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## Distribution and community structure of First Coast shark assemblages and their relative trophic niche dynamics

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Distribution and community structure of First Coast shark assemblages and their relative trophic niche dynamics

by

Clark Raymond Morgan

A thesis submitted to the Department of Biology in partial fulfillment of the requirements for the degree of Master of Science in Biology

UNIVERSITY OF NORTH FLORIDA

COLLEGE OF ARTS AND SCIENCES

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## Certificate of Approval

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## Abstract

Nearshore marine environments are known to be highly productive systems with relatively high faunal diversity and abundances, but these systems are particularly vulnerable to negative impacts from anthropogenic disturbances that can result in habitat degradation. Despite these challenges, many shark species of various life stages utilize coastal shelf habitats, inshore estuaries, and bays. The inshore habitats of Cumberland and Nassau Sounds in northeast Florida have been proposed as potential nursery grounds by earlier work, but this suggestion did not satisfy all of the standard criteria of shark nursery designation. It has recently been stated that the combination of surveys inside and outside suspected nursery habitats, especially those incorporating mark-recapture studies, would provide a very comprehensive test of the nursery criteria. A primary objective of the present study was to initially describe the composition and abundance of shark populations utilizing the nearshore habitats of northeast Florida, while also comparing them to inshore communities, with emphasis on spatial and temporal variations in assemblages. Fishery-independent longline sampling was conducted across the region and while considerable overlap of species were observed, significant differences in community structure between inshore and nearshore locations were detected. Specifically, the inshore waters of the First Coast support nursery habitat designation for Atlantic sharpnose, blacktip, and sandbar sharks after satisfying the accepted criteria. Given the high amounts of spatial and temporal overlap observed along the First Coast, relative trophic niche dynamics were also investigated via stable isotope analysis of two tissue types. These results revealed varying trophic niche sizes in the long term, but suggest some degree of shared resource use when animals are present on the First Coast. The identification of factors that influence coastal shark habitat utilization, such as competition and resource use, can contribute to understanding and predicting how they may respond to future environmental changes.

## **Chapter 1 Title:** Distribution and community structure of First Coast shark assemblages

### **Introduction**

Nearshore marine environments are known to be highly productive systems with relatively high faunal diversity and abundances (Blaber *et al.* 1989, Beck *et al.* 2001). These habitats are often characterized by large fluctuations in physical parameters that can create challenging conditions for inhabitants, as well as being vulnerable to rapid changes in characteristics caused by sudden events like extreme weather (Knip *et al.* 2010). Marine systems are threatened worldwide due to anthropogenic disturbances such as pollution, overexploitation, and coastal development that can result in habitat degradation (Pan *et al.* 2013). Such impacts have resulted in trophic cascades (Pershing *et al.* 2015), localized species extinctions (Ceballos *et al.* 2015), and regime shift shifts (Rocha *et al.* 2015) in marine communities and ecosystems. Furthermore, overfishing of shark populations in the northwest Atlantic resulted in rapid declines of their pre-exploited biomass (Baum *et al.* 2003).

Despite these challenges, various life stages of many shark species utilize coastal shelf habitats, inshore estuaries, and bays (Dodrill 1977, McCandless *et al.* 2007). Sharks are considered apex predators in many marine systems and can impact ecosystems through direct and behaviorally influenced indirect interactions with prey (Heithaus *et al.* 2008). Given their proximity to land, nearshore shark populations are highly susceptible to

exploitation, and differences in life histories can often make them more vulnerable to populations threats (Knip *et al.* 2010). In particular, slow growth rates, late maturity, and relatively low fecundity make sharks more susceptible to population declines (Musick *et al.* 2000).

In response to observed large-scale population declines, the National Marine Fisheries Service began delineating “essential fish habitat” (EFH) which sparked research focused on identifying shark nursery grounds (NOAA 1996, McCandless *et al.* 2007). Much debate surrounding the operational definition of nursery grounds subsequently followed, with Heupel *et al.* 's (2007) proposed criteria becoming a widely accepted standard for habitat utilization investigations. Specifically, it required that 1) young sharks are more commonly encountered in the specific area relative to other areas, 2) sharks remain or return for extended periods of time, and 3) the habitat is used repeatedly across years. However, it was later reemphasized that all life stages should be considered for proper management (Kinney and Simpfendorfer, 2009). It is believed that a combination of ecological factors like environmental characteristics, resource abundance and distribution, and/or the presence of other competing species likely influences nearshore habitat use by sharks (Knip *et al.* 2010). Considering the known ecological importance of sharks during a time when the future health of marine environments is uncertain (Pan *et al.* 2013), the identification of factors that influence coastal shark habitat utilization can contribute to the understanding and predicting of how they may respond to environmental changes (Yates *et al.* 2015). Understanding the relationship between sharks and their environment is crucial for sustainable management and conservation of shark populations (Simpfendorfer and Heupel, 2012).

Several nearshore environments along the east coast of Florida have been shown to be productive and vital habitats for many coastal shark species at varying life stages. Aubrey (2001) reported young of year spinner sharks (*Carcharhinus brevipinna*) inhabiting the shallow waters off Cape Canaveral Bight, along with neonate and juvenile Atlantic sharpnose (*Rhizoprionodon terraenovae*), blacktip (*Carcharhinus limbatus*) and scalloped hammerheads (*Sphyrna lewini*). Adams and Paperno (2007) further described the occurrence of neonate scalloped hammerheads in the nearshore waters of Cape Canaveral, while also noting their absence from the inshore waters of Indian River Lagoon. Reiher *et al.* (2008) contributed to the description of this same area by documenting seasonal aggregations of juvenile lemon sharks (*Negaprion brevirostris*) in the nearshore waters of Cape Canaveral during the winter. Last, Kaijura and Tellman (2016) quantified substantial seasonal aggregations of large blacktip sharks within 200 meters from the shoreline in Palm Beach County. Although these studies focused on mostly beach habitats, other studies have revealed differences in species composition by habitat. Ulrich *et al.* (2007) showed that blacknose sharks (*Carcharhinus acronotus*) were far more abundant in the nearshore waters of South Carolina versus estuarine habitats, while bonnethead shark (*Sphyrna tiburo*) abundance was higher in estuaries compared to nearshore waters. Furthermore, Bethea *et al.* (2015) reported differences in shark community structure across coastal regions in the Gulf of Mexico, with emphasis on the species-life stage.

In Northeast Florida, only one study has thoroughly described the shark populations, focusing on inshore habitats. McCallister *et al.* (2013) characterized the shark assemblages of inshore waters of Nassau and Cumberland Sounds and suggested the area served as nursery grounds for Atlantic sharpnose and blacktip sharks while also noting the

presence of juveniles for several other shark species. However, some dated catch records (Hueter 1991, Trent *et al.* 1997), as well as the aforementioned studies on other geographic locations, suggest that there may be differences in assemblages in the nearshore waters compared to the inshore estuarine waters. The findings of McCallister *et al.* (2013) satisfied the latter two of the three nursery criteria put forth by Heupel *et al.* (2007). It has recently been stated that the combination of surveys inside and outside suspected nursery habitats, especially those incorporating mark-recapture studies, would provide a very comprehensive test of the nursery criteria (Heupel *et al.* 2018). A primary objective of the present study was to describe the composition and abundance of shark populations utilizing the nearshore habitats of northeast Florida, while also comparing them to inshore communities described by McCallister *et al.* (2013). This was accomplished by comparing data from a new nearshore survey of north Florida waters with ongoing sampling in the sites described by McCallister *et al.* (2013), which has continued to the present time. This not only provided a unique opportunity to elaborate on the initial findings of McCallister *et al.* (2013), but also allowed for direct investigation of Heupel *et al.*'s (2007) Criteria 1 that juveniles more regularly encountered in the inshore than the surrounding areas.

The purpose of this study was to further the knowledge of habitat utilization by sharks on the First Coast initially described by McCallister *et al.* (2013). Specifically, this study aimed to extend inshore sampling efforts while also expanding to adjacent nearshore environments to investigate potential differences in community assemblages. The objectives of this study were to: 1) compare shark community abundances and compositions between inshore and nearshore habitats, 2) examine temporal variations in abundances and assemblages, 3) investigate how environmental variables impact shark

distributions, and 4) further assess criteria for nursery grounds along the First Coast. Addressing these questions may provide valuable insight related to sustainable management and conservation of regional and First Coast shark populations.

## **Methods**

### *Sampling Locations*

Sampling occurred across a region of northeast Florida known as the “First Coast”, with efforts focused around extensive river and estuarine systems that form inlets leading to the Atlantic Ocean and the adjacent beach habitats.

The two inshore systems sampled in this study include the more northerly Cumberland Sound, where the St. Mary’s and Amelia Rivers meet at the coastline, and an adjacent sound to the south, Nassau Sound, where the Nassau River splits between Amelia Island and the Talbot Islands. Both systems, including their surrounding rivers and creeks, were independently surveyed but together comprise the inshore estuarine habitats that were grouped as “Inshore” sites and were previously sampled by McCallister *et al.* (2013). (Figure 1-3).

The nearshore habitats sampled in this study were the beaches adjacent to the St. Marys River inlet and the St. Johns River inlet. Serving as a partial northern border between Georgia and Florida, north of the St. Marys River inlet is Cumberland Beach of Cumberland Island in Georgia while Fernandina Beach of Amelia Island exists to the south in Florida. All sampling in beach habitats was combined to represent the “St. Marys” location. Directly north of the St. Johns River inlet is Huguenot Beach of Little Talbot Island and to the south of the inlet is Mayport Beach of San Pablo Island. In this study, all beach habitat



surrounding the St. Johns River inlet are combined as “Mayport”. Together, the surrounding beach habitats of St. Marys and Mayport were grouped as “Nearshore”. See Figure 1-5 for a geographic overview of these areas.

### *Animal collection*

Bottom longline fishing was used to sample sharks in inshore waters, following the gear configuration described by McCallister *et al.* (2013). The entire configuration includes a 250-meter braided nylon mainline to which 50 gangions consisting of 1-m, 90-kg test monofilament leader, a tuna clip, a swivel, and a 12/0 barbless circle hook were attached. Hooks were baited with mackerel (*Scomber* spp.). Each end of the mainline was attached to a 10-kg anchor connected to a 15-m buoy line.

The nearshore longline gear utilized was a combination of two sections of gear types, each made up of 50 gangions attached to 250 meters of braided nylon mainline. One section was a duplicate of the aforementioned inshore longline containing 50 gangions of 1-m, 90-kg test monofilament leader and 12/0 barbless circle hooks baited with mackerel. The second section of 250-m mainline consisted of gangions made of 1-m, 200-kg test monofilament leader, a tuna clip, a swivel, and a 16/0 barbless circle hook baited with mackerel. In total, the 500m longline contained 100 hooks with 10-kg anchors connected to a 15-m buoy line on each end.

### *Survey Design*

Fishery-independent longline sampling was conducted in the inshore waters of Cumberland and Nassau Sounds from 2012-2018 at least monthly from April to September, with the majority of effort occurring from May to August. Each sampling day targeted 3-5

bottom longline sets and, when possible, multiple sampling days per site each month occurred. Longlines soaked for 30 min set, and the specific location of each longline set was selected haphazardly depending on weather conditions, tides, and maritime traffic.

The nearshore habitats of St. Marys and Mayport were sampled from 2014-2018, with the majority of effort occurring in 2016 and 2017. This survey also aimed to sample each location at least once a month from April to September, and when possible, multiple samplings per month occurred. Nearshore longlines were set parallel to the beach (north/south orientation) in three targeted depth gradient zones: 4-6m, 7-9m, and 10-12m. The specific set location relative to the jetties at each study site was haphazardly selected based on weather conditions and maritime traffic, and each longline was set with a 30 min soak time.

In addition to longlines, benthic drumlines were also deployed to target larger sharks. Each drumline set up consisted of a 15 kg concrete anchor to which a 15-m buoy line and a 15-m hook line are attached. The hook line was a single length of 400-kg test monofilament, with one end shackled to a swivel on the anchor and the other end connected to a swivel and a 16/0 circle hook. The drumlines were baited with available shark from the family Carcharhinidae, or mackerel (*Scomber* spp.).

Environmental data including bottom water temperature, salinity, and dissolved oxygen content were measured at every set depth using a YSI Pro2030 while a Secchi disc measured vertical turbidity for nearshore survey locations. Minimum and maximum depth were recorded, and the resulting average depth was used for analysis. An onboard GPS unit recorded the specific coordinates of each set location.

### *Biological sampling*

All sharks caught were identified to species, measured, and sexed. Measurements followed standard elasmobranch procedures of precaudal length (PCL), fork length (FL), and stretched total length (STL). When applicable, the condition of the umbilical scar was recorded in young of year (YOY) sharks; sharks with open umbilical scars were considered neonates while those with closed but visibly healed scars were YOYs. For females, life stage was determined by length per the published literature, while the presence/absence of calcified claspers was used to assess maturity in males. Sharks of appropriate size and condition were tagged with uniquely identifiable roto-tags in the first dorsal fins and pre/post capture condition recorded.

### *Data Analysis*

Catch rates of the benthic longline survey were expressed as catch per unit effort (CPUE), calculated as the number of sharks caught per 50 hooks set. Trends in abundance were examined by comparing CPUEs for each study location across years and also by month; nearshore CPUEs were compared across hook sizes as well. Additionally, the association between hook size and shark size was examined in nearshore sites, while differences in shark sizes by overall location was investigated. Data were assessed for homogeneity of variances via Levene's test before analysis, and if assumptions of parametric tests were not met, appropriate non-parametric methods were used. Kruskal-Wallis tests were utilized if parametric ANOVA testing was unavailable, and post hoc stepwise step-down multiple comparisons were used to depict homogenous subsets among CPUE measures for each location. Chi-square tests were used to assess species-specific

differences in sex ratios, while Shannon-Wiener diversity indices were calculated for each location based on the species encountered and their relative proportions. Statistical significance of all analyses was determined based on an alpha level of 0.05. Species-specific size distribution plots for each location, as well as sex-specific length frequency plots for both inshore and nearshore sharks of appropriate abundances, were constructed. Lines for length at 50% maturity for both sexes were added to length frequency plots when catch distributions warranted (Branstetter 1987, Carrier and Luer 1990, Loefer and Sedberry 2002, Driggers *et al.* 2004, Carlson *et al.* 2006, Drymon *et al.* 2006, Baremore and Hale 2012, Frazier *et al.* 2014, Kohler *et al.* 2014, Natanson *et al.* 2014). All abundance, length, and sex analyses were performed using the SPSS statistical software package (v.22, IBM).

Multivariate methods were used to assess shark community structure by geographic location and season from 2014-2018 when all four locations were simultaneously sampled. Seasons were categorized as the following: Spring (March-May), Summer (June-August), Fall (September-October), and Winter (November-December). A Bray-Curtis similarity matrix was constructed using the 4<sup>th</sup>-root transformed CPUEs for species-life stage for all sets with a positive catch (n=314). The 4<sup>th</sup>-root transformation is intended to even the contributions of overabundant and rare species, although species with total counts less than ten were omitted from analyses. This matrix was then used to conduct a two-way crossed analysis of similarity (ANOSIM) to test the effects of location and season on shark community and life-stage structure. A similarity percentage (SIMPER) analysis was then conducted to investigate which species-life stage contributed the most to dissimilarities among locations and seasons. Nine hundred and ninety-nine permutations were used in both the ANOSIM and SIMPER analyses. Following community assemblage analyses,

biological data from all sets with a positive catch that recorded full environmental data (depth, temperature, salinity, dissolved oxygen) (n=216) underwent further analysis of environmental drivers of shark assemblages. Environmental data were normalized and converted into a Euclidean distance-based matrix to undergo a RELATE test to examine agreement in the multivariate pattern between the biological and environmental resemblance matrices. Sample patterns of shark assemblages and environmental data were then best matched using a BEST analysis (Bio-env). Non-metric dimensional scaling (nMDS) and principal component analysis (PCA) was used to visually assess sample dispersion and environmental drivers of the community assemblages. All multivariate community analyses were conducted using PRIMER statistical software (Version 7.0; Clarke *et al.* 2015).

In addition to the analysis of environmental parameters included in the multivariate assemblage investigations, environmental data from all longline sets in both the inshore and nearshore habitats were used to examine their effect on shark catch. To explore what parameters influenced the presence or absence of all shark species, environmental data were used to produce generalized linear count data models. Of 441 inshore longline sets, 151 had catches of zero sharks (34%) while 66 out of 238 nearshore longline sets caught zero sharks (28%). Inshore and nearshore habitat was analyzed individually, and a final model was produced for all longline sets in the study area. All data sets were tested for agreeance with Poisson dispersion and then tested for compatibility with several generalized linear count data model types, including Poisson, negative binomial, Hurdle, and zero-inflated models. Log(theta) and AIC values were used to select the best models for each habitat. All count data models were produced using R Studio (Version 1.1.456) with

*MASS*, *AER*, and *pscl* packages. Potential significant interactions of environmental variables were explored in SPSS, but none were found.

## **Results**

### *Overall catch data*

A total of 1763 sharks representing 14 species were caught across all four study locations from a combined 711 bottom longline sets from 2012-2018. The nearshore study locations of Mayport and St. Marys, sampled only from 2014-2018, captured 317 and 391 sharks respectively, totaling 708 animals. The inshore study locations of Cumberland and Nassau Sounds, sampled from 2012-2018, captured 704 and 351 sharks respectively, totaling 1055 animals (Table 1-1).

Catch per unit effort (CPUE), measured as sharks caught per 50 hooks set, was analyzed annually and seasonally for each study location. For Mayport, overall CPUE for 12/0 hooks averaged 2.9 ( $\pm 3.3$ ) sharks and 1.9 ( $\pm 2.0$ ) sharks for 16/0 hooks. St. Marys average CPUEs were higher with 4.0 ( $\pm 4.3$ ) sharks for 12/0 and 3.2 ( $\pm 3.4$ ) sharks for 16/0 hooks. For inshore, Cumberland had a higher average of 2.7 ( $\pm 3.0$ ) sharks compared to Nassau's 1.7 ( $\pm 2.5$ ) sharks.

Overall abundance, represented by CPUE, varied annually and monthly at each study location. Cumberland seasonal abundances peaked in August, while June was the most productive month for Nassau. Although both inshore location's abundances of all sharks fluctuated across the seven years of the study, there is a general trend of stability. No sharks were caught in November or December in Cumberland, and no sharks were caught in April or October in Nassau. Overall, average abundances were higher in the nearshore

than inshore. Mayport CPUE stabilized from 2016-2018 after significantly decreasing from the first two years, likely as a result of greater sampling effort. St. Marys' CPUE averages were higher than Mayport, and no significant annual decreases in productivity were detected.

To avoid misinterpretation of CPUEs, post-hoc analyses were conducted to differentiate homogenous subsets because effort varied annually and seasonally (Figures 1-18:1-21).

This study also implemented the use of drum lines to target larger individuals and encountered nine species of rays throughout the survey. While these animals were excluded from abundance and CPUE analyses, their total composition counts can be found in Tables 1-3:1-6.

#### *Inshore Species and Life Stage Composition*

Atlantic sharpnose sharks were the most abundant species captured in the inshore longline survey with 366 animals representing 34.6% of the total inshore catch. Sandbar sharks (*Carcharhinus plumbeus*) were the second most abundant species with 276 animals captured representing 26.2% of the inshore total, followed by 176 blacktips (16.7%), 69 finetooth (*Carcharhinus isodon*) (6.5%), and 63 bonnethead (6%). The nine other species caught each represented less than 5% of the total inshore catch, as follows: 33 blacknose (3%), 23 smooth dogfish (*Mustelus canis*) (2%), 18 scalloped hammerhead (2%), 12 nurse (*Ginglymostoma cirratum*) (1%), 9 spinner (<1%), 4 lemon (<1%), 4 bull (*Carcharhinus leucas*) (<1%), 1 great hammerhead (*Sphyrna mokarran*) and 1 tiger shark (*Galeocerdo cuvier*). Total longline catch composition for Nassau and Cumberland Sounds individually

can be found in Table 1-3 and Table 1-4, respectively, while proportional catch graphs can be found in Figure 1-15.

Of the 366 Atlantic sharpnose sharks captured at inshore sites, 195 were classified as mature (53.3%) with two adult females caught. Only 3 of the 276 sandbar sharks were adults, and 38 (13.8%) were considered YOYs. Only 288 (27.3%) of the total animals caught inshore were mature. Of the 767 immature sharks, 366 (34.7%) were YOYs and 378 were juveniles (35.8%). Length-frequency plots for all species caught inshore can be found from Figure 1-3:1-14.

#### *Nearshore Species and Life Stage Composition*

A total of 363 Atlantic sharpnose sharks were captured at the Mayport and St. Marys study locations combined, representing 51% of the total nearshore catch. Blacknose sharks were the second most abundant species caught with 219 animals comprising 31% of the nearshore total. Nine other shark species were captured in the longline survey: 41 blacktip (5.8%), 39 finetooth (5.5%), 18 spinner (2.5%), 14 sandbar (2%), 6 scalloped hammerhead (<1%), 4 bonnethead (<1%), 2 nurse (<1%), 1 bull and 1 tiger shark. Total longline catch composition for Mayport and St. Marys individually is shown in Table 1-5 and Table 1-6, respectively, while proportional catch graphs can be found in Figure 1-16.

Of the 363 Atlantic sharpnose sharks captured between both beaches, 318 (87.6%) were determined to be mature, and only one was a mature female. The majority of blacknose sharks were also mature (90%), but both sexes were equally represented. In total, 584 (82.5%) of the sharks captured on the beaches were classified as mature. Of the remaining 120 immature animals, 55 were considered young of year (YOY) while the other 64 were



juveniles. Length-frequency plots for all species caught nearshore can be found from Figure 1-3:1-14.

### *Sex Ratios*

Male Atlantic sharpnose sharks were significantly more abundant than females in each of the four study locations separately ( $p < 0.0001$ ), as well as when analyzed by inshore and nearshore combined groupings ( $p < 0.0001$ ). While sex ratios (F:M) for blacknose sharks deviated from parity at Mayport and St. Marys sites independently ( $p = 0.002$  and  $p < 0.0001$ , respectively), male and female abundance was evenly represented when data from both locations were combined ( $p = 0.246$ ). Female blacktips were significantly more abundant at both beach locations and as an entire nearshore grouping ( $p = 0.019$ ), while the inshore blacktips were equally represented by both sexes across Cumberland, Nassau, and combined inshore categories (Inshore  $p = 0.759$ ). Inshore bonnethead females were significantly more abundant than males ( $p < 0.0001$ ) while sandbars were equally represented ( $p = 0.583$ ). The six most abundant inshore species and the five most abundant nearshore species were all analyzed for sex ratio parity and results can be found in Table 1-9.

### *Relative Abundance Trends*

The three most abundant species caught in the inshore systems and the nearshore systems were analyzed for annual trends in relative abundance, as measured by species-specific CPUE. For all longline sets in the Cumberland Sound system from 2012-2018, the average Atlantic sharpnose abundance was 1.11 ( $\pm 1.9$ ) sharks per 50 hooks. For Nassau, the average abundance was 0.39 ( $\pm 0.83$ ) sharks per 50 hooks. Atlantic sharpnose relative abundance averaged 1.44 ( $\pm 2.35$ ) sharks per 50 hooks for Mayport and 1.47 ( $\pm 2.64$ ) sharks

per 50 hooks for St. Marys from 2014-2018. In general, Atlantic sharpnose relative abundance declined in all locations except for St. Marys, where there was no difference in catch rates across years (Figure 1-22).

Blacktip sharks experienced declining relative abundance trends across all four study sites, with Nassau's average CPUE of 0.58 ( $\pm 1.4$ ) sharks as the highest (Figure 1-23).

Blacknose sharks did not experience any significant changes in relative abundance. The average CPUE from 2014-2018 was 0.59( $\pm 0.95$ ) sharks per 50 hooks for Mayport and 1.33 ( $\pm 2.43$ ) sharks per 50 hooks for St. Marys (Figure 1-24).

The sandbar shark was the only species to reveal an increase in relative abundance from 2012-2018. Cumberland Sound abundance did not significantly change and had an average of 0.85 ( $\pm 1.58$ ) sharks per 50 hooks. However, Nassau sandbar shark relative abundance had an overall average of 0.30 ( $\pm 1.31$ ) sharks and fluctuated from 2012-2017 until a significant increase in 2018 (Figure 1-25).

#### *Gear Selectivity and Length Related Patterns of Occurrence*

The average CPUE for nearshore 12/0 hooks was 2.53 ( $\pm 3.15$ ) sharks. For nearshore 16/0 hooks, the average was 2.48 ( $\pm 2.78$ ) sharks. Comparison of overall CPUE by hook size revealed no significant difference in capture efficiency between the two ( $F=0.021$ ,  $p=0.886$ ). There was no significant difference between FL and hook size for Atlantic sharpnose sharks across both nearshore locations ( $F=3.168$ ,  $p=0.076$ ). Atlantic sharpnose sharks were smallest in the Nassau Sound system (mean FL=52.5  $\pm 22.1$  cm) and largest at Mayport (FL=71.3 $\pm 13.5$  cm). There was no difference in average FL for nearshore blacknose sharks caught on either hook size ( $F=0.065$   $p=0.799$ ). Blacknose shark average FL ranged from 90.5

to  $97.1 \pm 4.5$ - $8.0$ cm across all four sites. The nearshore blacktip sharks did not experience any significant difference in average FL between 12/0 and 16/0 hook sizes ( $F=0.261$ ,  $p=0.613$ ). There was, however, a clear difference between inshore and nearshore average FLs amongst sites. Blacktips in Nassau and Cumberland Sounds averaged  $60.4 \pm 18.7$  cm and  $65.0 \pm 26.1$  cm FL respectively, while Mayport and St. Marys blacktips averaged  $107.4 \pm 32.7$ cm and  $102.7 \pm 23.8$  cm FLs respectively. Average, maximum, and minimum fork length distributions at each location for abundant species can be found in Figures 1-3a:1-14a.

#### *Neonate and YOY occurrence*

Of the 1763 total sharks caught across all four locations, 421 (23.9%) were classified as YOY. From these 421 sharks, 132 individuals representing 8 species were captured with open umbilical wounds such that they were determined to be neonates (7.5% of total catch). Most newborn sharks were captured in Nassau with a total of 72, 55 of which were blacktips, 10 Atlantic sharpnose, 3 bull sharks, 2 scalloped hammerheads, 1 finetooth, and 1 sandbar. The 48 neonates caught in Cumberland were comprised of 21 blacktips, 14 Atlantic sharpnose, 6 sandbars, 4 finetooth, 2 spinners, and 1 lemon shark. Six Atlantic sharpnose neonates and one finetooth neonate were captured at St. Marys, and all five neonate sharks caught at Mayport were Atlantic sharpnose. Two Atlantic sharpnose and one blacktip from Cumberland were caught in August, along with one Atlantic sharpnose from Nassau. All other neonates were caught in May, June, and July.

### *Recapture Reports*

Over the course of this study, there were a limited amount of recaptured animals. A male juvenile sandbar shark was tagged inshore of Cumberland Sound in June of 2017, was recaptured by a recreational fisherman 78 days later inshore of Cumberland Sound 3 km away from the original location, and then recaptured for a second time 295 days later by a commercial fisherman. The second recapture was 3 nm from the first recapture event but occurred outside of the St. Marys river inlet on the beach of Amelia Island. A female juvenile sandbar shark was tagged in May of 2016 and was recaptured 452 days later by UNF, less than 500m from the original location within the creeks of Cumberland Sound. A third male sandbar shark was recaptured in August 2017 by UNF in the creeks of Cumberland Sound 123 days after its initial tagging, less than 2 km away. A mature male Atlantic sharpnose shark was initially captured in June of 2016 in the St. Marys nearshore habitat. It was recaptured 743 days later by UNF less than 3km from the original tagging location. Last, a mature male blacknose shark initially tagged in August 2017 was recaptured in June 2018 by a recreational fisherman, 310 days later. It was 50 km from the original location within the same vicinity around Mayport.

### *Species Diversity by Location*

Both inshore locations had higher Shannon indices of species diversity than the nearshore study locations with corresponding equitability scores as follows: Nassau  $H' = 1.87$  ( $E_H = 0.82$ ), Cumberland  $H' = 1.58$  ( $E_H = 0.62$ ), St. Marys  $H' = 1.39$  ( $E_H = 0.60$ ), and Mayport  $H' = 1.12$  ( $E_H = 0.51$ ). While the species present across each location are very similar, differences in the relative abundances drive the slight range of values observed in the indices

calculated from each location's total composition. Investigations of diversity by overall habitat revealed that inshore locations still ranked higher with  $H'=1.77$  ( $E_H=0.67$ ) compared to  $H'=1.31$  ( $E_H=0.55$ ) for nearshore locations combined (Table 1-8). The overall similarity of shark assemblages across locations demonstrated with non-metric multidimensional scaling (nMDS) can be seen in Figure 1-27.

### *Similarities in Community Structure*

Overall, two-way crossed ANOSIM indicated that location significantly influenced shark species-life stage assemblages ( $R=0.18$ ,  $p=0.001$ ). Season also had a significant influence on shark species-life stage assemblage, although the differences were less defined ( $R=0.052$ ,  $p=0.012$ ). In total, subsequent pairwise analyses between specific locations revealed significant variability in shark communities and life stages in 5/6 comparisons. Comparison of Mayport and St. Marys indicated that minimal separation exists between the two nearshore assemblages and that they were most similar ( $R=0.016$ ,  $p=0.124$ ). The shark communities of Mayport and Cumberland observed the greatest separation of the sites studied ( $R=0.257$ ,  $p=0.001$ ). Mayport and Nassau revealed the second highest degree of assemblage separation ( $R=0.245$ ,  $p=0.001$ ), followed by St. Marys and Cumberland ( $R=0.237$ ,  $p=0.001$ ). Nassau and St. Marys were less separated ( $R=0.193$ ,  $p=0.001$ ), while the inshore locations of Cumberland and Nassau had the least significant difference in similar shark assemblages ( $R=0.131$ ,  $p=0.001$ ) (Table 1-12).

Pairwise tests between seasons revealed non-significant results in two comparisons. Fall and spring revealed the most significant separation of seasons ( $R=0.223$ ,  $p=0.004$ ), while summer and spring were only slightly significantly different ( $R=0.057$ ,  $p=0.001$ ). Summer

and fall were the most similar ( $R=0.027$ ,  $p=0.261$ ). Fall and winter pairwise testing resulted in an  $R$ -value of 0 ( $p=0.7$ ), but this is likely due to a low number of possible permutations from a limited sample size of winter surveying.

The SIMPER analysis allowed for the drivers of assemblage similarities and differences to be parsed out by species life stage. Mayport and St. Marys received the lowest average dissimilarity score of 67.75%, driven almost equally by adult Atlantic sharpnose and adult blacknose sharks (25% and 24.7% contributions, respectively). St. Marys and Cumberland had the highest average dissimilarity of 86.75%, with significant contributions coming from adult blacknose (21%), juvenile sandbar (18%), adult Atlantic sharpnose (17%), YOY Atlantic sharpnose (10%), and adult finetooth sharks (6%). Comparisons between Mayport and Cumberland, Mayport and Nassau, St. Marys and Nassau, and Cumberland and Nassau all produced dissimilarity averages of ~82-86%, with varying relative contributions from species life stages throughout. All specific location comparisons and corresponding species life stage contributions can be found in Table 1-14.

The lowest dissimilarity score of SIMPER season and location analysis was produced by the interaction of fall and winter (34.69%). Ignoring this result as a likely outlier, all season by location comparisons resulted in average dissimilarity scores of ~70-75% (Table 15). When comparing species contributions to seasonal similarities alone, adult Atlantic sharpnose sharks had the highest significant relative abundance (0.89) to the spring season's highest average similarity score of 39.67% (Table 1-15). Summer as a group received the lowest average similarity score of 26.84%, driven by contributions from adult blacknose (40%), adult Atlantic sharpnose (23%), and juvenile sandbar sharks (20%).

## *Environmental Analysis*

The results of the RELATE test indicated significant agreement in the multivariate pattern between the Bray-Curtis similarity matrix of shark assemblages and the Euclidean distance-based resemblance matrix of the environmental data ( $\rho=0.169$ ,  $p=0.001$ ). The subsequent Bio-env BEST analysis revealed that the combination of environmental parameters salinity and dissolved oxygen provided the best match between shark assemblages ( $\rho=0.221$ ). While all Spearman rank correlation values produced by the BEST analysis were low (0.133-0.221), dissolved oxygen ( $\rho=0.205$ ) and salinity ( $\rho=0.168$ ) were the only individual variables retained in the top 10 combinations of variables. (Table 1-16). Species-specific summaries of environmental averages and ranges for all inshore and nearshore sets can be seen at Table 1-10 and Table 1-11, respectively.

Generalized linear count data model analysis revealed that the inshore environmental data was overdispersed ( $Z=6.218$ ,  $p<0.0001$ ), and AIC values indicated that a negative binomial distribution model was a better fit than Poisson (1296.3 vs. 1596.6, respectively). Temperature was the most significant factor impacting the presence or absence of sharks inshore, followed by depth. The nearshore data was also overdispersed ( $Z=6.2182$ ,  $p<0.0001$ ) and thus a better fit for a negative binomial model than Poisson (AIC 693.34 vs. 819.16). Salinity had more of an impact than temperature in predicting the presence of sharks, but both were significant. Finally, all environmental data were used in a negative binomial generalized linear model after proving to be overdispersed ( $Z=7.88$ ,  $p<0.0001$ ) and a better fit than a Poisson GLM (AIC 2004.6 vs. 2494.2). In this model, temperature received the highest Z value, followed by salinity and depth. In all three models,

dissolved oxygen was not a significant factor, and all intercepts were statistically significant. An overview of all model outputs can be seen in Table 1-17.

Principal Component Analysis was conducted on environmental data from sets in all locations when all four environmental parameters were collected (n=247)(Figure 1-26). PC1 accounted for 45.6% of variation, while PC2 comprised 25.7% of variation (Table 18). The visual distribution of environmental factors across location implies that nearshore habitats had higher salinities and higher oxygen content, while higher temperatures were recorded inshore.

## **Discussion**

This study represents the second attempt to characterize the abundance and distributions of shark populations in the nearshore and inshore estuarine waters of the First Coast. Although the first attempt by McCallister *et al.* (2013) provided important findings inspiring this study, the scope of the original project was spatially limited. The present study was able to extend the shark population survey in inshore estuarine waters and expand to the true nearshore habitats found outside of the major river inlets and adjacent to the beaches. Thus, this study highlights several differences and similarities of shark assemblages of the First Coast.

Overall, fourteen species of shark and nine species of ray were detected along the First Coast habitats, verifying that the area supports a high diversity of elasmobranch species. Aside from the smooth dogfish, all 13 other species fall into the large coastal sharks (LCS) or small coastal sharks (SCS) complexes as determined by NMFS (NMFS, 1999). The Atlantic sharpnose shark dominated total catch in every habitat except for Nassau, where



blacktip sharks were most abundant. Across all four locations combined, sandbar sharks were the second most abundant species and represented 16.5% of all sharks caught. However, of the 290 sandbars captured, only 14 were caught in the nearshore locations, and 279 classified as immature animals. Blacknose sharks were the third most abundant species captured overall, with 87% caught in nearshore habitats. Blacktip sharks were the last remaining species to make up more than 10% of the overall total catch (12.3%), with 176 of 217 total animals caught in Cumberland or Nassau. The general dominance of total catch by Atlantic sharpnose matches what has been observed in coastal surveys in South Carolina (Ulrich *et al.* 2007), Georgia (Belcher 2010), and the northeastern Gulf of Mexico (Bethea *et al.* 2015). The dominance of Atlantic sharpnose and proportion of blacktip sharks captured inshore is very similar to what was observed by McCallister *et al.* (2013) in the same habitats. Furthermore, the disproportionate abundances of blacknose sharks in the nearshore compared to inshore habitats matches the findings of Ulrich *et al.* (2007), such that blacknose sharks predominantly inhabit coastal waters.

Newborn and juvenile sandbar sharks have been reported in Delaware Bay (Merson and Pratt, 2001), Chesapeake Bay (Grubbs *et al.* 2005), and South Carolina (Shiffman *et al.* 2014). However, the observed proportion of sandbar sharks caught in the inshore versus nearshore habitats of this study does not agree with the findings of Ulrich *et al.* (2007), where total catches were more similar across habitats in South Carolina. McCallister *et al.* (2013) captured 36 sandbar sharks in the three years of their study, 34 of which were classified as juvenile. In the current study, sandbar sharks only experienced a significant increase in inshore relative abundance in Nassau in 2018; annual catch rates of sandbar sharks did not significantly change in Cumberland. Once heavily exploited (SEDAR 2006), it

is possible that the First Coast is observing stabilization of this local population as seen elsewhere in the southeastern United States (Romine *et al.* 2011; SEDAR 2011). Given the small relative proportion of sandbar sharks captured in this study compared to the abundances reported from Delaware and Chesapeake Bays, it is unlikely that the population of sandbar sharks inhabiting the First Coast significantly contributes to the regional stock. However, this does not undermine the potential implications of the population fluctuations at the local level and may merit more thorough species-specific studies. Additionally, the nearshore habitats of the First Coast are designated as Essential Fish Habitat for all life stages of the sandbar shark, but currently does not include any inshore areas. This study suggests that both Nassau and Cumberland Sounds may be worthy of EFH designation for the sandbar shark, particularly for the neonate and juvenile life stages.

Although annual CPUEs fluctuated for each specific hook size, there was no difference in overall CPUE between hook sizes across both nearshore habitats. This suggests that there were no differences in capture efficiency of gear types and thus utilizing two hook sizes did not bias this survey. While there were statistically significant differences in average size for some species at each location, gear did not influence these results in the nearshore habitat. Significant differences in sizes of species per location are thus assumed to be a result of habitat differentiation by life stage, not gear. While surveys can be biased based on factors like longline configuration or mesh size of gill nets (Hubert *et al.* 2012) , circle hook size also did not bias shark catch in a pelagic longline fishery (Yokota *et al.* 2006).

The observed sex ratios varied by species and by habitat. Male Atlantic sharpnose far outnumbered females in both habitats due to the high numbers of adults, but particularly in the nearshore locations. This matches the patterns of sexual segregation by habitat seen in the north-central Gulf of Mexico (Parsons and Hoffmayer 2005), where mature females usually inhabit offshore waters and only come inshore for pupping. The sex ratio of inshore Atlantic sharpnose was also significantly different than 1:1, but higher abundances of females were likely encountered because young animals that had yet to experience their ontogenetic habitat shift. Species that had higher abundances of juvenile life stages, like the sandbars and blacktips captured inshore, had more balanced sex ratios.

The majority of all newborn sharks were captured in the late spring or early summer, coinciding with the parturition patterns observed in other seasonally utilized systems as well as with the previous findings in the southeastern U.S. (Castro 1993, Ulrich *et al.* 2007, McCallister *et al.* 2013). Aside from one finetooth shark captured at St. Marys, all other 11 neonate sharks caught in the nearshore habitats were Atlantic sharpnose. The highest abundance of nearshore YOYs was Atlantic sharpnose sharks, showing that these young sharks co-occur with adults in both inshore and nearshore habitats of the First Coast as seen in regions of the Gulf of Mexico (Bethea *et al.* 2015).

Relative abundances of nearshore Atlantic sharpnose remained stable at St. Marys, and blacknose relative abundances were stable throughout both beach locations. Conversely, the inshore relative abundance of Atlantic sharpnose and blacktips declined at both locations, while blacktip nearshore relative abundance also declined. Given that the spatial scope of this study is limited when considering the migratory behaviors of these

coastal species, these localized results are unlikely to reflect species declines. Additionally, in considering the age structure differences between habitats, these trends emphasize the importance of investigating abundances at multiple life stages for appropriate conservation and management strategies (Kinney and Simpfendorfer, 2009). A preliminary recovery of depleted coastal shark populations in the southeastern United States has recently been reported, providing support for effective management strategies (Peterson *et al.* 2017).

There was little separation of assemblages by season observed. This could be a result of the systems of the First Coast being used seasonally, such that the most significant differences are detected between the transitional periods when animals are migrating in and out of the area. Given that sampling in the defined "winter" season was considerably lower than the rest of the year, increased survey effort from October-March may provide more clearly defined seasonal differences. For example, two longline sets in Nassau in January 2013 resulted in the only *M. canis* captured in the overall survey. In other regions of the Atlantic coast of the United States, smooth dogfish are known to make seasonal migrations in responses to changes in water temperature which supports the limited seasonal use evidence provided in this study (Havelin 2010). Additionally, ANOSIM and SIMPER analyses only utilized abundance data when sharks are captured. More insightful than the multivariate seasonal comparisons may be the range of environmental parameters each species was captured in, as well as the presence/absence models.

The results of the Bio-Env BEST test indicate that salinity and dissolved oxygen were the most significant variables impacting shark assemblages. Dissolved oxygen concentrations have been shown to influence bull shark distributions in the Everglades and

concentrations in estuaries are predicted to be impacted by future anthropogenic changes (Heithaus *et al.* 2009). Salinity has influenced the distribution of bonnethead sharks in southwestern Florida estuaries (Ubeda *et al.* 2009). Freshwater runoff and precipitation are expected to be drivers of local fluctuations in salinity and likely have a greater influence on nearshore shark distributions compared to species that occur further offshore (Schlaff *et al.* 2014). Thus, these results may help elucidate interactions if assemblages or environmental conditions change in the future.

Although salinity was weakly correlated with assemblages from the Bio-Env BEST test, only the nearshore presence/absence model produced salinity as a significant factor. Temperature was the most significant factor determined by inshore presence/absence models. Aside from the smoothhound dogfish, no sharks were caught inshore below 20.1°C. Temperature was also a significant factor for the nearshore presence/absence model. In the beach locations, a single sandbar shark was captured in December at 15.1°C. Considering the extremely low catch total of this species in the nearshore habitats, this animal may have been captured on its way out of the First Coast systems to overwintering grounds. Aside from that individual, the lowest temperature of nearshore capture was 17.8°C for Atlantic sharpnose and blacknose sharks. This further strengthens the claim that the First Coast habitat is primarily used seasonally by sharks (McCallister *et al.* 2013) and aligns with the influence of temperature in similar studies (Ulrich *et al.* 2007, Grubbs *et al.* 2007). In general, temperature is known to influence both broad-scale seasonal migrations and local habitat utilization, while salinity is more strongly correlated with finer-scale localized movements (Schlaff *et al.* 2014). However, photoperiod has also been hypothesized as the environmental trigger for fall and spring migrations for sandbar sharks in the Chesapeake Bay region in

consideration of abnormal seasonal temperature thresholds (Grubbs *et al.* 2007). Recently, an increase in juvenile bull shark abundance in North Carolina inshore waters has been associated with increasing water temperatures and salinities during the time of parturition and has resulted in the colonization of new nursery habitat that appears historically unused by the species (Bangley *et al.* 2018). This more northerly colonization highlights the importance of gathering information on the interactions of shark assemblages and their environments to better understand how populations may respond to large-scale disturbances associated with climate change.

Although limited, the few cases of available recapture data provided in this study provide powerful insight into the use of the First Coast habitat. First, the juvenile sandbar shark recaptured twice is of particular interest. Not only did this individual remain in the immediate area for 78 days after the initial tagging, but it also appeared to have returned to the region the following year (assuming it migrated away for overwintering elsewhere). Under the same assumptions, a separate sandbar shark tagged and recaptured by UNF seems to have followed a similar trend of returning after overwintering given its recapture 452 days later less than 500m from the original tagging location. The final recaptured juvenile sandbar shark presented suggests that individuals may remain in the area throughout the summer following capture. The recapture of a mature Atlantic sharpnose by UNF almost exactly two years from the initial capture date in June in St. Marys suggests that the individual either returned to inhabit the same area or followed the same migration path, both of which would be expected. The same inference applies to the mature male blacknose shark initially tagged and recaptured 310 days later around Mayport. Juvenile sandbar sharks are known to inhabit inshore estuaries during the summer and then move offshore

to deeper waters for overwintering before returning to estuaries the following spring (Conrath and Musick 2008). Blacknose sharks in the southeastern United States are known to migrate northward from the east coast of Florida to the coastal habitats of the Carolinas in the summer, returning to Florida again in the winter (Schwartz 1984; Ulrich *et al.* 2007). In northeast Florida, Atlantic sharpnose sharks utilize inshore estuaries seasonally (McCallister *et al.* 2013), while nearshore abundances varied with temperature in South Carolina; Atlantic sharpnose sharks were not captured in waters less than 13.5° (Ulrich *et al.* 2007). Regardless of the exact movements undertaken between recapture of the aforementioned individuals, the data provided suggests some degree of philopatry occurring along the First Coast, which may have underlying impacts of population structure (Chapman *et al.* 2015). Furthermore, aside from the specific mentions of sharks recaptured by UNF, the other recapture data were generated from reports submitted by commercial and recreational fishermen. This emphasizes the effectiveness and value of community involvement in regards to reporting when implementing tag-recapture studies of highly mobile species like sharks.

The present study aimed to assess the requirements of the nursery criteria proposed by Heupel *et al.* (2007). Criteria 2 and 3 were directly satisfied by the initial description of the inshore habitats provided by McCallister *et al.* (2013) and this study further strengthened those findings. Regarding Criteria 2, all age 0 and juvenile sharks were recaptured the same year they were tagged by McCallister *et al.* (2013). The present study provides compelling evidence of repeated use in subsequent years by juvenile sandbar sharks. Unfortunately, the roto-tags used to tag individuals in this study were too large to tag particularly small sharks such as neonate Atlantic sharpnose, limiting the explicit testing of

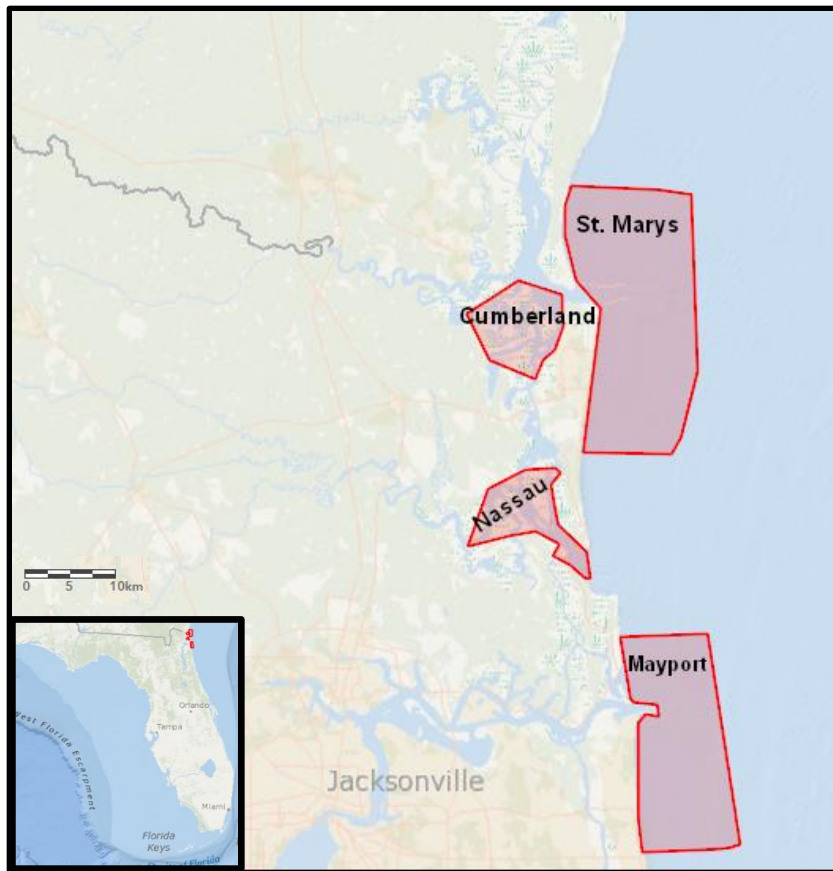
the most abundant species. McCallister *et al.* (2013) also satisfied Criteria 3 that the inshore habitat is used repeatedly across years, and the present study strengthens this initial finding with the continued annual abundances of respective YOY and juvenile sharks. The initial uncertainty in fulfilling the nursery ground criteria existed with Criteria 1, but the current study showed that young sharks are far more commonly encountered in the specific inshore areas of Cumberland and Nassau than they are in the adjacent nearshore areas of Mayport and St. Marys

## **Conclusion**

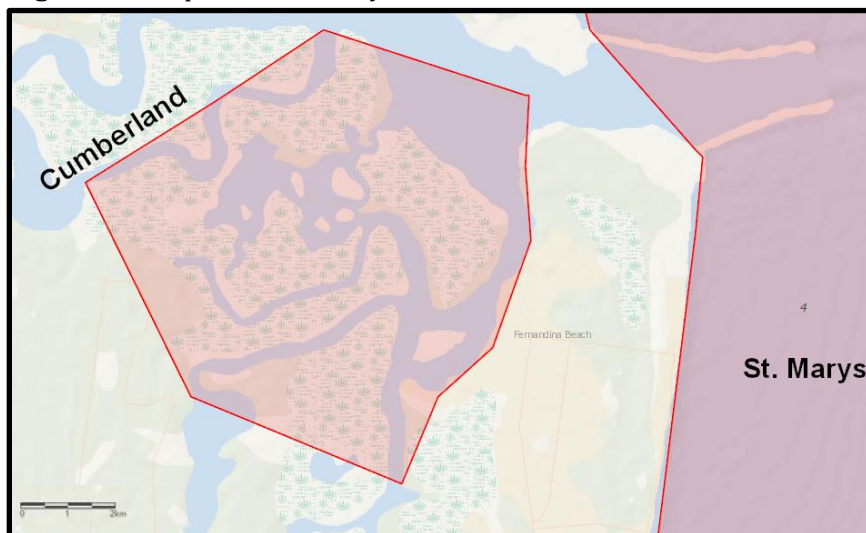
In conclusion, this study determined that there is a significant difference in community structure between inshore and nearshore areas and that relative abundance are higher in nearshore waters. Aside from Mayport and St. Marys, there are significant differences in assemblages between every location. While there are differences in life-stages of assemblages, there is a considerable overlap of species in every location, which is expected considering the proximity of the habitats along the First Coast. Differences between seasons were less defined, but abundances varied annually and by month at each location. Dissolved oxygen and salinity are the most important environmental parameters influencing distribution when sharks are present, and temperature appears to be the driving force behind seasonal utilization of First Coast habitats. Finally, this study confirms the initial suggestion that the inshore habitats of the First Coast serve as nursery grounds for Atlantic sharpnose and blacktip sharks. It also provides evidence that the inshore waters of Cumberland Sound serve as a nursery ground for sandbar sharks. In doing so, this study may serve to inspire future studies assessing nursery habitat use and comparing



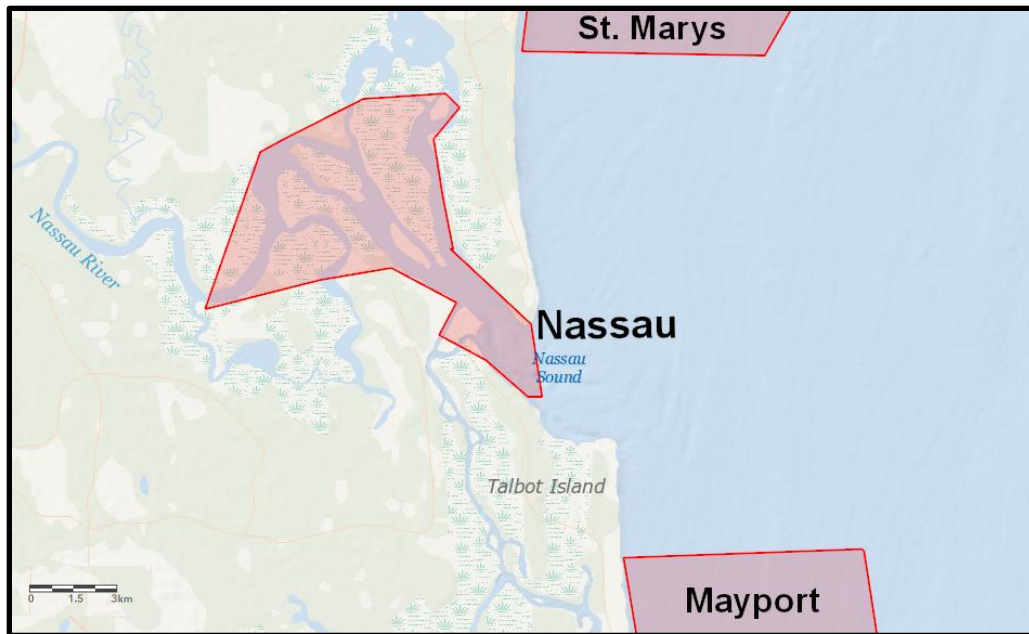
against other locations. This study also suggests that the inshore areas of the First Coast, especially Cumberland Sound, should be considered for Essential Fish Habitat designation for juvenile sandbar sharks. Given the uncertainty surrounding future environmental health of marine environments, the information gathered in this study can contribute to sustainable management and conservation of First Coast and regional shark populations.



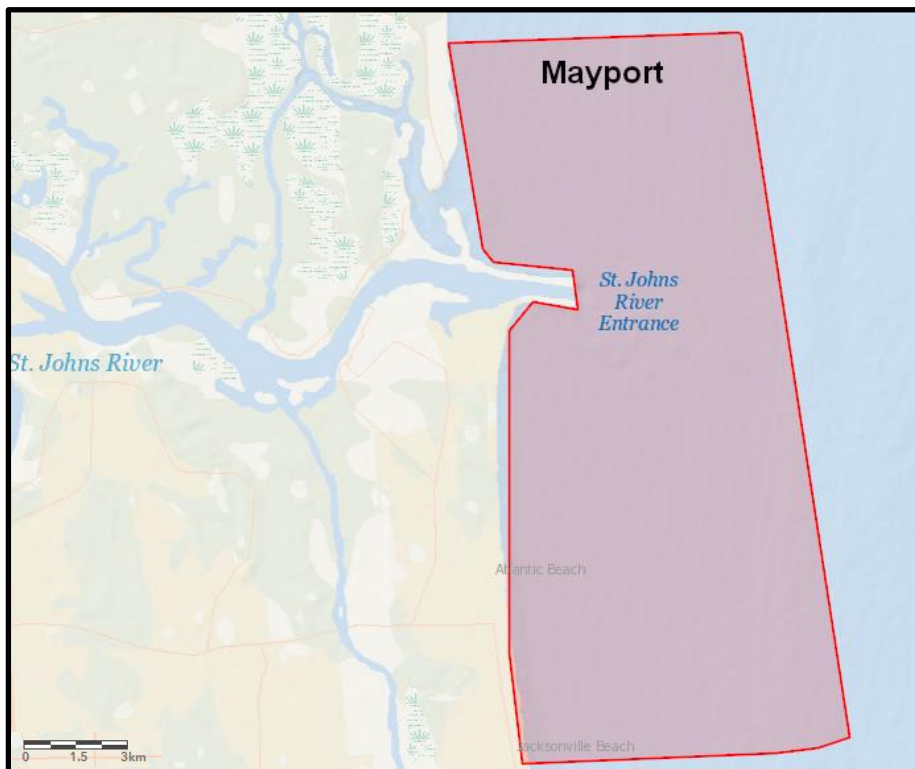
**Figure 1-1.** Map of all four study locations.



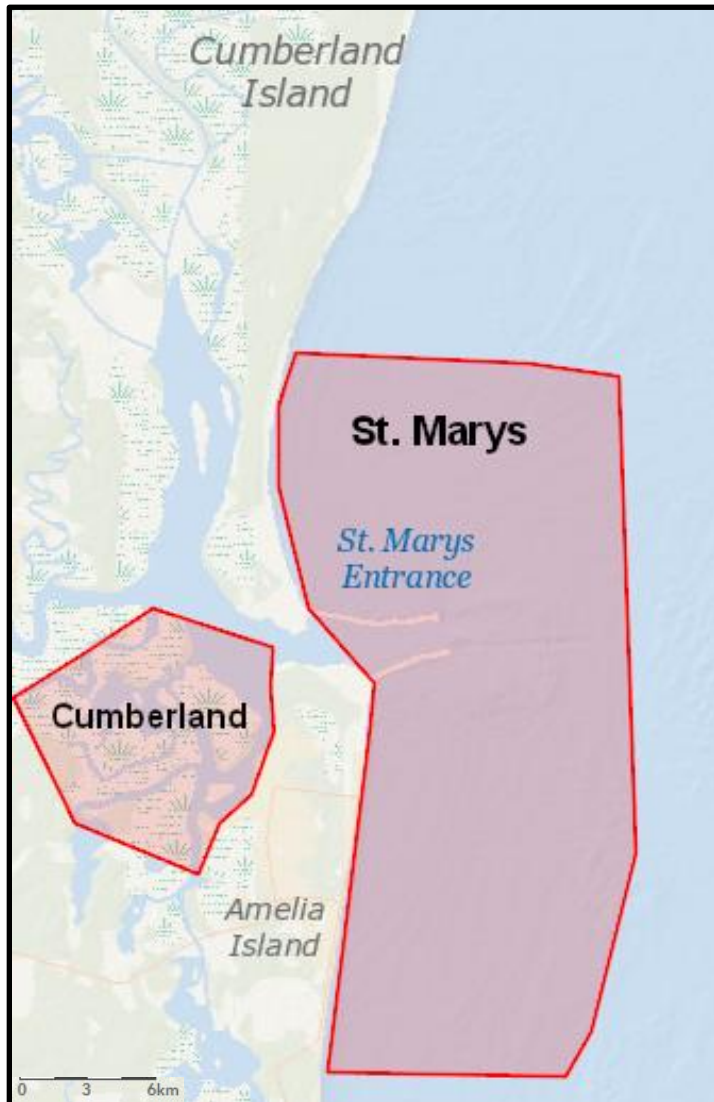
**Figure 1-2a.** Map of inshore habitat Cumberland.



**Figure 1-2b.** Map of inshore habitat Nassau.



**Figure 1-2c.** Map of nearshore habitat Mayport.



**Figure 1-2d.** Map of nearshore habitat St. Marys and inshore habitat Cumberland.

**Table 1-1a.** Total shark catch composition from all 4 location longlines combined from 2012-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Atlantic Sharpnose</b>	729	41.35	625	92	12	186	24	513	6	510	2
<b>Sandbar</b>	290	16.45	144	139	7	38	241	9	2	3	2
<b>Blacknose</b>	252	14.29	124	122	6		21	227	4	116	5
<b>Blacktip</b>	217	12.31	100	111	6	137	47	25	8	8	5
<b>Finetooth</b>	108	6.13	58	45	5	24	36	42	6	21	
<b>Bonnethead</b>	67	3.80	15	51	1	6	9	50	2	12	37
<b>Spinner</b>	27	1.53	15	12		12	10	5		3	
<b>Scalloped</b>	24	1.36	8	16		14	10				
<b>Smoothhound</b>	23	1.30	10	13			23				
<b>Nurse</b>	14	0.79	8	5	1		13	1		1	
<b>Bull</b>	5	0.28	3	1	1	3	2				
<b>Lemon</b>	4	0.23	1		3	1	3			1	
<b>Tiger</b>	2	0.11			2		2				
<b>Great Hammer</b>	1	0.06	1				1				
<b>Total</b>	1763	100.00									

**Table 1-1b.** Total ray catch composition from all 4 location longlines combined from 2012-2018.

<b>Rays</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Southern</b>	75	53.19	18	55	2		20	50	5	13	37
<b>Bluntnose</b>	20	14.18	9	11			7	12	1	7	5
<b>Cownose Ray</b>	15	10.64	4	10	1		3	11	1	2	9
<b>Atlantic Smooth Butterfly</b>	14	9.93	6	6	2		2	10	2	3	4
<b>Roughtail</b>	7	4.96	1	6			2	5			4
<b>Roughtail</b>	4	2.84		3	1		3		1		
<b>Clearnose Skate</b>	3	2.13		3			3				
<b>Lesser Devil Ray</b>	2	1.42	1		1			2		1	
<b>Manta</b>	1	0.71			1				1		
<b>Total</b>	141	100.00									

**Table 1-2a.** Total shark catch composition from nearshore habitats Mayport and St. Marys longlines combined from 2014-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
Atlantic Sharpnose	363	51.27	341	19	3	43	2	318		317	1
Blacknose	219	30.93	99	116	4		20	197	2	91	104
Blacktip	41	5.79	13	28		3	18	20		8	12
Finetooth	39	5.51	18	18	3	1	2	33	3	12	20
Spinner	18	2.54	10	8		5	8	5		3	2
Sandbar	14	1.98	5	9			8	6		2	4
Scalloped	6	0.85	1	5		3	3				
Bonnethead	4	0.56	3	1				4		3	1
Nurse	2	0.28	2				1	1		1	
Bull	1	0.14		1			1				
Tiger	1	0.14			1		1				
<b>Total</b>	<b>708</b>	<b>100</b>									

**Table 1-2b.** Total shark catch composition from inshore habitats Cumberland and Nassau longlines combined from 2012-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
Atlantic Sharpnose	366	34.69	284	73	9	143	22	195	6	193	2
Sandbar	276	26.16	139	130	7	38	233	3	2	1	2
Blacktip	176	16.68	87	83	6	134	29	5	8		5
Finetooth	69	6.54	40	27	2	23	34	9	3	9	
Bonnethead	63	5.97	12	50	1	6	9	46	2	9	37
Blacknose	33	3.13	25	6	2		1	30	2	25	5
Smoothhound	23	2.18	10	13			23				
Scalloped	18	1.71	7	11		11	7				
Nurse	12	1.14	6	5	1		12				
Spinner	9	0.85	5	4		7	2				
Lemon	4	0.38	1		3	1	3			1	
Bull	4	0.38	3		1	3	1				
Great Hammer	1	0.09	1				1				
Tiger	1	0.09			1		1				
<b>Total</b>	<b>1055</b>	<b>100</b>									

**Table 1-3a.** Total shark catch composition for Nassau longlines from 2012-2018.

Shark Species	# caught	% of catch	Male	Female	NS	Age 0	Juv	Adult	NR	Adult Male	Adult Female
Blacktip	113	32.19	54	53	6	87	17	3	6		3
Atlantic Sharpnose	82	23.36	60	20	2	43	2	33	4	33	
Blacknose	21	5.98	13	6	2		1	18	2	13	5
Sandbar	56	15.95	35	21		4	52				
Bonnethead	23	6.55	4	19		1	2	20		4	16
Finetooth	15	4.27	4	10	1	6	4	3	2	3	
Smoothhound	22	6.27	10	12			22				
Scalloped	8	2.28	5	3		7	1				
Nurse	7	1.99	2	4	1		7				
Bull	4	1.14	3		1	3	1				
<b>Total</b>	<b>351</b>	<b>100</b>									

**Table 1-3b.** Total ray catch composition for Nassau longlines from 2012-2018.

Ray Species	# caught	% of catch	Male	Female	NS	Age 0	Juv	Adult	NR	Adult Male	Adult Female
Southern	13	35.14		11	2		2	8	3		8
Bluntnose	10	27.03	4	6			5	5		3	2
Atlantic	5	13.51	5	0			2	2	1	2	0
Smooth Butterfly	5	13.51		5			1	4			4
Clearnose Skate	2	5.41		2			2				
Cownose Ray	1	2.70		1				1			1
Roughtail	1	2.70		1			1				
<b>Total</b>	<b>37</b>	<b>100</b>									

**Table 1-3c.** Total shark catch composition for Nassau drumlines from 2012-2018.

Shark Species	# caught	% of catch	Male	Female	NS	Age 0	Juv	Adult	NR	Adult Male	Adult Female
Atlantic Sharpnose	1	50		1				1			1
Blacknose	1	50		1				1			1
<b>Total</b>	<b>2</b>	<b>100</b>									

**Table 1-4a.** Total shark catch composition for Cumberland longlines from 2012-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
Atlantic Sharpnose	284	40.34	224	53	7	100	20	162	2	160	2
Sandbar	220	31.25	104	109	7	34	181	3	2	1	2
Blacktip	63	8.95	33	30		47	12	2	2		2
Finetooth	54	7.67	36	17	1	17	30	6	1	6	
Bonnethead	40	5.68	8	31	1	5	7	26	2	5	21
Blacknose	12	1.70	12					12		12	
Scalloped	10	1.42	2	8		4	6				
Spinner	9	1.28	5	4		7	2				
Nurse	5	0.71	4	1			5				
Lemon	4	0.57	1		3	1	3			1	
Great Hammer	1	0.14	1				1				
Smoothhound	1	0.14		1			1				
Tiger	1	0.14			1		1				
<b>Total</b>	<b>704</b>	<b>100</b>									

**Table 1-4b.** Total ray catch composition for Cumberland longlines from 2012-2018.

<b>Rays</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
Southern	29	45.31	8	21			10	17	2	4	13
Cownose	12	18.75	3	8	1		1	10	1	2	8
Bluntnose	10	15.63	5	5			2	7	1	4	3
Atlantic	7	10.94	1	4	2			7		1	4
Lesser Devil	2	3.13	1		1			2		1	
Roughtail	2	3.13		2			2				
Clearnose Skate	1	1.56		1			1				
Smooth Butterfly	1	1.56		1				1			
<b>Total</b>	<b>64</b>	<b>100</b>									

**Table 1-4c.** Total shark catch composition from Cumberland drumlines from 2012-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
Sandbar	5	41.67	2	3			4	1		1	
Blacktip	3	25.00	1	2				3			
Lemon	3	25.00	1	1	1		2	1			
Tiger	1	8.33		1			1				
<b>Total</b>	<b>12</b>	<b>100</b>									



**Table 1-5a.** Total shark catch composition from Mayport longlines from 2014-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Atlantic Sharpnose</b>	192	60.57	181	8	3	21	1	170		169	1
<b>Blacknose</b>	80	25.24	54	23	3		7	72	1	48	22
<b>Blacktip</b>	17	5.36	6	11			12	5		2	3
<b>Finetooth</b>	13	4.10	4	8	1		2	10	1	3	7
<b>Spinner</b>	7	2.21	4	3			5	2		1	1
<b>Bonnethead</b>	3	0.95	2	1				3		2	1
<b>Scalloped</b>	2	0.63	1	1		2					
<b>Nurse</b>	2	0.63	2				1	1		1	
<b>Sandbar</b>	1	0.32		1				1			1
<b>Total</b>	317	100									

**Table 1-5b.** Total ray catch composition from Mayport longlines from 2014-2018.

<b>Rays</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Southern</b>	16	84.21	6	10			3	13		6	7
<b>Roughtail</b>	1	5.26			1				1		
<b>Atlantic</b>	1	5.26		1				1			
<b>Manta</b>	1	5.26			1				1		
<b>Total</b>	19	100									

**Table 1-5c.** Total shark catch composition from Mayport drumlines from 2014-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Blacktip</b>	6	37.50		6				6			6
<b>Blacknose</b>	3	18.75		3				3			3
<b>Spinner</b>	2	12.50		2							2
<b>Lemon</b>	2	12.50		1	1			2			1
<b>Atlantic Sharpnose</b>	1	6.25	1					1		1	
<b>Sandbar</b>	1	6.25		1			1				
<b>Bull</b>	1	6.25	1				1				
<b>Total</b>	16	100									

**Table 1-6a.** Total shark catch composition from St. Marys longlines from 2014-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Atlantic Sharpnose</b>	171	43.73	160	11		22	1	148		148	
<b>Blacknose</b>	139	35.55	45	93	1		13	125	1	43	82
<b>Finetooth</b>	26	6.65	14	10	2	1		23	2	9	13
<b>Blacktip</b>	24	6.14	7	17		3	6	15		6	9
<b>Sandbar</b>	13	3.32	5	8			8	5		2	3
<b>Spinner</b>	11	2.81	6	5		5	3	3		2	1
<b>Scalloped</b>	4	1.02		4		1	3				
<b>Bonnethead</b>	1	0.26	1					1		1	
<b>Bull</b>	1	0.26		1			1				
<b>Tiger</b>	1	0.26			1		1				
<b>Total</b>	391	100									

**Table 1-6b.** Total ray catch composition from St. Marys longlines 2014-2018.

<b>Rays</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Southern</b>	17	94.44	4	13			5	12		3	9
<b>Atlantic</b>	1	5.56		1					1		
<b>Total</b>	18	100									

**Table 1-6c.** Total shark catch composition from St. Marys drumlines 2014-2018.

<b>Shark Species</b>	<b># caught</b>	<b>% of catch</b>	<b>Male</b>	<b>Female</b>	<b>NS</b>	<b>Age 0</b>	<b>Juv</b>	<b>Adult</b>	<b>NR</b>	<b>Adult Male</b>	<b>Adult Female</b>
<b>Blacktip</b>	9	50.00	1	8				9		1	8
<b>Blacknose</b>	1	5.56		1				1			1
<b>Lemon</b>	3	16.67	2	1			1	2		1	1
<b>Great Hammer</b>	3	16.67		1	2			3			1
<b>Bull</b>	1	5.56		1			1				
<b>Nurse</b>	1	5.56	1				1				
<b>Total</b>	18	100									

**Table 1-7.** Breakdown of all gear types annual effort across all four locations.

Mayport	2014	2015	2016	2017	2018	Total		
Longline Sets 12/0	2	2	13	29	14	60		
Longline Sets 16/0	5	10	13	29	14	71		
Drumlines	11	3	6	38	19	77		
St. Marys	2014	2015	2016	2017	2018	Total		
Longline Sets 12/0	5	4	11	26	5	51		
Longline Sets 16/0	5	6	15	26	5	57		
Drumlines	11	0	6	37	5	59		
Cumberland	2012	2013	2014	2015	2016	2017	2018	Total
Longline Sets 12/0	48	63	12	19	31	42	29	244
Longline Sets 16/0	0	0	6	4	0	5	1	16
Drumlines	12	12	0	2	0	20	8	54
Nassau	2012	2013	2014	2015	2016	2017	2018	Total
Longline Sets 12/0	27	65	16	23	24	25	17	197
Longline Sets 16/0	5	0	7	3	0	0	0	15
Drumlines	0	0	5	0	0	6	3	14

**Table 1-8.** Diversity indices for each location and combined habitats. Inshore habitats based on total shark catch from 2012-2018, nearshore habitats based on total shark catch from 2014-2018. H'=index of species diversity, E<sub>H</sub>=equitability.

Location	H'	E
Nassau	1.87	0.82
Cumberland	1.58	0.62
Inshore Combined	1.77	0.67
Mayport	1.12	0.51
St. Marys	1.39	0.6
Nearshore Combined	1.31	0.55

**Table 1-9.** Male and female total counts and corresponding sex ratios for each of the four study locations and for combined habitats (\* indicates significance). Sex ratios were not calculated for species when  $n < 10$  at a location or  $< 18$  in an overall habitat.

Location	Species	Males	Females	F:M Ratio	Chi Square	p value
<b>Nassau</b>						
	Atlantic Sharpnose	60	21	1:2.86	18.778	<0.0001*
	Sandbar	35	21	1:1.67	3.5	0.061
	Blacktip	52	50	1:1.04	0.039	0.843
	Finetooth	9	5	1:1.8	1.143	0.285
	Blacknose	13	7	1:1.86	1.8	0.18
	Bonnethead	4	19	1:2.1	9.783	0.002*
<b>Cumberland</b>						
	Atlantic Sharpnose	226	53	1:4.27	107.272	<0.0001*
	Sandbar	106	113	1:0.94	0.224	0.636
	Blacktip	34	33	1:1.03	0.015	0.903
	Finetooth	36	17	1:2.12	6.811	0.009*
	Blacknose	14	0	NA	NA	NA
	Bonnethead	8	29	1:0.28	11.919	0.001*
	Scalloped	2	8	1:0.25	3.6	0.058
<b>Inshore Combined</b>						
	Atlantic Sharpnose	284	73	1:3.9	124.709	<0.0001*
	Sandbar	139	130	1:1.07	0.301	0.583
	Blacktip	87	83	1:1.05	0.094	0.759
	Finetooth	40	27	1:1.5	2.522	0.112
	Blacknose	25	6	1:4.2	11.645	0.001*
	Bonnethead	12	50	1:0.24	23.29	<0.0001*
	Scalloped	7	11	1:0.64	0.889	0.346
<b>Mayport</b>						
	Atlantic Sharpnose	182	8	1:22.75	159.347	<0.0001*
	Blacknose	54	26	1:2.08	9.8	0.002*
	Finetooth	4	8	1:0.5	1.333	0.0248*
	Blacktip	6	17	1:0.35	5.261	0.022*
<b>St. Marys</b>						
	Atlantic Sharpnose	160	9	1:17.78	134.917	<0.0001*
	Blacknose	45	94	1:0.48	17.273	<0.0001*
	Finetooth	10	14	1:0.71	0.667	0.414
	Blacktip	8	25	1:0.32	8.758	0.003*
	Spinner	6	5	1:1.2	0.091	0.763
	Sandbar	5	8	1:0.63	0.692	0.405
<b>Nearshore Combined</b>						
	Atlantic Sharpnose	341	19	1:17.9	288.011	<0.0001*
	Blacknose	99	116	1:0.85	1.344	0.246
	Finetooth	18	18	1:1	0	1
	Blacktip	13	28	1:0.46	5.488	0.019*
	Spinner	10	8	1:1.25	0.222	0.637
	Sandbar	5	9	1:0.56	1.143	0.285

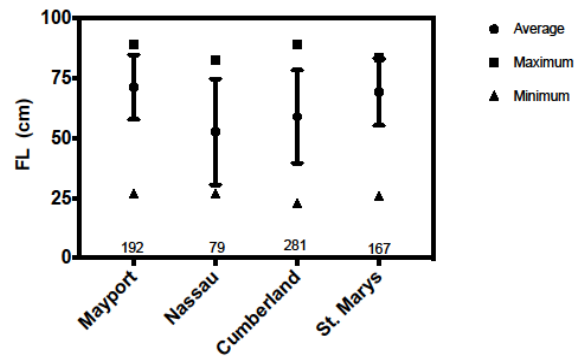
**Table 1-10.** Inshore environmental conditions of longline sets that caught each shark species, as well as no sharks, in the habitats of Cumberland and Nassau from 2012-2018. Means with  $\pm$  standard deviations are listed and (ranges) of conditions are in parenthesis. Species are listed in order of total nearshore abundance.

Species	Depth (m)	Temperature (°C)	Salinity (‰)	DO (mg/L)
<b>All Sharks</b>	7.6 $\pm$ 3.4	27.6 $\pm$ 2.3	30.2 $\pm$ 4.1	5.2 $\pm$ 0.9
	(0.7-19.0)	(14.3-31.9)	(10.5-36.3)	(2.8-7.9)
<b>Atlantic Sharpnose</b>	7.5 $\pm$ 3.3	27.2 $\pm$ 2.3	31.0 $\pm$ 3.6	5.5 $\pm$ 1.1
	(0.8-19.0)	(20.1-31.9)	(14.0-36.3)	(3.1-7.5)
<b>Sandbar</b>	8.8 $\pm$ 3.4	27.8 $\pm$ 2.2	29.1 $\pm$ 4.2	4.8 $\pm$ 0.9
	(1.7-18.0)	(20.7-31.4)	(14.0-36.3)	(3.1-7.5)
<b>Blacktip</b>	6.3 $\pm$ 2.9	28.2 $\pm$ 1.9	30.1 $\pm$ 3.7	4.8 $\pm$ 0.6
	(0.7-17.5)	(20.9-31.8)	(22.1-36.3)	(3.8-5.8)
<b>Finetooth</b>	7.4 $\pm$ 3.7	27.4 $\pm$ 2.6	30.7 $\pm$ 2.8	5.1 $\pm$ 0.9
	(1.4-17.5)	(21.1-31.8)	(24.2-36.3)	(3.1-7.0)
<b>Bonnethead</b>	6.8 $\pm$ 3.4	28.1 $\pm$ 1.6	29.3 $\pm$ 5.0	5.1 $\pm$ 0.7
	(0.8-17.5)	(24.5-31.4)	(14.0-36.3)	(3.2-6.2)
<b>Blacknose</b>	8.2 $\pm$ 3.4	27.7 $\pm$ 1.6	33.4 $\pm$ 2.2	5.8 $\pm$ 0.4
	(1.8-17.2)	(24.7-30.5)	(28.4-36.0)	(5.0-6.5)
<b>Smoothhound</b>	10.7 $\pm$ 2.8	19.1 $\pm$ 5.6	30.5 $\pm$ 2.5	7.0 $\pm$ 1.2
	(7.0-14.7)	(14.3-25.3)	(27.7-32.5)	(5.6-7.9)
<b>Scalloped</b>	8.2 $\pm$ 3.7	27.3 $\pm$ 2.8	28.4 $\pm$ 5.3	5.0 $\pm$ 0.7
	(2.2-18.0)	(20.9-31.9)	(15.5-33.8)	(4.0-6.4)
<b>Nurse</b>	8.3 $\pm$ 3.2	28.2 $\pm$ 1.5	30.7 $\pm$ 3.3	4.9 $\pm$ 0.9
	(1.7-14.7)	(25.3-29.8)	(26.4-35.2)	(3.3-6.3)
<b>Spinner</b>	9.7 $\pm$ 2.6	28.1 $\pm$ 1.6	31.7 $\pm$ 2.5	5.4 $\pm$ 0.6
	(6.6-14.0)	(26.1-29.8)	(29.5-35.6)	(4.8-6.2)
<b>Bull</b>	6.7 $\pm$ 1.8	28.3 $\pm$ 0.2	18.5 $\pm$ 7.0	4.3 $\pm$ 1.0
	(4.9-10.8)	(28.1-28.4)	(10.5-23.4)	(3.4-5.3)
<b>Lemon</b>	5.3 $\pm$ 3.7	27.9 $\pm$ 1.8	28.6 $\pm$ 10.0	3.8 $\pm$ 1.5
	(0.9-10.3)	(26.0-30.2)	(17.2-35.6)	(2.8-4.9)
<b>No sharks</b>	6.9 $\pm$ 2.5	26.7 $\pm$ 2.5	29.5 $\pm$ 6.0	5.4 $\pm$ 1.2
	(0.7-15.5)	(16.7-31.9)	(4.2-36.2)	(2.4-7.6)

**Table 1-11.** Nearshore environmental conditions of longline sets that caught each shark species, as well as no sharks, in the habitats of Mayport and St. Marys from 2014-2018. Means with  $\pm$  standard deviations are listed and (ranges) of conditions are in parenthesis. Species are listed in order of total inshore abundance.

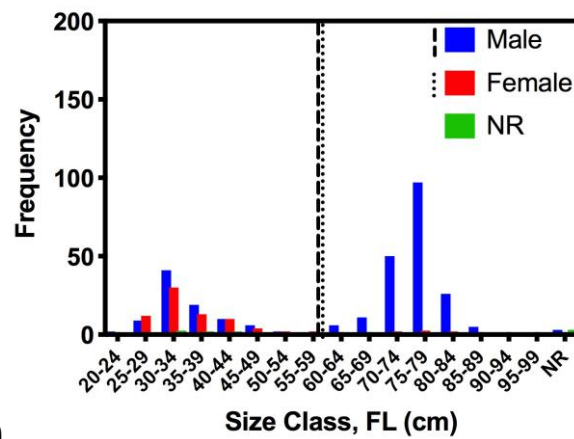
Species	Depth (m)	Temperature (°C)	Salinity (‰)	DO (mg/L)	Secchi (m)
<b>All sharks</b>	8.4 $\pm$ 2.0	26.6 $\pm$ 2.7	33.9 $\pm$ 1.9	6.2 $\pm$ 0.9	3.0 $\pm$ 1.4
	(2.7-13.0)	(15.1-31.0)	(26.3-36.7)	(2.9-9.4)	(1.1-7.5)
<b>Atlantic Sharpnose</b>	8.0 $\pm$ 1.9	26.2 $\pm$ 2.6	34.0 $\pm$ 1.6	6.3 $\pm$ 0.8	3.2 $\pm$ 1.3
	(2.7-12.0)	(17.8-30.3)	(30.2-36.6)	(3.1-7.8)	(1.1-6.4)
<b>Blacknose</b>	8.3 $\pm$ 2.1	26.7 $\pm$ 2.7	33.6 $\pm$ 2.1	6.3 $\pm$ 0.9	3.1 $\pm$ 1.5
	(2.7-13.0)	(17.8-31.0)	(26.3-36.7)	(3.6-9.4)	(1.1-7.5)
<b>Blacktip</b>	9.1 $\pm$ 1.8	27.4 $\pm$ 1.9	34.3 $\pm$ 2.0	6.2 $\pm$ 1.0	2.8 $\pm$ 1.2
	(5.7-12.0)	(23.2-31.0)	(27.8-36.6)	(4.2-8.0)	(2.0-6.4)
<b>Finetooth</b>	8.4 $\pm$ 1.7	27.4 $\pm$ 2.1	34.6 $\pm$ 1.8	5.9 $\pm$ 1.1	3.1 $\pm$ 2.0
	(5.0-12.0)	(20.6-30.4)	(30.4-36.7)	(3.6-8.0)	(1.7-7.5)
<b>Spinner</b>	7.8 $\pm$ 1.4	26.8 $\pm$ 1.6	34.3 $\pm$ 1.4	6.8 $\pm$ 0.7	2.7 $\pm$ 1.0
	(5.7-10.2)	(25.1-29.1)	(32.2-36.5)	(5.9-7.8)	(1.4-4.0)
<b>Sandbar</b>	9.1 $\pm$ 2.0	23.1 $\pm$ 5.2	32.7 $\pm$ 1.6	6.1 $\pm$ 1.3	1.9 $\pm$ 0.8
	(6.2-12.8)	(15.1-29.6)	(30.4-34.7)	(4.7-7.8)	(1.1-2.9)
<b>Scalloped</b>	9.0 $\pm$ 2.5	26.8 $\pm$ 1.4	34.0 $\pm$ 1.4	6.4 $\pm$ 0.7	2.4 $\pm$ 0.4
	(6-12.8)	(25.6-28.8)	(33.1-36.0)	(5.8-7.4)	(2.1-2.9)
<b>Bonnethead</b>	8.5 $\pm$ 2.0	26.7 $\pm$ 2.7	34.3 $\pm$ 2.8	5.8 $\pm$ 0.2	
	(4.8-10.5)	(23.1-28.7)	(30.3-36.5)	(5.7-5.9)	
<b>Nurse</b>	7	26.3	35.7	6.7	-
<b>Bull</b>	8.4	29.8	36.6	-	-
<b>No sharks</b>	8.4 $\pm$ 1.9	20.2 $\pm$ 5.4	31.0 $\pm$ 2.1	7.1 $\pm$ 1.0	2.3 $\pm$ 0.5
	(5.7-12.2)	(12.8-28.7)	(25.8-33.3)	(5.8-8.8)	(1.8-3.0)

Atlantic Sharpnose shark, *Rhizoprionodon terraenovae*



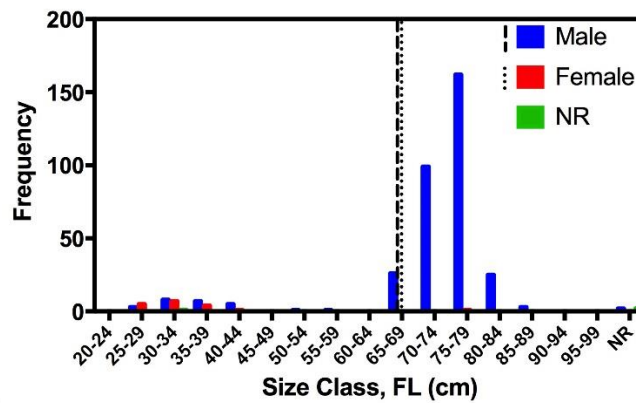
a)

Inshore Atlantic Sharpnose



b)

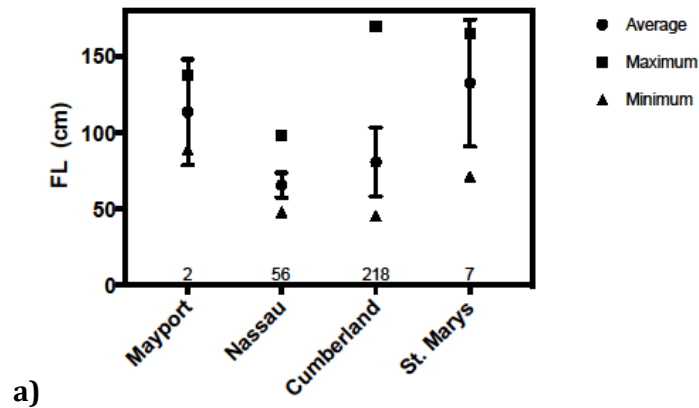
Nearshore Atlantic Sharpnose



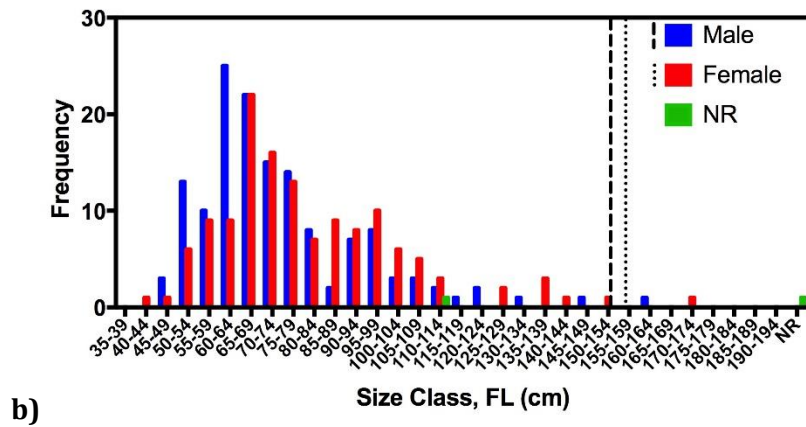
c)

**Figure 1-3a-c.** Mean fork length (error bars=standard deviation) of Atlantic Sharpnose sharks caught in each location from south to north. b) Length-frequency plot for male and female Atlantic Sharpnose sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female Atlantic Sharpnose sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

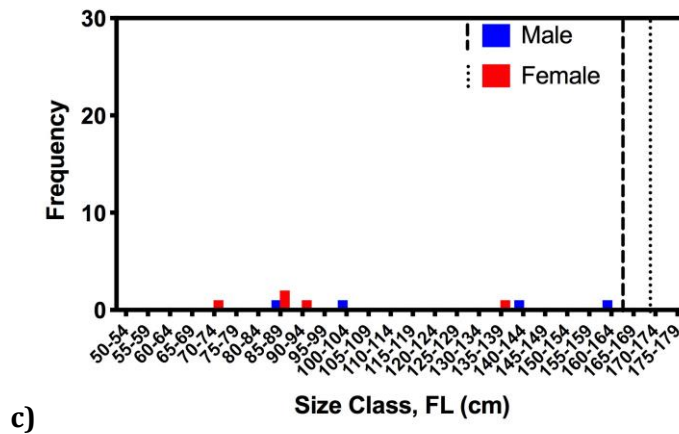
### Sandbar shark, *Carcharhinus plumbeus*



### Inshore Sandbar



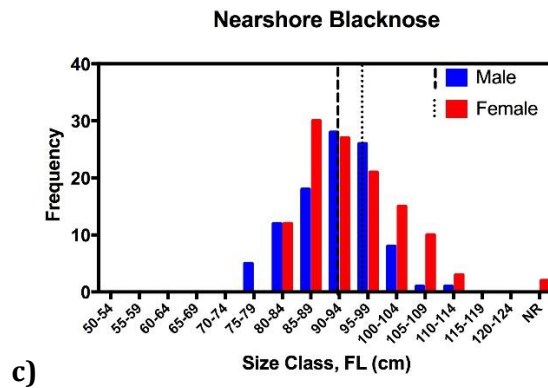
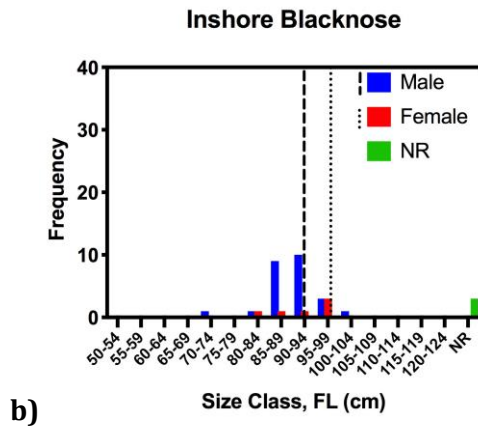
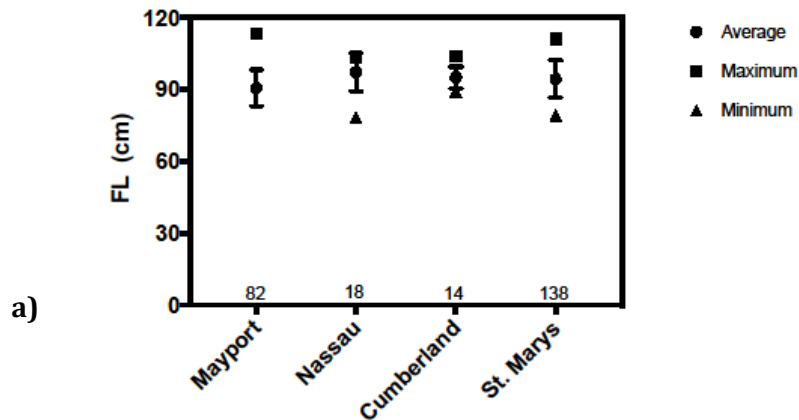
### Nearshore Sandbar



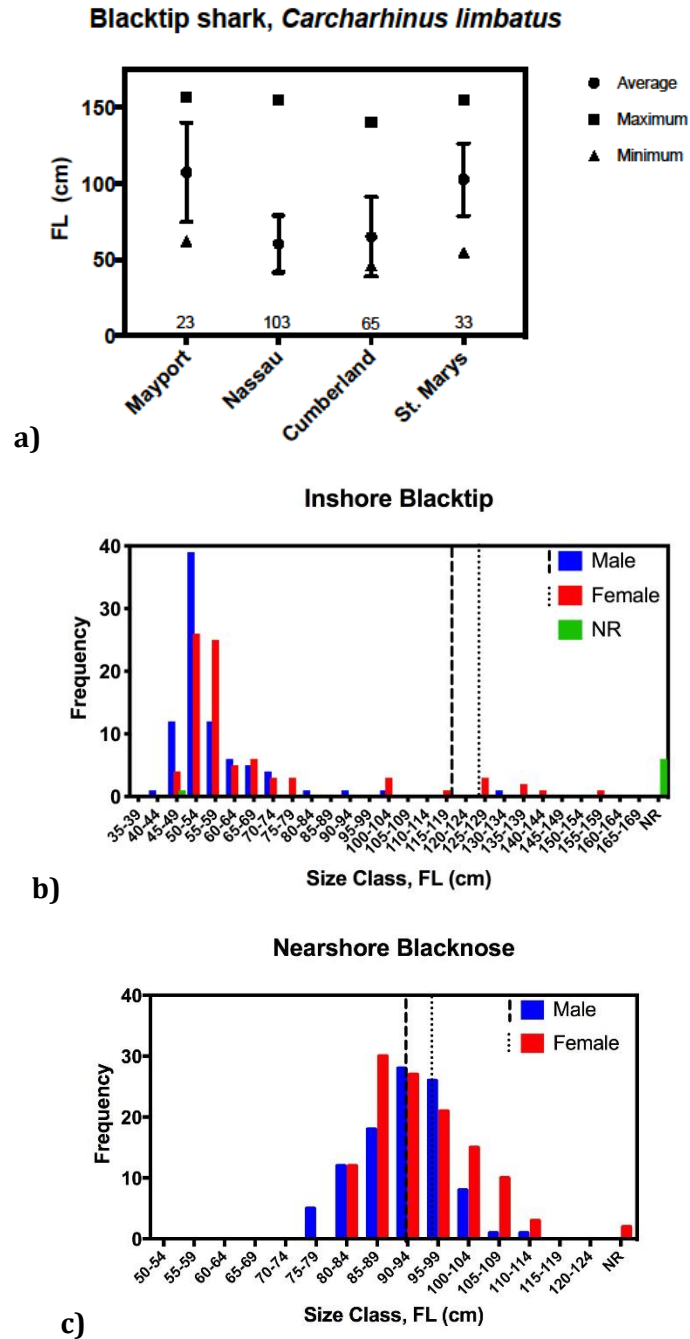
**Figure 1-4a-c.** Mean fork length (error bars=standard deviation) of sandbar sharks caught in each location from south to north. b) Length-frequency plot for male and female sandbar sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female sandbar sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.



### Blacknose shark, *Carcharhinus acronotus*

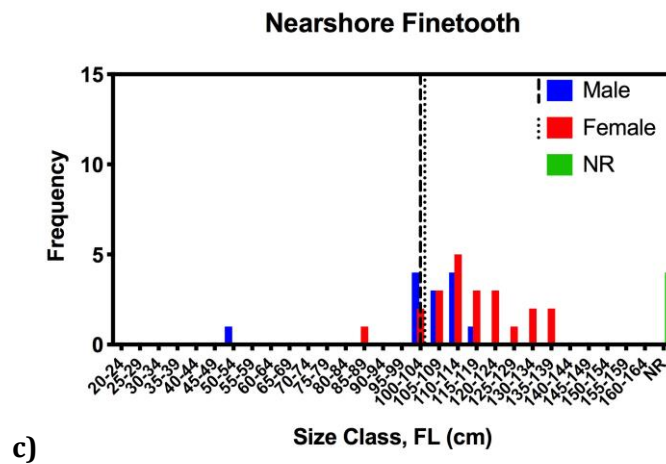
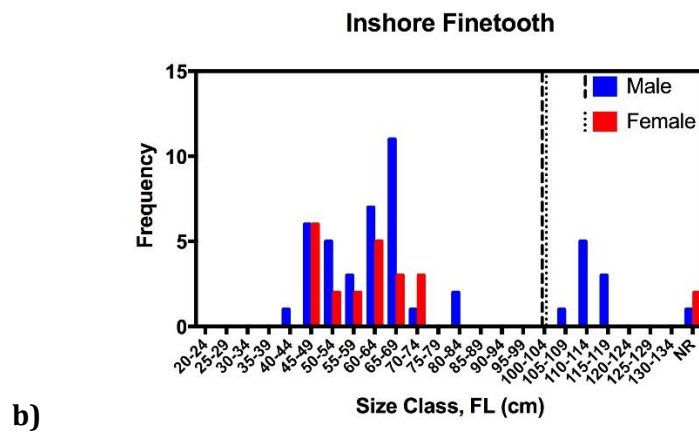
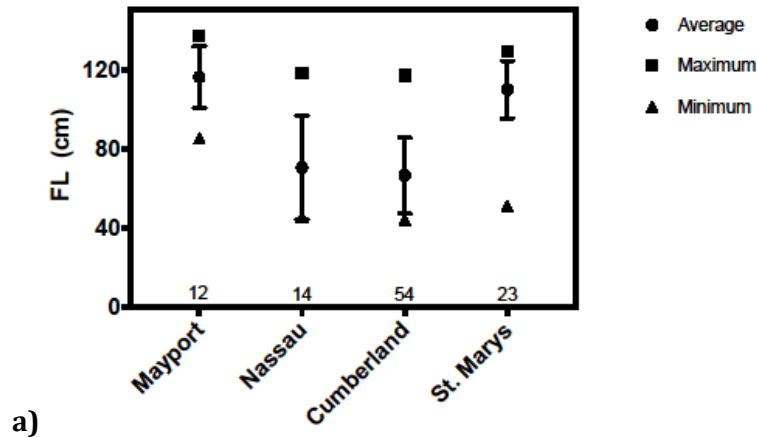


**Figure 1-5a-c.** Mean fork length (error bars=standard deviation) of blacknose sharks caught in each location from south to north. b) Length-frequency plot for male and female blacknose sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female blacknose sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

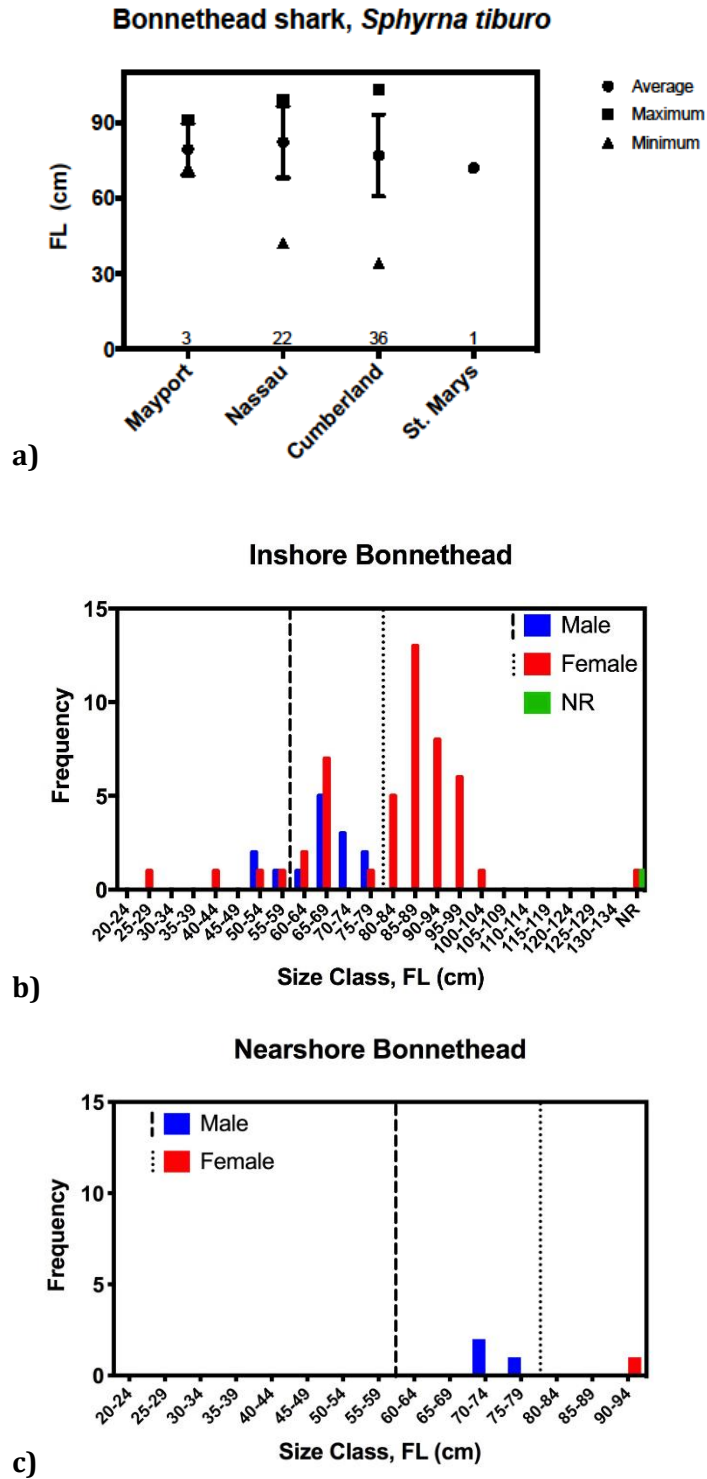


**Figure 1-6a-c.** Mean fork length (error bars=standard deviation) of blacktip sharks caught in each location from south to north. b) Length-frequency plot for male and female blacktip sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female blacktip sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

### Finetooth shark, *Carcharhinus isodon*

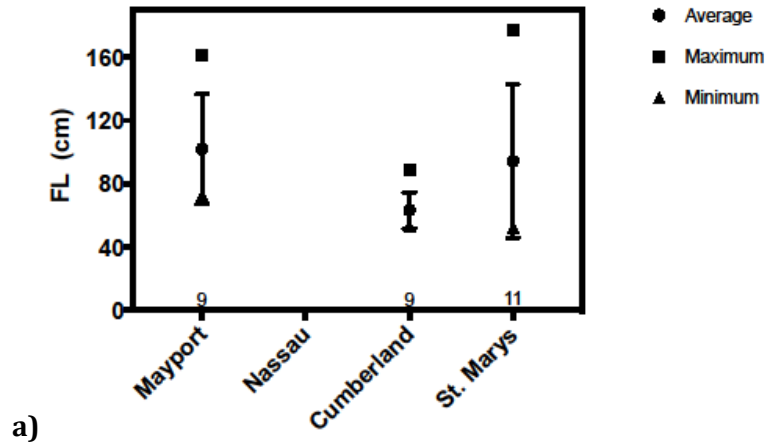


**Figure 1-7a-c.** Mean fork length (error bars=standard deviation) of finetooth sharks caught in each location from south to north. b) Length-frequency plot for male and female finetooth sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female finetooth sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

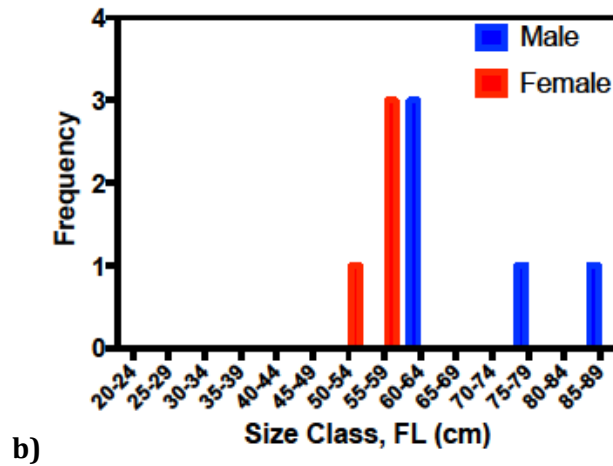


**Figure 1-8a-c.** Mean fork length (error bars=standard deviation) of bonnethead sharks caught in each location from south to north. b) Length-frequency plot for male and female bonnethead sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female bonnethead sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

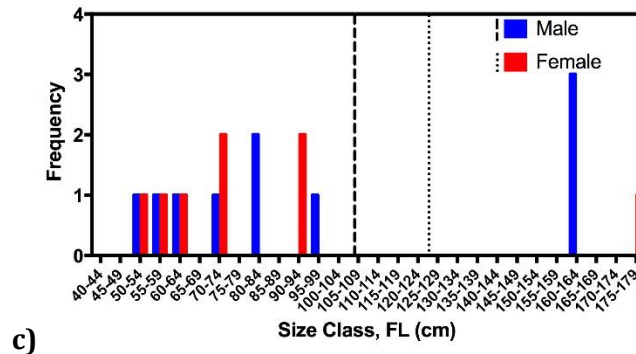
### Spinner shark, *Carcharhinus brevipinna*



### Inshore Spinner

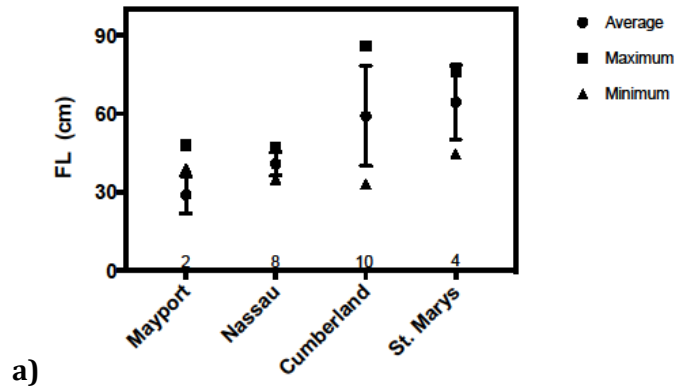


### Nearshore Spinner

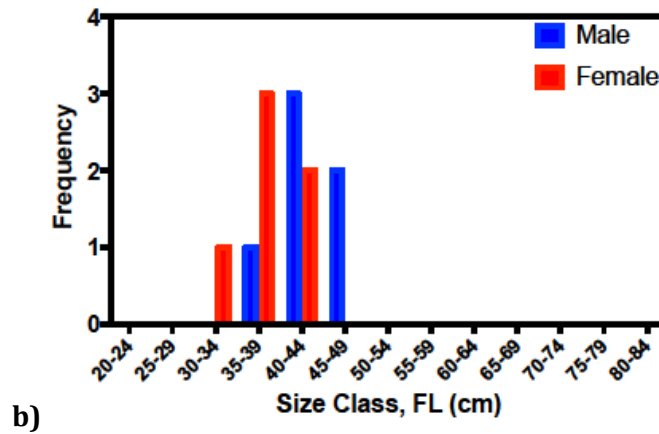


**Figure 1-9a-c.** Mean fork length (error bars=standard deviation) of spinner sharks caught in each location from south to north. b) Length-frequency plot for male and female spinner sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female spinner sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

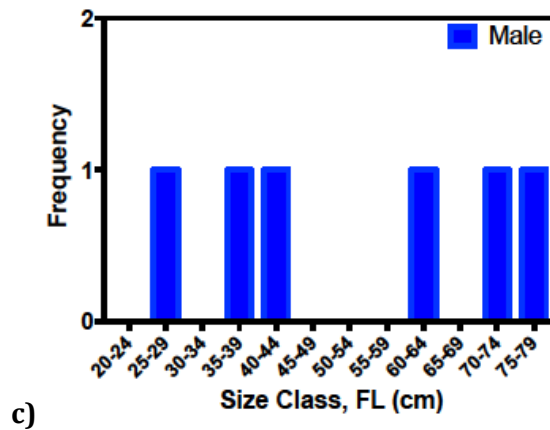
Scalloped hammerhead shark, *Sphyrna lewini*



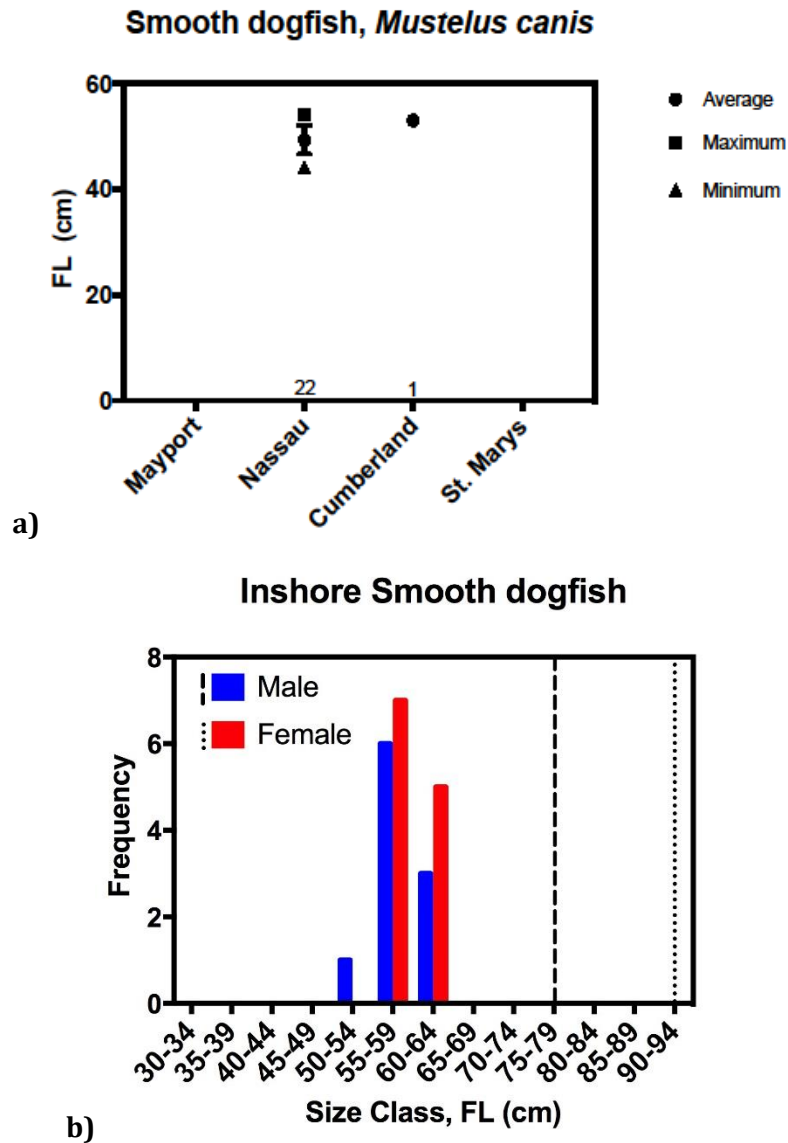
Inshore Scalloped hammerhead



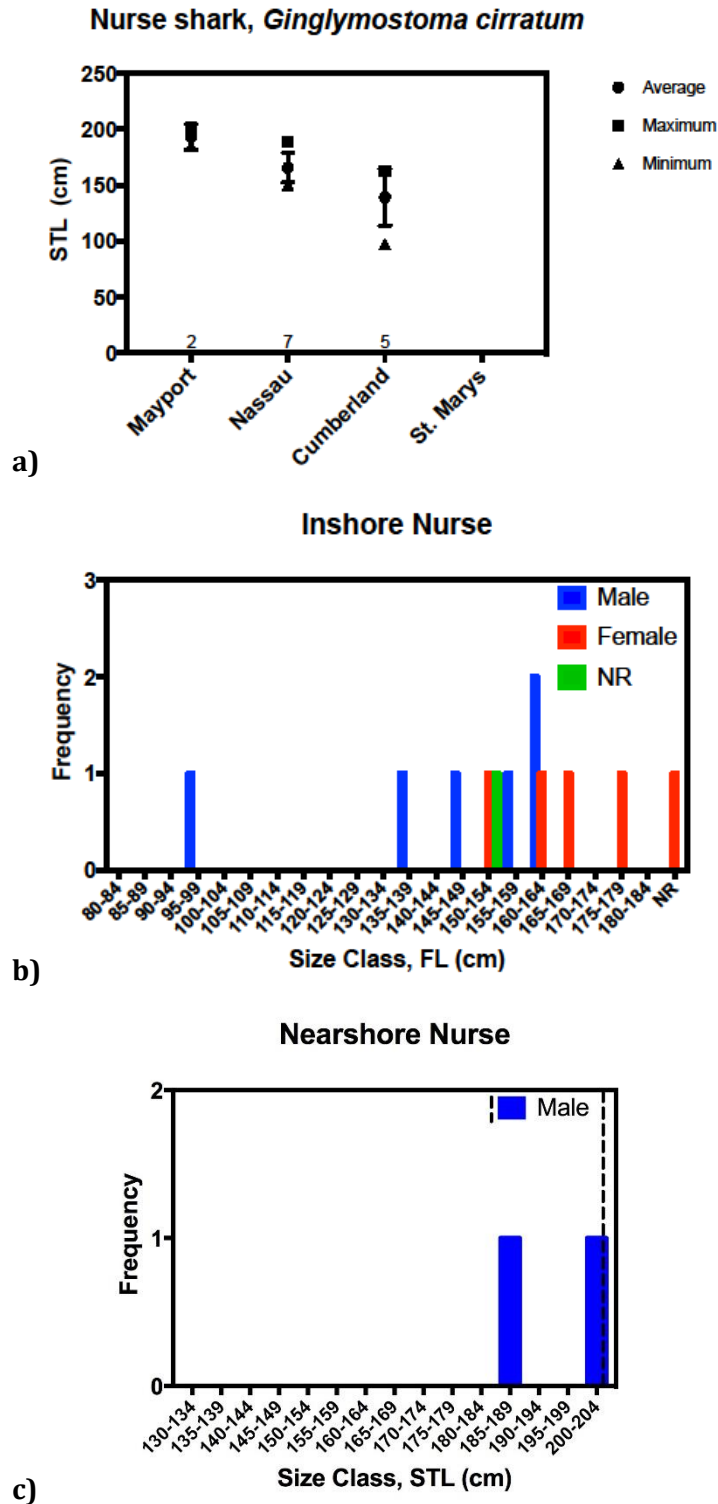
Nearshore Scalloped hammerhead



**Figure 1-10a-c.** Mean fork length (error bars=standard deviation) of scalloped hammerhead sharks caught in each location from south to north. b) Length-frequency plot for male and female scalloped hammerhead sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male scalloped hammerhead sharks caught from Mayport and St. Marys combined from 2014-2018.

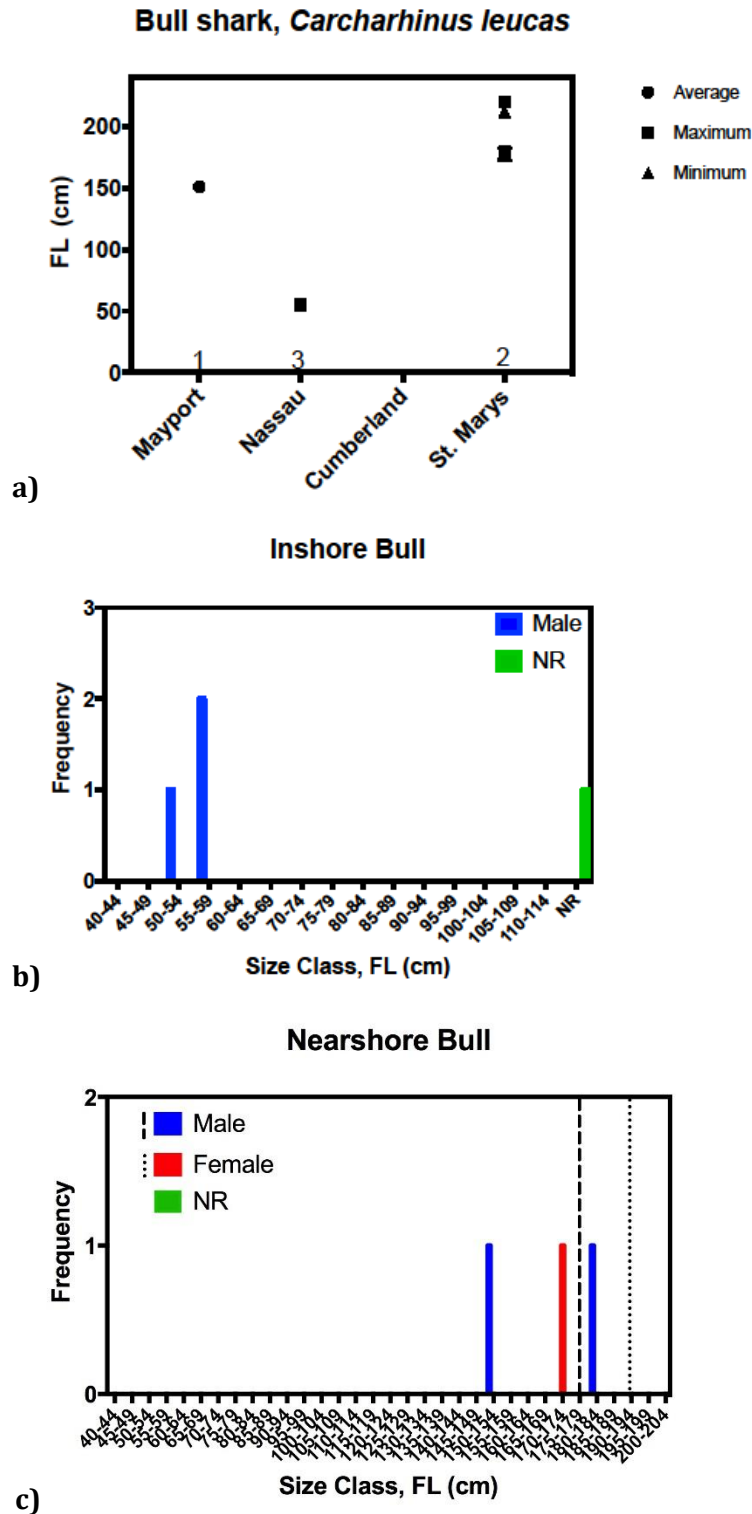


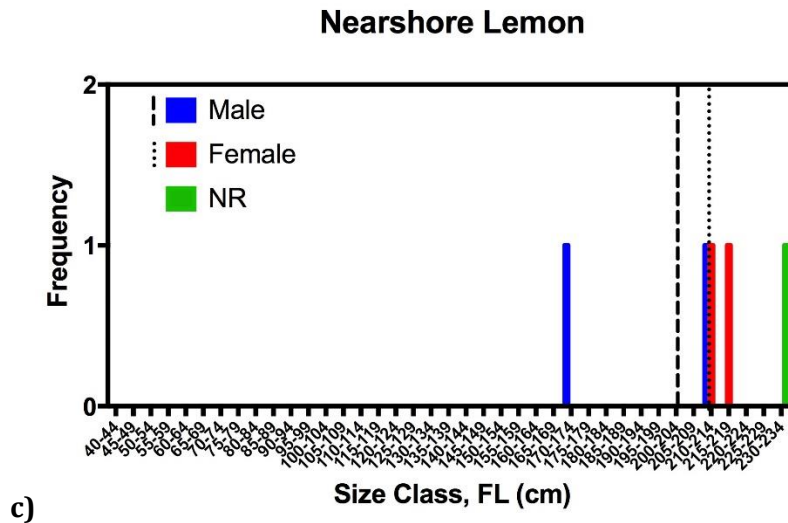
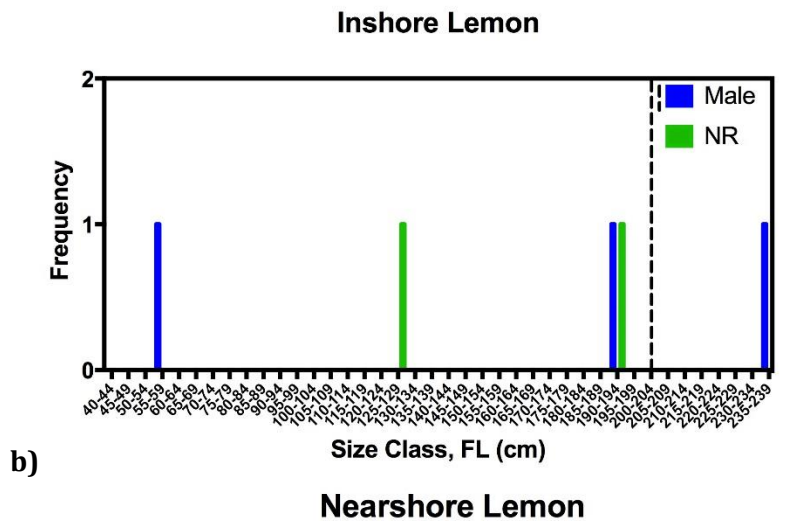
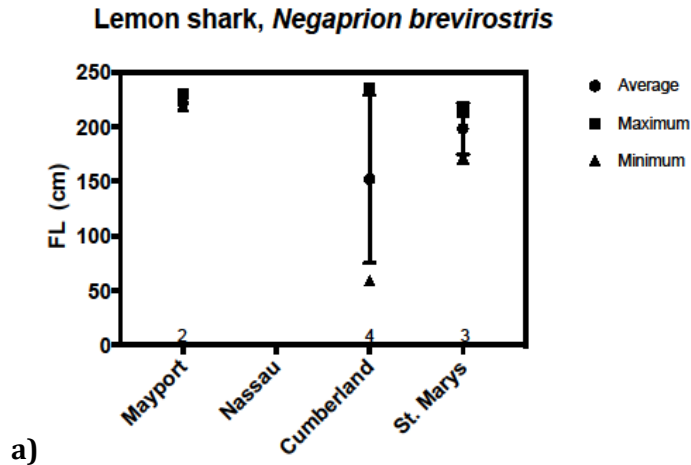
**Figure 1-11a-b.** Mean fork length (error bars=standard deviation) of smooth dogfish sharks caught in each location from south to north. b) Length-frequency plot for male and female smooth dogfish sharks caught from Cumberland and Nassau combined from 2012-2018. Dashed and dotted lines indicate 50% maturity.



**Figure 1-12a-c.** Mean stretched total length (error bars=standard deviation) of nurse sharks caught in each location from south to north. b) Length-frequency plot for male and female nurse sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male nurse sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed line indicate 50% maturity.

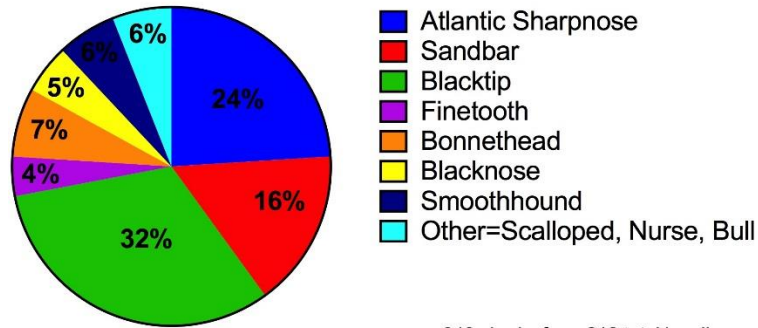






**Figure 1-14a-c.** Mean fork length (error bars=standard deviation) of lemon sharks caught in each location from south to north. b) Length-frequency plot for male lemon sharks caught from Cumberland and Nassau combined from 2012-2018. c) Length-frequency plot for male and female lemon sharks caught from Mayport and St. Marys combined from 2014-2018. Dashed and dotted lines indicate 50% maturity.

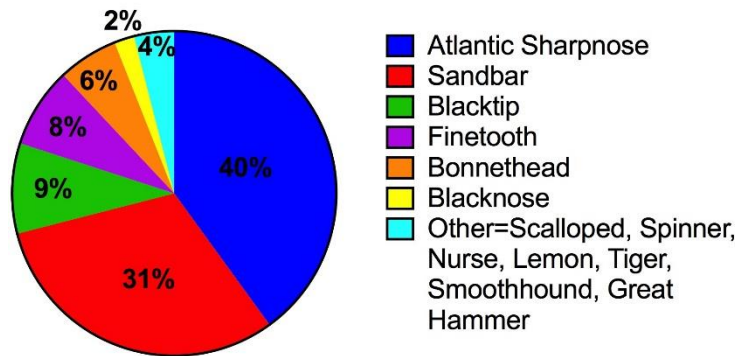
### Nassau Longline Species Composition



n=349 sharks from 212 total longlines

a)

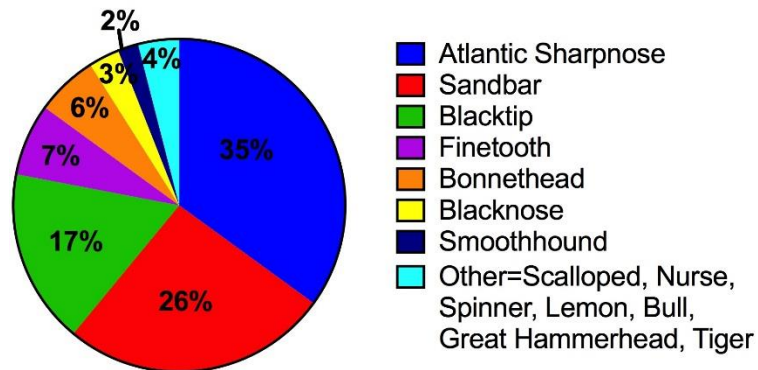
### Cumberland Longline Species Composition



n=706 sharks from 260 total longlines

b)

### Inshore Longline Total Species Composition

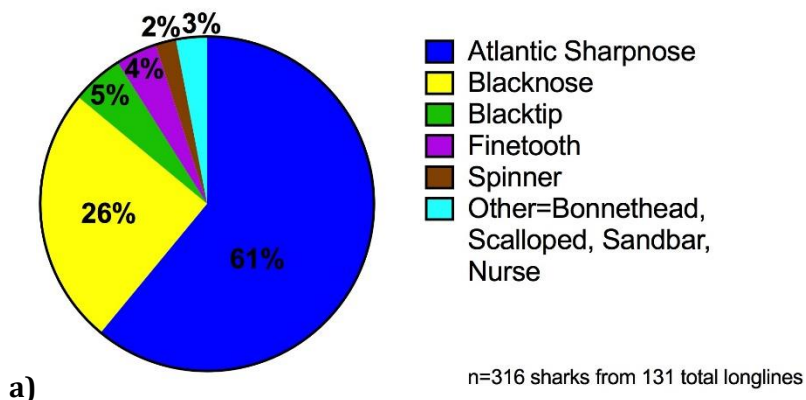


n=1055 from 472 total longlines

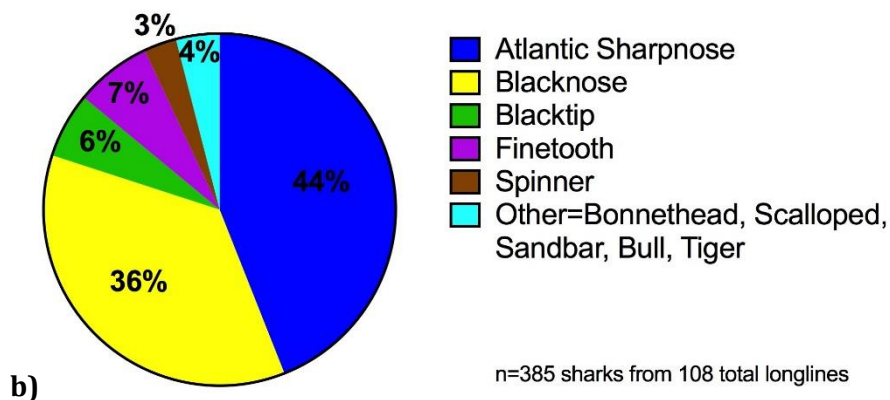
c)

**Figure 1-15a-c.** Proportional catch of all shark species captured by longline from 2012-2018 inshore habitats of a) Nassau. b) Cumberland. c) Nassau and Cumberland combined.

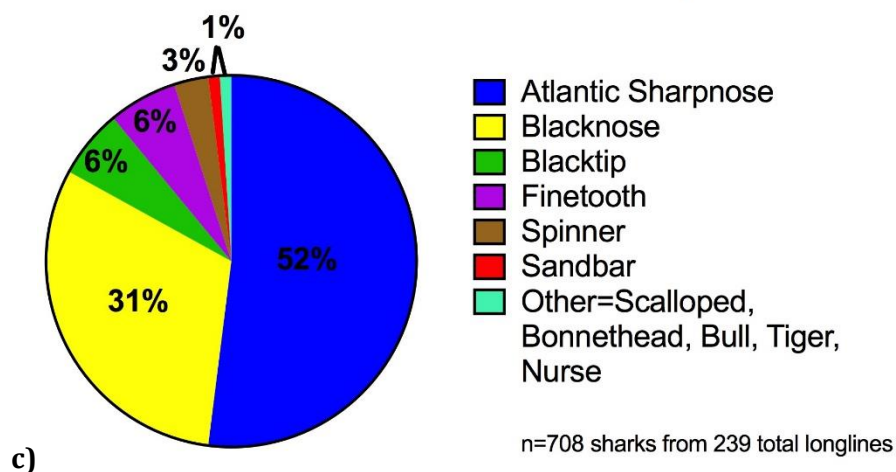
### Mayport Longline Species Composition



### St. Marys Longline Species Composition

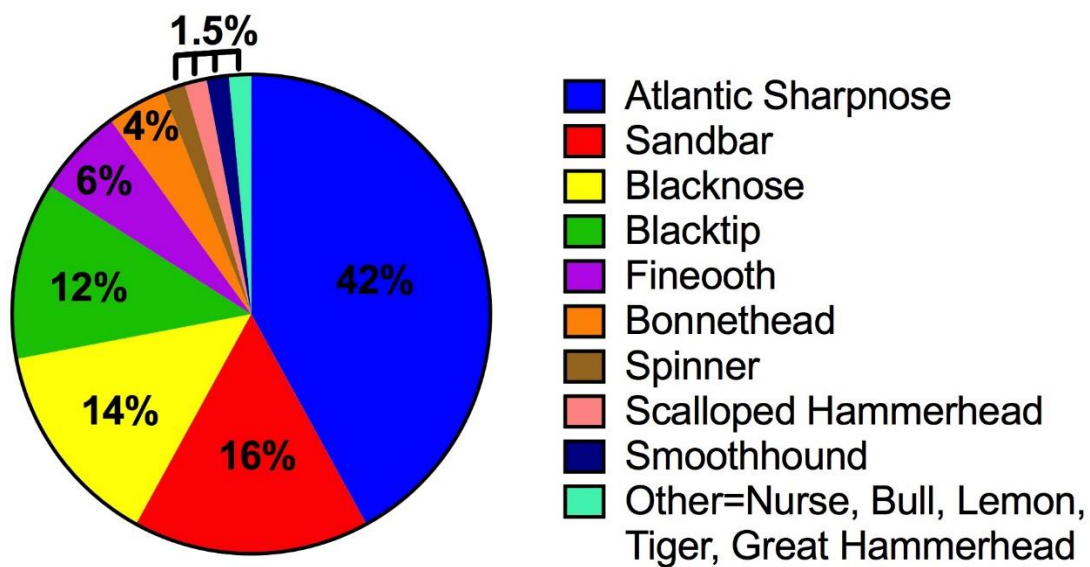


### Nearshore Longline Total Species Composition



**Figure 1-16a-c.** Proportional catch of all shark species captured by longline from 2014-2018 nearshore habitats of a) Mayport. b) St. Marys. c) Mayport and St. Marys combined.

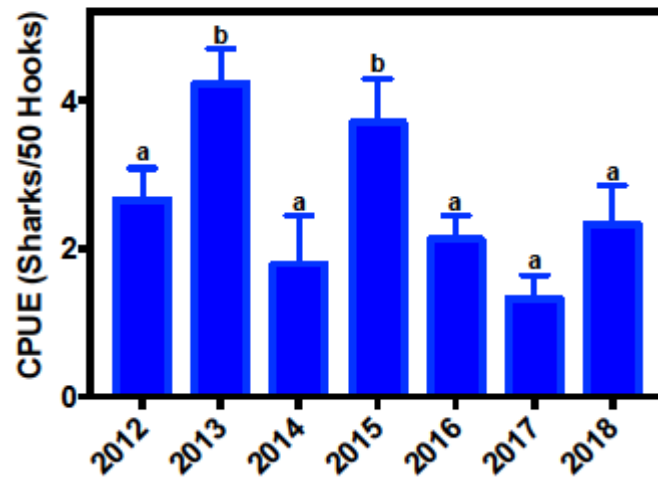
## First Coast Longline Total Species Composition



n=1763 sharks from 711 total longlines

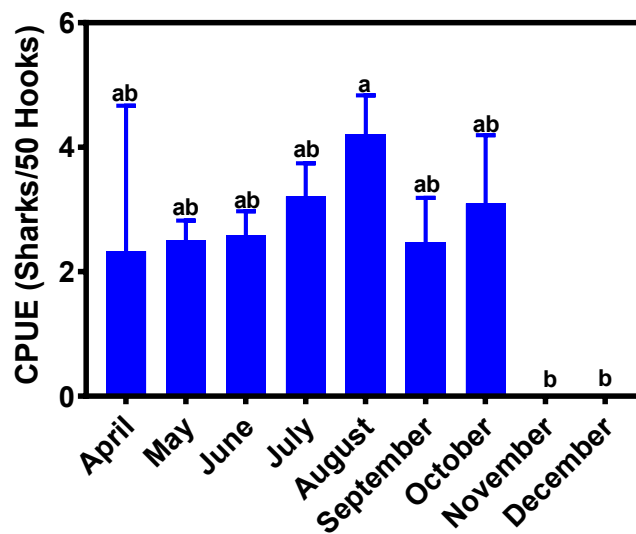
**Figure 1-17.** Proportional catch of all sharks species captured by longline from 2012-2018 from all inshore and nearshore habitats combined.

### Cumberland Annual



a)  $H=33.481$ ,  $p<0.0001$ .

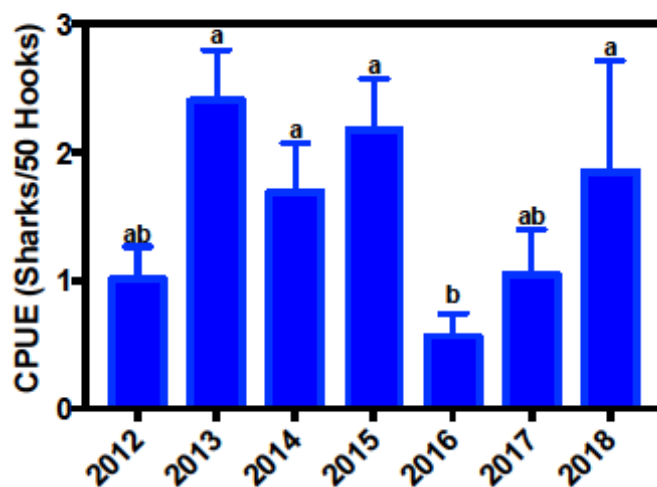
### Cumberland Seasonal



b)  $H=19.856$ ,  $p=0.011$ .

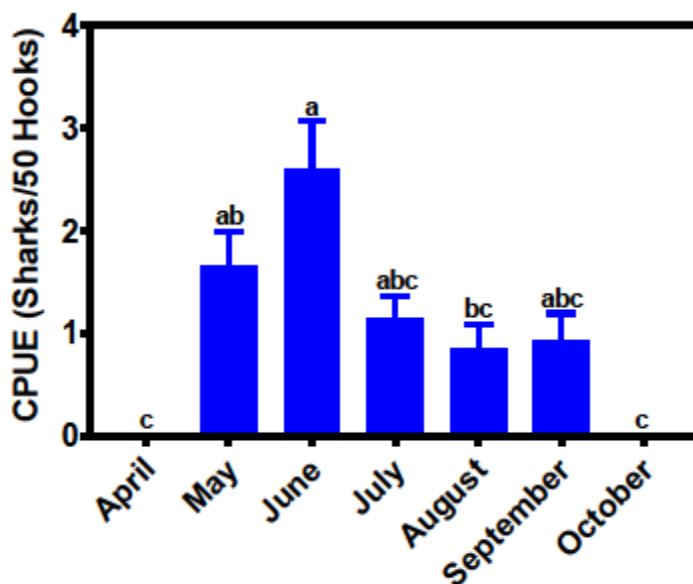
**Figure 1-18a-b.** Mean catch per unit effort (CPUE) of all sharks from 2012-2018 a) by year and b) by month for Cumberland. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test. If the seasonal graph is missing a letter representing a homogenous subset, no sampling was conducted.

### Nassau Annual



a)  $H=17.158, p=0.009$ .

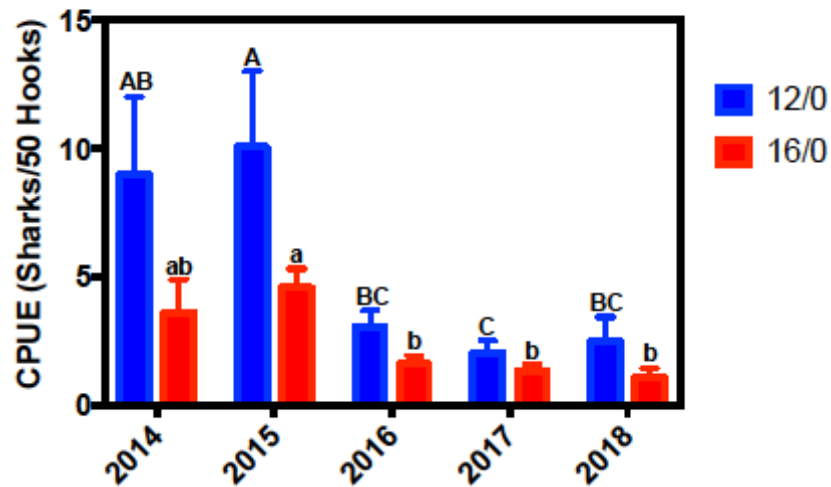
### Nassau Seasonal



b)  $H=18.108, p=0.006$ .

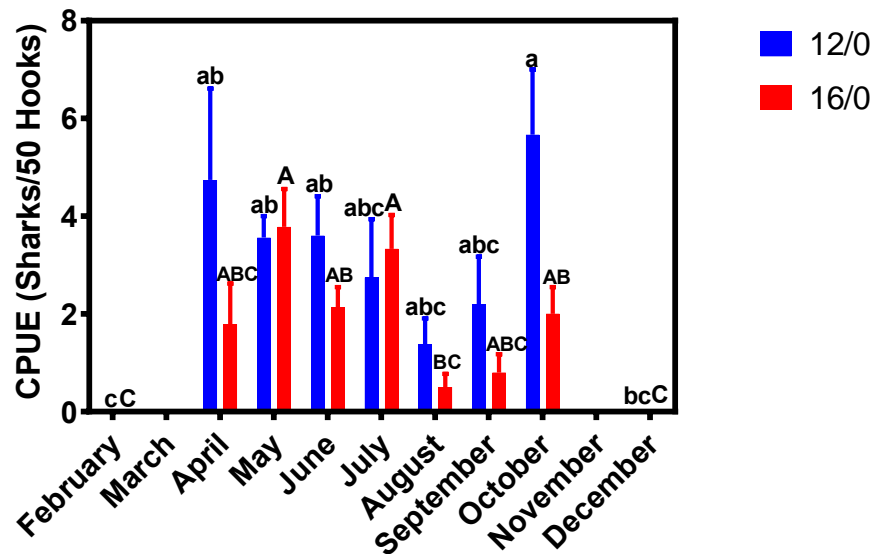
**Figure 1-19a-b.** Mean catch per unit effort (CPUE) of all sharks from 2012-2018 a) by year and b) by month for Nassau. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test. If the seasonal graph is missing a letter representing a homogenous subset, no sampling was conducted.

### Mayport Annual



a) 12/0:  $H=13.523$ ,  $p=0.009$ . 16/0:  $H=19.170$ ,  $p=0.001$ .

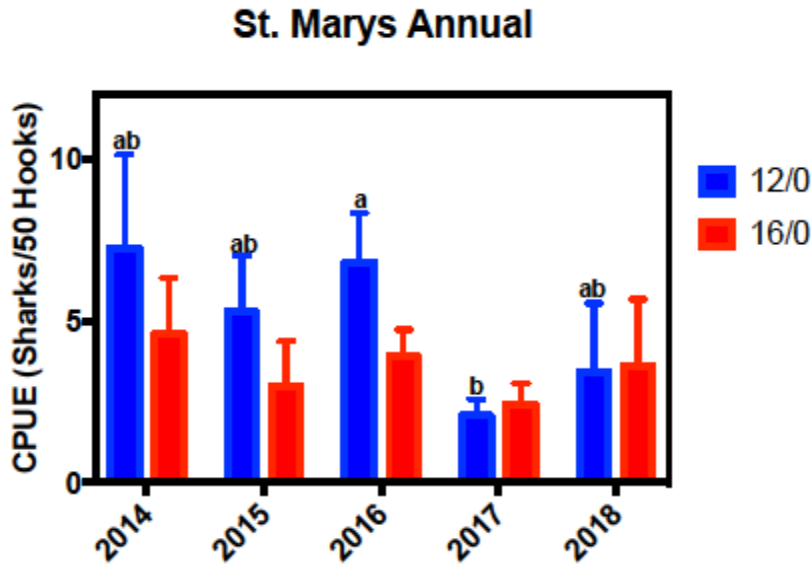
### Mayport Seasonal



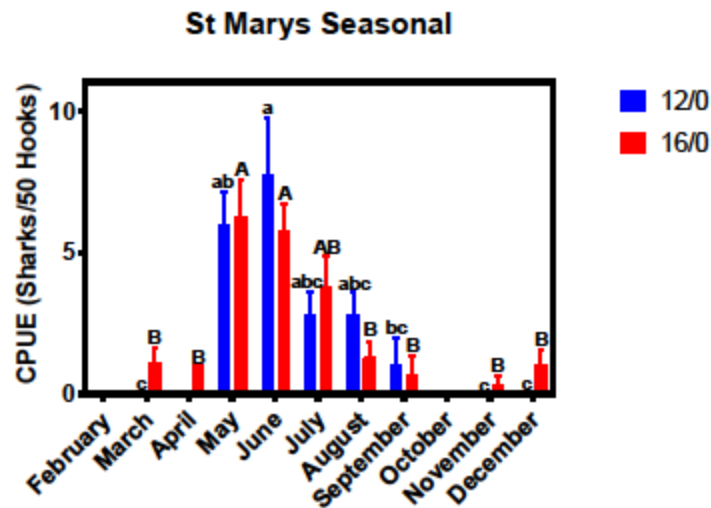
b) 12/0:  $H=18.895$ ,  $p=0.015$ . 16/0:  $H=25.575$ ,  $p=0.001$ .

**Figure 1-20a-b.** Mean catch per unit effort (CPUE) of all sharks from both hook sizes from 2014-2018 a) by year and b) by month for Mayport. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test. If the seasonal graph is missing a letter representing a homogenous subset, no sampling was conducted.





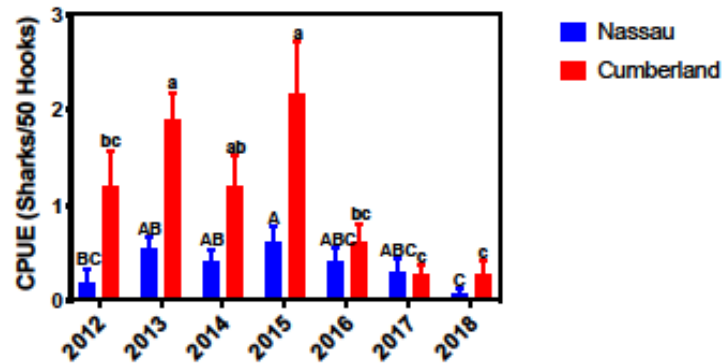
a) 12/0:  $H=12.118$ ,  $p=0.016$ . 16/0:  $H=5.137$ ,  $p=0.274$ .



b) 12/0:  $H=24.819$ ,  $p=0.001$ . 16/0:  $H=25.475$ ,  $p=0.001$ .

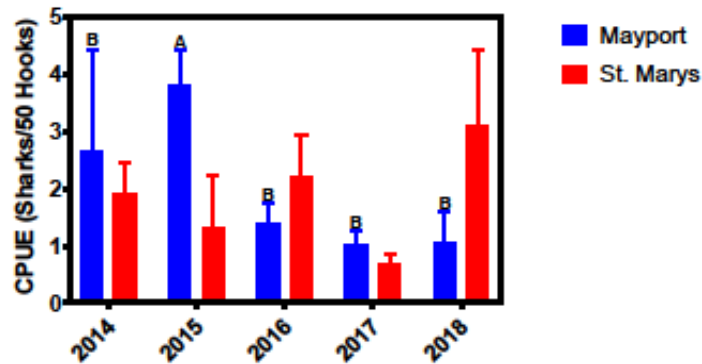
**Figure 1-21a-b.** Mean catch per unit effort (CPUE) of all sharks from both hook sizes from 2014-2018 a) by year and b) by month for St. Marys. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test. If the seasonal graph is missing a letter representing a homogenous subset, no sampling was conducted.

### Atlantic Sharpnose Inshore Relative Abundance



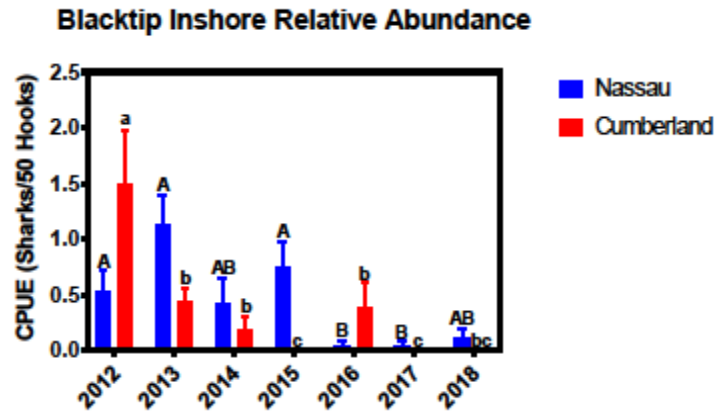
a) Nassau:  $H=16.882$ ,  $p=0.010$ . Cumberland:  $H=52.915$ ,  $p<0.0001$ .

### Atlantic Sharpnose Nearshore Relative Abundance

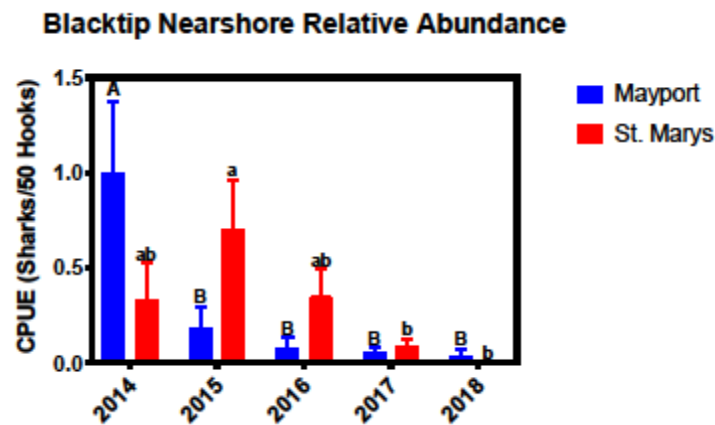


b) Mayport:  $H=26.548$ ,  $p<0.0001$ . St. Marys:  $H=7.959$ ,  $p=0.093$ .

**Figure 1-22a-b.** Mean catch per unit effort (CPUE) of Atlantic Sharpnose sharks by year for a) inshore habitats and b) nearshore habitats. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test.



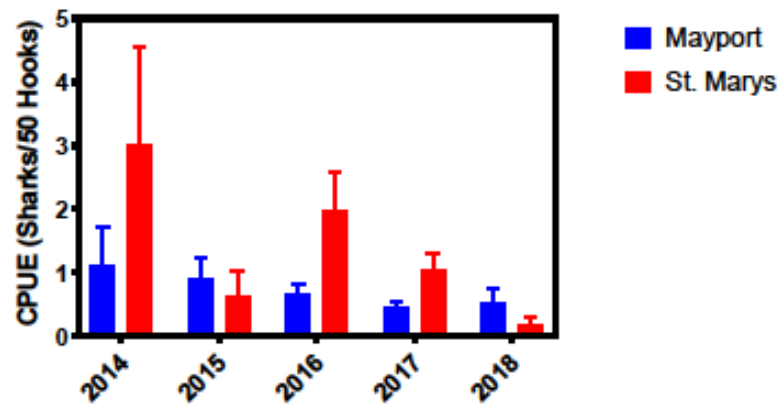
a) Nassau:  $H=20.206$ ,  $p=0.003$ , Cumberland:  $H=47.656$ ,  $p<0.0001$ .



b) Mayport:  $H=24.413$ ,  $p<0.0001$ . St. Marys:  $H=13.155$ ,  $p=0.011$ .

**Figures 1-23a-b.** Mean catch per unit effort (CPUE) of blacktip sharks by year for a) inshore habitats and b) nearshore habitats. Error bars represent standard error of the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test.

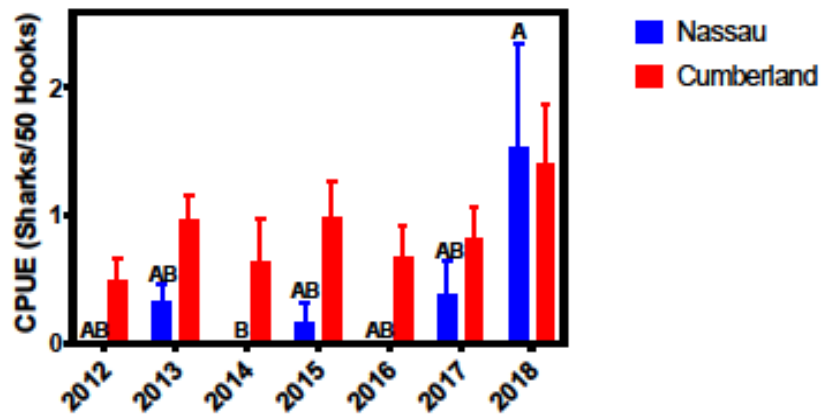
### Blacknose Nearshore Relative Abundance



Mayport:  $H=4.682$ ,  $p=0.321$ . St. Marys:  $H=7.955$ ,  $p=0.093$ .

**Figure 1-24.** Mean catch per unit effort (CPUE) of blacknose sharks by year for nearshore habitats. Error bars represent the standard error the mean.

### Sandbar Inshore Relative Abundance



Nassau:  $H=12.813$ ,  $p=0.046$ . Cumberland:  $H=8.631$ ,  $p=0.195$ .

**Figure 1-25.** Mean catch per unit effort (CPUE) of sandbar sharks by year for inshore habitats. Error bars represent the standard error the mean. Letters represent significant homogenous subsets as determined by Tukey's post hoc test following Kruskal-Wallis H test.

**Table 1-12.**ANOSIM 2x2 Location Season Pairwise Test Results

Location Groups		R Statistic	Significance Level %	Possible Permutations	Actual Permutations	# ≥ Observed
Mayport	St. Marys	0.016	12.4	very large	999	123
Mayport	Cumberland	0.257	0.1	very large	999	0
Mayport	Nassau	0.245	0.1	very large	999	0
St. Marys	Cumberland	0.237	0.1	very large	999	0
St. Marys	Nassau	0.193	0.1	very large	999	0
Cumberland	Nassau	0.131	0.1	very large	999	0
Sample Statistic	(Average R)	0.18	0.1			
Season Groups						
Summer	Fall	0.027	26.1	very large	999	260
Summer	Spring	0.057	1	very large	999	9
Summer	Winter	0.082	30.7	22100	999	306
Fall	Spring	0.223	0.4	very large	999	3
Fall	Winter	0	70	10	10	7
Spring	Winter	0.234	6.8	2925	999	67
Sample Statistic	(Average R)	0.052	1.2			

**Table 1-13a.** SIMPER 2x2 Location Species Contributions Results

<i>Group Mayport</i>		<i>Average similarity: 35.12</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.56	18.83	0.64	53.62	53.62
RterAdult	0.69	13.7	0.51	39.01	92.63
<i>Group St. Marys</i>		<i>Average similarity: 30.51</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.75	15.97	0.7	52.32	52.32
RterAdult	0.6	9.41	0.48	30.84	83.16
<i>Group Cumberland</i>		<i>Average similarity: 23.51</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CpluJuv	0.61	15.1	0.54	64.25	64.25
RterAdult	0.4	5.34	0.3	22.73	86.98
<i>Group Nassau</i>		<i>Average similarity: 21.79</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.39	10.63	0.41	48.79	48.79
RterYOY	0.2	3.43	0.24	15.76	64.55
ClimYOY	0.22	3.24	0.24	14.89	79.44

**Table 1-13b.** SIMPER 2x2 Season Species Contributions Results

<i>Group Summer</i>		<i>Average similarity: 26.84</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.43	10.72	0.47	39.93	39.93
RterAdult	0.4	6.09	0.34	22.7	62.63
CpluJuv	0.23	5.48	0.3	20.43	83.06
<i>Group Fall</i>		<i>Average similarity: 30.84</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.5	14.74	0.62	47.78	47.78
CacrAdult	0.47	10.94	0.51	35.49	83.27
<i>Group Spring</i>		<i>Average similarity: 39.67</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.89	30.93	0.88	77.98	77.98
<i>Group Winter</i>		<i>Average similarity: 30.45</i>			
<b><u>Species</u></b>	<b><u>Av.Abund</u></b>	<b><u>Av.Sim</u></b>	<b><u>Sim/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.73	30.45	0.58	100	100

**Table 1-14.** SIMPER 2x2 Locations Species Contributions Results

<i>Groups Mayport &amp; St. Marys</i>			<i>Average dissimilarity = 67.75</i>			
<b>Species</b>	<b>Mayport <u>Av.Abund</u></b>	<b>St. Marys <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.69	0.6	16.94	0.96	25.01	25.01
CacrAdult	0.56	0.75	16.75	1.03	24.72	49.72
RterYOY	0.17	0.2	9.03	0.67	13.32	63.04
CisoAdult	0.08	0.17	5.47	0.51	8.07	71.11
<i>Groups Mayport &amp; Cumberland</i>			<i>Average dissimilarity = 86.49</i>			
<b>Species</b>	<b>Mayport <u>Av.Abund</u></b>	<b>Cumberland <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.56	0.05	18.4	0.98	21.28	21.28
RterAdult	0.69	0.4	18.04	0.92	20.86	42.14
CpluJuv	0.01	0.61	17.97	0.9	20.78	62.92
RterYOY	0.17	0.17	9.66	0.62	11.17	74.09
<i>Groups St. Marys &amp; Cumberland</i>			<i>Average dissimilarity = 86.75</i>			
<b>Species</b>	<b>St. Marys <u>Av.Abund</u></b>	<b>Cumberland <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.75	0.05	18.26	1.1	21.05	21.05
CpluJuv	0.09	0.61	15.66	0.88	18.06	39.11
RterAdult	0.6	0.4	15.14	0.87	17.45	56.56
RterYOY	0.2	0.17	9.04	0.65	10.42	66.98
CisoAdult	0.17	0.05	4.87	0.46	5.62	72.6
<i>Groups Mayport &amp; Nassau</i>			<i>Average dissimilarity = 81.62</i>			
<b>Species</b>	<b>Mayport <u>Av.Abund</u></b>	<b>Nassau <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.56	0.12	17.11	0.97	20.96	20.96
RterAdult	0.69	0.39	16.52	0.92	20.24	41.2
RterYOY	0.17	0.2	10.56	0.66	12.93	54.13
ClimYOY	0	0.22	7.82	0.54	9.58	63.71
ClimJuv	0.11	0.17	7	0.54	8.57	72.28
<i>Groups St. Marys &amp; Nassau</i>			<i>Average dissimilarity = 81.96</i>			
<b>Species</b>	<b>St. Marys <u>Av.Abund</u></b>	<b>Nassau <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.75	0.12	17.49	1.09	21.34	21.34
RterAdult	0.6	0.39	13.99	0.87	17.07	38.41
RterYOY	0.2	0.2	9.32	0.66	11.37	49.78
ClimYOY	0	0.22	6.6	0.51	8.05	57.83
ClimJuv	0.11	0.17	6.29	0.55	7.68	65.5
CisoAdult	0.17	0.04	4.73	0.46	5.77	71.27
<i>Groups Cumberland &amp; Nassau</i>			<i>Average dissimilarity = 84.73</i>			
<b>Species</b>	<b>Cumberland <u>Av.Abund</u></b>	<b>Nassau <u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CpluJuv	0.61	0.2	18.56	0.94	21.9	21.9
RterAdult	0.4	0.39	12.47	0.76	14.72	36.62
RterYOY	0.17	0.2	10.65	0.64	12.57	49.19
ClimYOY	0.06	0.22	9.06	0.58	10.69	59.88
ClimJuv	0.05	0.17	6.21	0.51	7.33	67.21
CacrAdult	0.05	0.12	5.81	0.42	6.85	74.06



**Table 1-15.** SIMPER 2x2 Season Species Contributions Results

<i>Groups Summer &amp; Fall</i>			<i>Average dissimilarity = 70.77</i>			
<b>Species</b>	Summer <b><u>Av.Abund</u></b>	Fall <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.4	0.5	16.78	0.94	23.7	23.7
CacrAdult	0.43	0.47	14.71	0.88	20.78	44.48
ClimJuv	0.11	0.21	7.62	0.56	10.76	55.25
RterYOY	0.27	0.05	7.41	0.54	10.46	65.71
CpluJuv	0.23	0.28	6.33	0.45	8.95	74.66
<i>Groups Summer &amp; Spring</i>			<i>Average dissimilarity = 75.23</i>			
<b>Species</b>	Summer <b><u>Av.Abund</u></b>	Spring <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.4	0.89	22.02	1.13	29.27	29.27
CacrAdult	0.43	0.23	10.71	0.67	14.24	43.51
CpluJuv	0.23	0.24	9.4	0.57	12.49	56
RterYOY	0.27	0.02	7.49	0.54	9.95	65.96
ClimJuv	0.11	0.06	4.11	0.39	5.47	71.42
<i>Groups Fall &amp; Spring</i>			<i>Average dissimilarity = 69.47</i>			
<b>Species</b>	Fall <b><u>Av.Abund</u></b>	Spring <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.5	0.89	23.94	1.17	34.46	34.46
CacrAdult	0.47	0.23	12.17	0.79	17.53	51.99
CpluJuv	0.28	0.24	8.69	0.53	12.5	64.49
ClimJuv	0.21	0.06	7.36	0.52	10.59	75.08
<i>Groups Summer &amp; Winter</i>			<i>Average dissimilarity = 74.07</i>			
<b>Species</b>	Summer <b><u>Av.Abund</u></b>	Winter <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CacrAdult	0.43	0.73	19.78	1.05	26.71	26.71
RterAdult	0.4	0	13.66	0.72	18.44	45.15
CpluJuv	0.23	0.33	11.23	0.66	15.17	60.32
RterYOY	0.27	0	9.03	0.63	12.19	72.5
<i>Groups Fall &amp; Winter</i>			<i>Average dissimilarity = 34.69</i>			
<b>Species</b>	Fall <b><u>Av.Abund</u></b>	Winter <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
CpluJuv	0.28	0.33	20.94	1.29	60.37	60.37
CacrAdult	0.47	0.73	13.75	0.81	39.63	100
<i>Groups Spring &amp; Winter</i>			<i>Average dissimilarity = 75.61</i>			
<b>Species</b>	Spring <b><u>Av.Abund</u></b>	Winter <b><u>Av.Abund</u></b>	<b><u>Av.Diss</u></b>	<b><u>Diss/SD</u></b>	<b><u>Contrib%</u></b>	<b><u>Cum.%</u></b>
RterAdult	0.89	0	28.13	1.28	37.2	37.2
CacrAdult	0.23	0.73	19.63	1.02	25.96	63.16
CpluJuv	0.24	0.33	12.63	0.72	16.7	79.85

**Table 1-16.** BIO-ENV BEST test results.

# of Variables	Spearman Correlation ( $\rho$ )	Variables Selected
2	0.221	Salinity, Dissolved Oxygen
1	0.205	Dissolved Oxygen
3	0.190	Temperature, Salinity, Dissolved Oxygen
3	0.186	Depth, Salinity, Dissolved Oxygen
4	0.169	Depth, Temperature, Salinity, Dissolved Oxygen
1	0.168	Salinity
2	0.159	Temperature, Dissolved Oxygen
2	0.149	Temperature, Salinity
2	0.141	Depth, Dissolved Oxygen
2	0.133	Depth, Salinity

**Table 1-17.** Comparison of negative binomial GLM Presence/Absence models for environmental parameters for inshore, nearshore, and all locations.

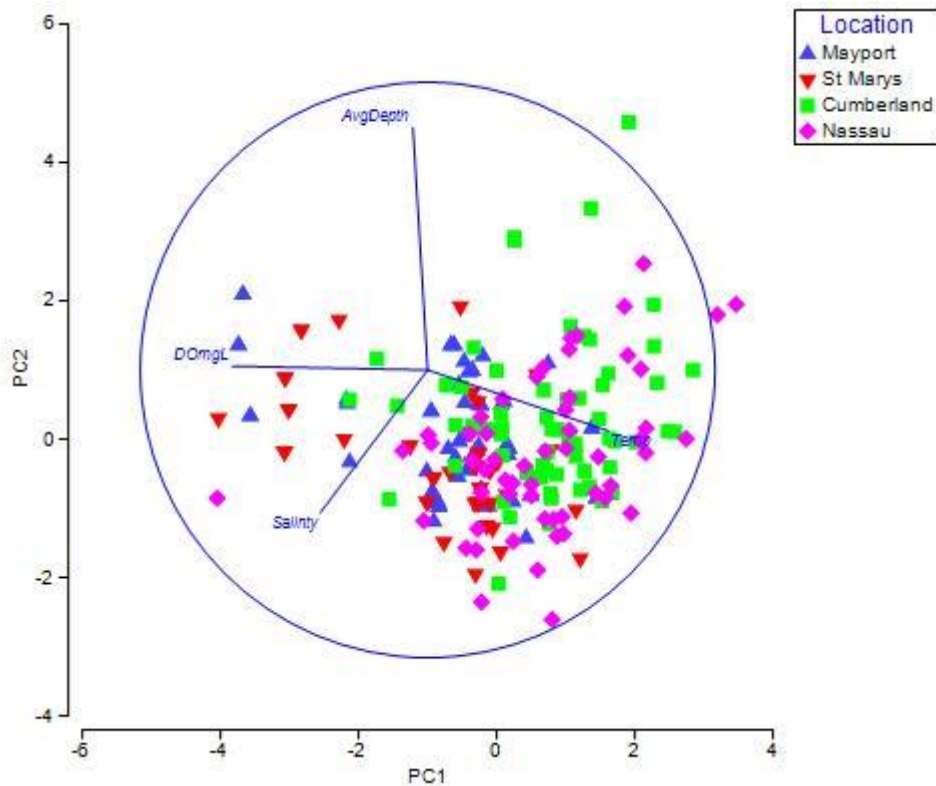
<b>Inshore</b>	<b>Coefficient Estimate</b>	<b>Std. Error</b>	<b>Z Value</b>	<b>Pr (&gt; z )</b>
<b>Intercept</b>	-2.4398	0.99754	-2.446	0.014453*
<b>Depth</b>	0.05793	0.02587	2.239	0.025141*
<b>Temperature</b>	0.09766	0.02864	3.41	0.000649***
<b>Salinity</b>	0.00544	0.01515	0.359	0.719495
<b>DO</b>	-0.01457	0.03924	-0.371	0.710415
<b>AIC</b>	1296.3		<b>df=334</b>	
<b>Theta</b>	0.863			
<b>Std. Error</b>	0.111			
<b>2xlog-likelihood</b>	-1284.271			

<b>Nearshore</b>	<b>Coefficient Estimate</b>	<b>Std. Error</b>	<b>Z Value</b>	<b>Pr (&gt; z )</b>
<b>Intercept</b>	-10.006955	3.06593	-5.677	0.000000333***
<b>Depth</b>	0.009792	0.06348	0.215	0.82949
<b>Temperature</b>	0.076997	0.04811	2.965	.00303**
<b>Salinity</b>	0.27157	0.08091	5.118	.0000000309***
<b>DO</b>	-0.009746	0.19016	-0.553	0.58010
<b>AIC</b>	693.34		<b>df=174</b>	
<b>Theta</b>	1.175			
<b>Std. Error</b>	0.222			
<b>2xlog-likelihood</b>	-681.344			

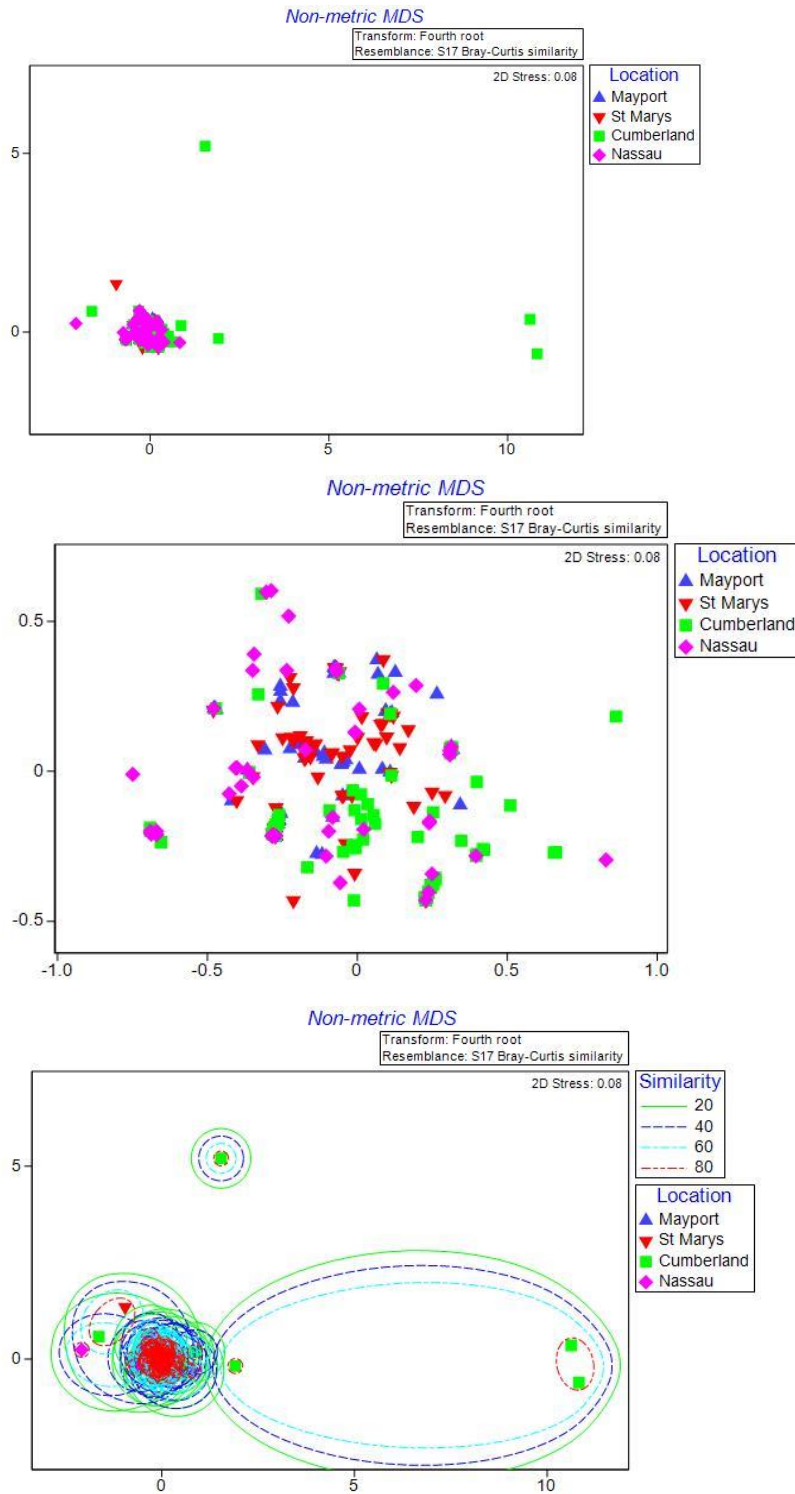
<b>All Locations</b>	<b>Coefficient Estimate</b>	<b>Std. Error</b>	<b>Z Value</b>	<b>Pr (&gt; z )</b>
<b>Intercept</b>	-3.504954	0.723516	-4.844	0.00000127***
<b>Depth</b>	0.050338	0.02247	2.24	0.02508*
<b>Temperature</b>	0.104866	0.018902	5.548	0.0000000289***
<b>Salinity</b>	0.038071	0.013573	2.805	0.00503**
<b>DO</b>	-0.006846	0.017997	-0.38	0.70366
<b>AIC</b>	2004.6		<b>df=509</b>	
<b>Theta</b>	0.8695			
<b>Std. Error</b>	0.0891			
<b>2xlog-likelihood</b>	-1992.605			



**Figure 1-26.** Plot from Principal Component Analysis of environmental data.

**Table 1-18.** Results from Principal Component Analysis of environmental data.

<b><i>Eigenvalues</i></b>				
PC	Eigenvalues	%Variation	Cum.%Variation	
	1	1.81	45.6	45.6
	2	1.02	25.7	71.3
	3	0.853	21.5	92.8
	4	0.287	7.2	100
<b><i>Eigenvectors</i></b>				
Variable	PC1	PC2	PC3	PC4
AvgDepth	-0.051	0.842	-0.536	-0.02
Temp	0.629	-0.212	-0.367	-0.652
Salinty	-0.373	-0.496	-0.751	0.224
DOmgL	-0.68	0.013	0.113	-0.724



**Figure 1-27.** Spatial similarity of shark assemblages demonstrated with non-metric multidimensional scaling. Each point represents the fourth root transformed species abundance for all location collected from each longline set. Note change in scale of axes from plot zooms. Ovals indicate similarity as a result of CLUSTER analysis. 2-D stress: 0.08.

## **Chapter 2 Title: Trophic niche dynamics of sharks on First Coast beaches**

### **Introduction**

Nearshore marine environments are known to be highly productive systems with relatively high faunal diversity and abundances that form diverse communities across many taxa, which in turn support broad ecological niches (Blaber *et al.* 1989, Beck *et al.* 2001; Plumlee and Wells 2016). In marine food webs, sharks are known to be high trophic level predators (Cortes 1999a) and thus have important roles in structuring their biological communities (Bascompte *et al.* 2005). As predators, sharks can impact ecosystems through direct and behaviorally influenced indirect interactions with prey (Heithaus *et al.* 2008). However, there is a general lack of information on the potential influence of competition and its impact on the distribution of elasmobranchs (Papastamatiou *et al.* 2006). Dietary resource partitioning has been observed in a communal shark nursery, indicating that the habitat overlap of many young populations resulted in high levels of competition (Kinney *et al.* 2011). Co-occurring shark populations in the Everglades that overlapped in spatial habitat use also overlapped in trophic niches (Gallagher *et al.* 2017). Conversely, three coastal shark species with significant range overlaps in the Gulf of Mexico were suggested to have distinct feeding strategies and thus occupy different trophic niches (Plumlee and Wells 2016). A combination of ecological factors such as resource abundance and distribution, and/or the presence of other competing species likely influences distribution patterns of nearshore sharks (Knip *et al.* 2010). Thus, identifying factors that influence

distribution patterns and resource-use of coastal sharks can aid in predicting how populations may respond to environmental changes in abiotic conditions or prey availability (Yates *et al.* 2015; Bangley *et al.* 2018). Understanding population dynamics is critical for implementing effective conservation and management of coastal sharks (Hansell *et al.* 2018). Information of resource use among sympatric species, particularly predators like sharks, may be used to better understand co-occurrence and also predict potential changes in community structure (Shipley *et al.* 2018). Additionally, information on the structure of animal communities and the mechanisms shaping species coexistence and persistence can be gathered from studying food web interactions, including trophic niche dynamics (Richards *et al.* 2018).

Recently, a study was conducted on the shark assemblages of northeast Florida beaches in the nearshore habitats adjacent to the St. Marys and St. Johns River inlets (see Chapter 1). This study utilized fishery independent longline sampling to survey the nearshore shark populations of the First Coast and investigate temporal trends in abundance. In total, 708 sharks of 11 different shark species were captured. Catches were dominated by adult Atlantic sharpnose (*Rhizoprionodon terraenovae*) (51%) and adult blacknose (*Carcharhinus acronotus*) (31%) sharks. Blacktip sharks (*Carcharhinus limbatus*) were third most abundant (6%) and comprised both mature and juvenile individuals. The results of this survey indicate a high degree of spatial and temporal overlap for these three species, providing support of sympatric interactions. As a result of this co-occurrence, there is potential for shared resource use and trophic niche differentiation. Considering the aforementioned implications regarding community interactions, it is important to examine if the temporal overlap in habitat use also results in trophic niche overlap.

Therefore, the purpose of this study was to examine trophic niche dynamics of abundant species found on northeast Florida beaches through the use of stable isotope analysis. Traditional studies that have examined trophic niche dynamics have been based on stomach content analysis, but such analyses are often confounded; some drawbacks include animals having empty stomachs when examined, or stomach contents only representing recent prey consumption (Hyslop 1980). Instead of relying on stomach contents to investigate trophic niches, stable isotope analysis has become a more common technique to study trophic ecology of both individuals and systems (Martínez del Rio *et al.* 2009). Stable isotope analysis often utilizes non-lethal sampling of small tissue amounts, which is particularly useful when research efforts are conservation oriented (Hussey *et al.* 2012). Stable isotope analysis can utilize the ratio of naturally occurring heavy and light isotopes to examine shark feeding ecology (Logan and Lutcavage 2010, Hussey *et al.* 2012).  $\delta^{13}\text{C}$  values can be used to trace the original base source of dietary carbon of a consumer in a food web (e.g., pelagic plankton vs coastal seagrass), while  $\delta^{15}\text{N}$  values can be indicative of the relative trophic position (Peterson and Fry 1987, Post 2002). Another advantage of stable isotope analysis is that isotopic signatures are incorporated into different tissue types at various rates, which allows for comparison of values across time (Matich *et al.* 2011). The differences in time for integration of diet into various tissues allows for potential investigations of temporal resource use stability, ontogenetic diet shifts, and migration patterns.

The goal of this study was examine the trophic dynamics of coastal shark populations using naturally occurring stable isotope signatures of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  generated from multiple tissue types. Specifically, this study sought to quantify trophic niche overlap



as a means to better understand competition and resource use by addressing the following questions:

- 1) Do co-occurring species of the First Coast niche's overlap? If so, to what extent?
- 2) Do individual species' niches appear to vary temporally based on analysis of multiple tissue types?
- 3) Do the entire community resource use patterns vary with time based on multiple tissue types?
- 4) Are ontogenetic resource shifts occurring?

## **Methods and Materials**

### *Sampling Locations and Gear*

Sampling occurred on the "First Coast", the region of northeast Florida that was first colonized by European settlers and includes the Atlantic coast of St. John's, Duval, Nassau, Clay, and Baker counties. Also recognized for its historical relevance and included in this grouping is Camden County in coastal southeastern Georgia. Within these coastal counties are extensive river and estuarine systems that form inlets leading to the Atlantic Ocean. The nearshore habitats sampled in this study were the beaches adjacent to the St. Marys River inlet and the St. Johns River inlet. Serving as a partial northern border between Georgia and Florida, north of the St. Marys River inlet is Cumberland Beach of Cumberland Island in Georgia while Fernandina Beach of Amelia Island exists to the south in Florida. Directly north of the St. Johns River inlet is Huguenot Beach of Little Talbot Island and to the south of the inlet is Mayport Beach of San Pablo Island.

Sharks were captured via fishery independent benthic longline sampling in both beach habitats from June 2017 to July 2018. The longline gear utilized was a combination of two sections of gear types, each made up of 50 gangions attached to 250 m of braided nylon mainline. One section of 50 gangions was constructed of 1-m, 90-kg test monofilament leader, a tuna clip, a swivel, with a 12/0 barbless circle hook attached. The second section of 250-m mainline consisted of gangions made of 1-m, 200-kg test monofilament leader, a tuna clip, a swivel, and a 16/0 barbless circle hook. In total, the 500m longline contained 100 hooks with 10-kg anchors connected to a 15-m buoy line on each end. Each hook was baited with mackerel (*Scomber* spp.), relative to hook size.

In addition to longlines, benthic drumlines were also deployed to target larger sharks. Each drumline set up consisted of a 15 kg concrete anchor to which a 15-m buoy line and a 15-m hook line are attached. The hook line was a single length of 400-kg test monofilament, with one end shackled to a swivel on the anchor and the other end connected to a swivel and a 16/0 circle hook. The drumlines were baited with available shark from the family Carcharhinidae, or mackerel (*Scomber* spp.).

#### *Animal collection and biological sampling*

All sharks caught were identified to species, measured, and sexed. Measurements included were precaudal length (PCL), fork length (FL), and stretched total length (STL). For females, life stage was determined by length per the published literature, while the presence/absence of calcified claspers was used to assess maturity in males.

Approximately 1 g of white muscle tissue was sampled from the base of the first dorsal fin using a sterilized scalpel and stored in a dry cryovial on ice until returning to the laboratory, where it was then stored at -20°C until further processing. Approximately 3 mL of whole blood was obtained via caudal venipuncture, and transferred to a vacutainer containing 350 µL of elasmobranch anticoagulant (elasmobranch acid citrate dextrose, E-ACD, Walsh and Luer 2004) and stored on ice until returning to the laboratory. Upon returning to the lab, whole blood sample was centrifuged at 1500g for 5 minutes to separate major constituents (red blood cells, plasma, white blood cells); plasma and red blood cells were transferred into cryovials and stored at -20°C.

#### *Stable Isotope Analysis*

Samples were oven-dried for 72 h at 60°C and crushed to a powder using a mortar and pestle. Both muscle tissue and blood plasma were analyzed in this study because of the respective turnover times for isotopic signatures to be integrated from diet. Shark muscle is known to have a relatively slow turnover times for both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  (approximately 400-600 d, MacNeil *et al.* 2006; Kim *et al.*, 2012), while plasma is estimated to have a 95% turnover of around 72-100 d (Matich *et al.* 2011). For muscle tissue, nitrogenous polar compounds were extracted via a triple deionized water rinse (Carlisle *et al.* 2017). Approximately 0.3 mg of dried tissue was weighed into 5 x 3.5-mm tin capsules and analyzed on a Thermo-Delta V Plus isotope ratio mass spectrometer coupled with an Isolink Elemental Analyzer (EA-IRMS) at Stony Brook University School of Marine and Atmospheric Sciences (Stony Brook, NY).

Stable isotope values are reported in the  $\delta$  notation of either  $\delta^{13}\text{C}$  or  $\delta^{15}\text{N}$ .  $\delta$  values are calculated by the following formula:  $\delta X = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$ , where X is the isotope of interest, R corresponds to the ratio of either  $^{13}\text{C}:^{12}\text{C}$  or  $^{15}\text{N}:^{14}\text{N}$  as permil (‰) differences from international reference standards of Vienna Pee-Dee Belemnite carbonate (V-PDB) for  $\delta^{13}\text{C}$  and Atmospheric nitrogen for  $\delta^{15}\text{N}$ . Analytical precision and instrument drift were assessed using certified reference materials USGS65, IU-L Glutamic Acid, Andrew IAEA-600, and an in-house working standard (IVA Urea), which were placed between every 5 samples, and fell within certified ranges as determined from repeat analysis of duplicates.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  standard deviations for each reference material were USGS65:  $\pm 0.10\text{‰}$ ,  $\pm 0.48\text{‰}$ ; IU-L Glutamic Acid:  $\pm 0.08\text{‰}$ ,  $\pm 0.26\text{‰}$ ; IAEA-600:  $\pm 0.09\text{‰}$ ,  $\pm 0.16\text{‰}$ ; and IVA Urea:  $\pm 0.56\text{‰}$ ,  $\pm 0.26\text{‰}$ . Across all runs, one in eight samples were run in duplicate, and duplicate precision (SD) did not exceed  $\pm 0.56\text{‰}$  for  $\delta^{13}\text{C}$  and  $\pm 0.48\text{‰}$  for  $\delta^{15}\text{N}$ . For individuals with a muscle C:N > 3.4, a lipid normalization based on Post *et al.* (2007) was applied because of its simplicity as a linear function as follows:  $\delta^{13}\text{C}_{\text{Corrected}} = \delta^{13}\text{C} - 3.32 + 0.99 \times \text{C:N}_{\text{Bulk}}$ . To account for the influence of E-ACD on carbon isotope values, a  $-1.2\text{‰}$  offset was applied to plasma  $\delta^{13}\text{C}$  values (Lemons *et al.* 2012, Madigan *et al.* 2015).

### *Statistical Analysis*

Overall comparisons of mean isotopic values for both elements and both tissues for all three species were conducted using ANOVA followed by Tukey's HSD test. All data were assessed for normality using Shapiro-Wilk tests and heteroscedasticity was examined via Levene's tests. To first define the trophic niche of each species, trophic niche width was estimated by calculating the total area of convex hull (TA) and standard ellipse area (SEA)

using the R package Stable Isotope Bayesian Ellipses in R (SIBER, Jackson *et al.* 2011). Standard ellipse area provides a bivariate estimate of isotopic scatter, i.e., the relative diversity of resource use exhibited by individuals within a sampling population, and incorporates ~40% of the available data displayed on an isotopic biplot (Jackson *et al.* 2011; Shipley *et al.* 2018). Due to low sample sizes for some species and tissue types, small sample-size corrected SEA (SEA<sub>C</sub>) and Bayesian-derived SEA (SEA<sub>B</sub>) were also calculated. Because trophic/isotopic niche overlap estimates can be biased by the proportion of data included into ellipse calculations (i.e., as a result of intra-specific variability in resource use), estimates of niche overlap between the three species was calculated based on an ellipse encompassing approximately 95% of the data defined here as the total trophic niche (Shipley *et al.* 2018). Total trophic niche overlap was estimated using nicheROVER (Swanson *et al.* 2015), which provides unbiased estimates of niche overlap (in %) where the probability that the trophic niche of species A is found inside that of species B, and vice-versa (Swanson *et al.* 2015). All metrics were calculated for both muscle and blood plasma values for general comparisons, and SEA of both muscle and blood plasma were displayed on the same biplot for temporal comparisons. To broadly assess whether community trophic niche dynamics varied across time, the community metrics of nitrogen range (NR), carbon range (CR), total area of the convex hull (TA), mean distance to centroid (CD), mean nearest neighbor distance (MNND), and standard deviation of nearest neighbor distances (SDNND) were calculated for all muscle and all plasma values, respectively (Layman *et al.* 2007). NR is a representation of vertical structure within a food web, CR indicates basal resource diversity, TA is a proxy for total trophic diversity within a food web, CD is a measure of the average degree of trophic diversity within a food web, MNND is measure of

the overall density of species packing, and SDNND is a measure of the evenness of species packing in biplot space (Layman *et al.* 2007). Lastly, to test for potential ontogenetic shifts in trophic niche dynamics, size-based relationships with  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  were examined through least squares regression. All statistical analyses were performed in R Studio (Version 1.1.456).

## **Results**

A total of 45 paired samples of muscle and blood plasma were analyzed from three sharks species, comprised of Atlantic sharpnose ( $n=20$ ), blacknose ( $n=15$ ), and blacktip ( $n=10$ ) sharks. Across the entire community, muscle values of  $\delta^{13}\text{C}$  ranged from -17.65 to -15.35 and from 12.15 to 15.46 for  $\delta^{15}\text{N}$ . For plasma values of the entire community,  $\delta^{13}\text{C}$  ranged from -16.56 to -14.95, and  $\delta^{15}\text{N}$  ranged from 11.07 to 14.80. Statistically significant differences between mean values were only detected for  $\delta^{15}\text{N}$  muscle ( $F=12.205$ ,  $p>0.001$ ), with Atlantic sharpnose having the lowest average value. Multiple comparisons by Tukey HSD grouped Atlantic sharpnose separately from blacknose and blacktip combined for muscle  $\delta^{15}\text{N}$  ( $p=0.001$ ). Comparison of average  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for blood plasma across all three species revealed no statistically significant differences ( $F=0.969$ ,  $df=2$ ,  $p=0.388$  and  $F=0.753$ ,  $df=2$ ,  $p=0.477$ , respectively) (Table 2-1, Figure 2-1).

Estimates of TA and standard ellipse area varied across species and tissue types. Blacknose sharks exhibited the largest SEA for muscle tissue ( $1.08\text{‰}^2$ ). SEA of the two other species was smaller than the blacknose shark and were similar, with values of  $0.8\text{‰}^2$  and  $0.78\text{‰}^2$  for blacktip and Atlantic sharpnose, respectively. However, when comparing core trophic niches from blood plasma, the blacknose shark had the smallest estimate

(0.46‰<sup>2</sup>) while blacktip and Atlantic sharpnose had SEA values of 0.98‰<sup>2</sup> and 1.09‰<sup>2</sup>, respectively.

For muscle tissue, the highest estimate of trophic niche overlap was observed between the total trophic niches of the blacktip shark with blacknose shark (92.23%, Table 2-2a). 57.38% and 71.54% of the blacknose shark trophic niche overlaps with the niches of both the Atlantic sharpnose and blacktip sharks, respectively. The lowest total trophic overlap based on muscle tissue observed was the Atlantic sharpnose shark overlapping with only 45.06% of the blacktip niche.

Total trophic niche overlap estimates from muscle tissue contrasted with that of blood plasma. For blood plasma, blacknose sharks had >91% overlap with both other species of shark. Conversely, total trophic niche overlap between the Atlantic sharpnose and blacknose shark was 59.28%, while the blacktip overlap with the blacknose shark was 59.28%. The highest total trophic niche overlap was observed between the blacknose shark with the Atlantic sharpnose shark (96.59%, Table 2-2b).

Community-wide metrics of trophic structure differed between muscle and blood plasma, indicating that the community changed over time. Carbon range calculated from muscle tissue was 0.021 compared to 0.18 for blood plasma. A larger difference was observed between the nitrogen ranges of the two tissue types, with a NR of 0.93 for muscle tissue versus 0.36 for blood plasma. The TA value for muscle tissue was 0.04 while blood plasma had a TA value of 0.03. CD and MNND for the muscle tissue community was 0.42 and 0.37, respectively, while the blood plasma was again much smaller with respective

values of 0.17 and 0.24. Lastly, the SDNDD for muscle tissue was 0.48, considerably larger than 0.02 for blood plasma (Table 2-1).

Linear regressions only revealed statistically significant relationships between fork length and  $\delta^{15}\text{N}$  of blood plasma for blacktip sharks ( $F=7.63$ ,  $r^2=0.48$ ,  $p=0.025$ ). All other relationships were not statistically significant ( $p>0.05$ , Table 2-3, Figure 2-6 and 2-7).

## **Discussion**

This study represents the first investigation of trophic niche dynamics of shark communities along the First Coast utilizing stable isotope analysis. There is clear evidence of trophic niche shifts between the two tissue types, suggesting some degree of foraging plasticity. Core trophic niches of the blacknose shark decreased in the short term, but the two other species core trophic niches expanded. The amount of trophic niche overlap among species also varied by tissue type, and overlap metrics were higher for blood plasma suggesting more shared resources in the short term. Additionally, significant size relationships between fork length and plasma  $\delta^{15}\text{N}$  values were detected in blacktip sharks, suggestive of prey partitioning between size classes. The results of this study demonstrate that the high spatial overlap of these three abundant species results in relatively high overlap of trophic structure, and highlights this unique opportunity to investigate trophic niche differentiation in sympatric species.

The broad scale differences in trophic niche dynamics represented by the Layman metrics reflect the similar patterns seen from the ellipses analyses, suggesting that trophic niches shifted and became more similar recently. The greatest difference in Layman metrics was the decrease in NR from muscle to blood plasma. Although the actual



differences in values is slight, it supports the general trend of decreased trophic diversity on a more recent time scale and suggests that less trophic levels may exist when investigating the short term interactions. The minor decrease in CR between the two tissues does not suggest a shift in basal resources, and the range of  $\delta^{13}\text{C}$  values observed does not support the idea of multiple basal resources on either time scale. Both TA and CD values are relatively low, but as this metric also decreases from muscle to blood plasma, suggests a general decrease in trophic diversity. The smaller values for MNND and SDNND of the blood plasma samples further supports increased trophic redundancy and more even distribution of trophic niches in the more recent time frame compared to the long term muscle tissue. Detection of diet shifts via stable isotope analysis has been reported in oceanic whitetip sharks (*Carcharhinus longimanus*), such that isotopic signatures from plasma contrasted that of muscle and reflected signatures of suspected prey during seasonal aggregations (Madigan *et al.* 2015).

The muscle tissue suggests that over long time frames, the most distinct niche differentiation occurs between blacktip and Atlantic sharpnose sharks. Blacknose and blacktip sharks, however, appear to overlap considerably in delta space. For blood plasma, there is far more trophic niche overlap among the three species. The Atlantic sharpnose and blacktip sharks exhibit trophic niche expansion, whereas blacknose sharks exhibit a narrower trophic niche. The blacknose shark's decrease in trophic niche suggests a more specific foraging strategy compared to the other species. This equates to the blacknose shark potentially having a less taxonomically diverse diet and that it may feed evenly throughout its prey base, whereas greater trophic plasticity suggests opportunistic feeding across a larger prey base with less numerically available prey (Plumlee and Wells 2016).

Although the isotopic trophic niches presented here cannot relate directly to prey sources, other studies of stomach content analysis of the species investigated corroborate the niche overlap observed here. In the southeastern United States, blacktip sharks are known to feed primarily on small teleosts and small elasmobranchs (Castro 1993). From the inshore waters of the First Coast, a diet study on the Atlantic sharpnose shark showed that this species primarily fed on crustaceans and sciaenid fishes (McCallister 2012 unpublished data). Along the southeastern United States, sciaenids were also found to be the most abundant prey in a stomach content analysis of blacknose sharks (Ford 2012, unpublished data). In the Mediterranean, a study utilizing both stomach content and stable isotope analyses in demersal sympatric shark species revealed that despite some differences in the specific diets, long-term patterns supported similar diet habits and similar trophic relations (Barría *et al.* 2018). Thus, while the possibility of prey variability, particularly with regards to size of prey, may exist, it would not be surprising if similar prey directly resulted in the overlap observed in this study.

The blood plasma is likely reflecting resource use while animals inhabit the First Coast, but muscle tissue may also be integrating parts of species-specific migration routes outside of the immediate region. Blacknose sharks in the southeastern United States are known to migrate northward from the east coast of Florida to the coastal habitats of the Carolinas in the summer, and return to Florida again in the winter (Schwartz 1984; Ulrich *et al.* 2007). Blacktip sharks are also known to migrate north from Florida along the east coast of the United States to the Carolinas in the spring and summer, then returning to form large aggregations in south Florida during the winter (Kajiura and Tellman, 2016). These similar migration patterns could be the reason behind the highest niche overlap value of  $\delta^{15}\text{N}$

blacktip and blacknose sharks based on muscle tissue, suggesting potential overlap of resources during large-scale movements. In northeast Florida, Atlantic sharpnose sharks are known to utilize First Coast habitats seasonally (McCallister *et al.* 2013; Chapter 1) while adult abundances varied with temperature in nearshore South Carolina waters (Ulrich *et al.* 2007) such that this species likely moves south and/or offshore as well but does not directly compete with blacknose or blacktips.

All  $\delta^{13}\text{C}$  average values increased from muscle tissue to blood plasma, however the differences were minute. The relatively enriched  $\delta^{13}\text{C}$  values observed are indicative of marine carbon sources (Matich *et al.* 2017). Given the difficulty of inferring which food webs are being utilized, especially without directly investigating  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of primary producers of the region, this study limits its ecological claims to trophic niche dynamics. Stable isotopes have been used to trace migrations and detect differences in coastal versus offshore foraging of white sharks (Malpica-Cruz *et al.* 2013); however our data were not significant to support such findings. It is also possible that the movements of the species studied do not support distinguishable differences in  $\delta^{13}\text{C}$ .

The observation of only one significant relationship between size and isotopic values to investigate ontogenetic niche shifts is not surprising given the sampling locations and known shark demographics of the habitats (Chapter 1). All Atlantic sharpnose sharks included in this study were mature adult males captured in the nearshore habitats, and thus ontogenetic diet shifts likely already occurred (Bethea *et al.* 2006). Blacknose sharks were also only captured in the nearshore habitats, but were comprised of mature adults or juveniles very close to maturity of both sexes. Because juvenile and adult blacktip sharks

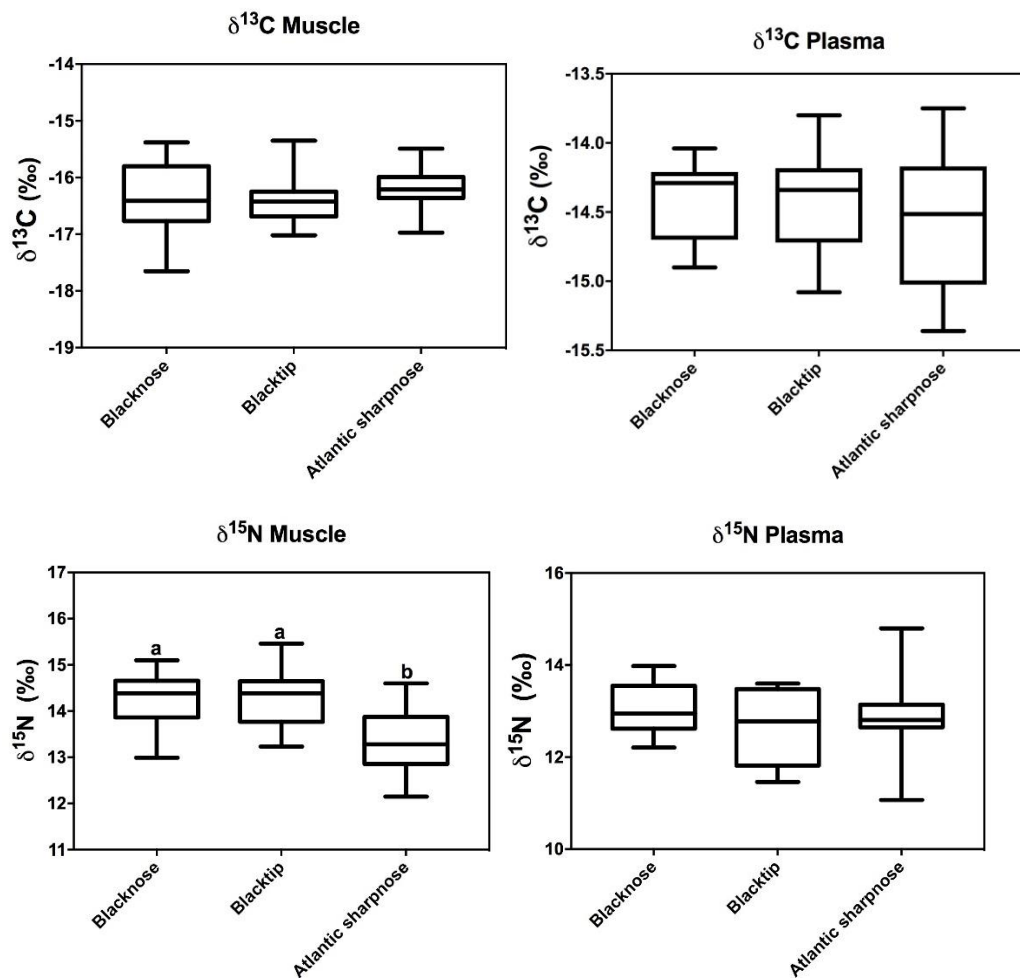
utilize the same habitat along the First Coast, they represent the broadest size range of all species from the nearshore environment. Ontogenetic diet shifts were also observed in blacktip sharks in the Gulf of Mexico (Plumlee and Wells 2016); however this study does not support changes in  $\delta^{13}\text{C}$  indicative of range expansion.

## **Conclusion**

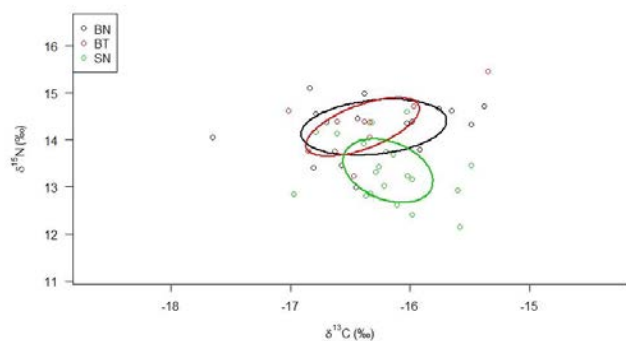
In conclusion, the results of this study suggest that the spatial and temporal overlap of habitat use of First Coast sharks relates to relatively high amounts of overlap in trophic niches determined from stable isotope analysis. Although trends of trophic structure vary by tissue type, there is evidence that when nearshore sharks inhabit the First Coast, they are likely sharing common resource pools. The estimation of niche dynamics provided here might be useful for future ecosystem models, as well as important to understanding ecosystem dynamics given the migratory behavior of the species studied.

**Table 2-1.** Summary information for elasmobranchs sampled on the First Coast by tissue type. Isotope values are presented in per mil (‰) ±1 SD in parenthesis. Total area of the convex hull (TA), maximum likelihood estimated of the core trophic niche standard ellipse area (SEA, core trophic niche) and small sample size correction (SEAc), and Bayesian standard ellipse area (SEAB)(‰<sup>2</sup>) are presented. SEAB correspond to mean values. Layman metrics: NR (nitrogen range), CR (carbon range), TA (total area of the convex hull), CD (mean distance to centroid), MNND (mean nearest neighbor distance), and SDNND (standard deviation of nearest neighbor distance).

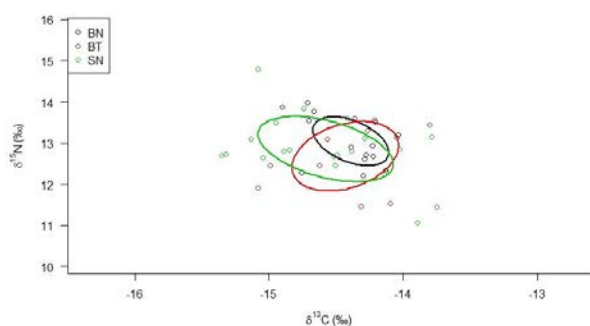
Muscle										
Species	Common name	n	Size Range (FL, cm)	δ <sup>13</sup> C	δ <sup>15</sup> N	C: N	TA	SEA	SEA <sub>c</sub>	SEA <sub>B</sub>
<i>Carcharhinus acronotus</i>	Blacknose shark	16	79-111	-16.3(0.58)	14.27 (0.57)	3.51 (0.31)	2.65	1.08	1.16	1.15
<i>Carcharhinus limbatus</i>	Blacktip shark	10	68-155	-16.4 (0.45)	14.28 (0.59)	3.46 (0.21)	1.51	0.72	0.8	0.84
<i>Rhizoprionodon terrenovae</i>	Atlantic sharpnose shark	20	72-81	-16.18 (0.36)	13.35 (0.65)	3.62 (0.14)	2.41	0.74	0.78	0.78
Layman Metrics	NR	CR	TA	CD	MNND	SDNND				
	0.93	0.21	0.04	0.42	0.37	0.48				
Plasma										
Species	Common name	n	Size Range (FL, cm)	δ <sup>13</sup> C	δ <sup>15</sup> N	C: N	TA	SEA	SEA <sub>c</sub>	SEA <sub>B</sub>
<i>Carcharhinus acronotus</i>	Blacknose shark	15	79-111	-15.59 (0.27)	13.05 (0.57)	2.02 (0.22)	1.08	0.46	0.50	0.48
<i>Carcharhinus limbatus</i>	Blacktip shark	10	68-155	-15.63 (0.37)	12.69 (0.79)	2.1 (0.21)	1.72	0.98	1.10	1.02
<i>Rhizoprionodon terrenovae</i>	Atlantic sharpnose shark	20	72-81	-15.78 (0.49)	12.86 (0.77)	2.3 (0.27)	3.32	1.09	1.15	1.16
Layman Metrics	NR	CR	TA	CD	MNND	SDNND				
	0.36	0.18	0.03	0.17	0.24	0.02				



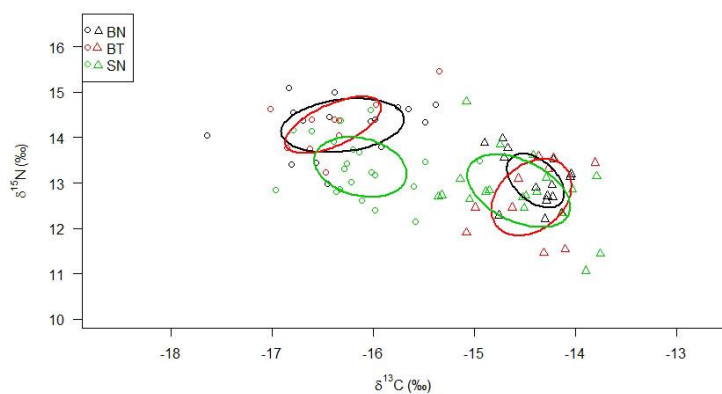
**Figure 2-1.** Boxplots highlight minimum, maximum, and average  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values for all three shark species for both muscle and blood plasma. Letters represent homogenous subsets determined by Tukey HSD tests.



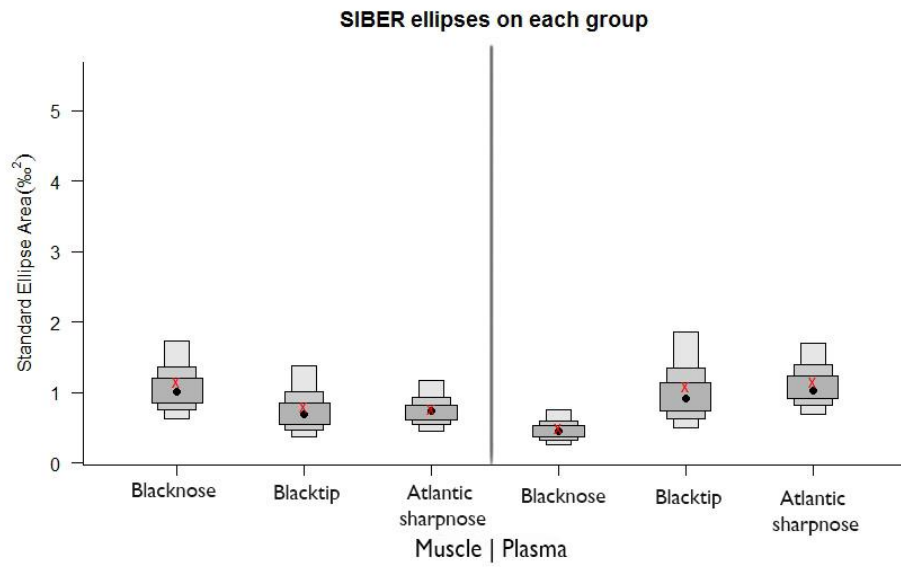
**Figure 2-2a.** Core trophic niches (SEA) of all three shark species from muscle tissue.



**Figure 2-2b.** Core trophic niches (SEA) of all shark species from blood plasma.

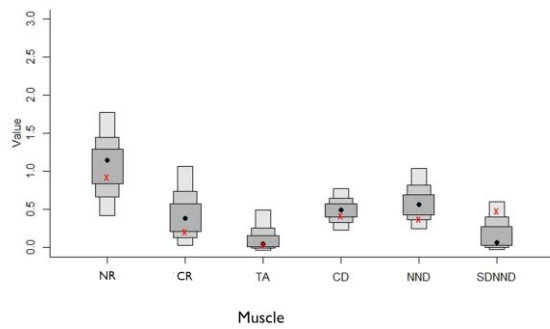


**Figure 2-2c.** Core trophic niches (SEA) of all three shark species from both tissue types. Circles represent muscle, triangles represent blood plasma.

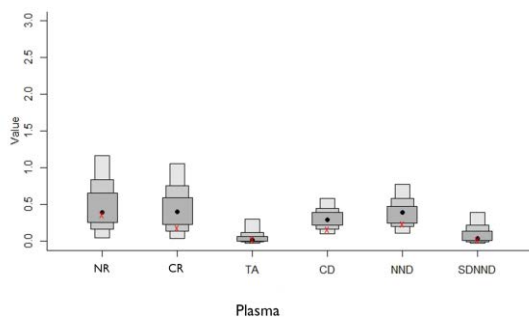


**Figure 2-3.** Bayesian derived estimates of standard elliptical area (SEA<sub>B</sub>) for each species from both tissue types with associated 95% credibility intervals. Red x's indicate maximum likelihood estimated SEA.

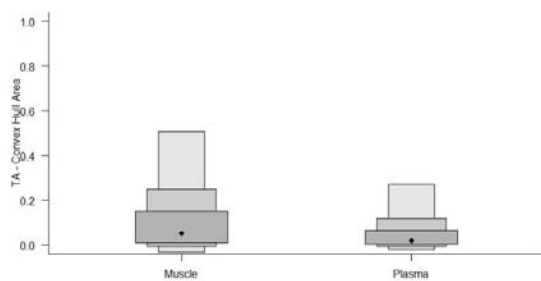




**Figure 2-4a.** Layman metrics for muscle tissue. NR (nitrogen range), dX range=CR (carbon range), TA (total area of the convex hull), CD (mean distance to centroid), MNND (mean nearest neighbor distance), and SDNND (standard deviation of nearest neighbor distance).



**Figure 2-4b.** Layman metrics for plasma tissue. NR (nitrogen range), dX range=CR (carbon range), TA (total area of the convex hull), CD (mean distance to centroid), MNND (mean nearest neighbor distance), and SDNND (standard deviation of nearest neighbor distance).



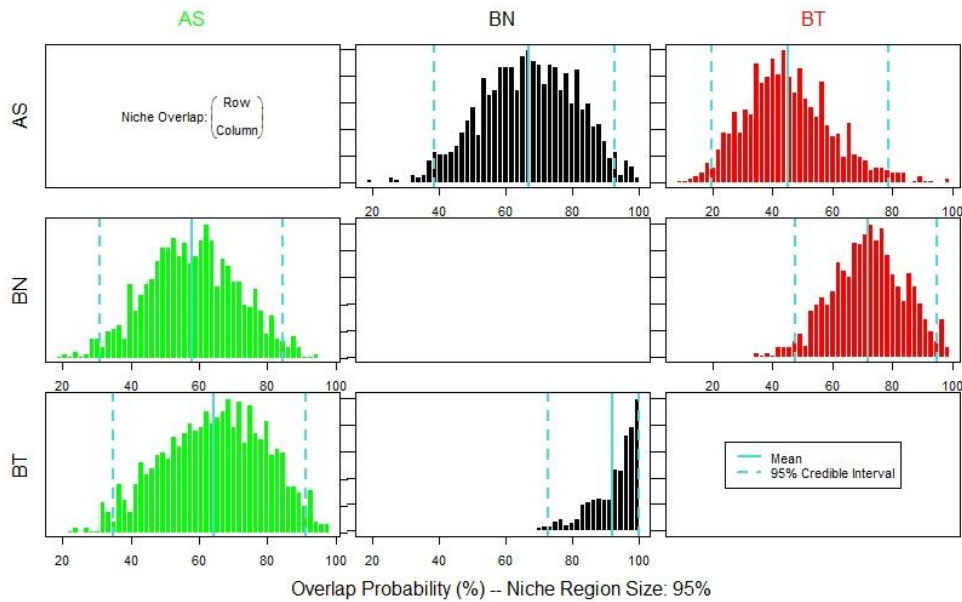
**Figure 2-4c.** Layman metric of TA of Community 1: muscle tissue vs Community 2: blood plasma.

**Table 2-2a.** Total trophic niche overlap (%) between sharks sampled on the First Coast based on muscle tissue. AS: Atlantic sharpnose shark, BN: blacknose shark, BT: blacktip shark, SB: sandbar shark. Overlap is based upon ellipses encompassing 95% of the data and represents the isotopic niche of Species A within the isotopic niche of Species B.

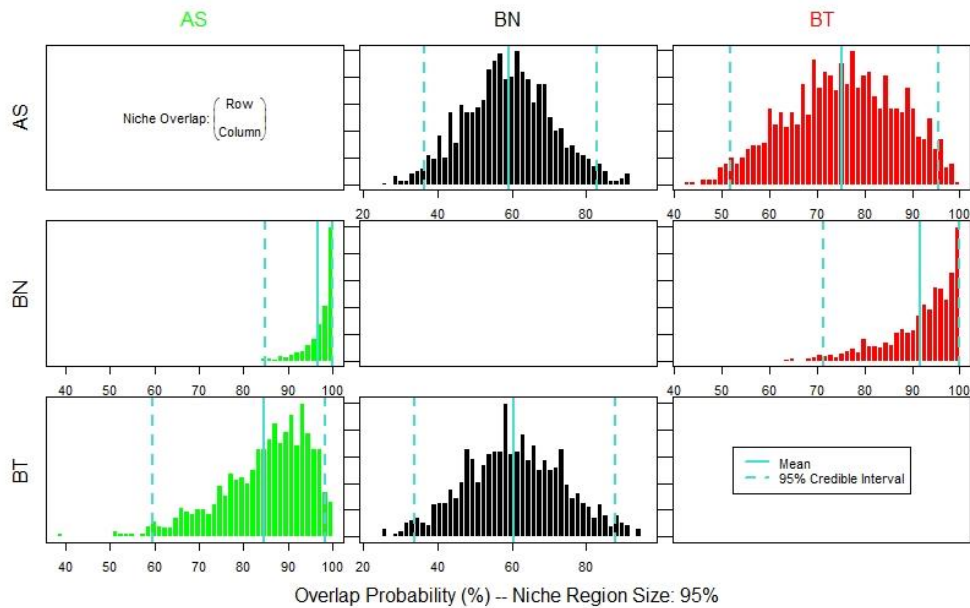
<i><b>Muscle</b></i>			
<b>Species A</b>	<b>Species B</b>		
	<b>AS</b>	<b>BN</b>	<b>BT</b>
<b>AS</b>	-	66.36	45.06
<b>BN</b>	57.38	-	71.54
<b>BT</b>	64.29	92.23	-

**Table 2-2b.** Total trophic niche overlap (%) between sharks sampled on the First Coast based on plasma tissue. AS: Atlantic sharpnose shark, BN: blacknose shark, BT: blacktip shark, SB: sandbar shark. Overlap is based upon ellipses encompassing 95% of the data and represents the isotopic niche of Species A within the isotopic niche of Species B.

<i><b>Plasma</b></i>			
<b>Species A</b>	<b>Species B</b>		
	<b>AS</b>	<b>BN</b>	<b>BT</b>
<b>AS</b>	-	59.28	74.96
<b>BN</b>	96.59	-	91.59
<b>BT</b>	84.07	60.31	-



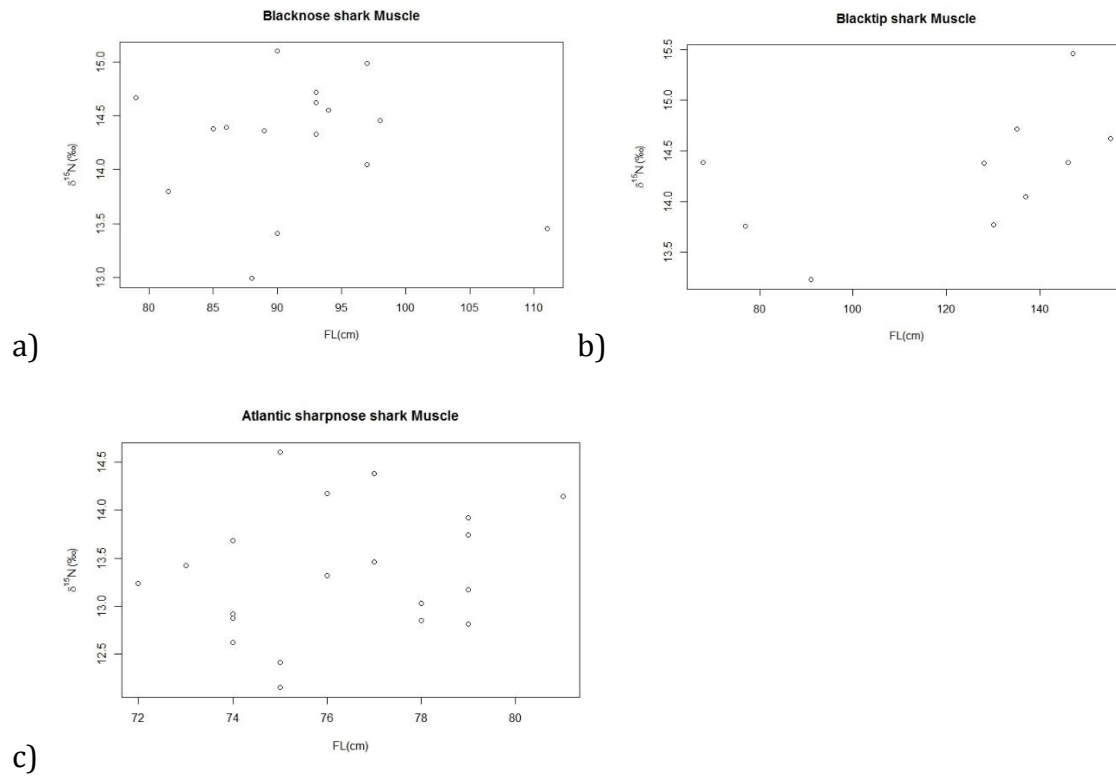
**Figure 2-5a.** Total trophic niche overlap results from muscle tissue. Posterior distribution of the probabilistic niche overlap metric (%) for a niche region ( $N_R$ ) of 95%. Overlap probability is shown of the species displayed in rows onto those displayed in columns. The posterior means and 95% credible intervals are displayed in turquoise.



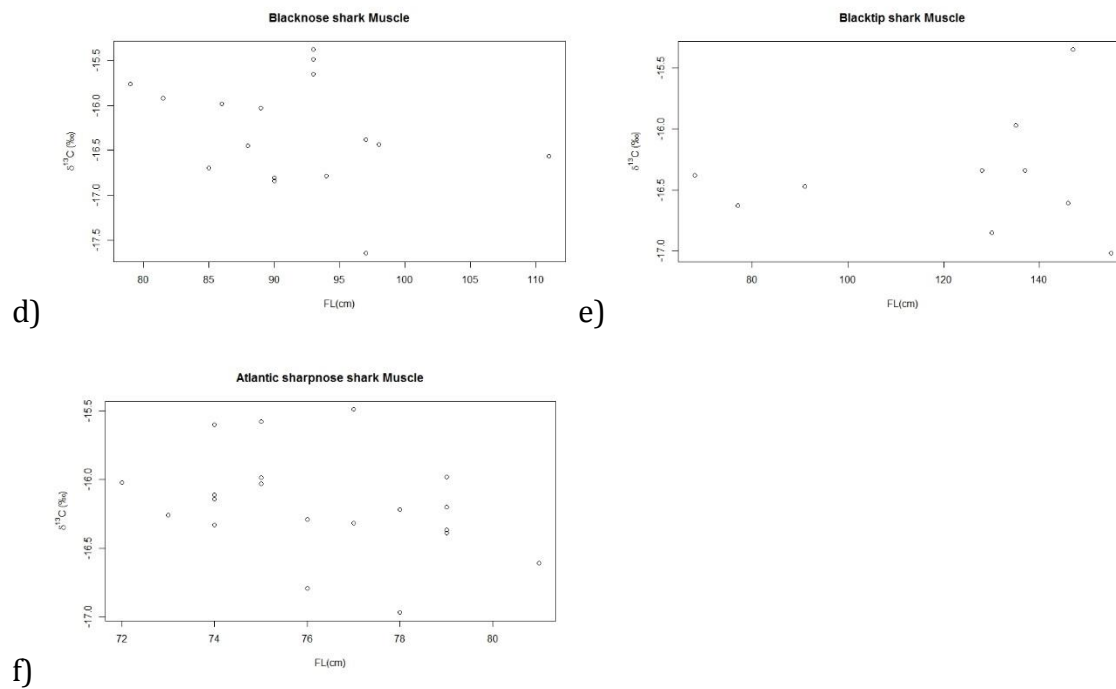
**Figure 2-5b.** Total trophic niche overlap results from blood plasma. Posterior distribution of the probabilistic niche overlap metric (%) for a niche region ( $N_R$ ) of 95%. Overlap probability is shown of the species displayed in rows onto those displayed in columns. The posterior means and 95% credible intervals are displayed in turquoise.

**Table 2-3.** Output from species-specific linear regression compared fork length (FL, cm) to isotope values. Significant results are in bold.

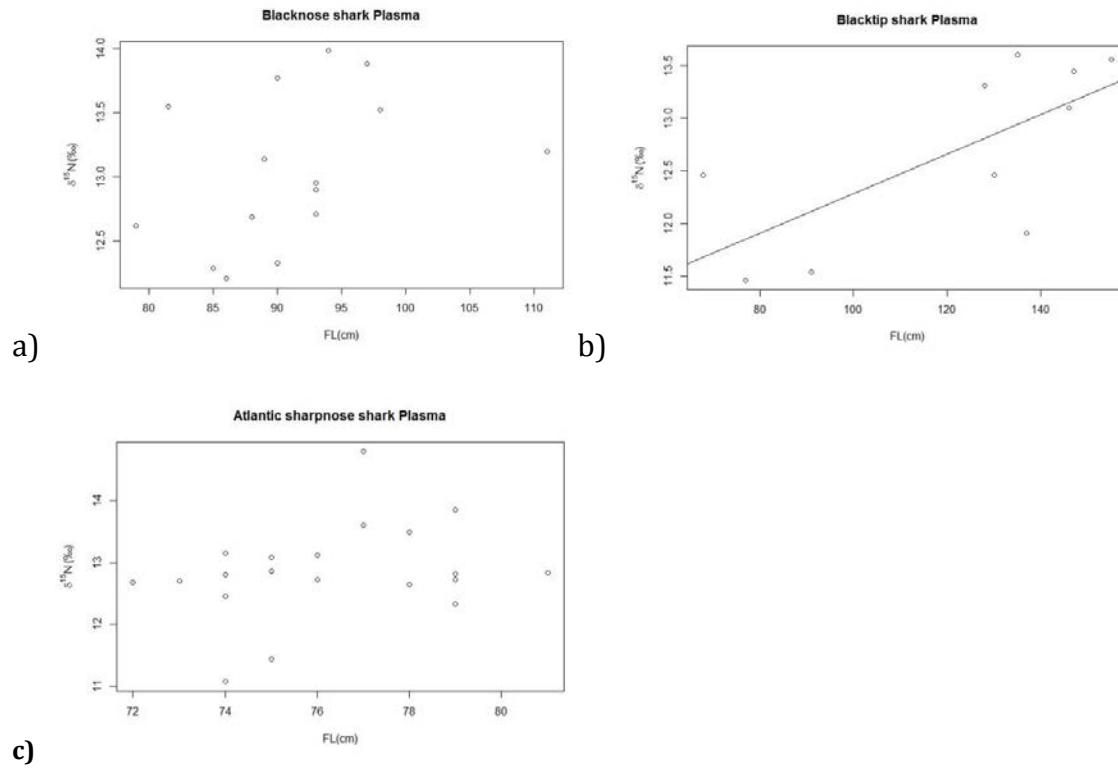
Blacknose			F value	r <sup>2</sup>	p-value
	Muscle	δ <sup>13</sup> C	1.329	0.0867	0.268
		δ <sup>15</sup> N	0.1768	0.0125	0.681
	Plasma	δ <sup>13</sup> C	0.7796	0.0566	0.393
		δ <sup>15</sup> N	2.002	0.1135	0.181
Blacktip					
	Muscle	δ <sup>13</sup> C	0.1126	0.0139	0.746
		δ <sup>15</sup> N	0.7816	0.0567	0.393
	Plasma	δ <sup>13</sup> C	0.4287	0.0509	0.531
		δ <sup>15</sup> N	<b>7.631</b>	<b>0.4882</b>	<b>0.0245</b>
Atlantic sharpnose					
	Muscle	δ <sup>13</sup> C	2.762	0.3559	0.114
		δ <sup>15</sup> N	1.256	0.0653	0.277
	Plasma	δ <sup>13</sup> C	1.013	0.0541	0.324
		δ <sup>15</sup> N	1.64	0.0835	0.217



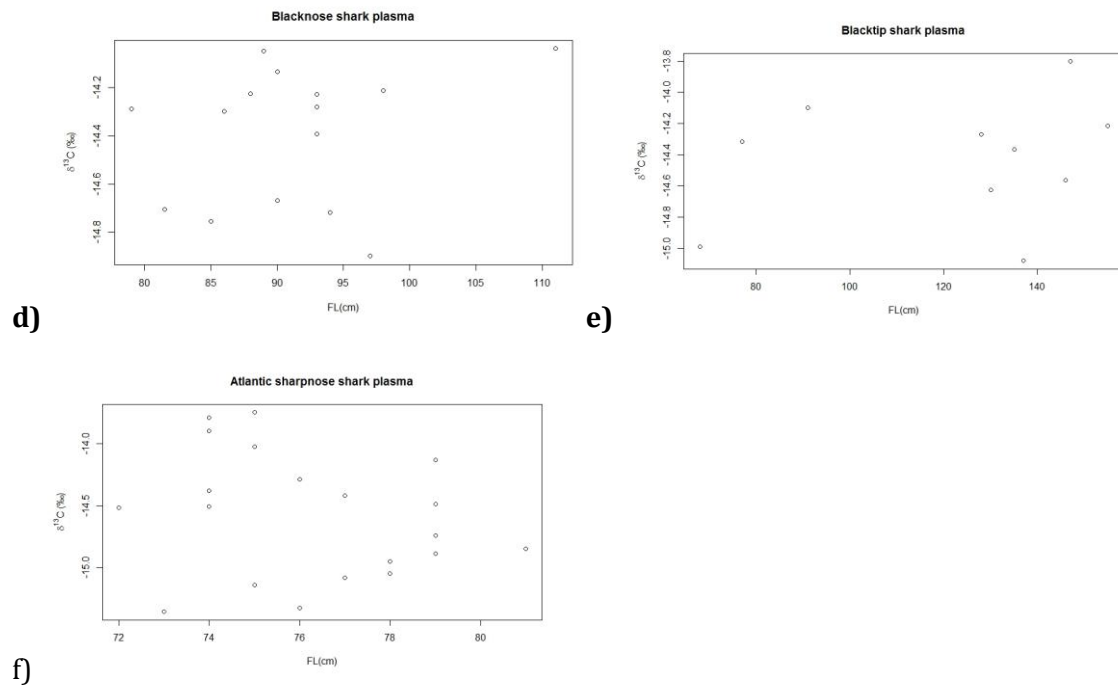
**Figure 2-6a-c.** Size (FL) versus  $\delta^{15}\text{N}$  relationships based on muscle tissue for a) blacknose shark, b) blacktip shark, and c) Atlantic sharpnose shark..



**Figure 2-6d-f.** Size (FL) versus  $\delta^{13}\text{C}$  relationships based on muscle tissue for d) blacknose shark, e) blacktip shark, and f) Atlantic sharpnose shark.



**Figure 2-7a-c.** Size (FL) versus  $\delta^{15}\text{N}$  relationships based on blood plasma for a) blacknose shark, b) blacktip shark (blacktip plasma  $\delta^{15}\text{N}$  equation:  $y=10.41+0.019x$ ;  $r^2=0.49$ ), and c) Atlantic sharpnose shark.



**Figure 2-7d-f.** Size (FL) versus  $\delta^{13}\text{C}$  relationships based on blood plasma for d) blacknose shark, e) blacktip shark, and f) Atlantic sharpnose shark.

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## **Vita**

### **Education:**

B.S. Biology, Florida State University, Tallahassee, FL 2014

M.S. Biology, University of North Florida, Jacksonville, FL, 2018

### **Professional/Research Experience:**

September 2015-December 2018. University of North Florida. Jacksonville, FL. *Graduate Research Assistant.*

December 2015-February 2016. GTM NERR, Ponte Vedra Beach, FL. *American Eel Field Project Manager.*

April 2015. Rodney Fox Shark Expeditions, Port Lincoln, South Australia, Australia. *Divemaster.*

June 2014-March 2015. Shark Bay Ecosystem Research Project, Shark Bay, Western Australia, Australia. *Field Research Assistant.*

October-November 2014. Macquarie University Field Station, Jervis Bay, New South Wales, Australia. *Field Research Assistant.*

July 2012-May 2014. Florida State University Coastal & Marine Laboratory, St. Teresa, FL. *Field Research Assistant.*

August-December 2013. Florida State University Academic Diving Program, Tallahassee, FL. *Teaching Assistant.*

June-August 2013. Cape Eleuthera Institute, Shark Research & Conservation Program, Eleuthera, The Bahamas. *Research Intern.*

October 2012-May 2013. Florida State University Coastal & Marine Laboratory, St. Teresa, FL. *Laboratory Technician.*

August-December 2012. Florida State University Biology Department, Tallahassee, FL. *Sea-To-See Instructor.*

August-December 2011. Florida State University Coastal & Marine Laboratory, St. Teresa, FL. *Laboratory Technician.*

### **Academic Awards**

August 2015-December 2018

Joan Van Vleck Fellowship for Coastal Biology

First recipient of a \$10,000 annual award to support my tuition costs.

### **Professional Memberships:**

2017-Present                      American Fisheries Society

2016-Present                      American Elasmobranch Society