reef (Calich et al., 2018), which may be why so few were detected. Unfortunately with only three individuals, it is difficult to generalize how great hammerhead sharks utilize Gray's Reef.

Acknowledgements

We thank Dr. Steven Kessel (Shedd Aquarium) and the staff of the Bimini Biological Field Station for contributing detection and tag metadata for this species. We also thank Mitchell Rider from University of Miami for compiling individual and tag metadata for this species.

Results

3.2.7 Lemon Shark *(Negaprion brevirostris)*

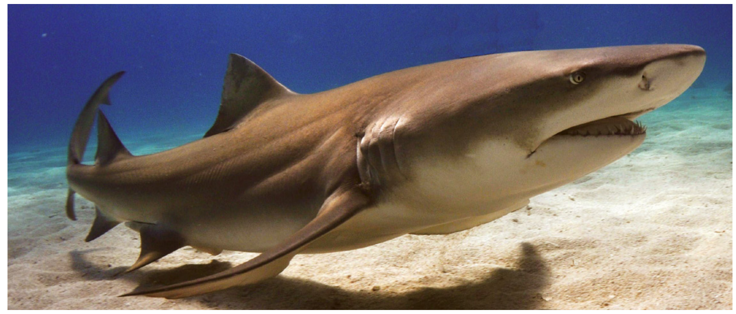


*Figure 3.20. Adult lemon shark (*Negaprion brevirostris*) Credit: A. Kok, licensed under CC BY-SA 3.0*

Species Description

Lemon sharks (*Negaprion brevirostris*; Figure 3.20) are coastal predators that feed on teleosts, crustaceans, and mollusks, and achieve a maximum size of 280 cm PCL (Gruber and Stout, 1983; Cortes and Gruber, 1990). They occur in tropical and subtropical waters along both sides of the Atlantic as well as the eastern Pacific Ocean (Cortes and Gruber, 1990; Feldheim et al., 2001). Lemon sharks reach maturity near 12 years of age (225-240 cm total length; Brown and Gruber, 1988) and only reproduce once every two years, with litters ranging from 2-18 pups (Feldheim et al., 2002). Both juveniles and adults undergo a temperature-mediated migration as far north as North Carolina in the summer and back south to Florida in the winter, with juvenile winter aggregations off Cape Canaveral and adult winter aggregations off Jupiter, Florida (Kessel et al., 2014; Reyier et al., 2014).

Table 3.8. Lemon shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Steven Kessel	Shedd Aquarium	3	59	Nov. 2009-July 2016

Movements Through GRNMS

Three adult lemon sharks (2.6 ± 0.06 m TL) have been detected at Gray's Reef, one each in 2009, 2010, and 2016 (Figure 3.21; Table 3.8). Two visited during late spring/early summer months, while one visited in fall, spending an average of 1.67 (±0.7 SE) days at the sanctuary (Figure 3.21). All three individuals were tagged during spring months off the coast of Jupiter, Florida, 526 (±15.3 SE) km south of Gray's Reef (Figure 3.22). Two individuals (both female) were detected off Jupiter FL, 68 (±2.3 SE) days prior to arrival at Gray's Reef (Figures 3.21 and 3.22). None were re-detected after their visit to Gray's Reef despite expected transmitter life of 7-8 years. All individuals only visited the sanctuary once.

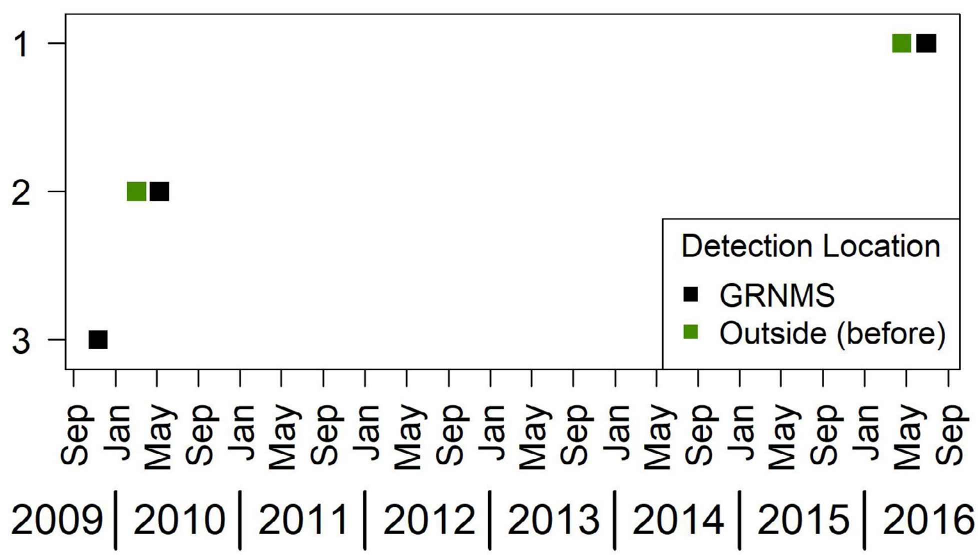


*Figure 3.21. Detections of individual lemon sharks (*Negaprion brevirostris*). Black points indicate detections at Gray's Reef. Green points indicate the last detection outside of Gray's Reef, directly before their detection at the sanctuary.*

Significance of Connectivity

Detections of lemon sharks at Gray's Reef suggest the sanctuary may be a stop-over during summer migrations. Seasonality of lemon shark visits to Gray's Reef matches timing of their migrations described by Kessel et al. (2014), with two visits occurring in spring/summer during their northern migration. Two individuals made very similar migrations over a period of ~68 days but six years apart (Figures 3.21 and 3.22). They went from south Florida to Gray's Reef (499±10.4 km) during the early spring and lingered there for 1-2 days before departing. Gray's Reef has an abundance of small fishes, a main component of lemon shark diet (Cortes and Gruber, 1990), and may serve as foraging grounds for these sharks during their migration. Unfortunately, it is difficult to generalize the timing and role of Gray's Reef in lemon shark migrations with data from only three individuals.

Acknowledgements

We thank Dr. Steven Kessel (Shedd Aquarium) for contributing detection and tag metadata for this species.

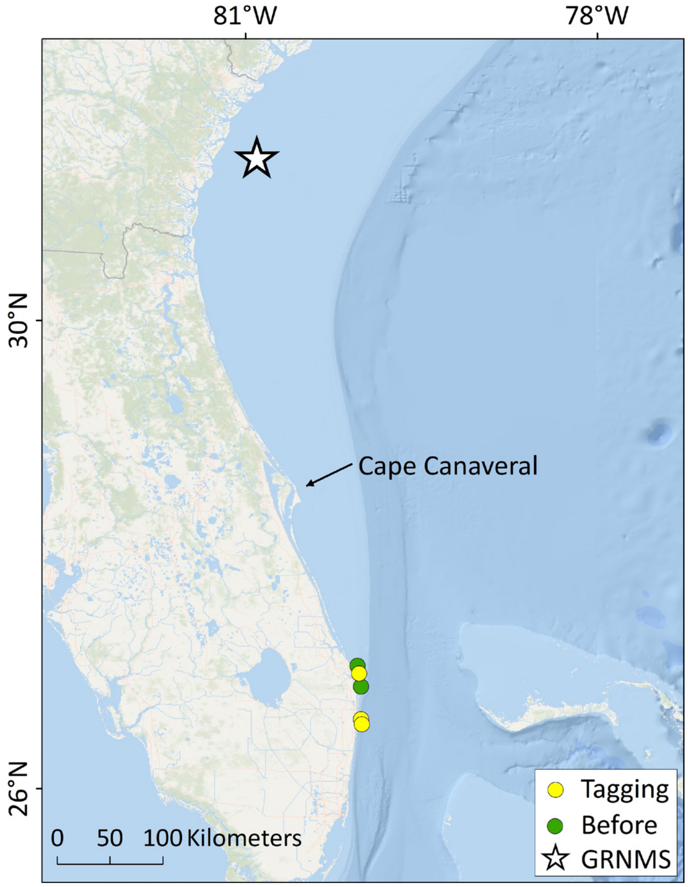


*Figure 3.22. Lemon shark (*Negaprion brevirostris*) tagging and detection locations before arriving at Gray's Reef. No data are available for individuals' locations after leaving Gray's Reef.*

3.2.8 Sand Tiger Shark *(Carcharias taurus)*

Citation: Williams, B.L., D. Fox, and M.S. Kendall. 2019. Sand tiger shark (*Carcharias taurus*) use of Gray's Reef National Marine Sanctuary. pp. 34-35. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

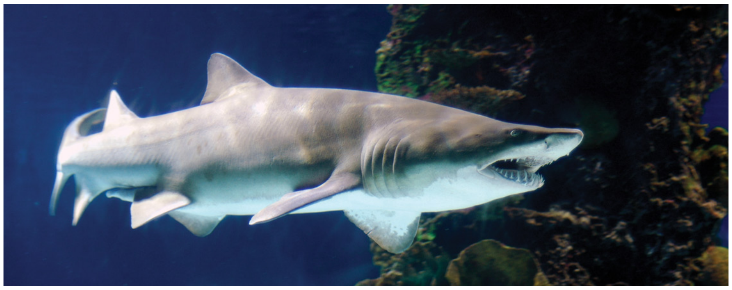


*Figure 3.23. Adult sand tiger shark (*Carcharias taurus*) Credit: J. Kubina, licensed under CC BY 2.0.*

Species Description

Sand tiger sharks (*Carcharias taurus*; Figure 3.23) are large coastal predators that feed primarily on fish and other elasmobranchs and also on invertebrates (Compagno, 1984; Gelsleichter et al., 1999). Sand tigers occur almost globally in tropical and warm temperate waters. Their range in the western Atlantic extends from Maine, United States to Argentina (Compagno, 1984). They are primarily an inhabitant of continental shelf waters less than 25 m deep and are often associated with rocky bottom or other structure (Compagno, 1984). Maturity is reached at ~200 cm and maximum size is ~300 cm TL (Gilmore et al., 1983; Branstetter and Musick, 1994). Mating is thought to occur bi-annually, with birth in winter/spring of typically only 2 large pups due to uterine cannibalism (Gilmore et al., 1983). Sand tigers undergo extensive coastal migrations, moving between summer (June-October) habitat (Maine to Delaware Bay) and winter (December-April) habitat (Cape Hatteras to central Florida) (Kneebone et al., 2014; Haulsee, 2017). Although now protected, due to decades of exploitation, slow growth, and low reproductive rates, sand tigers are listed as "vulnerable" on the IUCN Red List and as a species of concern by NOAA (Musick et al., 1993; Pollard and Smith, 2009; Carlson et al., 2009).

Table 3.9. Sand tiger shark data contributors.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Danielle Haulsee	University of Delaware	2	30	Mar. 2013, Apr. 2017
Dr. Dewayne Fox	Delaware State University	4	306	Apr. 2012-Mar. 2015

Movements Through GRNMS

Six sand tiger sharks have been detected at Gray's Reef (Figure 3.24; Table 3.9). Five were adult males (1.83 ± 0.02 m FL) and one a juvenile female, measuring 1.32 m FL (Figure 3.24). All sand tiger sharks detected were tagged in Delaware Bay, ~995 km northeast of Gray's Reef (Figure 3.25A). This species was detected at the sanctuary in spring months, exclusively, spending 1-4 days during each visit (Figure 3.24). Detections prior to and after their visits to the

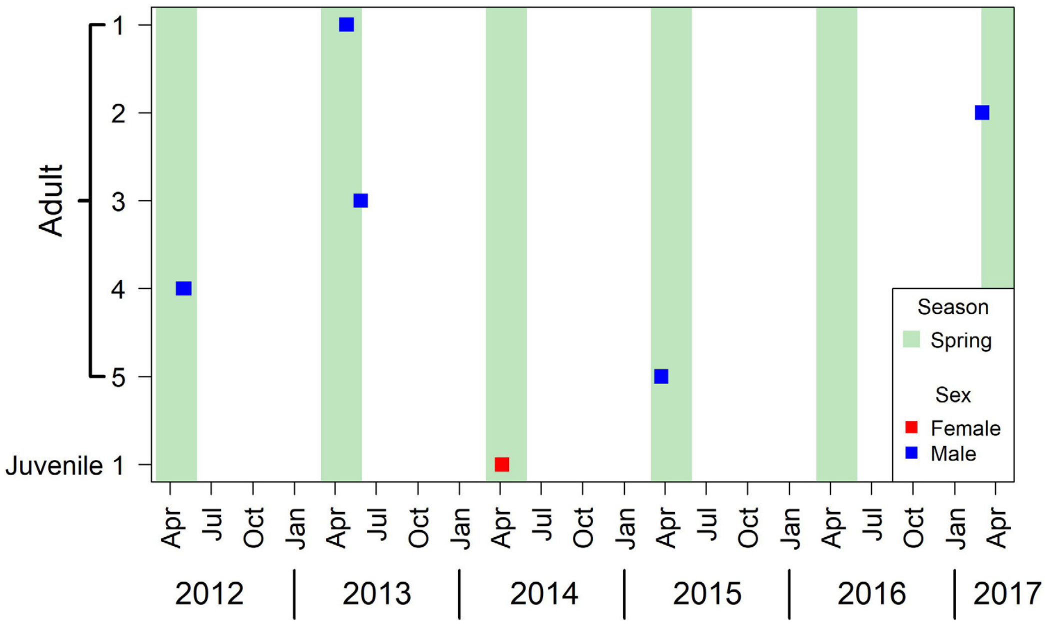


*Figure 3.24. Detections of individual sand tiger sharks (*Carcharias taurus*) at Gray's Reef.*

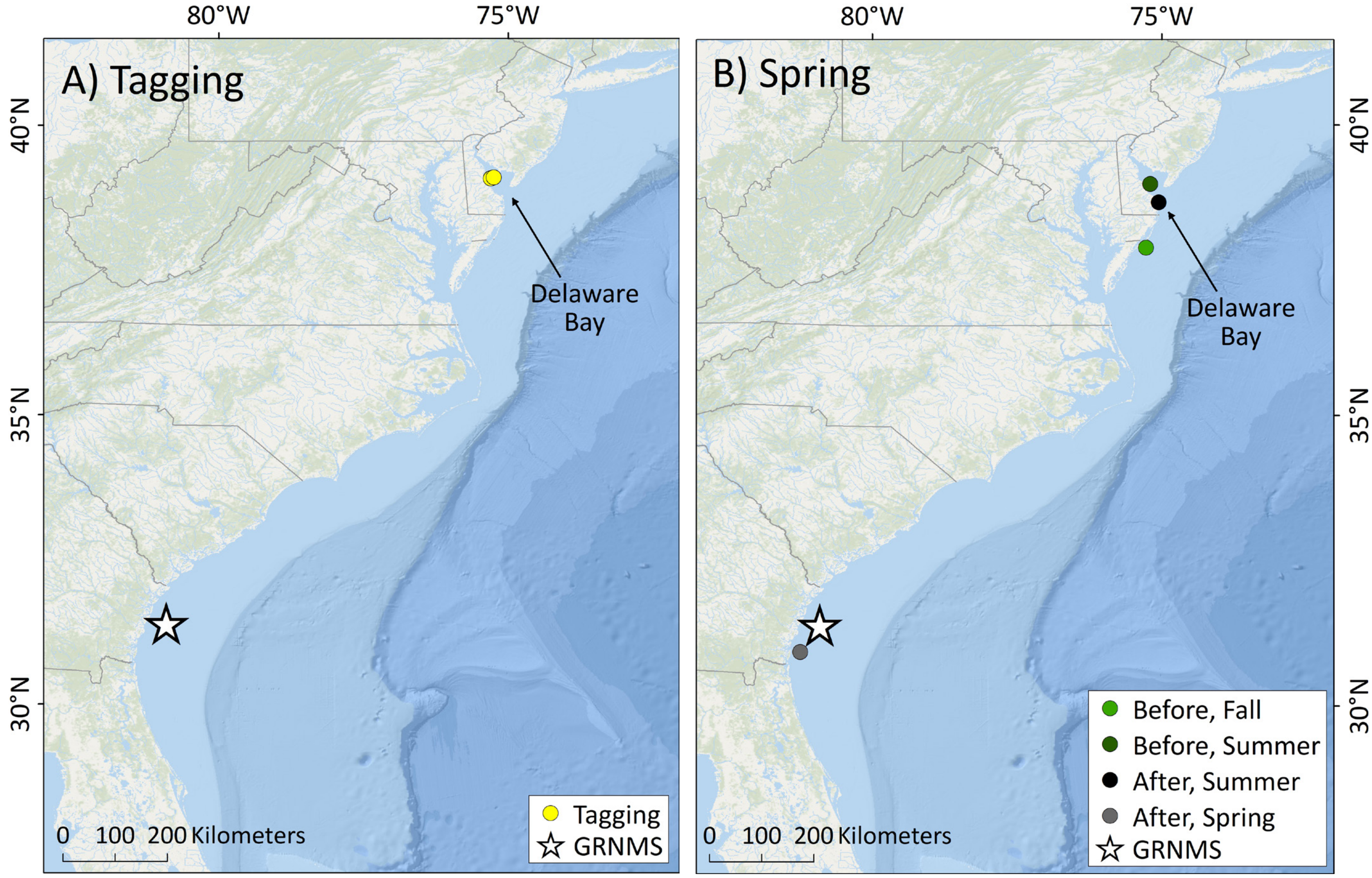


*Figure 3.25. Sand tiger sharks (*Carcharias taurus*) A) tagging locations and B) location before and after spring visits to Gray's Reef. Detections before and after visits to Gray's Reef do not necessarily occur in spring.*

sanctuary were available for two adult males. One individual was detected off the Delmarva Peninsula in fall 2012, 6.5 months prior to its arrival at the sanctuary in spring 2013, and returned to Delaware Bay in summer 2013, 2 months after its departure (Figure 3.25B). The other was detected in Delaware Bay in summer 2016, 7.5 months prior to its detection at the sanctuary in spring 2017, and 62.4 km southwest of the sanctuary 27 days after its departure (Figure 3.25B). All sand tiger sharks only visited the sanctuary once.

Significance of Connectivity

Detections of sand tiger sharks at Gray's Reef indicate use of the sanctuary during migrations to and from their winter habitat. Seasonal migrations of sand tiger sharks from Delaware Bay specifically have been studied via acoustic and satellite tagging, revealing large males' movements out of the bay in fall and southward towards Florida, while large females moved offshore to deeper waters or southward (Teter et al., 2014; Haulsee, 2017). Sand tiger sharks from Delaware Bay were only detected at Gray's Reef during spring months, when they are known to occur between Cape Hatteras and central Florida (Kneebone et al., 2014; Haulsee, 2017). Detections of individuals before and after their visits to Gray's Reef also correspond with the timing of their known migrations, with two occurring in Delaware Bay in the summer, one south of the bay in the fall, and one in the spring just south of Gray's Reef near Brunswick, Georgia (Figure 3.25B). Most individuals spent less than one day at the sanctuary, indicating they pass through Gray's Reef quickly during their migratory movements.

Acknowledgements

We thank Dr. Danielle Haulsee and Dr. Matt Oliver for contributing detection and individual metadata for this species.

Results

3.2.9 Sandbar Shark *(Carcharhinus plumbeus)*

Citation: Williams, B.L., C. Collatos, and M.S. Kendall. 2019. Sandbar shark (*Carcharhinus plumbeus*) use of Gray's Reef National Marine Sanctuary. pp. 36-38. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

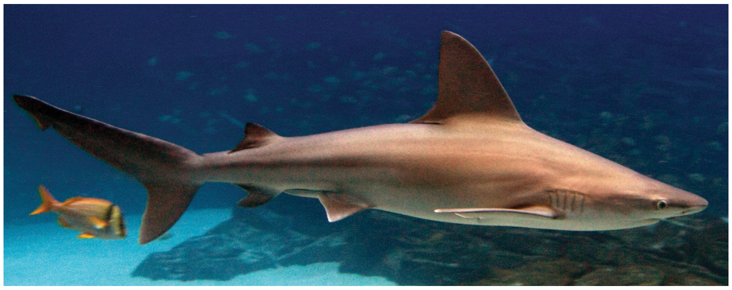


*Figure 3.26. Adult sandbar shark (*Carcharhinus plumbeus*). Credit: B. Gratwicke, licensed under CC BY 2.0.*

Species Description

Sandbar sharks (*Carcharhinus plumbeus*; Figure 3.26) are large coastal-pelagic predators that feed on fish, small elasmobranchs, cephalopods, mollusks, and crustaceans (Ellis and Musick, 2006). They occur globally in tropical and temperate waters, growing to a maximum size of 181 cm FL (Compagno, 1984; Hale and Baremore, 2013). In the northwest Atlantic, they are distributed from Massachusetts to Florida and the Gulf of Mexico and Caribbean (Compagno, 1984). Sandbar sharks reach maturity at 12-13 years (151-155 cm FL) and reproduce every other summer (Baremore and Hale, 2012; SEDAR, 2017). Pupping occurs in coastal estuaries, with a mean of eight pups born in each litter (Grubbs et al., 2007; Baremore and Hale, 2012). In the western North Atlantic, adults and juveniles migrate seasonally, spending summer between Florida and Long Island and winter between Florida and North Carolina (Springer, 1960; Conrath and Musick, 2008). Harvesting of sandbar sharks is currently prohibited in the U.S. and the species is listed as vulnerable on the IUCN red list due to overfishing, slow growth, and low fecundity (73 FR 40657, July 24, 2008; Camhi et al., 2009; SEDAR, 2017).

Table 3.10. Sandbar shark data contributors.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Caroline Collatos	Coastal Carolina University	3	81	Nov. 2016-Mar. 2017
Dr. Charles Bangley	Smithsonian Environmental Research Center	1	4	May 2015-Apr. 2016

Movements Through GRNMS

Four juvenile sandbar sharks (109.3 ± 2.9 cm FL), three females and one male, were detected at Gray's Reef from 2015-2017 (Figure 3.27; Table 3.10). All detections occurred in winter and spring months, and individuals spent 1-5 days at the sanctuary, although not detected consistently across days (Figure 3.27). Further, two of the females were detected at the sanctuary within a day of each other (Figure 3.27). Two individuals visited the sanctuary multiple times in consecutive years (Figure 3.27). Three individuals were

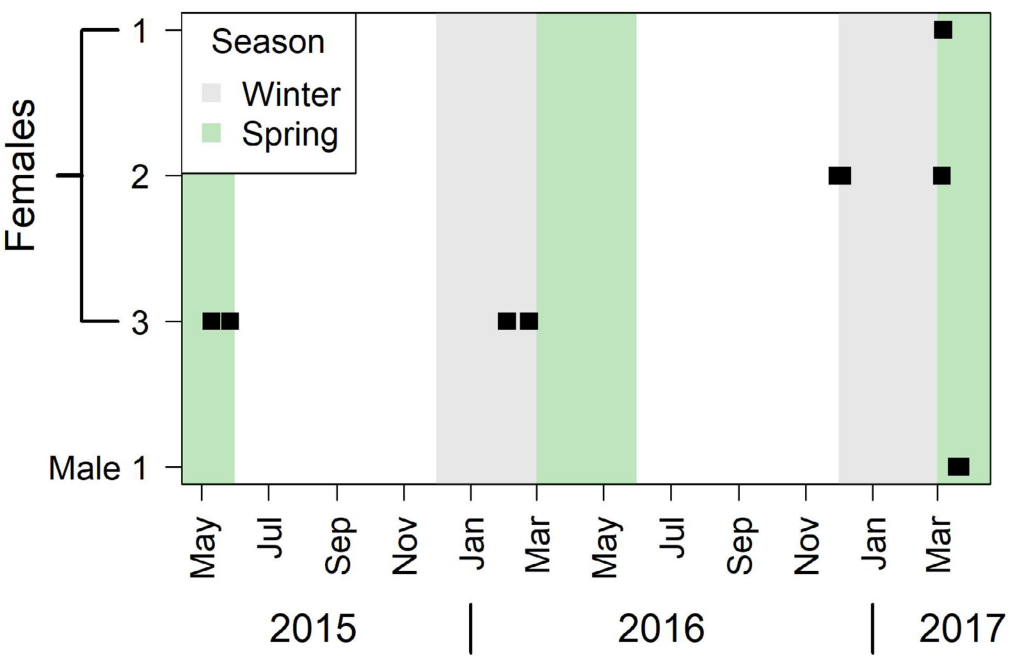


*Figure 3.27. Detections of individual sandbar sharks (*Carcharhinus plumbeus*) at Gray's Reef.*

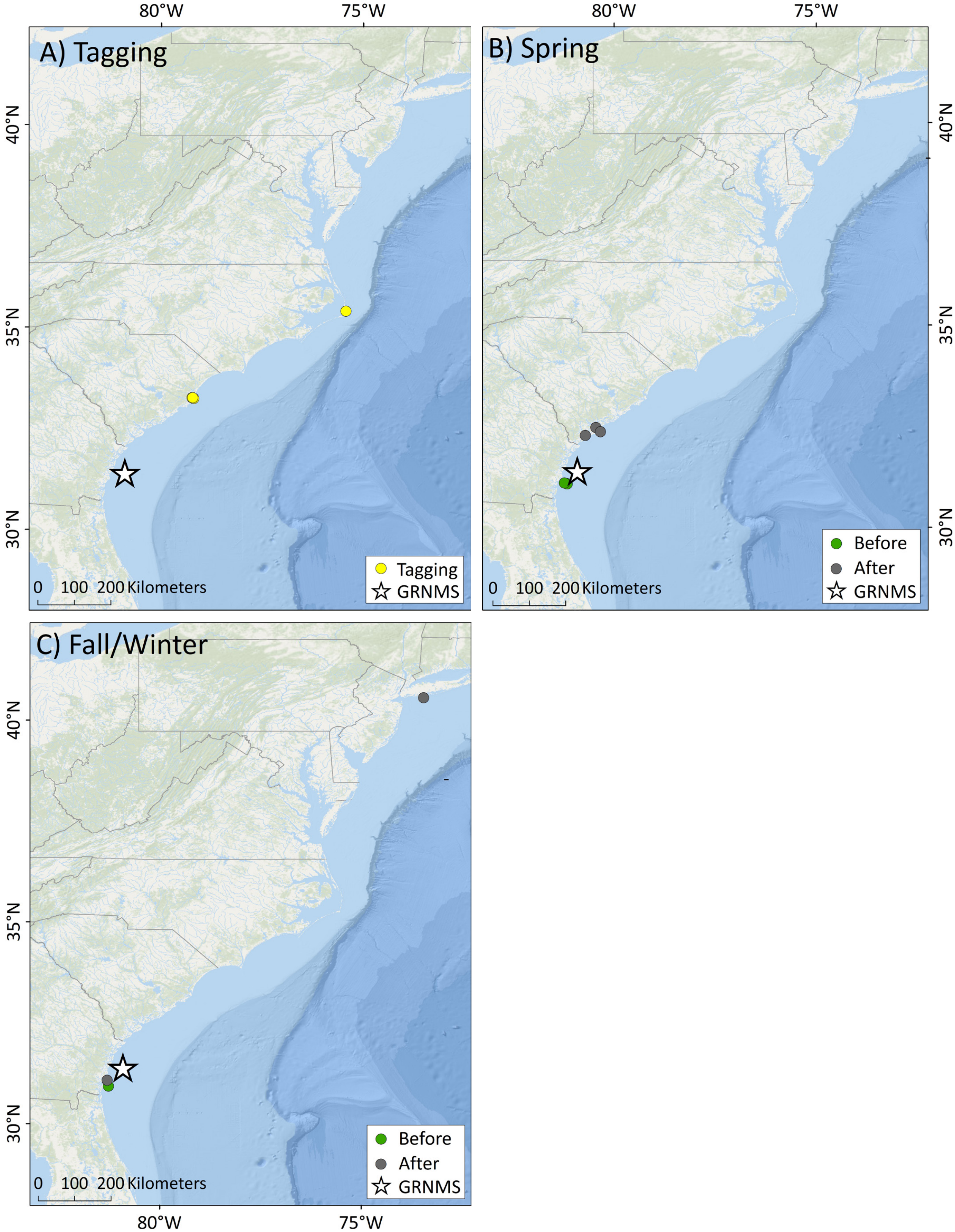


*Figure 3.28. Sandbar shark (*Carcharhinus plumbeus*) A) tagging locations before and after their visits to Gray's Reef in B) late winter/spring, and C) fall/early winter.*

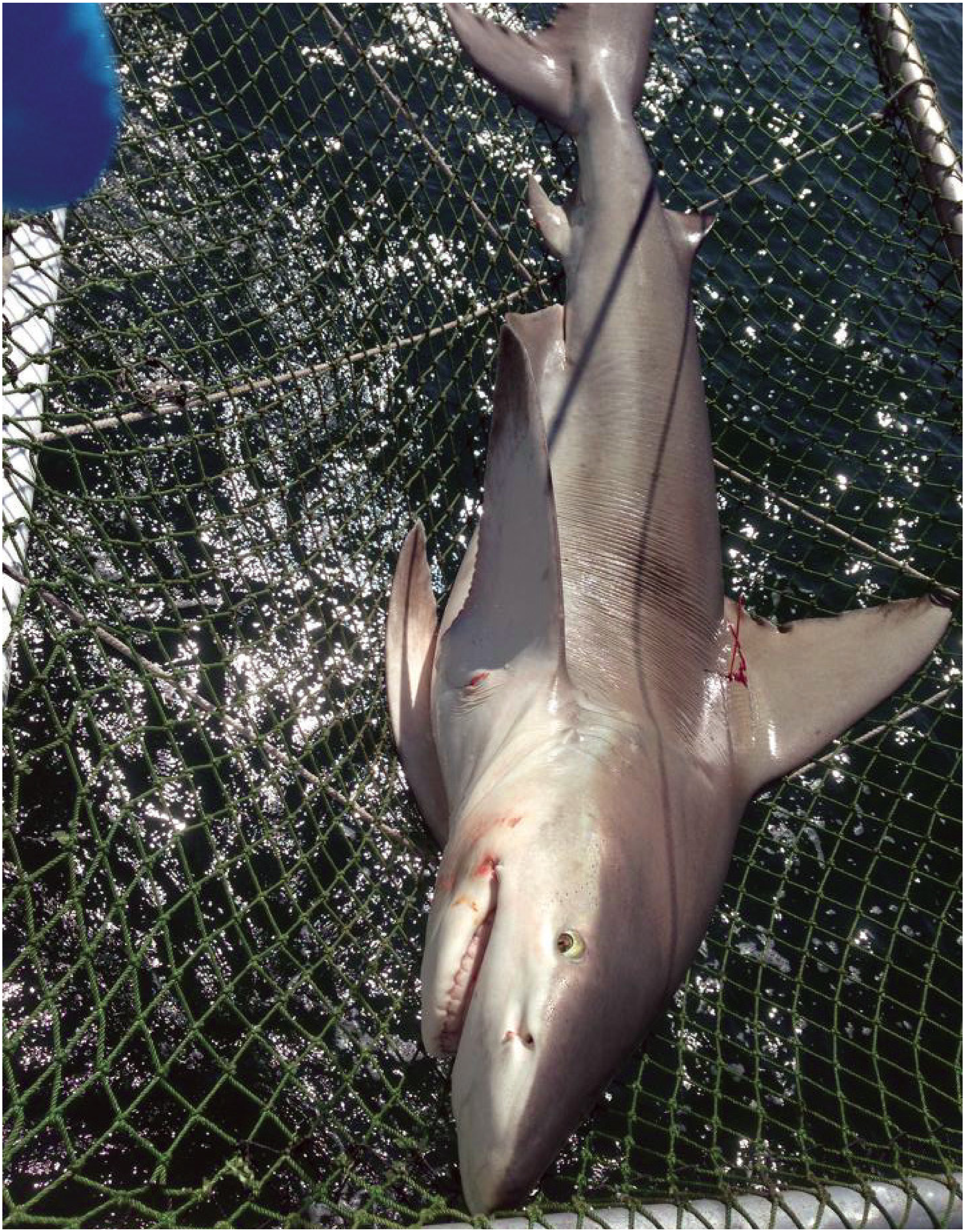
tagged in Winyah Bay, South Carolina, ~257 km north of Gray's Reef, and one off the Outer Banks, North Carolina, 671 km northeast (Figure 3.28A). Three of the individuals detected at Gray's Reef in the spring were found ~45 km southwest of the sanctuary 1-18 days before their arrival, and ~115 km northeast 9-35 days after their departure suggesting northward movement (Figure 3.28B). One individual visited the sanctuary in the winter, and was found ~58 km southwest of the sanctuary 7 days before arriving and 2 days after its departure suggesting less directional movement (Figure 3.28C). Another individual, which was detected at the sanctuary four times, was not detected elsewhere until the summer after its last detection at the sanctuary, off the coast of New York.

Significance of Connectivity

Seasonality of detections of sandbar sharks at Gray's Reef indicate the sanctuary is a winter and spring habitat for this species. Additionally, the northward directionality of individuals that visited in the spring indicate the sanctuary is a stop on their northward migration (Springer, 1960). Although sandbar sharks can be found anywhere from Florida to Long Island in the summer (Springer, 1960; Conrath and Musick, 2008), none were detected at the sanctuary during this season. During the time receivers were deployed at Gray's Reef, only juveniles were detected.

Acknowledgements

We thank Dr. Charles Bangley for contribution of tag and individual metadata for this species.



Sandbar shark from longline survey aboard R/V Bay Eagle. Credit: Multispecies Research Group, Virginia Institute of Marine Science

Results

3.2.10 Tiger Shark *(Galeocerdo cuvier)*

Citation: Williams, B.L., B. Frazier, N. Hammerschlag, and M.S. Kendall. 2019. Tiger shark (*Galeocerdo cuvier*) use of Gray's Reef National Marine Sanctuary. pp. 40-43. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.29. Adult tiger shark (*Galeocerdo cuvier*). Credit: A. Kok, licensed under CC BY-SA 3.0.*

Species Description

Tiger sharks (*Galeocerdo cuvier*; Figure 3.29) are large predators with a very diverse diet including fish, elasmobranchs, turtles, sea birds, seals, dolphins, and invertebrates (Randall, 1992). Tiger sharks occur globally in tropical and temperate regions where they inhabit coastal as well as open ocean waters, often in association with currents such as the Gulf Stream (Simpfendorfer, 2009; Hammerschlag et al., 2012; Lea et al., 2015). Their range in the western Atlantic extends from Cape Cod, Massachusetts to Uruguay, including the Gulf of Mexico and the Caribbean (Randall, 1992). Maturity is reached beginning around 300 cm TL and a maximum size of 450 cm TL (Sulikowski et al., 2016). In the northern hemisphere, mating is thought to be triennial, occurring in the late fall or early spring, with parturition in the late summer (Driggers et al., 2008; Simpfendorfer, 2009). Repeated migrations occur wherein adults often return to a localized home range during winter months around lower-latitude coasts and islands. They then migrate widely during summer into the higher latitude waters of the Gulf Stream and Sargasso Sea (Hammerschlag et al., 2012; Lea et al., 2015), however some individuals remain residential (Papastamatious et al., 2013). Tiger sharks are subject to recreational and commercial fisheries and also caught as bycatch in commercial longline fisheries (Berkeley and Campos, 1988; Musick et al., 1993; GSAFDF, 1996; Calich et al., 2018). In the U.S. Atlantic, tiger sharks are part of a multispecies management plan and IUCN status is listed as "near threatened" despite growth and reproductive rates that are relatively high among sharks (Simpfendorfer, 2009).

Table 3.11. Tiger shark data contributors.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Bryan Frazier	South Carolina DNR	22	913	Jun. 2014-Jul. 2017
Dr. Neil Hammerschlag	University of Miami	3	69	Apr. 2015-Mar. 2017

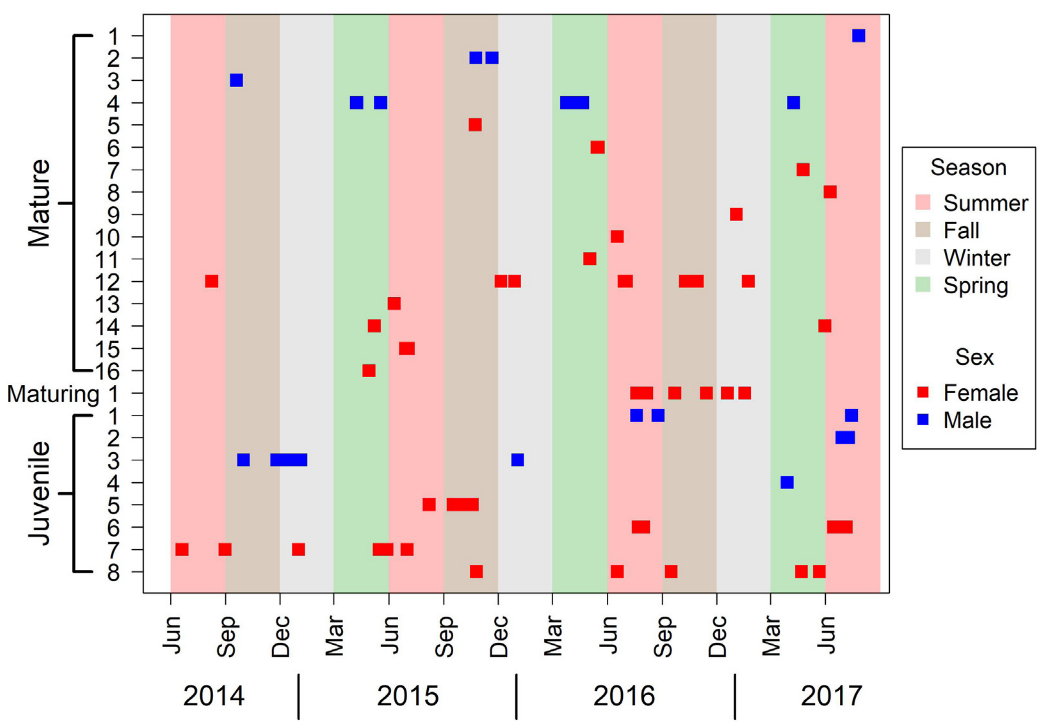


*Figure 3.30. Detections of individual tiger sharks (*Galeocerdo cuvier*) at Gray's Reef.*

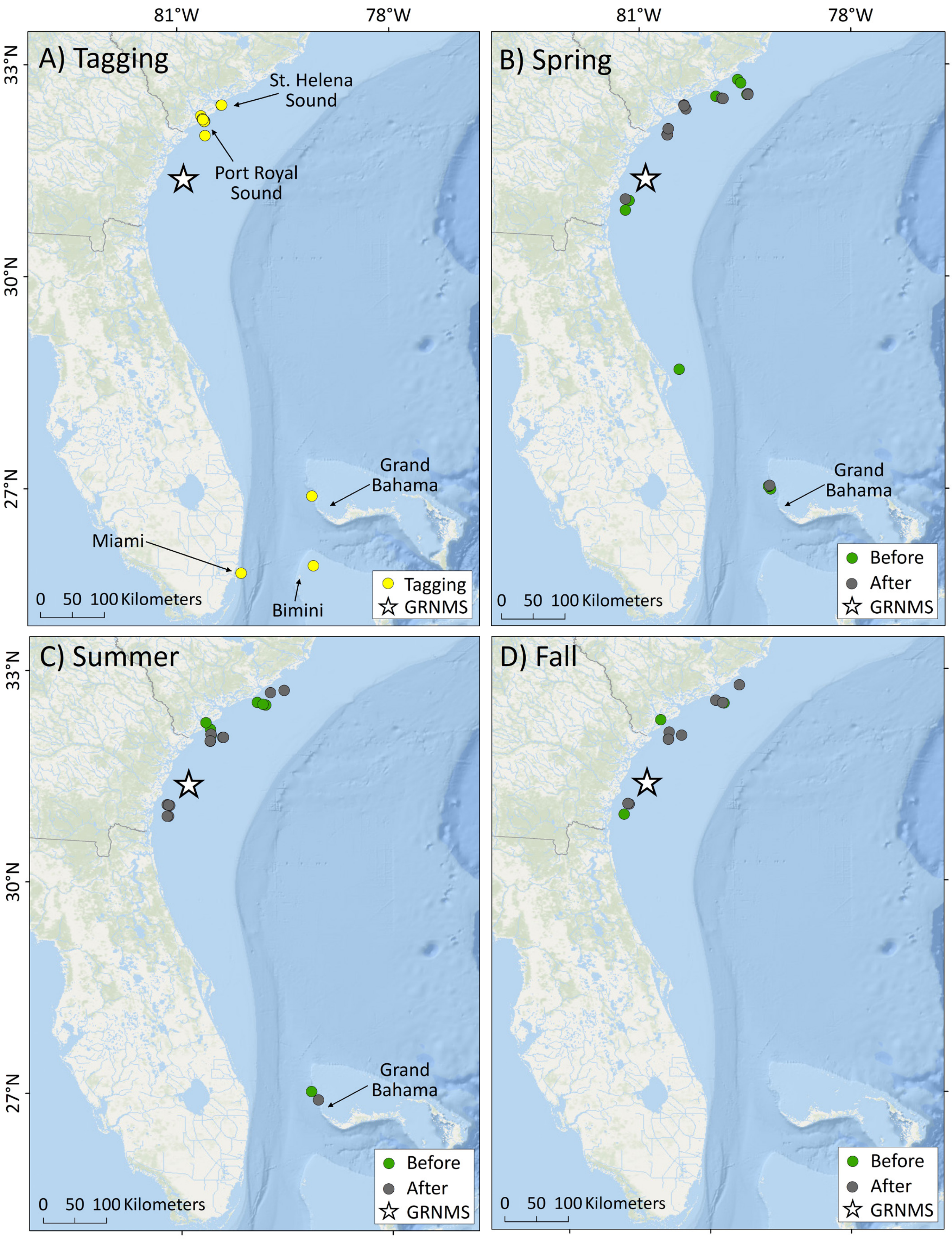


Figure 3.31. Tiger sharks (Galeocerdo cuvier) A) tagging locations, and locations before and after their visits to Gray's Reef across seasons B) spring, C) summer, D) fall, and E) winter. Season corresponds to season of visit to sanctuary, not necessarily season of detection. Note, due to overlapping coordinates, some detections may not be visible.

Movements Through GRNMS

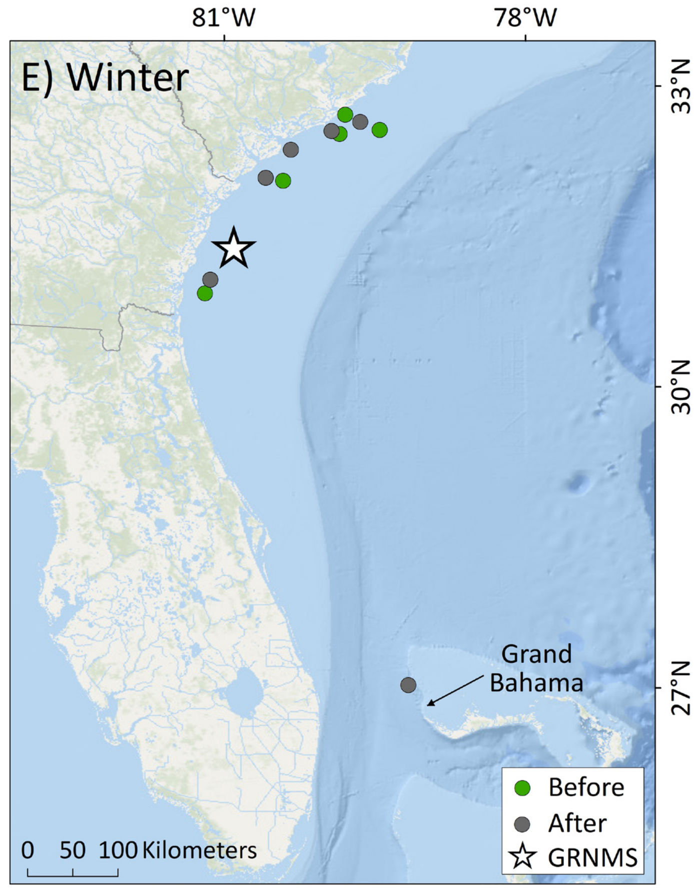


Figure 3.31. cont. Tiger sharks (Galeocerdo cuvier) *locations before, and after their visits to Gray's Reef in the E) winter season.*
Season corresponds to season of visit to sanctuary, not necessarily season of detection. Note, due to overlapping coordinates, some detections may not be visible.

Twenty-five tiger sharks, across a range of life stages, were detected at Gray's Reef from 2014-2017 (Figure 3.30; Table 3.11). Fifteen adults, twelve females and three males, were detected (294.6 ± 6.6 cm FL) along with nine immature individuals, four females and five males, (203.8 ± 15.2 cm FL) and one maturing female (205 cm) (Figure 3.30). More than twice as many females than males were detected at Gray's Reef, across life stages. Two adult females were pregnant upon tagging. One, tagged May 2014, visited the sanctuary in early August 2014, while another, tagged in September 2015, visited the sanctuary one month later. Individual sharks were detected on as many as seven separate occasions; however, some visits were only separated by one week to one month (Figure 3.30). Individual sharks were typically detected for less than one day during each visit. Over half (54%) of the tiger sharks were detected for multiple visits, 32% in separate years (Figure 3.30). Twenty-two individuals were tagged off coastal South Carolina 96.1 ± 2.5 km north of Gray's Reef and three were tagged in Florida and the Caribbean 593.8 ± 35.0 km south of Gray's Reef (Figure 3.31A). Tiger sharks were detected at Gray's Reef across all seasons, but 70% of detections, from 86% of individuals, occurred in spring and summer. Visitations across seasons were highly variable. Although a few individuals clearly visited Gray's Reef during their seasonal migrations, there was no consistent directional pattern in their movements and they were typically detected in coastal Georgia and South Carolina before and after their visits to the sanctuary (Figures 3.31B-E). One individual made the same migration through Gray's Reef from Grand Bahama to coastal South Carolina, in 2015 and 2017.

Significance of Connectivity

Both juvenile and adult tiger sharks can be present at Gray's Reef year-round. They travelled to Gray's Reef from as far as Bimini, Bahamas, but generally remained in coastal Georgia and South Carolina in the days surrounding their visits to the sanctuary. Adult tiger sharks migrate broadly from coastal overwintering habitats in lower latitudes to oceanic habitats at higher latitudes often following the Gulf Stream (Hammerschlag et al., 2012; Papastamatious et al., 2013; Lea et al., 2015). In contrast, juveniles often remain more residential, not participating in such wide migrations (Hammerschlag et al., 2012; Lea et al., 2015). At Gray's Reef, a lower latitude shelf habitat, the majority of adult tiger sharks were female, however this is likely a result of tagging bias. Some female tiger sharks exhibit skip or partial migration patterns depending on reproductive state, often remaining residential, and many exhibit high residency off coastal Georgia (Papastamatious et al., 2013; Hammerschlag et al., 2015; Calich et al., 2018). Their year-round presence at the sanctuary could be due to some individuals not participating in migration during the year of their visit. Further, eight of the twenty-five tiger sharks detected at Gray's Reef were juveniles, which often do not participate in oceanic migrations (Lea et al., 2015). Additionally, previous work suggests that coastal Georgia is a popular habitat for tiger sharks targeting loggerhead sea turtles (Hammerschlag et al., 2015). Ultimately, tiger sharks are a common transient apex predator present at Gray's Reef.

Acknowledgements
We thank Mitchell Rider from University of Miami for compiling individual and tag metadata for this species.

Tiger shark. Credit: Tanya Houppermans

Results

3.2.11 White Shark *(Carcharodon carcharias)*

Citation: Williams, B.L., G. Skomal, and M.S. Kendall. 2019. White shark (*Carcharodon carcharias*) use of Gray's Reef National Marine Sanctuary. pp. 44-45. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

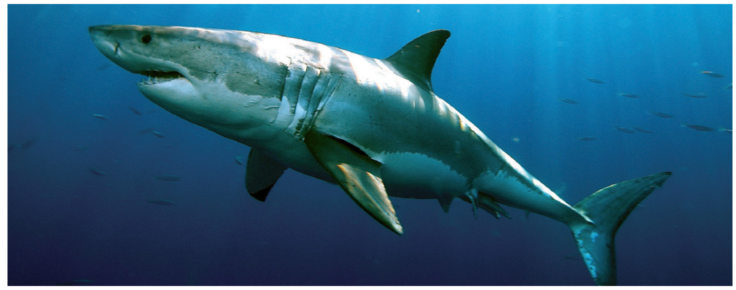


*Figure 3.32. Adult white shark (*Carcharodon carcharias*) Credit: G. Skomal, MA DMF*

Species Description

White sharks (*Carcharodon carcharias*; Figure 3.32) are one of the largest coastal and ocean predators. They occur in temperate and subtropical climates (Compagno, 2001). Growing to a maximum size of 6 m (Randall, 1973; Bruce, 2008), they experience an ontogenetic shift in diet at 3-4 m TL from fish to marine mammals (Estrada et al., 2006). Male and female white sharks reach maturity at 3.6-3.8 and 4.5-5 m TL, respectively (Francis, 1996; Pratt, 1996; Malcolm et al., 2001). Reproduction occurs every 2-3 years with litters ranging from 2-17 pups (Mollet and Cailliet, 2002; Bruce, 2008). In the western North Atlantic, juvenile white sharks (<3 m TL) are primarily coastal and migrate seasonally. They spend winter along the southeast U.S. coast and spring/summer between Cape Hatteras and Cape Cod (Curtis et al., 2014; Skomal et al., 2017). Sub-adult and adult distributions are similar to those of juveniles during summer months, but are more variable during fall, winter, and spring, with some traveling beyond the continental shelf (Skomal et al., 2017).

Table 3.12. White shark data contributor.

Tag Owner	Affiliation	Tagged Sharks Detected at GRNMS	Total Detections	Detection Range
Dr. Greg Skomal	MA Division of Marine Fisheries	22	731	Feb 2011-Apr 2017

Movements Through GRNMS

Twenty-two white sharks have been detected at Gray's Reef from 2011-2017 (Figure 3.33; Table 3.12). These individuals were tagged off Cape Cod, Massachusetts (n=19) and Charleston, South Carolina (n=3), approximately 1500 and 170 km north of Gray's Reef, respectively (Figure 3.34). Generally, white sharks visited Gray's Reef during winter and spring months, spending about 1 day at the sanctuary. Adults (4.12 ± 0.2 m TL) visited almost exclusively during winter months, sub-adults (3.76 ± 0.1 m TL) in both the spring and winter, and juveniles (2.52 ± 0.1 m TL) mostly in the spring months

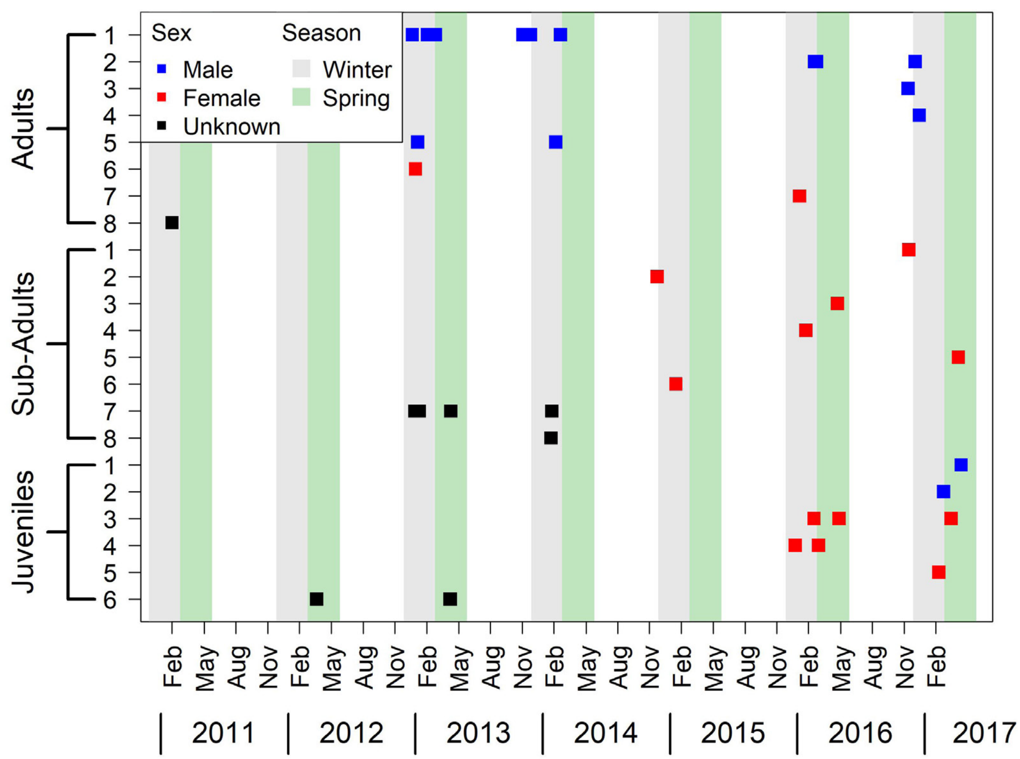


*Figure 3.33. Detections of individual white sharks (*Carcharodon carcharias*) at Gray's Reef.*

(Figure 3.33). No detection of white sharks occurred at Gray's Reef during summer. Overall, more females visited Gray's Reef than males (M:F = 0.64; Figure 3.33). However, sex ratio differs across life stages, with more adult males than adult females detected (M:F = 2.5; Figure 3.33) and more female sub-adults and juveniles detected than males of the corresponding life stage ($M{:}F_{sub\text{-}adult} = 0$, $M{:}F_{juvenile} = 0.33$; Figure 3.33), although these ratios are likely associated with tagging bias with more tagged females available than males. Sex of four individuals (1 juvenile, 2 sub-adults, and 1 adult) was not identified. Seven individuals (32%) made repeat visits to Gray's Reef. Four returned in the same year and six returned in multiple years. One individual made six return visits over 2 years (Figure 3.33).

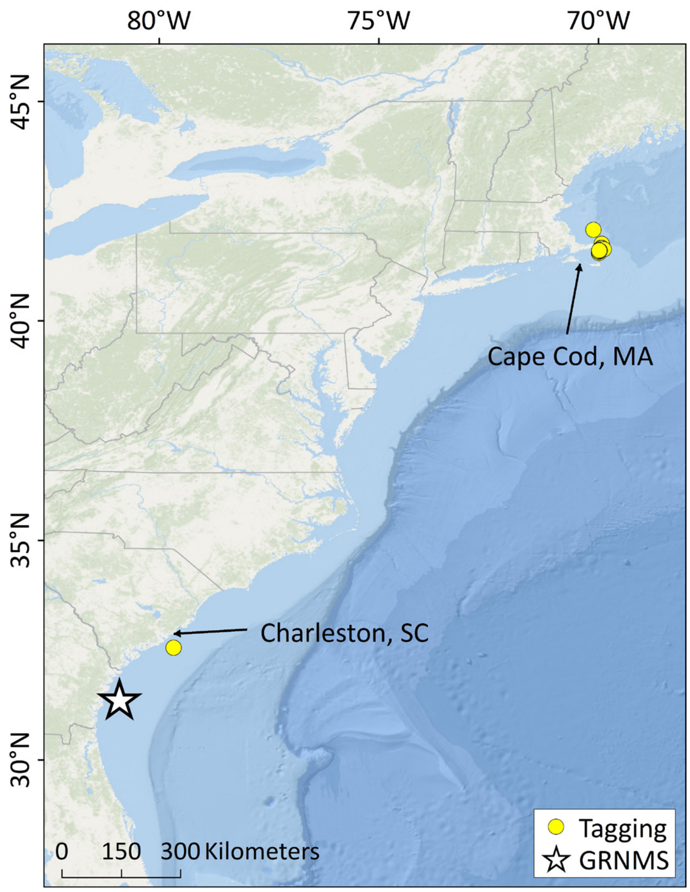


Figure 3.34. White shark (Carcharodon carcharias) tagging locations.

Significance of Connectivity

Detections of white sharks at Gray's Reef indicate this sanctuary is a seasonal coastal habitat for multiple life stages and both sexes of this species. Timing of these detections match their known seasonal distribution in the western Atlantic, occurring along the southeast U.S. coast during winter and spring (Curtis et al., 2014; Skomal et al., 2017). Although almost half of tagged sub-adult/adult white sharks move beyond the continental shelf in the winter and spring (Skomal et al., 2017), 17 sub-adults/adults visited Gray's Reef, a coastal habitat, during those seasons (Figure 3.33). Coastal habitats are important foraging grounds for white sharks of all life stages (Skomal et al., 2017), indicating Gray's Reef may also serve this function although sharks do not linger for more than a day. Additionally, white shark predation on North Atlantic right whales (*Eubalaena glacialis*) at their calving grounds off the coast of the southeastern U.S. (Taylor et al., 2013), further suggests the idea that they may serve this function. Generally, white sharks use Gray's Reef as habitat briefly throughout winter and spring, and often in recurring years suggesting that it is part of a detailed migratory pathway or known landmark.

3.3 TELEOSTS

3.3.1 Atlantic Bluefin Tuna *(Thunnus thynnus)*

Citation: Williams, B.L., B. Block and M.S. Kendall. 2019. Atlantic bluefin tuna (*Thunnus thynnus*) use of Gray's Reef National Marine Sanctuary. pp. 46-47. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.35. Atlantic bluefin tuna (*Thunnus thynnus*). Credit: W. Goldsmith, Lenfest Ocean Program*

Table 3.13. Atlantic bluefin tuna data contributor.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Dr. Barbara Block	Stanford University	2	4	Mar. 2013-Apr. 2014

Species Description

Atlantic bluefin tuna (*Thunnus thynnus;* Figure 3.35) are large pelagic predators that feed on fish and invertebrates, including sardines, herring, and squid (Fromentin and Powers, 2005; Pleizier et al., 2012). They occur throughout the North Atlantic and can grow up to 330 cm FL and 725 kg (ICCAT, 2017). In the western Atlantic, they reach maturity near 8 years of age and 200 cm and spawn in the Gulf of Mexico from April-May (Mather et al., 1995; Fromentin and Powers, 2005; ICCAT, 2017). Satellite tagging indicates that Atlantic bluefin tuna in the western Atlantic migrate seasonally along the continental shelf, sometimes following the Gulf Stream, from foraging areas in the north Atlantic to spawning areas in the Gulf of Mexico, where they remain in winter and spring (Block et al., 2001; Wilson et al., 2015; ICCAT, 2017 ; Block et al., 2019). Atlantic bluefin tuna are fished recreationally and commercially throughout their range, except in the Gulf of Mexico where harvest is prohibited (ICCAT, 2017). While they are currently not subject to overfishing in the western Atlantic, it is unknown if the population is overfished (ICCAT, 2017). In 2011, IUCN listed Atlantic bluefin tuna as "endangered" (Collette et al., 2011).

Movements Through GRNMS

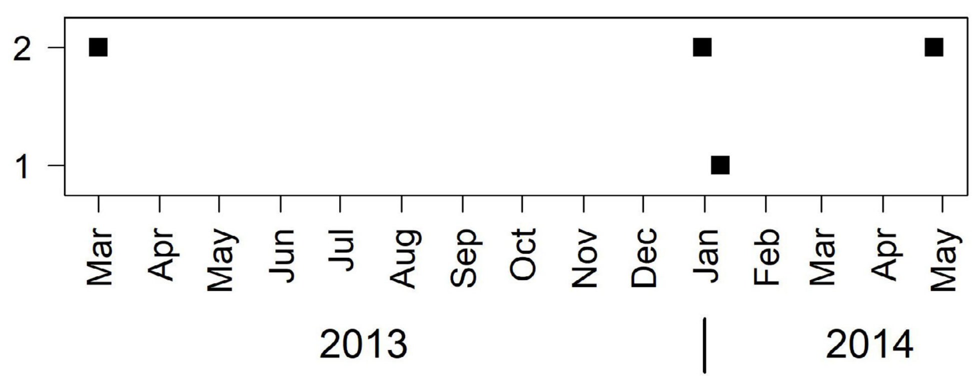


*Figure 3.36. Detections of individual Atlantic bluefin tuna (*Thunnus thynnus*) at Gray's Reef.*

Two Atlantic bluefin tuna (220 and 199 cm) have been detected at Gray's Reef (Figure 3.36; Table 3.13). Detections occurred only during winter and spring months (Figure 3.36). Both individuals were tagged in the Gulf of St. Lawrence, Canada, ~2,300 km northeast of Gray's Reef (Figure 3.37 ; Block et al., 2019). Both individuals were detected in the northwest Atlantic, one in October 2012 and one in October 2013, prior to their arrival at the sanctuary (Figure 3.37). During each visit, individuals were only detected once, quickly passing through the sanctuary. One individual was detected at the sanctuary on three occasions in two separate years, whereas the other was only detected once (Figure 3.36). Neither fish was detected after departing the sanctuary.

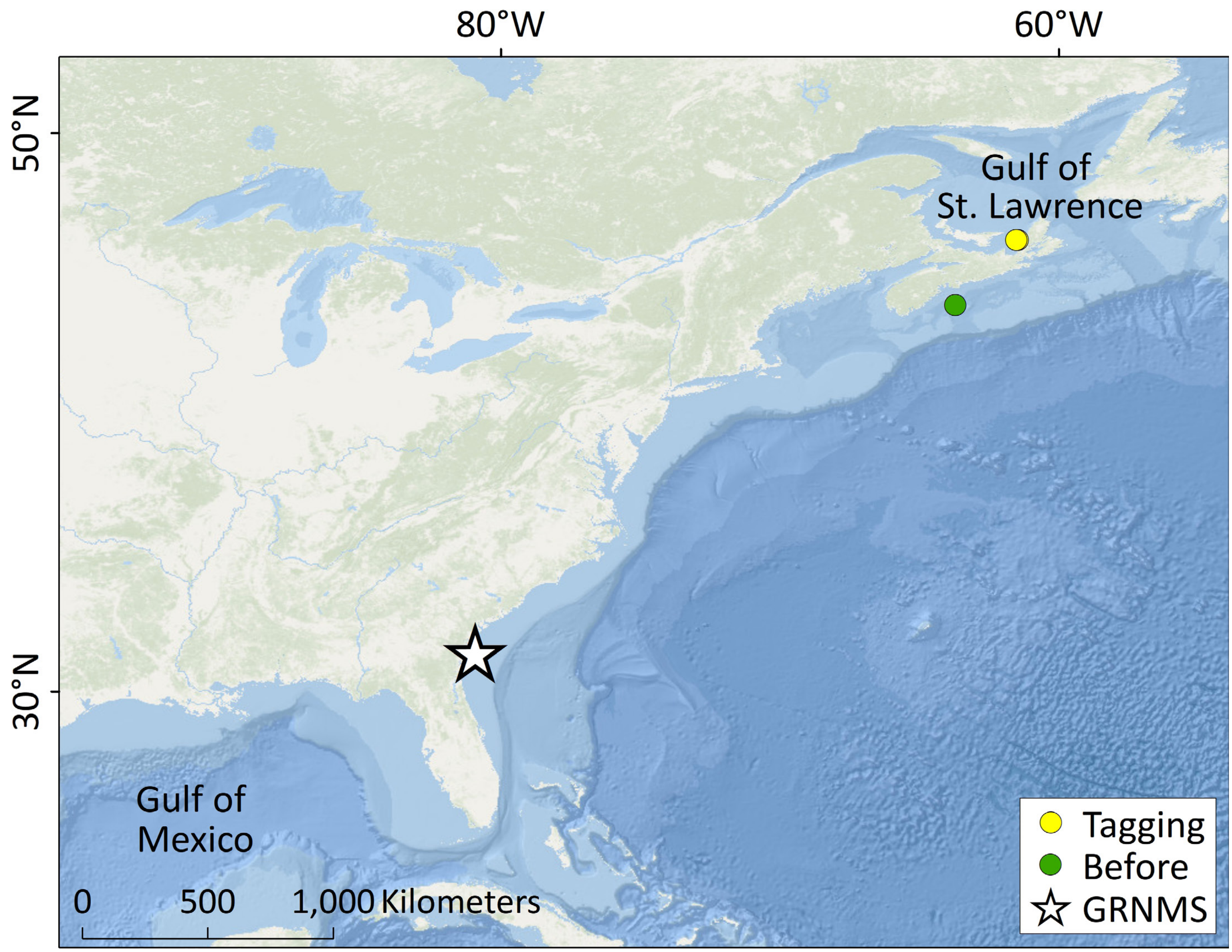


*Figure 3.37. Atlantic bluefin tuna (*Thunnus thynnus*) tagging locations and before their arrival to Gray's Reef. No data available for location after departing Gray's Reef.*

Significance of Connectivity

Detections of Atlantic bluefin tuna indicate they can pass through the sanctuary during their annual migrations to spawning grounds in the Gulf of Mexico. Adults depart the Gulf of St. Lawrence mid-October and arrive in the Gulf of Mexico from November-April (Wilson et al., 2015). The timing of the January and March detections at the sanctuary (Figure 3.36) suggests that these fish were passing through on their southward migration. Atlantic bluefin tuna depart the Gulf of Mexico between April and June to return north (Wilson et al., 2015). One individual was detected at the sanctuary twice within this period in two separate years, suggesting that it was passing through the sanctuary on its return migrations to the Gulf of St. Lawrence. Although it is difficult to make generalizations based on two individuals, the appearance of these fish at Gray's Reef during multiple legs of their migration cycle suggests they follow a regular route that could include the sanctuary.

Acknowledgements

We thank Michael Castleton for contribution of tag and individual metadata for this species.

3.3.2 Atlantic Sturgeon

(Acipenser oxyrinchus oxyrinchus)

Citation: Williams, B.L., D. Fox, B. Post, and M.S. Kendall. 2019. Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) use of Gray's Reef National Marine Sanctuary. pp. 48-51. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

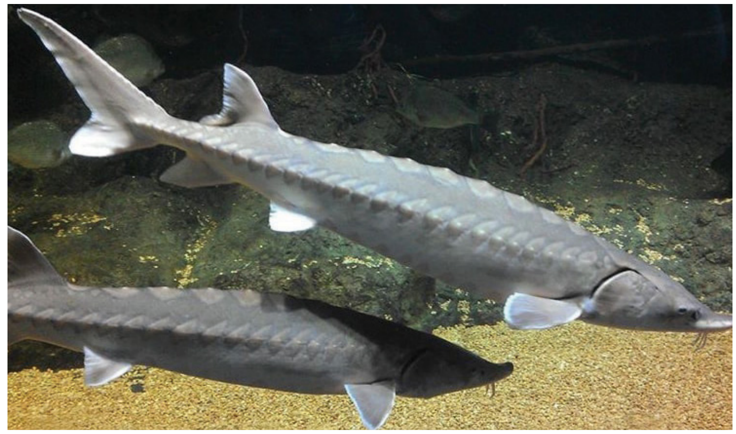


*Figure 3.38. Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Credit: NOAA NMFS.*

Species Description

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*; Figure 3.38) are anadromous benthic-oriented fish that feed primarily on polychaetes, crustaceans, and other invertebrates (Johnson et al., 1997). They range along the Canadian and U.S. Atlantic Coast from Labrador to Florida and can be divided into several distinct genetic stocks (Wirgin et al., 2000, 2015). Maturity is reached at ~180-230 cm TL and maximum size can exceed >400 cm (Vladykov and Greely, 1963). They migrate up rivers to spawn in spring months (summer in northern parts of their range). Spawning takes place every 2-5 years. Between spawning events, they can migrate extensively in estuarine and continental shelf waters (~10-50 m depth) where they forage primarily on sand and gravel bottom (Collins et al., 2000; Stein et al., 2004; Wirgin et al., 2015; Fox et al., 2018). Atlantic sturgeon populations have been recovering in some rivers following closure of U.S. fisheries in 1997, due to high levels of historical harvest, ongoing by-catch, and degradation of spawning habitat, all Atlantic sturgeon, except those that hatch in the Gulf of Maine, are listed as endangered under the Endangered Species Act (ASMFC, 1998; USFWS-NMFS, 1998; Stein et al., 2004; 77 FR 5879 April 6, 2012; 77 FR 5913 April 6, 2012).

Table 3.14. Atlantic sturgeon data contributors.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Joe Facendola, Chris Stewart, Dr. Chip Collier	North Carolina Division of Marine Fisheries	5	45	Jan. 2013-Feb. 2016
Dr. Keith Dunton	Monmouth University	1	17	Jan. 2011
Dr. Dewayne Fox	Delaware State University	13	360	Mar. 2010-Feb. 2016
Dr. Doug Peterson, Daniel Erickson	University of Georgia, University of Miami	1	59	Dec. 2010, Mar. 2011
Dr. Doug Peterson, Dr. Adam Fox	University of Georgia	2	29	Feb. 2014-Mar. 2014
Bill Post	South Carolina Department of Natural Resources	15	466	Nov. 2010-Feb. 2017

Movements Through GRNMS

Thirty-seven Atlantic sturgeon were detected at Gray's Reef from 2010-2017, primarily in the winter and spring (Figure 3.40; Table 3.14). Sixteen adults (176.0 ± 3.8 cm TL), five sub-adults (123.1 ± 3.8 cm TL), and one juvenile (95.6 cm TL) were detected. Six of the adults were female, four were male, and the remaining adults were not identified by sex. Length/life stage and sex information were not available for the remaining fifteen sturgeon. Atlantic sturgeon detected at the sanctuary were initially tagged throughout rivers and estuaries on the Atlantic coast from Georgia to New Jersey/New York, on average (± SE) 490 ± 65.6 km away from Gray's Reef (Figure 3.39A). They were usually detected at the sanctuary for less than one day. Some remained in the area up to 17 days, but were not detected continuously across days (Figure 3.40). Eight made repeat visits to the sanctuary, six in separate years (Figure 3.40). On five occasions,

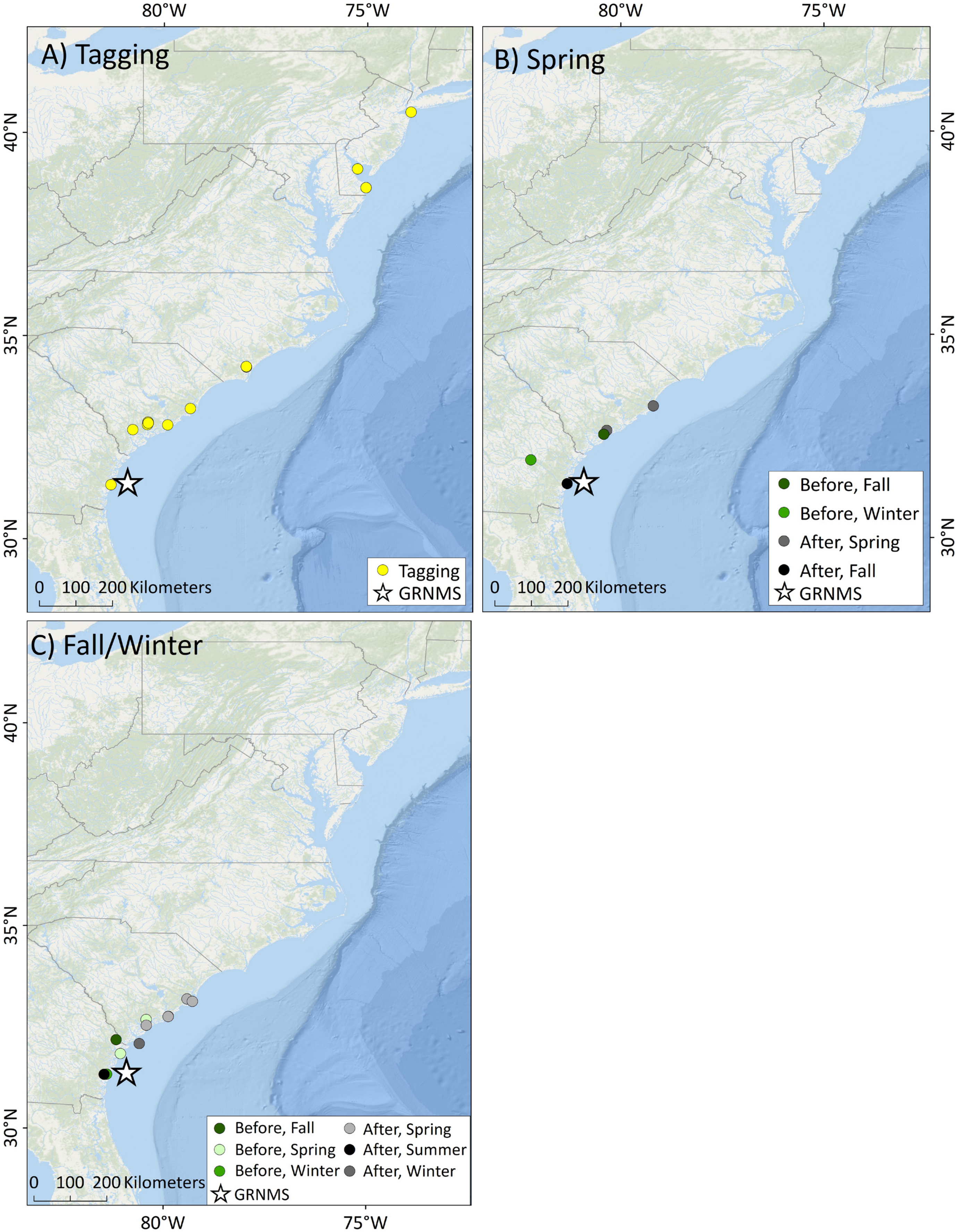


*Figure 3.39. Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) A) tagging locations and locations before, and after their visits to Gray's Reef across seasons B) spring, and C) fall/winter. Season corresponds to season of visit to sanctuary, not necessarily season of detection. Note, due to overlapping coordinates, some detections may not be visible.*

two different sturgeon were detected on the same day (Figure 3.40). Twice the co-occurring sturgeon were both individuals tagged in South Carolina less than a year prior to their arrival at the sanctuary. Three times, sturgeon tagged in Delaware were detected at Gray's Reef on the same day, twice at the same receiver 3.5-20 hours apart. Twelve were detected at the sanctuary in the spring. Both before and after their spring visits to Gray's Reef, three were detected in estuaries and rivers in Georgia and South Carolina, two in the rivers they were originally tagged (Figure 3.39B). Data were not available on detections of other individuals outside the sanctuary. Only four Atlantic sturgeon were detected at the sanctuary in the fall (Figure 3.39) while twenty-two Atlantic sturgeon were detected at Gray's Reef in the winter. Five of these fish were detected north of the sanctuary prior to their visit, then detected north of the sanctuary the following spring after their winter visit (Figure 3.39C), suggesting Gray's Reef was their southernmost detection during the winter season.

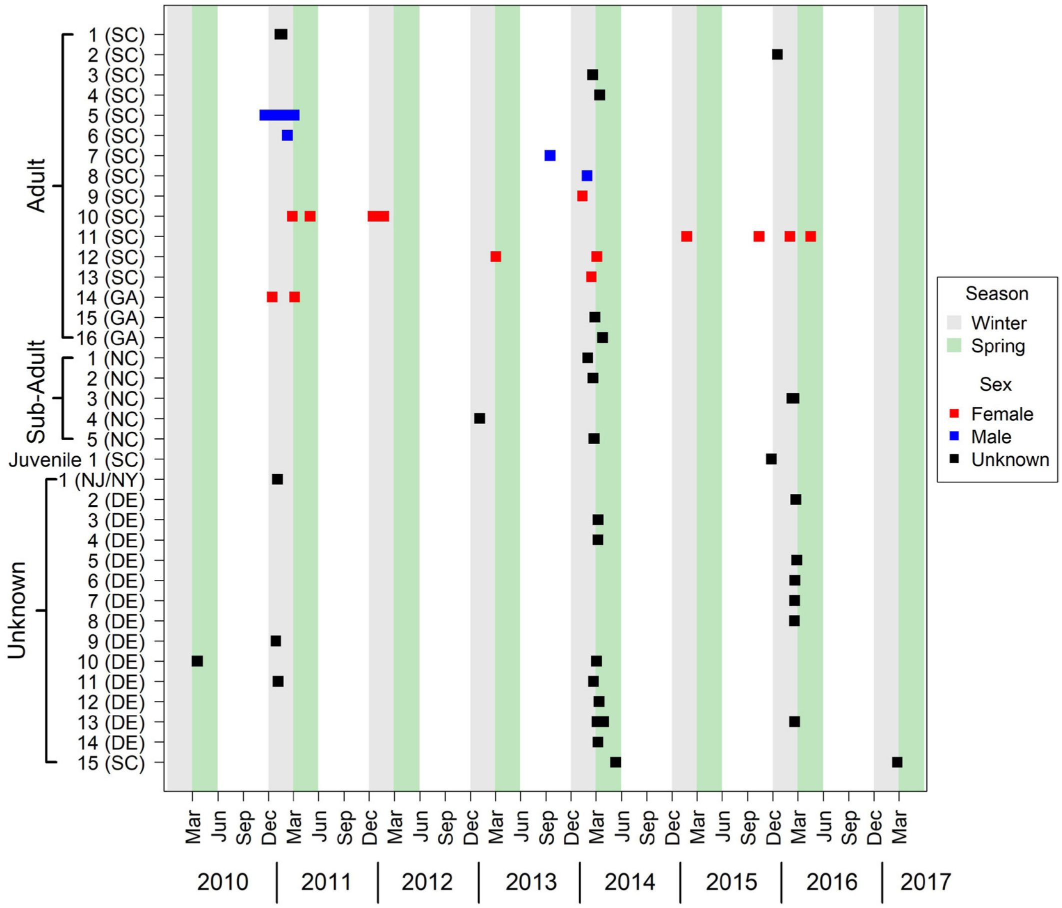


*Figure 3.40. Detections of individual Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) at Gray's Reef.*

Significance of Connectivity

Gray's Reef is a seasonal habitat for Atlantic sturgeon during a variety of life stages. Atlantic sturgeon come to Gray's Reef from at least as far away as coastal New Jersey and are generally found in rivers and estuaries in coastal Georgia and South Carolina before and after their visits to the sanctuary (Figures 3.39A-C), however locations directly before and after their visits to the sanctuary were only available for Atlantic sturgeon tagged in South Carolina and Georgia. Individuals tagged in North Carolina, Delaware, and New Jersey may exhibit different patterns. Most of the sturgeon to visit Gray's Reef were tagged in South Carolina and Delaware (Figure 3.39A; Figure 3.40). Seasonal usage of the sanctuary suggests sturgeon may pass through the sanctuary during their migrations (Collins et al., 2000; Stein et al., 2004). None of the individuals detected at the sanctuary were ever detected further south than the Altamaha River, Georgia, 41 km southwest of Gray's Reef, directly before or after their visits to the sanctuary. However, other individuals from these estuaries, including the Altamaha River, Georgia, Santee and Cooper Rivers, South Carolina, and coastal New York and New Jersey, have been detected as far south as St. Johns River, Florida (Fox et al., 2018). Ultimately, Gray's Reef is a habitat that Atlantic sturgeon pass through quickly, seasonally, and occasionally in multiple years.

Acknowledgements
We thank Drs. Douglas Peterson and Adam Fox from University of Georgia and Daniel Erickson from University of Miami for contributing detections and tag metadata to this study. We also thank Joe Facendola and Chris Steward from North Carolina Division of Marine Fisheries and Chip Collier from the South Atlantic Marine Fisheries Council for providing detection and metadata.

Atlantic sturgeon. Work is conducted under E.S.A. Sec. 10 permit # 20528-01. Credit K. Hackathorn, SCDNR

3.3.3 Cobia *(Rachycentron canadum)*

*Figure 3.41. Adult cobia (*Rachycentron canadum*). Credit: J. Alarcon and D. Benetti, NOAA NMFS.*

Species Description

Cobia (*Rachycentron canadum*; Figure 3.41) are a globally distributed coastal-pelagic species that feeds on fish and crustaceans (Shaffer and Nakamura, 1989; Arendt et al., 2001). Cobia reach maturity at 2-3 years of age and a maximum size exceeding 140 cm FL (SEDAR, 2013a; Kalinowsky et al., 2016; Dippold et al., 2017). Spawning occurs from April-September in coastal bays and estuaries, but sometimes offshore (Darden et al., 2014). Current research divides cobia into two distinct biological stocks: the Gulf of Mexico stock (extends from Texas to Ft. Pierce, Florida) and the Atlantic stock (South Carolina and north) (SEDAR, 2018). The degree of overlap in these stocks in the northern Florida and Georgia region is a topic of active research (SEDAR, 2018). While many studies of cobia migrations are ongoing, current literature suggests the Atlantic stock migrates inshore to coastal waters between Georgia and Virginia in the spring and summer, sometimes moving up the coast towards Chesapeake Bay. In the winter, cobia from the Atlantic stock are thought to migrate south to northern Florida, offshore, or some combination of both, but their overwintering grounds are not fully understood (Darden et al., 2014; Dippold et al., 2017; Weng et al., 2018; Perkinson pers. comm.). Cobia support recreational fisheries along the U.S. Atlantic and Gulf coasts and both stocks were not determined to be overfished during the most recent stock assessment (SEDAR, 2013a). A benchmark stock assessment is scheduled for 2019.

Table 3.15. Cobia data contributors.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Matt Perkinson	South Carolina DNR	20	544	Jun. 2016-Aug. 2017
Dr. Joy Young	Florida Fish and Wildlife Conservation Commission	2	59	Oct. 2016-May 2017

Movements Through GRNMS

Twenty-two cobia (twenty adults, two large juveniles/adults; 856.4 ± 24.2 mm FL) were detected at Gray's Reef throughout 2016 and 2017 (Figure 3.42; Table 3.15). Twenty cobia were tagged in coastal Georgia and South

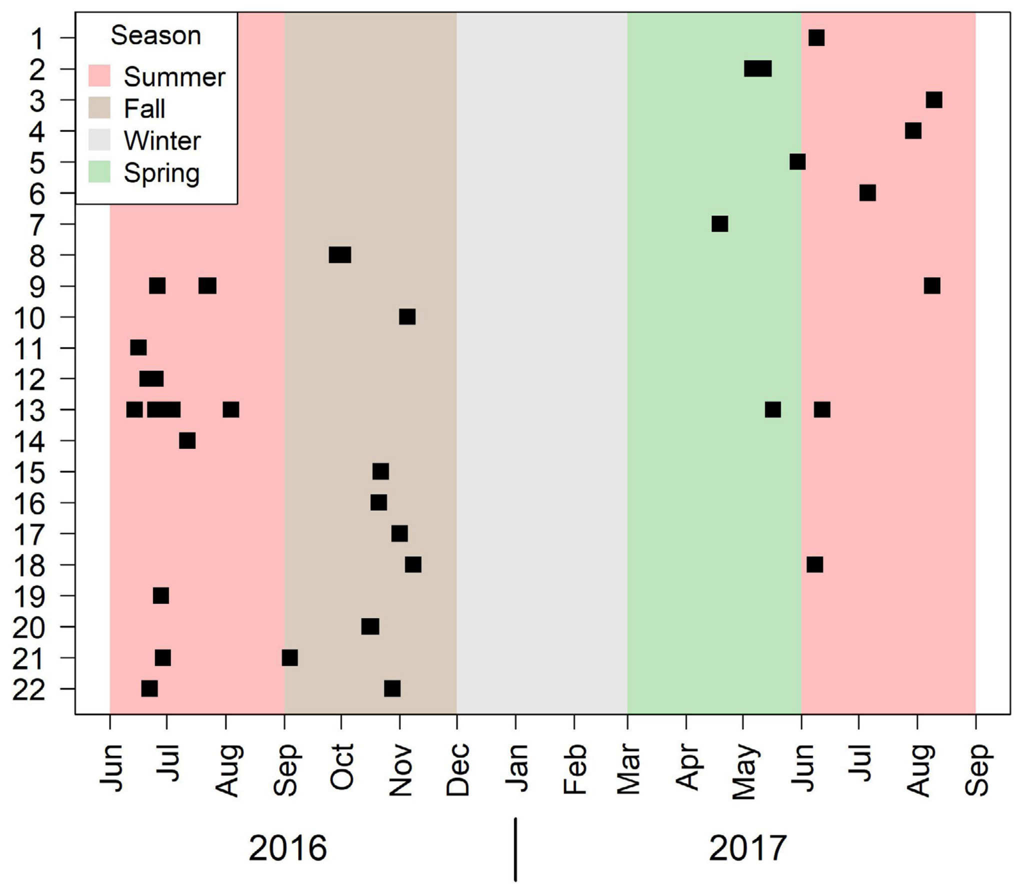


*Figure 3.42. Detections of individual cobia (*Rachycentron canadum*) at Gray's Reef.*

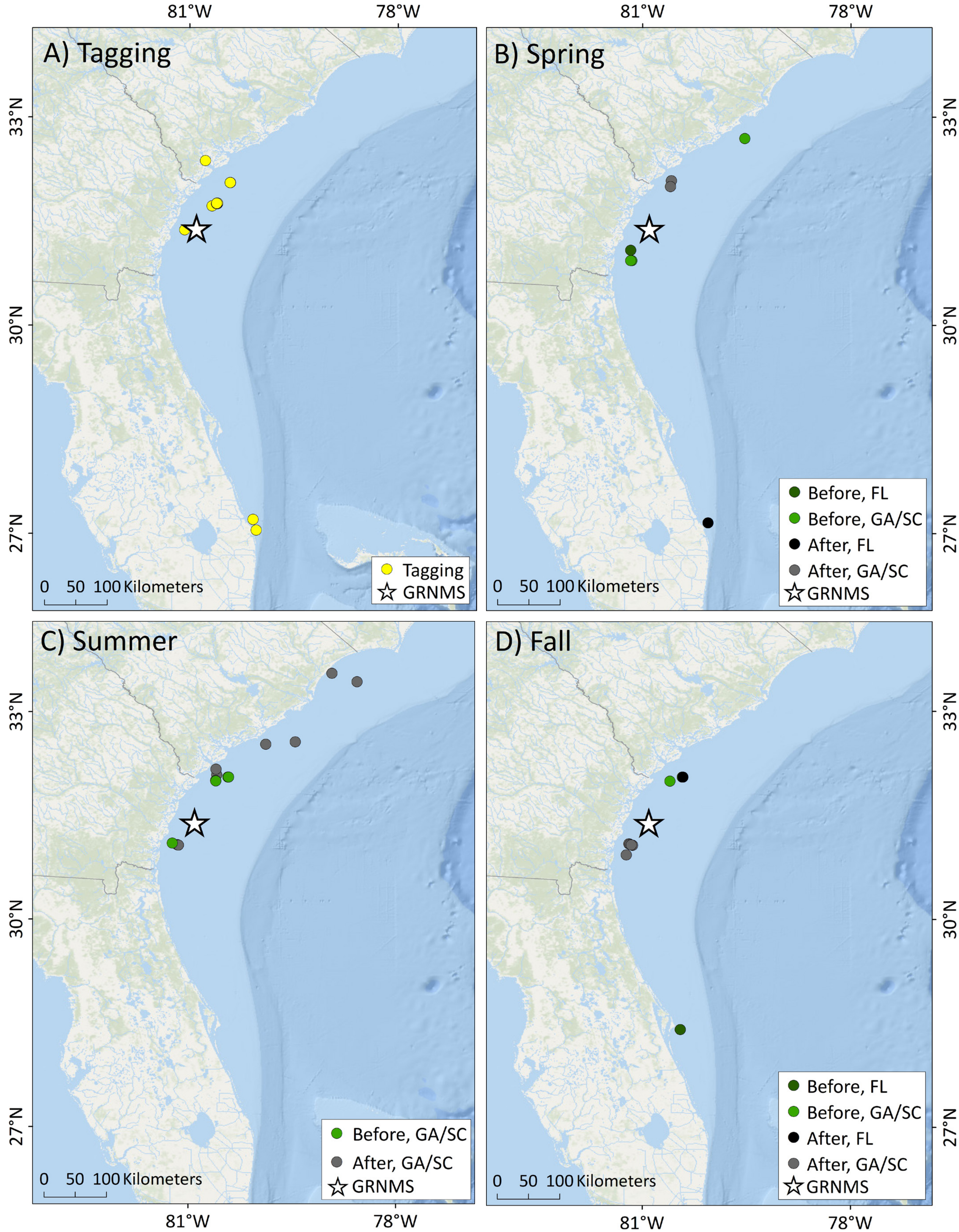


*Figure 3.43. Cobia (*Rachycentron canadum*) A) tagging locations, and locations before, and after their visits to Gray's Reef across seasons B) spring, C) summer, and D) fall. Season corresponds to season of visit to sanctuary, not necessarily season of detection. Darker shaded points denote individuals tagged off FL, while lighter shaded points denote individuals tagged off GA/SC. Note, due to overlapping coordinates, some detections may not be visible.*

Carolina, 61.8 ± 5.4 km away and primarily northward from Gray's Reef whereas two were tagged off St. Lucie, Florida approximately 478 km south of Gray's Reef (Figure 3.43A). Individual fish spent 1-7 days at the sanctuary but were not detected consistently across consecutive days. At most, two cobia were detected at the sanctuary on the same day but generally on different receivers and a few hours apart. Approximately, one-fourth of the cobia detected at the sanctuary made repeat visits in separate seasons and years, making up to six ventures to Gray's Reef (Figure 3.42). Peak visitation of cobia at Gray's Reef occurred in summer months (13 individuals) with fewer in fall (9) and spring (4). None were detected in winter (Figure 3.42). Individuals tagged in Georgia and South Carolina were detected across spring, summer, and fall, while those tagged in Florida were only detected in spring and fall. Cobia were generally found in coastal South Carolina and Georgia directly before and after their visits to the sanctuary (Figures 3.43B-D). During the spring and summer, there was no clear pattern in where cobia came to the sanctuary from or where they went after (Figures 3.43B-C), however, many individuals were not detected elsewhere in between their individual visits. In the fall, all but one individual (tagged in Florida) were detected north of the sanctuary prior to their arrival and south after their departure (Figure 3.43D), suggesting a southward movement. Four of these cobia were not detected until the following spring/summer.

Significance of Connectivity

The detections at Gray's Reef demonstrate that cobia are a common transient fish found seasonally at the sanctuary. Of note, Gray's Reef is a habitat for individuals from both the Gulf and Atlantic cobia stocks, and thus may include the region of overlap for these stocks (SEDAR, 2018). However, individuals from the Gulf stock were less common. Generally, cobia were found in coastal Georgia and South Carolina before and after their visits to Gray's Reef. Only cobia tagged in Florida were detected off coastal Florida directly after their visits to the sanctuary. Although cobia are thought to migrate south or offshore for the winter, none were detected at the sanctuary in the winter (December to March) indicating it is not typically part of their overwintering habitat (Shafer and Nakamura, 1989; Smith, 1995). Additionally, almost half the cobia detected at Gray's Reef in the fall were not detected anywhere else until the following spring, suggesting they may have moved offshore after these visits. However, their exact overwintering locations are unknown (Shafer and Nakamura, 1989; Smith, 1995).

Acknowledgements

We thank Matt Perkinson (South Carolina Department of Natural Resources) and Joy Young (Florida Fish and Wildlife Conservation Commission) for contributing detections and individual metadata for this species.

Cobia prior to tagging. Credit: D. Crear, Virginia Institute of Marine Science

Results

3.3.4 Red Drum *(Sciaenops ocellatus)*

Citation: Williams, B.L., C. Kalinowsky, and M.S. Kendall. 2019. Red Drum (*Sciaenops ocellatus*) use of Gray's Reef National Marine Sanctuary. pp. 56-57. In: B.L. Williams, K. Roberson, J. Young, and M.S. Kendall (eds.), Using Acoustic Telemetry to Understand Connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic Coastal Ocean. NOAA Technical Memorandum NOS NCCOS 259. Silver Spring, MD. 82 pp.

*Figure 3.44. Adult red drum (*Sciaenops ocellatus*). Credit: South Carolina Department of Natural Resources*

Species Description

Red drum (*Sciaenops ocellatus*; Figure 3.44) are medium sized fish that feed primarily on crabs, shrimp, and small fishes (Pattillo et al., 1997). They occur in coastal and continental shelf areas of the Atlantic and Gulf of Mexico coasts from New Jersey to Mexico (Chao, 2015). Maturity is reached at ~60-70 cm TL as 2-3 year olds and maximum size is ~150 cm TL (Pattillo et al., 1997). Spawning occurs annually in fall months in coastal inlets and channels (Lowerre-Barbieri et al., 2008, Reyier et al., 2011) with larvae recruiting back to estuarine nurseries (Stunz et al., 2002). Juveniles largely remain in estuaries then emigrate to continental shelf areas as they reach maturity (Pafford et al., 1990). Adults in the northern part of this species' range along the central U.S. east coast can migrate northward in spring from North Carolina to Virginia and southward in fall (Bacheler et al., 2009). Adults can be abundant in the surf zones during seasonal migrations. Individuals in the southern part of the range show less evidence of seasonal latitudinal migrations (Reyier et al., 2011). Red drum are primarily harvested in recreational fisheries and stocks have greatly improved since a series of regulations were implemented in the 1980's (Chao, 2015; SEDAR, 2015).

Table 3.16. Red drum data contributor.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Chris Kalinowsky	Georgia Department of Natural Resources	4	1,690	Nov. 2014-Jan. 2017

Movements Through GRNMS

Four adult red drum were detected at Gray's Reef (Figure 3.45; Table 3.16). All individuals detected were originally tagged in coastal Georgia estuaries, three in Ossabaw Sound, approximately 55 km northwest of Gray's Reef, and one in St. Simon's Sound, approximately 60 km southwest (Figure 3.46). Red drum were detected in all seasons. They were typically detected for only 1-2 days on each visit, however two individuals were detected for up to 24 days somewhat continuously, resulting in a high number of total detections (Figure 3.45). Every individual detected made repeat visits to Gray's Reef. Three fish made visits seasonally in multiple years (Figure 3.45).

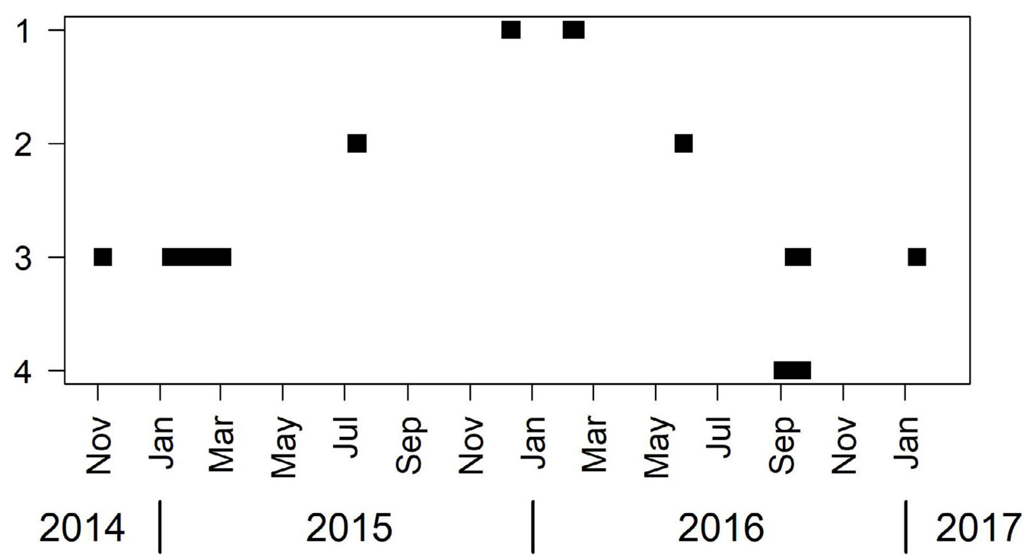


*Figure 3.45. Detections of individual red drum (*Sciaenops ocellatus*) at Gray's Reef.*

Significance of Connectivity

Gray's Reef is a potential year-round habitat for adult red drum. Adult red drum commonly inhabit the continental shelf (Pafford et al., 1990), making the sanctuary a likely habitat for them to occupy. Additionally, red drum utilize Gray's Reef across seasons. With only four individuals, it is not possible to broadly understand the importance of the sanctuary for this species. Regardless, the presence of a popular recreationally fished species is important to record.

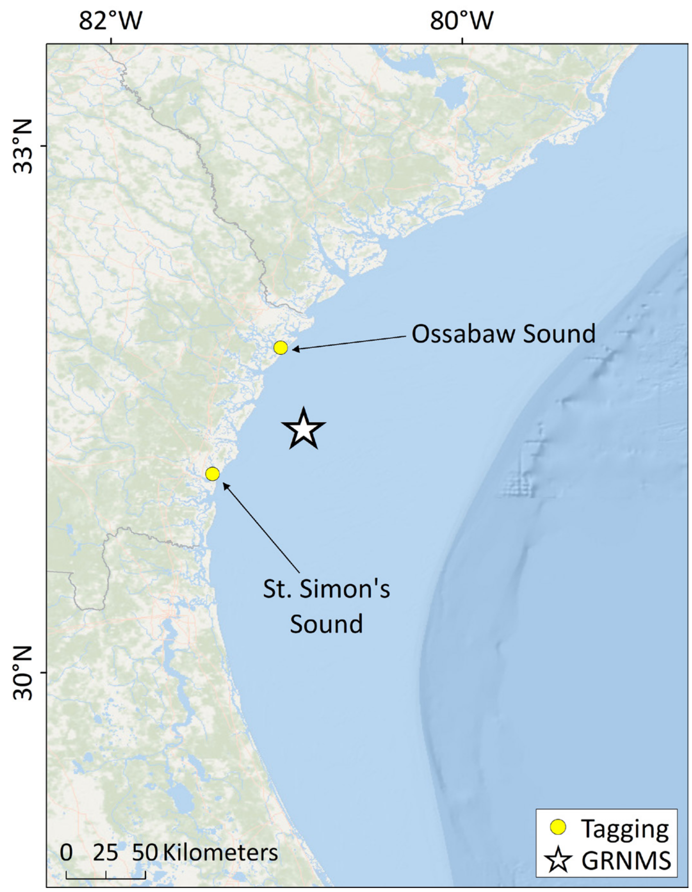


*Figure 3.46. Red drum (*Sciaenops ocellatus*) tagging locations.*

3.3.5 Southern Flounder

(Paralichthys lethostigma)

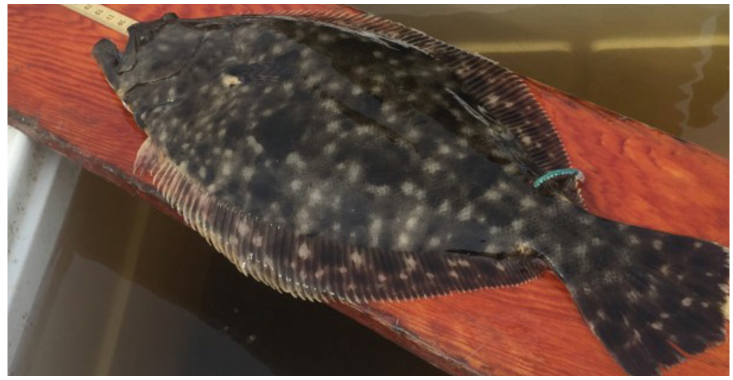


*Figure 3.47. Southern flounder (*Paralichtyhys lethostigma*). Credit: M. Hart, SCDNR.*

Species Description

Southern flounder (*Paralichthys lethostigma*; Figure 3.47) are bottom fish that feed primarily on small fishes and crustaceans (Stokes, 1977; Pattillo et al., 1997). Along the U.S. Atlantic coast, they occur from the Chesapeake Bay to southeastern Florida (Munro, 2015). Males are smaller than females with maximum size of largest females ~80 cm TL (Stokes, 1977). They spawn in offshore waters off the southeast U.S. between November and March often southward of their natal estuary (Safrit and Schwartz, 1998; Craig et al., 2015). Larvae recruit back to estuarine nurseries to grow and juveniles largely remain in estuaries prior to emigrating to inner continental shelf areas as they reach maturity (Burke et al., 1991; Craig et al., 2015). Adults may migrate back into estuaries in spring and summer, however, long distance migration is not common (Stokes, 1977; Pattillo et al., 1997). Southern flounder are commercially harvested and also a popular target among recreational fishermen. The IUCN has listed southern flounder as "near threatened" (Munro, 2015).

Table 3.17. Southern flounder data contributor.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Liz Vinyard	South Carolina Department of Natural Resources	1	5	Jan. 2017

Movements Through GRNMS

One southern flounder (368 mm TL at time of tagging) was detected at Gray's Reef in January 2017 for a period of ten minutes (Table 3.17). This individual was tagged in the Ashley River, South Carolina, approximately 181 km north of Gray's Reef, and detected there 54 days prior to its arrival at the sanctuary (Figure 3.48). After its departure from Gray's Reef it was not detected again.

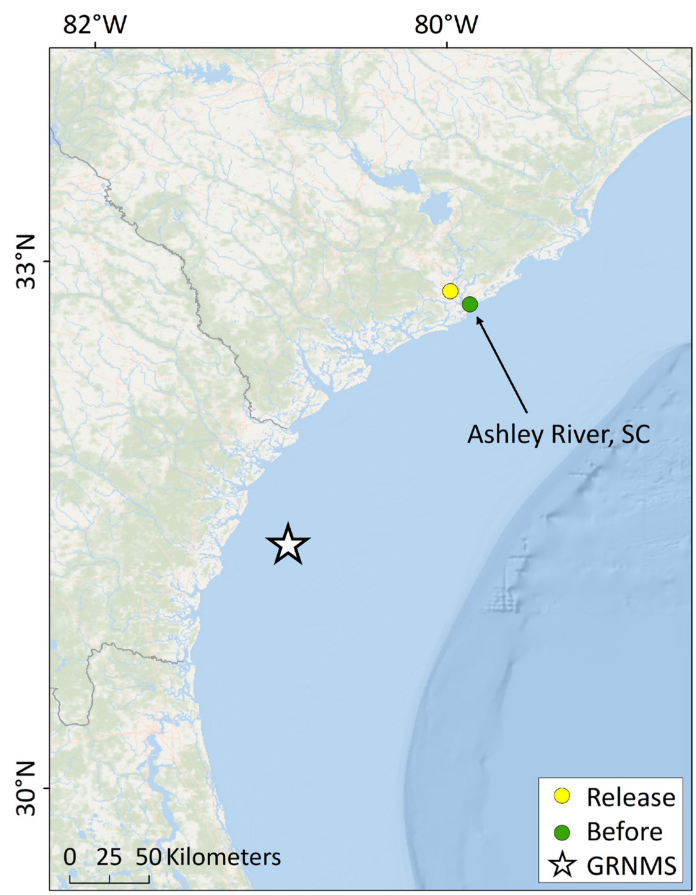


*Figure 3.48. Southern flounder (*Paralichtyhys lethostigma*) tagging locations and directly before visit to Gray's Reef.*

Significance of Connectivity

With only one individual, it is not possible to make generalizations about the role of Gray's Reef for southern flounder. However, it is interesting to note their presence at the sanctuary. Adult summer flounder often reside in shelf habitats, such as Gray's Reef (Burke et al., 1991; Craig et al., 2015). Southern flounder have been tagged in the coastal Carolinas, but only one individual has been detected at Gray's Reef so far.

Acknowledgements

We thank the staff from the Inshore Fisheries Research Section of the South Carolina Department of Natural Resources Marine Resources Research Institute for allowing us to include southern flounder tagged by their personnel in this report. Funding for the SCDNR research project was provided by the U.S. Fish and Wildlife Service through their Wildlife and Sport Fish Restoration Program under grant #215816232.

3.3.6 Striped Bass *(Morone saxatilis)*

*Figure 3.49. Striped bass (*Morone saxatilis*). Credit: NOAA NMFS.*

Species Description

Striped bass (*Morone saxatilis*; Figure 3.49) are an anadromous fish that feed primarily on smaller fishes and crustaceans (Walter and Austin, 2003). They occur along the coast and in rivers and estuaries from the Gulf of Mexico to the St. Lawrence River, Canada (Clark, 1968). Males reach maturity at 2-4 years of age, females mature later between 4-8 years, and maximum age can be up to 30 years with a maximum size of 140 cm FL (Rulifson and Dadswell, 1995; Berlinksy et al., 1995; Secor, 2000). Spawning occurs in the spring/summer when individuals migrate upriver to freshwater (Wingate and Secor, 2007). In the fall, adults move downriver to marine areas for overwintering, with populations in Chesapeake Bay and north undergoing coastal northward migrations, while southern populations remain residential (Dudley et al., 1977; Wingate and Secor, 2007). Striped bass are a popular recreationally fished species, but their harvest is prohibited in federal waters (61 FR 29320 July 1, 1996). Despite a fishery collapse in the 1980's, striped bass populations have rebounded and are currently not overfished (Richards and Rago, 1999; ASMFC, 2016).

Table 3.18. Striped bass data contributor.

Tag Owner	Affiliation	Tagged Fish Detected at GRNMS	Total Detections	Detection Range
Joel Fleming	Georgia Department of Natural Resources	1	4	Feb. 2016

Movements Through GRNMS

One female striped bass (90.5 cm TL) was detected at Gray's Reef in February 2016 for six minutes based on 4 detections at one receiver (Table 3.18). This individual was tagged in the Savannah River, Georgia, approximately 72 km northwest of Gray's Reef in the winter of 2014 (Figure 3.50).

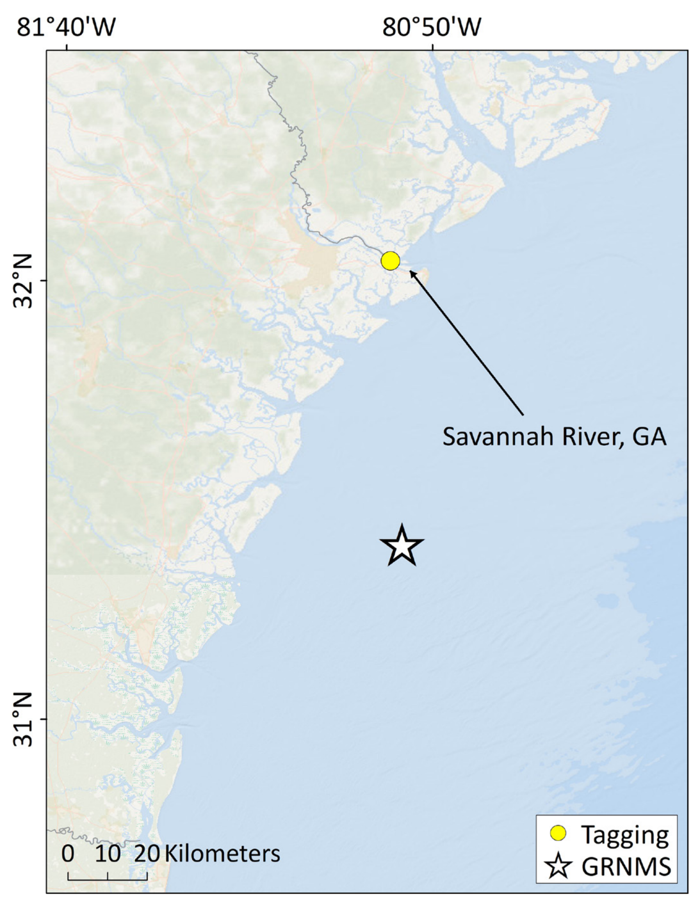


*Figure 3.50. Estimated tagging location of striped bass (*Morone saxatilis*).*

Significance of Connectivity

With only one individual, it is not possible to make generalizations about the role of Gray's Reef for striped bass. However, it is interesting to note their presence at the sanctuary. Although striped bass are a popular recreational fishery, their harvest is prohibited in federal waters (61 FR 29320, July 1, 1996), thus they cannot be fished at the sanctuary. Striped bass in this region of the U.S. do not participate in coastwide migrations and often remain in downstream waters and river mouths during the winter (Dudley et al., 1977), making its presence at Gray's Reef unusual. However, its occurrence in the winter matches the timing when this species is in its marine overwintering habitats (Wingate and Secor, 2007). Because the sanctuary is so far offshore, striped bass are likely an uncommon visitor to the sanctuary.

Acknowledgements

We thank Joel Fleming and Jackson Sibley at Georgia Department of Natural Resources for contributing detections and individual metadata to this study.

3.4 REPTILES

3.4.1 Loggerhead Sea Turtle *(Caretta caretta)*

*Figure 3.51. Loggerhead sea turtle (*Caretta caretta*) under ledge at Gray's Reef. Credit: G. McFall, NOAA OMAO*

Species Description

Loggerhead sea turtles (*Caretta caretta*; Figure 3.51) are highly migratory marine reptiles that feed on mollusks and crustaceans, achieving a maximum size of 99 cm curved carapace length (CCL; Plotkin, 1993; Casale et al., 2011). They occur in temperate and tropical waters along continental and insular shelves circumglobally (Dodd, 1988). Age at maturity varies from 9.5-22.3 years (Casale et al., 2009). Adult loggerhead sea turtles undergo reproductive- and foraging- driven migrations (Plotkin, 2003; Hawkes et al., 2011; Arendt et al., 2012). Females exhibit philopatry, returning to their natal beaches every three years for nesting in the late spring and summer months where they lay multiple clutches every two weeks (Dodd, 1988; Plotkin, 2003; Miller et al., 2003; Pike et al., 2006). In the western Atlantic, adults either migrate to winter foraging grounds, or maintain a southerly home range, after breeding and nesting (Hawkes et al., 2011; Arendt et al., 2012). Hatchlings make oceanic migrations to Sargassum habitats offshore, where they remain for multiple years (Luschi et al., 2003). The northwest Atlantic population of loggerhead sea turtles is listed as threatened under the Endangered Species Act (76 FR 58868, October 24, 2011). This has resulted in designation of critical habitat throughout the southeast coast of the United States, including nearshore reproductive habitat off the coast of Georgia approximately 33 km east of Gray's Reef (79 FR 39855, July 10, 2014).

Table 3.19. Loggerhead sea turtle data contributor.

Tag Owner	Affiliation	Tagged Turtles Detected at GRNMS	Total Detections	Detection Range
Dr. Michael Arendt	South Carolina DNR	2	64	June 2014, Dec. 2016

Movements Through GRNMS

Two neritic juvenile female loggerhead sea turtles have been detected at Gray's Reef, one in June 2014 and one in December 2016, each spending one day at the sanctuary (Table 3.19). One individual was tagged off Brunswick, Georgia, and the other off Charleston, South Carolina, 32 km southwest and 179 km northeast of Gray's Reef, respectively (Figure 3.52A). One individual was detected off Brunswick ten days after tagging, then detected at Gray's Reef two days later (Figure 3.52B). The second individual was detected off Charleston 47 days prior to arrival at Gray's Reef in December (Figure 3.52B). Neither were re-detected after their brief visits to Gray's Reef. All individuals only visited the sanctuary once.

Significance of Connectivity

Detections of loggerhead sea turtles and the abundance of prey at Gray's Reef indicate the sanctuary may be a brief foraging habitat for this protected species (NOAA, 2014). One individual arrived at Gray's Reef in June, while the other arrived at Gray's Reef in the winter, part of the foraging season (Hawkes et al., 2011). Individuals were not re-detected after visiting Gray's Reef, likely because they were spending time along the continental shelf, where acoustic receiver coverage is limited. While it is important to note the presence of a protected species at Gray's Reef, it is difficult to generalize the importance of the sanctuary for loggerhead

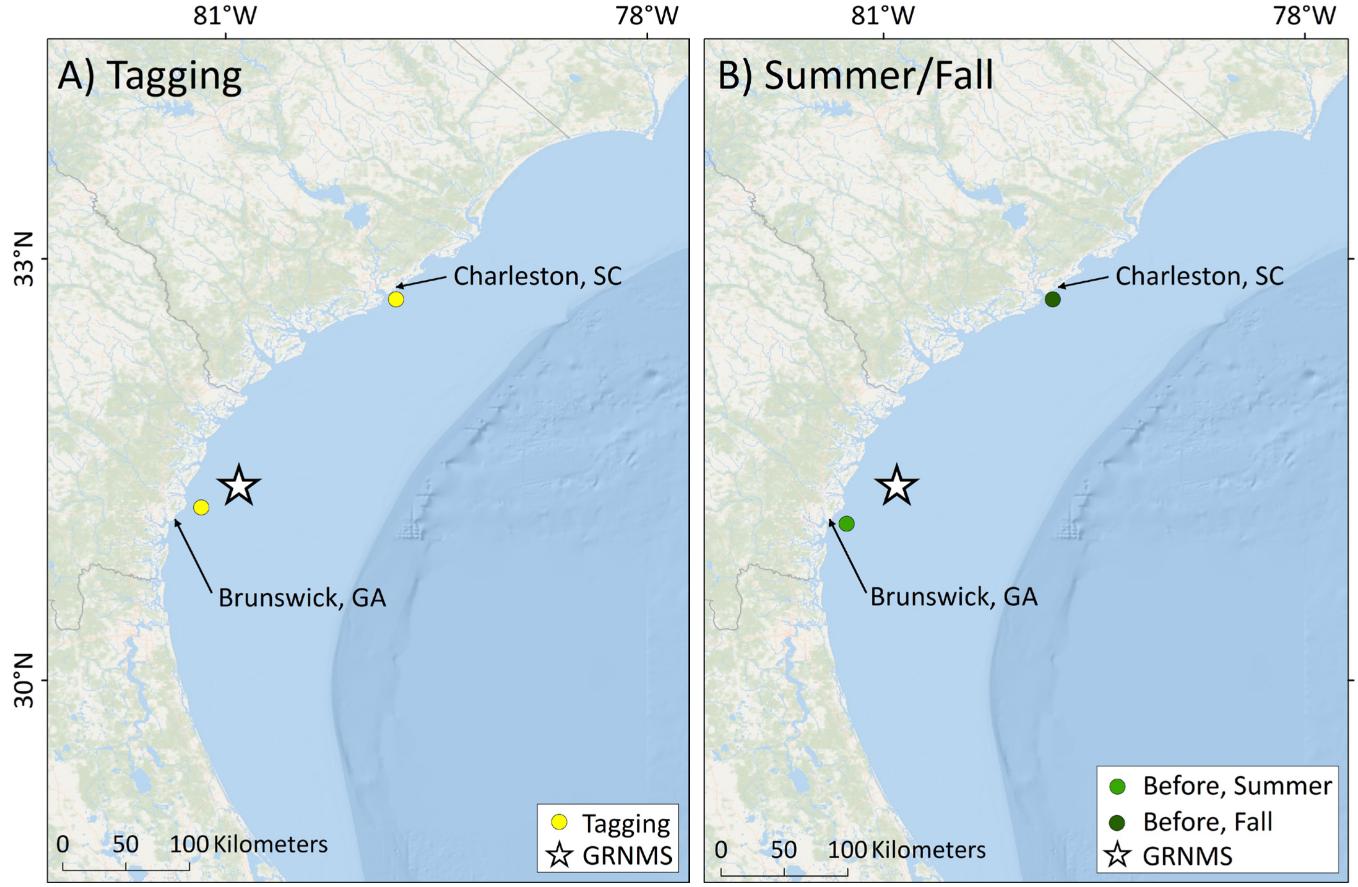


*Figure 3.52. Loggerhead sea turtle (*Caretta caretta*) A) tagging location and B) locations before arriving at Gray's Reef in the summer and fall. No data are available for individuals' locations after leaving Gray's Reef.*

sea turtles broadly due to limited data. At least seventy loggerhead sea turtles have been tagged in this region from 2014-2017 (Arendt, M. pers. comm.) but only two of these have been detected via acoustic telemetry. However, loggerheads are routinely observed both at the surface and underwater at Gray's Reef (Kendall, M. personal obs.). They are known to rest at undercut ledges and have been observed over multiple years.

Acknowledgements

We thank Dr. Michael Arendt from South Carolina Department of Natural Resources for contributing detection data and individual metadata for this species.

Great hammerhead shark. Credit: Tanya Houppermans

4.0 SUMMARY AND DISCUSSION

The goal of this report is to increase our understanding of how Gray's Reef is connected to the marine ecosystems along the eastern coast of the U.S. using acoustic telemetry. During the nine years that receivers were deployed at Gray's Reef, over 11 million detections were recorded. The vast majority of these detections were from resident fish species, such as black seabass (*Centropristis striata*). Detections from transient fish only made up 0.062% of detection data during this time period. Although detections were dominated by resident fish (n = 61 individuals) which spend almost the entirety of their tags' battery life at the sanctuary, individuals were numerically dominated by transient species (n = 164 individuals) which are present at the sanctuary for only brief periods of time.

4.1 TEMPORAL PATTERNS

Most of the species visiting Gray's Reef in this study passed through quickly, with 83.1% of individual visits occurring on a single day. At the other extreme, a red drum tagged in coastal Georgia, was detected for up to twenty-four days, although not continuously throughout that time period. The majority (66%) of individuals detected at the sanctuary only visited once, however, 34% made multiple trips to Gray's Reef over multiple years and often corresponding to known migratory behavior. For example, one Atlantic sturgeon made seven separate visits over 4 separate calendar years.

Many species exhibited seasonal patterns in their usage of Gray's Reef. For example, Atlantic sturgeon, blacktip sharks, sandbar sharks, and white sharks were primarily detected during winter and spring months. In contrast, bull sharks were more common during summer and fall. Sand tiger sharks were detected exclusively in spring months. Each of these corresponds well with the known or emerging understanding of migratory behavior for these taxa (Castro, 1983; Stein et al., 2004; Conrath and Musick, 2008; Curtis et al., 2014; Kneebone et al., 2014; Wirgin et al., 2015; Kajiura and Tellman, 2016; Haulsee, 2017; Skomal et al., 2017). However, data from some species, such as tiger sharks and striped bass, differed somewhat from patterns expected based on prior studies. For example, tiger sharks are known to migrate from coastal habitats at lower latitudes in winter to oceanic habitats at higher latitudes in summer (Lea et al., 2015), but this species was detected at Gray's Reef, a shelf habitat, year-round. Similarly, striped bass in this region are thought to overwinter in tidal estuaries (Dudley et al., 1977), but one was at Gray's Reef during the winter.

Despite seasonal patterns of use for some species, there was no overall pattern in seasonal use of the sanctuary (Figure 4.1B). Some peaks in visitation reflect seasonal use by specific species. For example, there is a small peak in individuals in winter 2014, due to the presence of six Atlantic sturgeon and four white sharks, which were consistently detected in winter and spring months at the sanctuary. However, seasonal visitation patterns are often out of sync among species which spreads out use of the sanctuary over the year. Other peaks in visitation can be explained by a surge in tagging activity for a particular species. For example, a peak in individuals in fall 2016 was due to cobia tagging projects in coastal Georgia and South Carolina in spring and summer 2016. Seasonal peaks in number of detections can be related to an increase in individuals or an individual spending a longer time at the sanctuary. For example, in fall 2010 the clear peak in detections is due to a bull shark that was detected at the sanctuary continuously for almost seventeen hours. Similarly, in winter 2015, a red drum was detected over 1000 times. Due to the broad spectrum of life histories, migration patterns, and ecology of species detected at the sanctuary, it is not surprising that there was no seasonal pattern in when transient fish were more common.

Over the nine years of electronic acoustic monitoring at Gray's Reef, the number of tagged individuals and detections at the sanctuary generally increased over time (Figure 4.1A). This is certainly due to the increasing use of acoustic telemetry technology to track animal movements (Hussey et al., 2015). More numerous and diverse detections of tagged animals can be expected to be recorded by the receivers at Gray's Reef in the coming years with continued monitoring.

Summary and Discussion

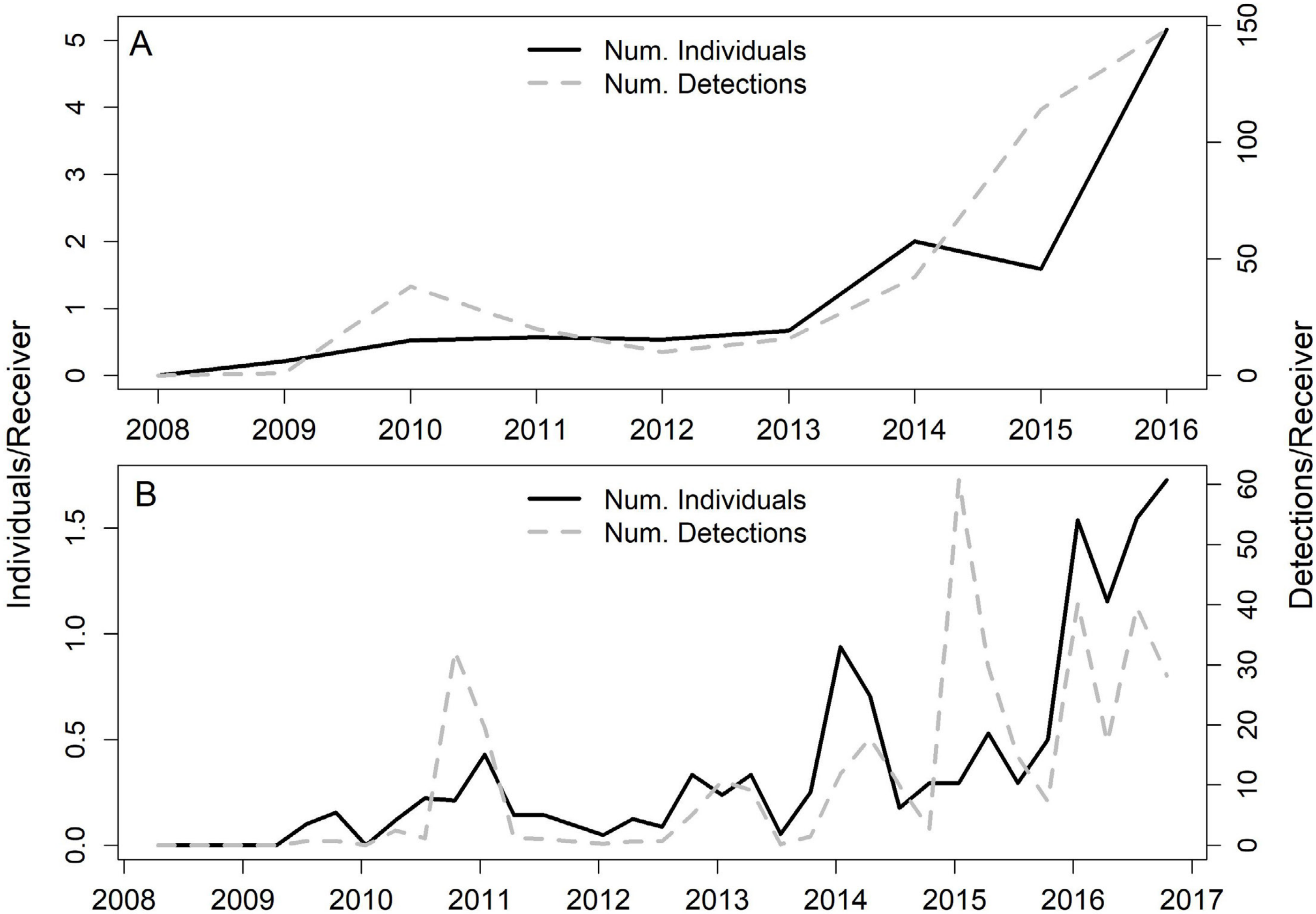


Figure 4.1. Number of individuals and detections at Gray's Reef through time summarized annually (A) and seasonally (B). Numbers of individuals and detections are standardized by the maximum number of receivers present in the sanctuary during the corresponding year and season for A and B, respectively.

4.2 SPATIAL PATTERNS

Transient species came to Gray's Reef from all along the western Atlantic coast, and were tagged an average of 510 km away from Gray's Reef. Nearly half of the species detected at the sanctuary were tagged in coastal Georgia and South Carolina, and another 21.4% were tagged in south Florida and the Caribbean (Figure 3.2). The individual tagged closest to the sanctuary was a cobia 16.4 km west. At the other extreme, an Atlantic bluefin tuna was tagged the furthest away, 2,340 km to the northeast in the Gulf of St. Lawrence, Canada (Figure 3.2).

There are two common movement patterns for transient/migratory species in this region. Animals can move north-south along the coast, often in response to changing water temperatures and foraging opportunities (Speed et al., 2010; Block et al., 2011). Others move west-east from estuaries, to the continental shelf, to areas farther offshore in response to ontogenetic shifts or reproductive requirements (Quinn and Dittman, 1990; Collins et al., 2000; Hawkes et al., 2011; Arendt et al., 2012). The location of an individual directly before their visit to the sanctuary and after their departure can help understand the sanctuary's role in regional connectivity. Many individuals that visited Gray's Reef were found north and south of the sanctuary directly before and after their visits, often corresponding to their seasonal migrations, including Atlantic sturgeon, blacknose sharks, blacktip sharks, bonnethead sharks, cobia, great hammerhead sharks, lemon sharks, sand tiger sharks, sandbar sharks, and tiger sharks. In contrast, very few individuals (e.g. one Atlantic sturgeon and southern flounder) were found west of the sanctuary directly before or after their visit and none could be recorded east of the sanctuary due to the absence of receivers in that direction. Indeed, tracking locations directly before and after visits to the sanctuary are dependent on the arrangement of other acoustic receivers in the region. Also obscuring consistent patterns was that individuals' before and after detections could occur in a different migration year before and after their visits to the sanctuary. Thus, they of course occupied other un-monitored areas throughout the region in between these detections.

4.3 MIGRATORY PATHWAY

Results from this study suggest Gray's Reef may be part of a regular migratory pathway for some species or individuals. Twelve of the eighteen species detected at the sanctuary potentially used Gray's Reef during their seasonal migrations, including Atlantic bluefin tuna, Atlantic sturgeon, blacknose sharks, blacktip sharks, bull sharks, bonnetheads, cobia, great hammerhead sharks, lemon sharks, sand tiger sharks, sandbar sharks, and white sharks. Seasonality of detections of these species, directionality of movements in the region, and brevity of visits to the sanctuary further suggest the role of the sanctuary as a migratory stop over. Repeated visits to the sanctuary by the same individuals across years also supports the concept that the sanctuary is a known landmark or stop-over during migrations for some fish. One Atlantic bluefin tuna even passed through at the sanctuary three times across two separate migration cycles during its annual movements to and from spawning ground in the Gulf of Mexico (Wilson et al., 2015). In several cases, animals tagged 100's of km away were detected at the sanctuary within days or even hours of each other during north-south migrations along the shelf. These include Atlantic sturgeon, blacktip sharks, bull sharks, cobia, and tiger sharks. Note that the continental shelf is ~130 km wide at the latitude of Gray's Reef. The sanctuary is 9 km wide or <7% of the shelf. It is very unlikely that so many individuals would repeatedly pass through this narrow patch of shelf by accident or randomly suggesting that the sanctuary is a part of the migratory pathway for a variety of species.

4.4 BIASES/CAVEATS

Although this study provides a broad understanding of Gray's Reef's role in regional connectivity and fish movements, it is far from comprehensive. A major limitation is that our understanding only extends to animals that have been acoustically tagged, and even for those that are tagged, lack of detection of an animal or species does not necessarily mean that it does not use the sanctuary regularly. For example, sharpnose sharks are a very common coastal shark species (Castro, 1983; Branstetter, 1990), but only one was detected at the sanctuary. Although this species is very common, few have been tagged within the cooperative telemetry networks, thus decreasing the number available to be detected at the sanctuary. Similarly, seventeen bull sharks, all tagged off the coast of south Florida, were detected at the sanctuary. However, other bull sharks tagged off Florida and North Carolina were not. In some cases, species known to migrate along the U.S. Atlantic coast, were not detected at the sanctuary. For example, recent work through acoustic tracking of cownose rays has revealed migrations between summer reproductive habitats in the mid-Atlantic to overwintering habitats off the coast of Florida (Ogburn et al., 2018). Although individuals were tagged in Chesapeake Bay and coastal Georgia, none were detected at Gray's Reef.

As noted throughout the results, our understanding of the importance of Gray's Reef for certain species is also constrained by sample size. In many cases, only a few individuals of a species were detected at the sanctuary. For eleven of the eighteen species that have visited Gray's Reef, less than 5 individuals of each were detected (Table 3.1).

Another limitation of acoustic telemetry is the lack of comprehensive coverage by acoustic receivers. The direction and distance measurements for individual movements before and after their visits to the sanctuary are controlled by the arrangement of receivers in the area. For example, the receiver array at Gray's Reef is one of the furthest offshore in this region, but is only one-third of the way offshore to the shelf edge. Unfortunately, it is not presently possible to track movements to and from more seaward destinations. Similarly, while we provide an extensive summary of transient species usage of Gray's Reef, we do not know how other habitats in the region are used and cannot compare the relative importance of the sanctuary for migratory species to those sites without a more comprehensive array of receivers deployed outside of sanctuary boundaries.

Detected individuals in this study are biased towards mature adults. It is unknown if this is due to actually greater use of Gray's Reef by adults or simply because more adults are tagged. At the time of initial tagging, 59.8% of individuals eventually detected at Gray's Reef were mature adults and 18.3% were immature/juveniles. However, many of the juveniles that visited Gray's Reef were detected 1-5 years after being tagged. During this time, they could have grown and matured from juvenile to adult. For example, a large juvenile bonnethead was detected at the sanctuary over a year after being tagged and could have grown to maturity by its second visit to the sanctuary (Frazier et al., 2013; Frazier et al., 2014; Cortés et al., 2016). Similarly, juvenile and sub-adult white sharks visited Gray's Reef up to two years from the date they were tagged, and could have also matured to another life stage during this time (Natanson and Skomal, 2015). Bull sharks, immature at tagging, were detected at Gray's Reef up to five years later, and also could have reached maturity (Cruz-Martinez et al., 2005).

Also of note, many species detected by the acoustic receivers have been observed from the surface or during underwater visual surveys conducted at Gray's Reef. Several sharks including bonnethead, great hammerhead, lemon, sandbar, tiger, and white sharks have been noted as well as Atlantic sturgeon, cobia, red drum, southern flounder, and loggerhead sea turtles (R. Munoz, and T. Recicar, pers. comm.). Other species are only known to Gray's Reef through the acoustic array. These include Atlantic bluefin tuna, striped bass, blacknose sharks, sharpnose sharks, and sand tiger sharks. While visual surveys can provide estimates of relative density of various species (Edgar et al., 2004), acoustic telemetry allows for long-term, continuous monitoring of an area and captures other metrics of fish presence, such as time spent and movements throughout the study area. Additionally, shy animals that move quickly or are too far away to be visually identified can be detected by acoustic telemetry.

4.5 RECOMMENDATIONS

This report relies entirely on the existence of cooperative acoustic telemetry networks. By collaborating across groups that have deployed acoustic receivers and tagged animals with vastly different life histories from throughout the U.S. Atlantic coast, we can better understand the role that specific areas play in regional connectivity. Not only does this study rely on collaboration between Gray's Reef and the owners of tags detected at the sanctuary, but also between tag owners and array owners elsewhere along the coast. Because cooperative telemetry networks are critical to the success of studies like this, we recommend continued and active participation in the Florida Atlantic Coast Telemetry, Atlantic Cooperative Telemetry Network, and iTAG in the Gulf of Mexico. Continued contribution of detection data from the array at Gray's Reef will help support a host of projects aimed at understanding movements of fishes along the U.S. Atlantic coast and promote future collaborations based on detection data at Gray's Reef. Additionally, to help inform management, tagging of key species within the sanctuary could be helpful. For example, cobia stock delineations and seasonal overlap are currently under investigation in the vicinity of Gray's Reef, and could help inform better management of these species (SEDAR, 2018). King mackerel (*Scomberomorus cavalla*), greater amberjack (*Seriola dumerili*), and barracuda (*Sphyraena barracuda*) are other coastal migrants of importance to Gray's Reef and along the southeast U.S. (Clardy et al., 2008; Auster et al., 2013; Campanella et al., 2019). As highly mobile apex predators often targeted by fishermen in the sanctuary, understanding the movements of fish tagged at the site is of interest. In addition, although initial telemetry studies on fish tagged at Gray's Reef focused on large grouper and snapper (Carroll, 2010), additional individuals should be tagged to increase sample size and because there are now many more receivers throughout the region to track potential movements.

Overall, Gray's Reef is a potential migratory hub for many transient species across a broad range of life histories, functional groups, and ecologies. Continued monitoring of the sanctuary through the acoustic array is critical to future understanding of sanctuary importance and supporting projects aimed at understanding species movements along the U.S. Atlantic Coast. As the use of acoustic telemetry technology continues to increase (Hussey et al., 2015), more individuals and species will be tagged, allowing for an ever more comprehensive understanding of the connectivity and importance of Gray's Reef in the future. Of note, the acoustic array at Gray's Reef is one of the furthest offshore in the region, and can provide critical information on inshore-offshore movements of fishes.

Based on the last nine years of detection data, certain sites in the sanctuary may be more valuable to maintain the presence of acoustic receivers. In terms of number of detections, the eastern and central western portions of the sanctuary were popular for transient/non-resident fish (Figure 4.2A). A similar pattern was observed for number of individuals and number of species (Figures 4.2B-C), suggesting these areas may be relative hotspots

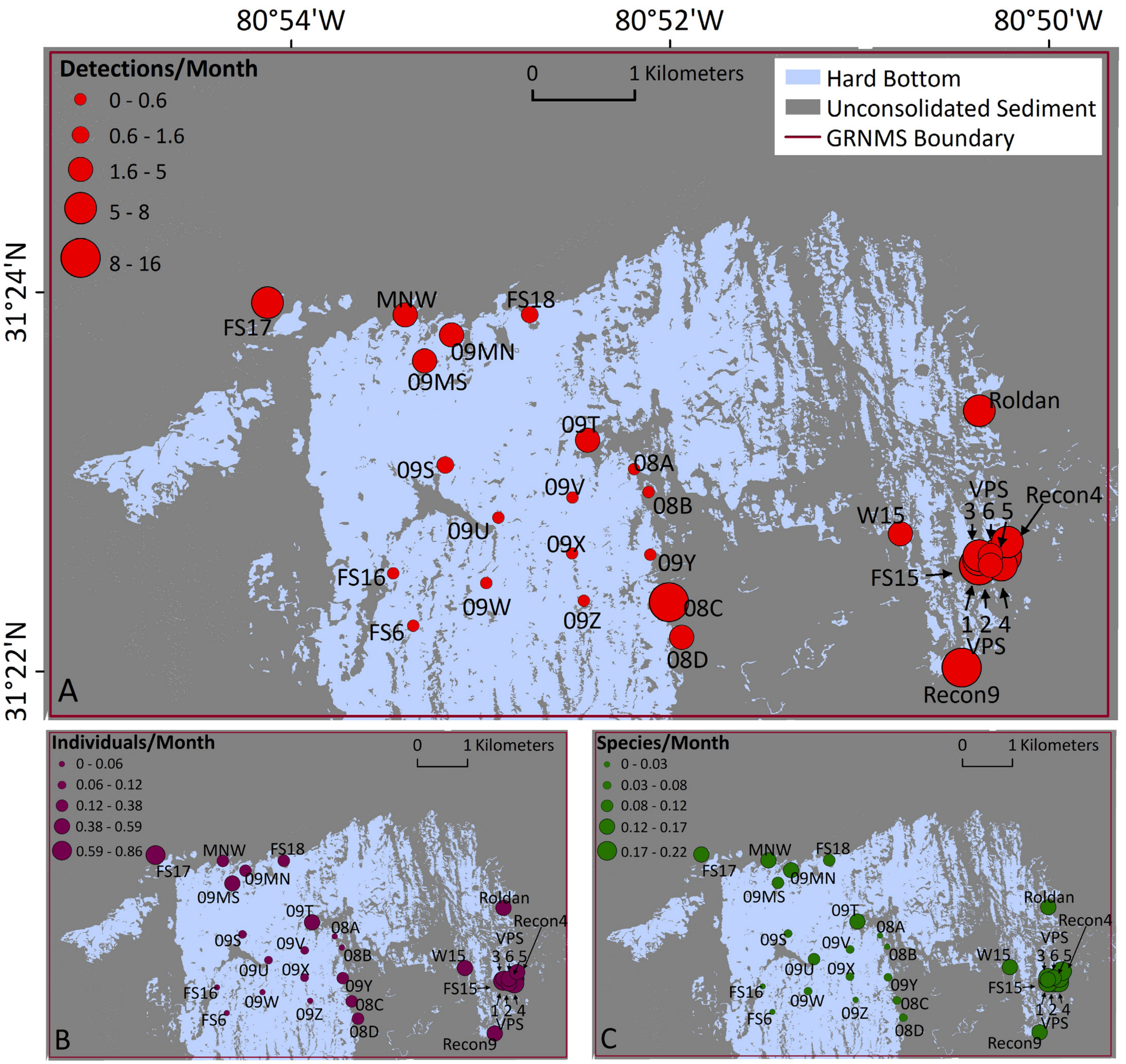


Figure 4.2. Number of A) detections, B) individuals, and C) species across acoustic receivers stations at Gray's Reef. Values are standardized by the amount of time receivers were deployed. Values are based on transient/non-resident individuals only, individuals tagged at the sanctuary are not included. For visualization, habitats have been simplified into two categories (hard bottom and unconsolidated sediments).

of activity for transient fish and important areas to maintain acoustic receivers to best capture visits from transient species. However, a more comprehensive analysis of the importance (Ellis et al., 2019) of various sites within Gray's Reef for both transient and resident fishes is still needed.

Finally, while this report demonstrates the use of the sanctuary by a variety of species, suggesting it is a focus of migratory activity, it is difficult to understand its importance compared to other areas in the region because they have not been monitored acoustically. The repeated and multi-year visits of many fish detected at Gray's Reef suggest that it is a hub of activity for them, however, it is possible that other individuals of the same species use other locations and landmarks during their migrations. To better demonstrate the importance of Gray's Reef, it is critical to compare its importance to other habitats in the region. To do this, we recommend deploying receivers on natural and artificial habitats near Gray's Reef, such as J Reef and a subset of the Navy Towers farther offshore, to determine if the sanctuary really is a hub of migratory activity compared to nearby habitats.

Live bottom at Gray's Reef. Credit: G. McFall, NOAA OMAO

Summary and Discussion

Sand tiger shark. Credit: Tanya Houppermans

Diver among live bottom habitat at Gray's Reef. Credit: G. McFall, NOAA OMAO

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National Oceanic and Atmospheric Administration

Neil Jacobs, *Acting Under Secretary of Commerce for Oceans and Atmosphere*

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