BioOne COMPLETE

Abundance and Distribution of Sharks in Northeast Florida Waters and Identification of Potential Nursery Habitat

Authors: McCallister, Michael, Ford, Ryan, and Gelsleichter, James

Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(5) : 200-210

Published By: American Fisheries Society

URL: https://doi.org/10.1080/19425120.2013.786002

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 5:200–210, 2013
© American Fisheries Society 2013
ISSN: 1942-5120 online
DOI: 10.1080/19425120.2013.786002

SPECIAL SECTION: ELASMOBRANCH LIFE HISTORY

Abundance and Distribution of Sharks in Northeast Florida Waters and Identification of Potential Nursery Habitat

Michael McCallister,* Ryan Ford,[1] and James Gelsleichter
Department of Biology, University of North Florida, 1 UNF Drive, Jacksonville, Florida 32224, USA

Abstract
Sharks are considered top predators in many marine ecosystems and can play an important role in structuring community ecology. As a result, it is necessary to understand the factors that influence their abundance and distribution. This is particularly important as fishery managers develop management plans for sharks that identify areas that serve as essential fish habitat, especially nursery habitat. However, our understanding of shark habitat use in northeast Florida waters is limited. The goal of this study was to characterize the abundance and distribution of sharks in northeast Florida estuaries and to examine the effect of abiotic factors on shark habitat use. A bottom longline survey conducted from 2009 to 2011 indicated that 11 shark species use the estuarine waters of northeast Florida during the summer months. Atlantic Sharpnose Sharks *Rhizoprionodon terraenovae*, Blacktip Sharks *Carcharhinus limbatus*, and Bonnetheads *Sphyrna tiburo* were the most abundant species and made up 81.4% of the total catch. Site, month, and bottom water temperature were the most important factors determining the presence and abundance of sharks and suggest both regional and seasonal variations in the use of northeast Florida waters. Depth, salinity, and dissolved oxygen were also important factors. Our data show that these waters serve as a nursery for Atlantic Sharpnose and Blacktip Sharks, with young-of-the-year and juveniles being present in the summer months. Limited tag–return data reveal that juvenile sharks remain in these waters throughout the summer and that some return in subsequent summers. This is the first study to characterize the abundance and distribution of sharks and identify potential nursery areas in northeast Florida estuaries.

Congress' reauthorization of the Magnuson–Stevens Fishery Conservation and Protection Act in 1996 affirmed the widely accepted notion that essential fish habitat (EFH) plays a critical role in the life history of many marine organisms. According to the act, EFH is defined as "those waters and substrate necessary to fish for spawning, feeding, breeding, or growth to maturity" and should include habitats used at any portion of the species' life cycle (Magnuson–Stevens Fishery and Conservation Act 1996). Of particular importance in their role as EFH are nearshore estuarine and marine ecosystems (e.g., seagrass meadows, marshes, and mangroves) that serve as nursery habitats, providing a selective advantage for juveniles. For sharks, this may include increased prey abundance and decreased risk of predation (Branstetter 1990; Castro 1993), both of which would have obvious benefits for survival and overall population growth.

The shark nursery concept was first put forth by Springer (1967), who described shark nurseries as discrete parts of a species' range where parturition occurs and/or juvenile sharks spend the early part of their lives. Shark nurseries were further defined by Bass (1978) by distinguishing between primary and secondary nurseries. According to Bass' definition, primary nursery habitats are those areas where young sharks are born and spend up to the first year of their life, while secondary nursery habitats are where slightly older but not yet mature individuals occur. Although these definitions have been well accepted, and

Subject editor: Eric Hoffmayer, Southeast Fisheries Science Center, Pascagoula, Mississippi

*Corresponding author: m.mccallister@unf.edu
[1]Present address: Florida Fish and Wildlife Conservation Commission, Marine Science Research Institute, Jacksonville University, 2800 University Boulevard North, Jacksonville, Florida 32211, USA.
Received October 10, 2012; accepted March 7, 2013

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

the concept of shark nursery habitat is well established, clear criteria that can be used to identify nursery areas have been lacking. However, more recently, the shark nursery concept was reexamined by Heupel et al. (2007), who proposed a definition with three criteria that could be used to quantitatively identify shark nursery habitat: (1) juvenile sharks are more commonly encountered in these areas than in others, (2) juvenile sharks will remain or return to these areas over an extended period of time, and (3) the areas will be utilized repeatedly across years. These criteria have provided researchers with a clearer set of end points for characterizing habitat use in juvenile sharks.

Concern about the susceptibility of shark populations to overfishing (FAO 2000) has prompted U.S. fishery managers to develop specific fishery management plans (FMPs) for sharks (NMFS 1999, 2003, 2006). A critical component of these management plans is the identification of EFH (NMFS 1999). Recognizing the importance of nursery habitat to the success of shark populations, fishery managers have developed FMPs that require the identification and delineation of suitable nursery habitat. This has resulted in numerous ongoing and detailed studies examining the presence of shark nurseries in most of the major estuaries along the Atlantic and Gulf coasts of the United States (see McCandless et al. 2007). However, close examination of the scientific literature reveals a noticeable gap in knowledge regarding shark habitat along the East Coast. Specifically, there have been no studies examining the presence of shark nursery habitat in northeast Florida.

In 2009, the University of North Florida established an annual shark abundance survey to examine shark populations in the coastal and estuarine waters from the Florida–Georgia border to St. Augustine, Florida. The goal of this project was to gather critical data on the use of northeast Florida's nearshore and estuarine waters as shark nursery habitat. Using data collected from 2009 to 2011, this paper characterizes the abundance and distribution of sharks in two northeast Florida estuaries, Cumberland Sound and Nassau Sound, and identifies EFH for juvenile sharks within these estuaries.

STUDY SITE

Cumberland and Nassau sounds are located in northeast Florida (Figure 1) on the northern and southern boundaries of Nassau County, respectively, and are part of the Nassau–St. Mary's water basin. Cumberland Sound is located at the mouth of the St. Mary's River between Cumberland Island, Georgia, and Amelia Island, Florida. Nassau Sound is situated between Amelia Island and Big Talbot Island at the confluence of Sister's Creek and the Nassau and Amelia rivers. Both of these estuaries can be considered healthy, with the last water quality assessment of the Nassau–St. Mary's water basin classifying the bodies of water that feed into Cumberland Sound as class III surface waters (suitable for maintaining a healthy, well-balanced population of fish and wildlife) and those that enter Nassau Sound as class II surface waters (suitable for shellfish harvest and propagation) (FLDEP 2007).

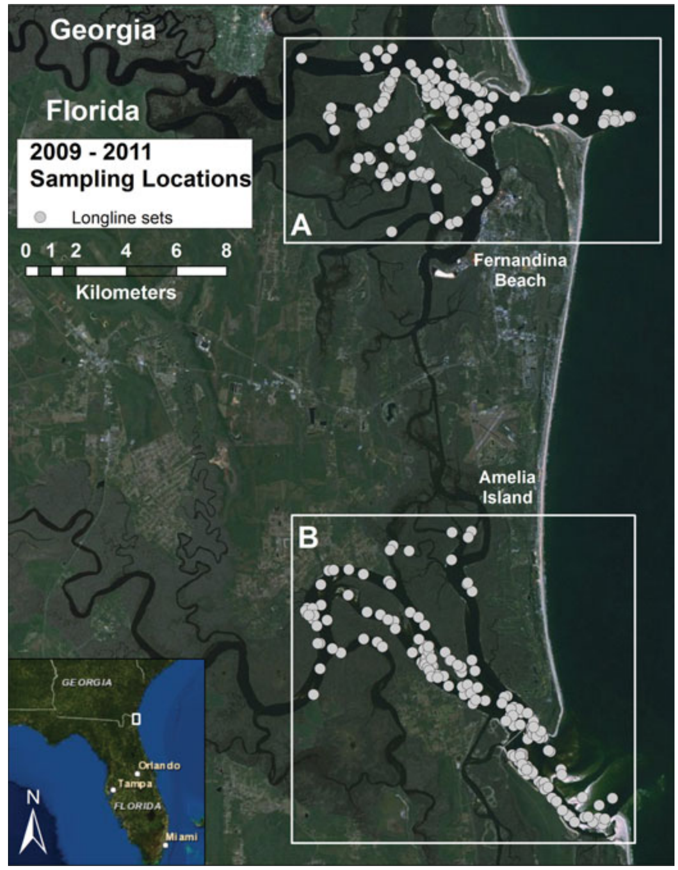

FIGURE 1. Aerial photograph of the **(A)** Cumberland Sound and **(B)** Nassau Sound study sites in northeast Florida. Grey circles show the locations of all longline sets from 2009 to 2011.

METHODS

Sampling.—Longline sampling was conducted in the nearshore and estuarine waters of Cumberland and Nassau sounds (Figure 1) from late April through November using bottom longline fishing. Weekly sampling occurred from May to August each year. During April, September, October, and November, each region was sampled only twice a month due to time and weather constraints. The longline consisted of a single 300-m #8 braided nylon mainline, anchored at both ends and marked with two buoys, containing 50 gangions, each composed of a 1-m, 90-kg test monofilament leader, size 120 stainless steel longline snap, 4/0 swivel, and a 12/0 barbless circle hook baited with Atlantic Mackerel *Scomber scombrus*. Initially, the sets were allowed to soak for 1 h; however, after the second week the soak time was reduced to 30 min to better minimize animal mortality. Five to six sets were fished each day, and the location of each set was selected haphazardly. Environmental data were collected at each sampling location after the longline was set. Bottom water temperature (°C),

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

salinity (‰), and dissolved oxygen (mg/L) were measured using an YSI-85 (YSI, Inc., Yellow Springs, Ohio). Water depth (m) was recorded at the beginning and end of each set. The mean depth for each set was calculated and used in all analyses.

All sharks caught during the survey were identified to species, and relevant biological data, including sex, length (cm), weight (kg), life stage, and umbilical scar status were recorded. Length measurements were taken for precaudal length (PCL), FL, TL, and stretched total length (STL). Life stage was classified as either young of the year (age 0; umbilical scar present), juvenile (not yet mature), or adult. Males were considered mature if their claspers were calcified and their lengths were in accord with previously published lengths at maturity. Female maturity was determined according to previously published lengths at maturity. The status of age-0 sharks was based on the degree of umbilical scar healing using the criteria described by Aubrey and Snelson (2007): 1 = umbilical remains present, 2 = open or fresh scar, 3 = partially open, some healing, 4 = well-healed, scar visible, and 5 = no scar present. All sharks caught alive were tagged in the dorsal fin with a numbered roto-tag provided by NOAA–Fisheries and released.

Data analysis.—Since the majority of hooks were recovered without bait, soak time was not included in the calculations of catch rates. Catch rates were expressed as catch per unit effort (CPUE), i.e., the number of sharks per 50 hooks. Overall CPUE was calculated on a monthly basis for all sharks caught in Cumberland and Nassau sounds. Generalized trends in abundance were examined by calculating mean monthly CPUE from 2009 to 2011. Analysis of variance (ANOVA) was used to test for differences in overall CPUE between years.

Two types of analysis were used to examine the effect of environmental data on shark catches. Due to the large number of sets that caught no sharks, catch data were split into presence/absence and abundance data. Presence/absence data were generated by determining whether or not each set caught at least one shark. Sets that caught zero sharks were then removed and abundance data were generated for each set that caught at least one shark. Analyses were performed using these data for the three most abundant shark species. Logistic regression models (proc logistic; SAS version 10.0) were developed using presence/absence data to determine which environmental factors had an effect on whether or not a set caught at least one shark. The factors included in the models were site, month, bottom water temperature, depth, salinity, dissolved oxygen (DO), and all biologically relevant interactions between factors. For all sets that caught at least one shark, general linear models (GLMs; proc glm; SAS version 10.0) were used to determine which factors had the greatest effect on shark abundance. The same factors used in the logistic regression models were also used in the GLMs. Final models for both the logistic regressions and GLMs were determined using a backwards stepping procedure. Nonsignificant interactions were eliminated first, followed by nonsignificant main effects. Factors were deemed significant if $P < 0.05$.

RESULTS

Overall Abundance

A total of 310 longline sets were made in Cumberland Sound ($n = 147$) and Nassau Sound ($n = 163$) from 2009 to 2011. A total of 622 sharks representing 11 species were caught (Table 1). Sixty-seven percent of all sets caught at least one shark, and the number of sharks caught (mean ± SE) per set (for sets that caught at least one shark) was 3.01 ± 0.19. The species composition included all four species of the small coastal shark complex (Atlantic Sharpnose Sharks, Bonnetheads, Blacknose Sharks, and Finetooth Sharks) and five species from the large coastal shark complex (Blacktip, Sandbar, Scalloped Hammerhead, Spinner, and Lemon sharks)

TABLE 1. Species composition, abundance, percent of total catch, sex, and life stage for all sharks caught in Cumberland and Nassau sounds from 2009 to 2011. Species are in order of overall abundance (most to least abundant); NS = sex unknown, NR = not recorded.

			Sex			Life stage			
Shark species	No. caught	% of catch	Male	Female	NS	Age 0	Juvenile	Adult	NR
Atlantic Sharpnose *Rhizoprionodon terraenovae*	348	55.9	274	68	6	128	19	196	5
Blacktip *Carcharhinus limbatus*	95	15.3	40	52	3	53	36	5	1
Bonnethead *Sphyrna tiburo*	63	10.1	11	49	3	4	8	49	2
Sandbar *C. plumbeus*	36	5.8	22	13	1	8	26	1	1
Scalloped Hammerhead *S. lewini*	22	3.5	17	4	1	4	17	0	1
Finetooth *C. isodon*	19	3.1	15	3	1	1	13	3	2
Blacknose *C. acronotus*	15	2.4	10	5	0	0	1	14	0
Spinner *C. brevipinna*	11	1.8	6	5	0	10	1	0	0
Nurse *Ginglymostoma cirratum*	9	1.4	4	3	2	0	9	0	0
Lemon *Negaprion brevirostris*	3	0.5	0	2	1	0	3	0	0
Smooth Dogfish *Mustelus canis*	1	0.2	0	1	0	0	0	1	0
Total	622	100.0							

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 2. Environmental conditions experienced by sharks caught in Cumberland and Nassau sounds from 2009 to 2011. Means and ranges (in parentheses) are given. Data are provided for all sharks as a group, the three most abundant species (in order of abundance), and sets that caught no sharks.

Shark species	Depth (m)	Bottom temp. (°C)	Salinity (‰)	DO (mg/L)
All sharks	6.0	27.2	33.5	5.2
	(1.8–12.8)	(19.1–36.2)	(24.2–37.7)	(2.96–9.58)
Atlantic Sharpnose	6.1	27.4	33.3	5.2
	(1.8–12.8)	(20.1–36.2)	(24.2–37.7)	(3.18–9.58)
Blacktip	5.3	28.1	33.1	5.1
	(2.3–11.8)	(22.6–36.2)	(24.2–36.8)	(3.1–8.77)
Bonnethead	5.8	27.8	33.3	4.6
	(1.8–12.0)	(20.9–31.0)	(24.2–37.0)	(2.96–6.40)
Sets with no sharks	6.2	25.6	33.0	5.4
	(2.0–14.3)	(17.3–30.6)	(9.8–37.1)	(1.28–8.16)

as well as Nurse Sharks and Smooth Dogfish. All 11 species were caught in Cumberland Sound and 9 species were caught in Nassau Sound. With the exception of the Blacknose Shark, all species were caught in greater numbers in Cumberland Sound than in Nassau Sound. Of the 622 sharks that were caught, Atlantic Sharpnose Sharks ($n = 348$), Blacktip Sharks ($n = 95$), and Bonnetheads ($n = 63$) were the most abundant species and accounted for 81.4% of the total catch.

The mean CPUE for all sharks from 2009 to 2011 was 1.60 sharks/50-hooks (SD = 1.96). Annual mean CPUE was highest for 2010 (2.15; SD, 1.96); however, there was no significant difference in CPUE between years ($F = 0.38$, $P > 0.05$). Mean monthly CPUE increased with increasing mean monthly temperature, from 0.18 sharks/50-hooks in April to a maximum of 3.27 sharks in July. After July, monthly CPUE decreased steadily through the late summer and fall (Figure 2).

Environmental Analysis

Sharks were caught in Cumberland and Nassau sounds in a wide range of environmental conditions (Table 2). Logistic regressions produced significant models for Atlantic Sharpnose Sharks, Blacktip Sharks, and Bonnetheads (Table 3). Site, month, bottom temperature, DO, and month × bottom temperature were significant factors for Atlantic Sharpnose Sharks. The probability of catching at least one shark was higher in Cumberland Sound than in Nassau Sound (Figure 3). Also, the mean bottom temperature was warmer for sets that caught at least one Atlantic Sharpnose Shark than for sets that did not (Figure 4). The factors that significantly influenced the presence/absence of Blacktip Sharks were month, site, bottom temperature, and depth. Sets that caught at least one Blacktip Shark were warmer than those that did not (Figure 4). Dissolved oxygen was slightly lower for sets that caught Blacktip Sharks (5.0 ± 0.12 mg/L) than for sets that did not (5.3 ± 0.06 mg/L). The only

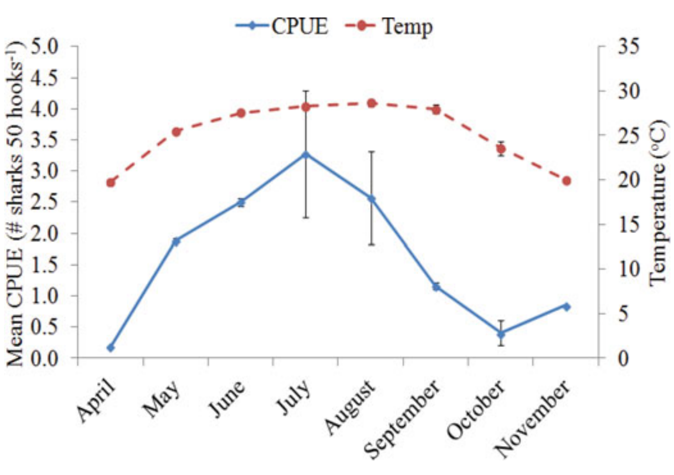

FIGURE 2. Mean monthly CPUE for all sharks caught in Cumberland and Nassau sounds from 2009 to 2011 and the corresponding mean monthly water temperatures (°C). Error bars denote SEs.

TABLE 3. Logistic regression results and significance ($P < 0.05$) of factors used in the models to examine the effect of environmental factors on the presence/absence of three shark species in Cumberland and Nassau sounds. Whole-model statistics are given in parentheses to the right of the species' names.

Variable(s)	Wald χ^2	P
Atlantic Sharpnose Sharks (log likelihood = 35.4; Wald $\chi^2 = 28.3$, $P < 0.0001$; df = 5)		
Site	15.5	< 0.0001
Bottom temp.	9.6	0.0019
Month × bottom temp.	4.8	0.0277
Dissolved oxygen	4.7	0.0307
Month	4.1	0.0421
Blacktip Sharks (log likelihood = 43.0; Wald $\chi^2 = 27.9$, $P < 0.0001$; df = 4)		
Bottom temp.	17.3	< 0.0001
Depth	5.6	0.0181
Site	5.3	0.0219
Month	4.9	0.0259
Bonnetheads (log likelihood = 20.5; Wald $\chi^2 = 17.9$, $P < 0.0001$; df = 1)		
Dissolved oxygen	17.9	< 0.0001

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

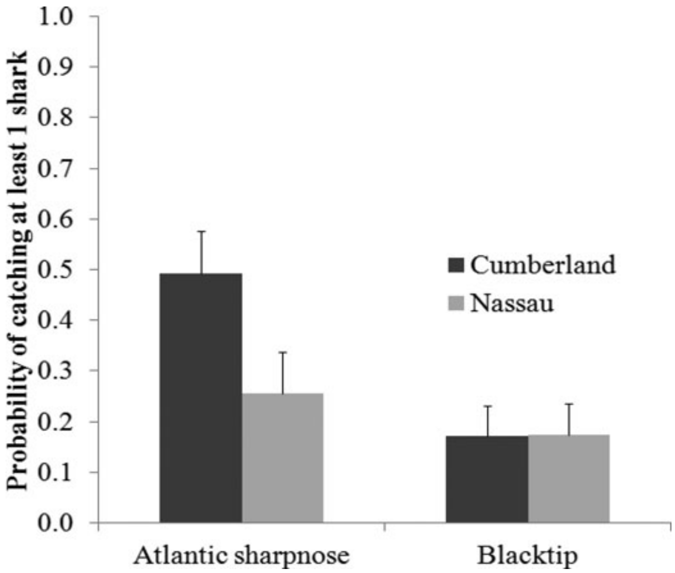

FIGURE 3. Mean probability of catching at least one Atlantic Sharpnose Shark or Blacktip Shark in Cumberland and Nassau sounds. Error bars denote SEs.

significant factor affecting the presence/absence of Bonnetheads was dissolved oxygen, with sets that caught them having a lower DO (4.59 ± 0.15 mg/L) than sets that did not (5.35 ± 0.06 mg/L).

Analysis of the abundance data using GLMs produced significant models for Atlantic Sharpnose and Blacktip sharks as well as Bonnetheads (Table 4). The factors that significantly influenced the abundance of Atlantic Sharpnose Sharks were site and bottom temperature. Atlantic Sharpnose Sharks were more abundant in Cumberland Sound (2.7 ± 0.3 sharks/set; $n = 228$) than in Nassau Sound (2.0 ± 0.2 sharks/set; $n = 128$), and sets that caught more than the mean number of sharks were in warmer water than sets that caught less than the mean number (Table 5). For Bonnetheads, the only significant factor in the GLM was salinity, with 60% of all Bonnethead captures occurring in salinities of 30‰ or more. The GLM for Blacktip Sharks was the most complex. Depth, bottom temperature, salinity, and DO were all significant factors, as were multiple interactions between these variables. Blacktip Shark abundance was higher in warm, deep water with lower levels of DO (Table 5). Seventy-nine percent of all Blacktip Sharks were caught in waters with a salinity of 30‰ or greater.

TABLE 4. Results of general linear models used to examine the effect of environmental factors on the abundance of sharks in Cumberland and Nassau sounds. See Table 3 for additional information.

Variable(s)	F–value	P
Atlantic Sharpnose Sharks ($F = 6.64$, $P = 0.0018$; $R^2 = 0.09$; df = 2)		
Bottom temp.	8.98	0.0032
Site	5.78	0.0175
Blacktip Sharks ($F = 3.96$, $P = 0.0012$; $R^2 = 0.40$; df = 8)		
Depth	13.2	0.0007
Bottom temp.	7.7	0.008
DO	7.0	0.0111
Salinity	4.1	0.0484
Depth × bottom temp.	13.9	0.0005
Depth × bottom temp. × DO	12.7	0.0009
Depth × DO	12.0	0.0011
Bottom temp. × DO	7.4	0.009
Bonnetheads ($F = 8.4$, $P = 0.0064$; $R^2 = 0.19$; df = 1)		
Salinity	8.4	0.0064

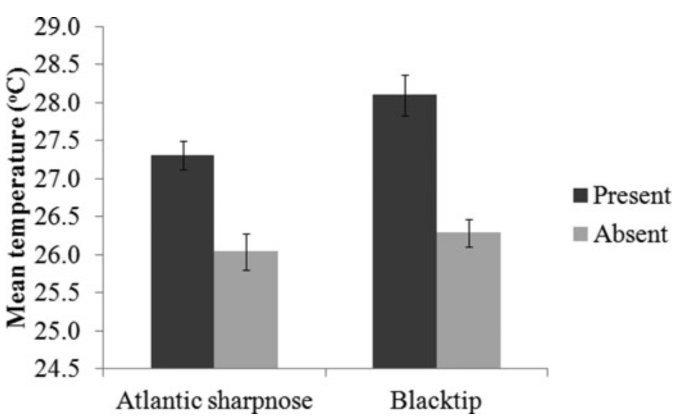

FIGURE 4. Mean bottom temperature for sets that caught at least one Atlantic Sharpnose Shark or Blacktip Shark (present) and sets that did not catch any sharks (absent) in Cumberland and Nassau sounds combined. Error bars denote SEs.

Species-Specific Results

Atlantic Sharpnose Sharks.—Atlantic Sharpnose Sharks ($n = 348$) were the most abundant species caught at the study sites and accounted for 55.9% of the total catch. Individuals were caught in all months of the survey except for April, with the highest number of sharks being caught between May and September (Figure 5a). The lengths of captured Atlantic Sharpnose Sharks ranged from 31 to 102 cm TL (Figure 6a). Mature sharks made up 57% of the total catch, were most abundant in May and June, and had a mean length of 89.0 cm TL. Age-0 individuals made up 37% of the total catch and were present from May to September, with greatest abundances occurring in July and August. They had a mean length of 40.9 cm. All age-0 individuals that were caught had umbilical scars that were mostly healed or well healed; none were found with umbilical remains or fresh/open umbilical scars. Juveniles, which were caught between June and October, made up only 6% of the total catch and had a mean length of 58.0 cm. The overall sex ratio of females to males was 1:4.03, significantly different from 1:1 ($\chi^2 = 122.88$, $P < 0.0001$), with males ($n = 274$) making up 78.8% of the catch. Of the 68 females caught, all but 1 were age-0 and juvenile

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 5. Mean ± SE bottom temperature, depth, and dissolved oxygen (DO) values for sets that caught ≥3 and <3 Atlantic Sharpnose and Blacktip sharks per set. Values are not provided for depth and DO for Atlantic Sharpnose Sharks because these factors were not significant.

	Bottom temp. (°C)		Depth (m)		DO (mg/L)	
Shark species	≥3	<3	≥3	<3	≥3	<3
Atlantic Sharpnose	27.8 ± 0.2	27.1 ± 0.3				
Blacktip	29.4 ± 0.4	27.9 ± 0.3	6.5 ± 0.8	5.1 ± 0.3	4.3 ± 0.1	5.2 ± 0.2

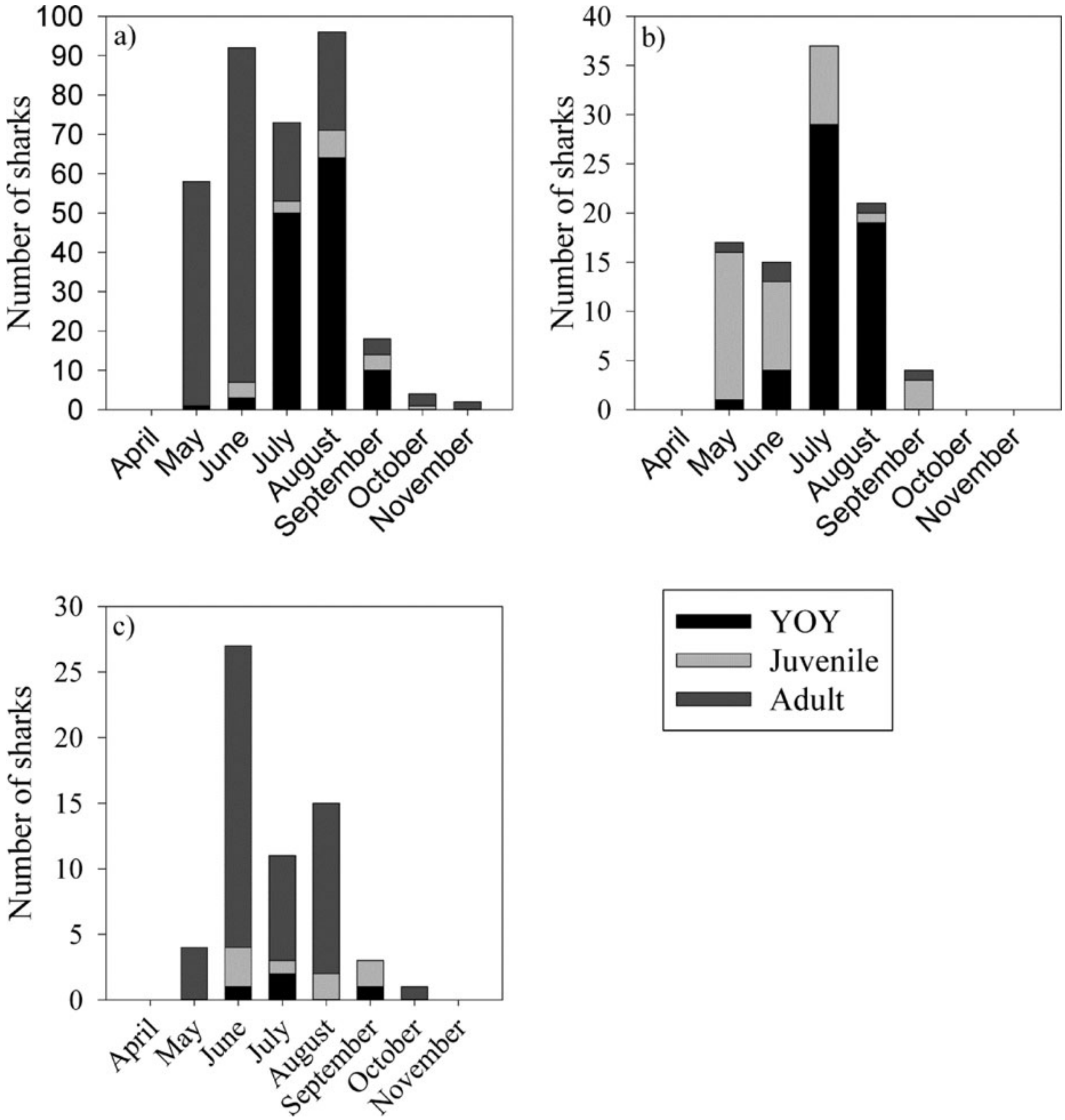

FIGURE 5. Monthly abundance of **(a)** Atlantic Sharpnose Sharks, **(b)** Blacktip Sharks, and **(c)** Bonnetheads in Cumberland and Nassau sounds from 2009 to 2011, by each life stage.

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

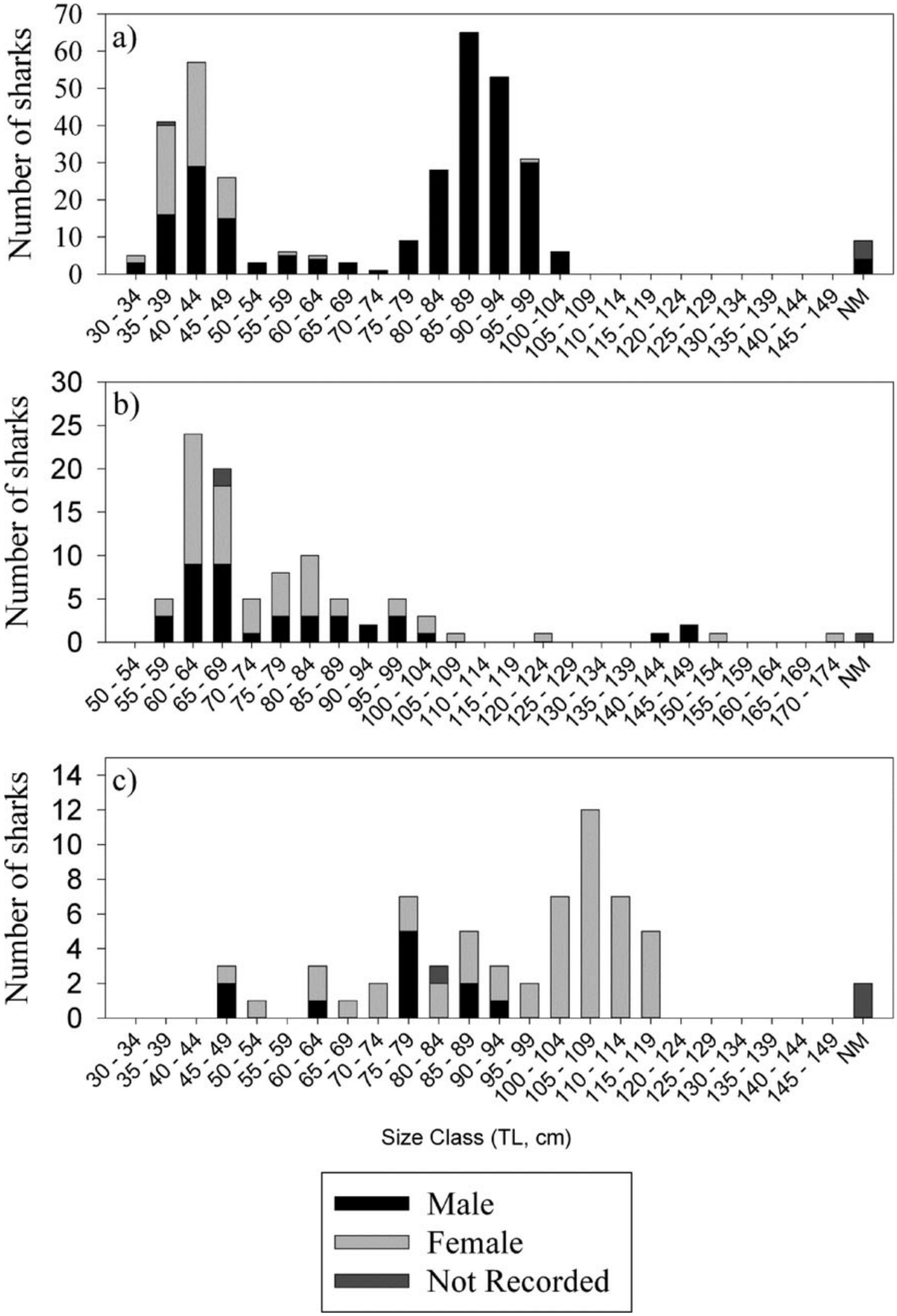

FIGURE 6. Length frequency plots for **(a)** Atlantic Sharpnose Sharks, **(b)** Blacktip Sharks, and **(c)** Bonnetheads caught in Cumberland and Nassau sounds from 2009 to 2011, by sex. Lengths are grouped into 5-cm length bins; NM = not measured.

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

individuals. A single gravid female (95 cm TL) was caught in Nassau Sound on May 19, 2010, and gave birth to three full-term pups while on the line.

Blacktip Sharks.—Blacktip Sharks ($n = 95$) were the second most abundant species caught in the survey and accounted for 15.3% of the total catch. This was the most abundant species caught in the large coastal shark complex. Individuals were only present from May to September, the greatest abundance being seen between June and August (Figure 5b). They ranged in size from 56 to 173 cm TL and included age-0, juvenile, and adult individuals (Figure 6b). Primarily age-0 (57%) and juvenile (38%) individuals were caught during the survey. Age-0 Blacktip Sharks (mean length = 64.1 cm) were present from May to August, with the greatest abundance occurring in July and August. Umbilical scars in various stages of healing (fresh to well-healed) were observed on all age-0 Blacktip Sharks. Juveniles (mean length = 87.2 cm) were present from May to September. Only five mature Blacktip Sharks (three males, two females) were caught during the survey (mean length = 152.8 cm).

Bonnetheads.—A total of 63 Bonnetheads were caught from 2009 to 2011. This was the third most abundant species caught during the survey and comprised 10.1% of the total catch. Bonnetheads were present from May to October, with the majority of animals being caught in the summer (Figure 5c). Bonnetheads were captured at lengths ranging from 41 to 118 cm TL (Figure 6c); the male-to-female ratio was 1:4.45, significantly different than 1:1 ($\chi^2 = 22.82$, $P < 0.0001$). Adult Bonnetheads (mean length = 100 cm) were most abundant from June to August, comprised 80% of the catch, and were mostly female. Very few juvenile ($n = 8$) and age-0 ($n = 4$) sharks were captured. Juveniles had a mean length of 68.1 cm, and age-0 individuals had a mean length of 47.9 cm.

Other species.—The remaining eight species made up a total of 18.6% of the total catch; only Sandbar Sharks (5.8%) comprised more than 5%. For most of these species, the majority of the animals captured were age-0 and juvenile individuals; however, only mature Blacknose Sharks were caught. Catches of Sandbar Sharks consisted primarily of juveniles, and they were the predominant species caught in the cooler months of the survey (April, October, and November). All of the Spinner Sharks caught during the survey were age-0 animals with healing umbilical scars, and they were only caught in July and August.

Tag–Recapture Data

A total of 419 sharks were tagged in Cumberland and Nassau sounds from 2009 to 2011, and 18 were recaptured (Table 6), for a recapture rate of 4.3%. Of the 18 sharks recaptured, 17 were initially tagged in Cumberland Sound and 1 in Nassau Sound. The longest time at liberty was 411 d for a mature male Atlantic Sharpnose Shark tagged in Cumberland Sound in May 2010 and recaptured in Cumberland Sound in June 2011 at a distance of 2.6 km from where it was tagged. The longest distance traveled was 190.5 km for a mature male Atlantic Sharpnose Shark tagged in Cumberland Sound in August 2009 and recaptured off Cape Canaveral, Florida, in March 2010. An Atlantic Sharpnose Shark was tagged in Cumberland Sound on July 1, 2009, and recaptured 14 d later in Nassau Sound having traveled ~21 km.

TABLE 6. Shark recaptures from 2009 to 2011 for individuals from Cumberland and Nassau sounds. Days refers to the number of days between initial capture and recapture; distance is the straight-line distance between the tagging and recapture locations. Abbreviations are as follows: M = male, F = female, CS = Cumberland Sound, and NS = Nassau Sound.

Shark species	Sex	Life stage	Date tagged	Location tagged	Location recaptured	Days	Distance (km)
Atlantic Sharpnose	M	Mature	Jul 1, 2009	CS	NS	14	20.6
	M	Mature	Aug 5, 2009	CS	CS	326	2.6
	M	Mature	Aug 5, 2009	CS	Daytona Beach	224	190.5
	M	Mature	Aug 5, 2009	CS	CS	32	2.1
	M	Mature	Aug 17, 2009	CS	CS	4	3.9
	M	Mature	May 4, 2010	CS	CS	411	3.5
	M	Mature	May 10, 2010	CS	CS	13	2.5
	M	Mature	May 25, 2011	CS	CS	352	3.7
Blacktip	M	Juvenile	Jul 15, 2009	CS	CS	63	3.1
	F	Age 0	Jul 15, 2009	CS	CS	71	7.3
	F	Juvenile	Sep 9, 2009	CS	CS	39	7
	M	Juvenile	June 2, 2010	NS	Little Talbot Island	100	18.1
	F	Juvenile	May 20, 2011	CS	CS	63	0.9
Bonnethead	F	Mature	May 6, 2010	CS	Fernandina Beach	23	7.3
	F	Age 0	Jul 13, 2011	CS	CS	4	3.8
Sandbar	M	Age 0	Jul 22, 2011	CS	CS	30	2.7
	M	Age 0	Aug 11, 2011	CS	CS	9	1.9
Spinner	M	Age 0	Aug 5, 2011	CS	CS	13	1.7

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

Fifteen of the 18 recaptured sharks were caught less than 10 km from where they were initially tagged. All 10 age-0 and juvenile sharks that were recaptured were recaught the same year they were tagged.

DISCUSSION

This study represents the first attempt to characterize the abundance and distribution of shark populations in the nearshore and estuarine waters of northeast Florida. Eleven species were caught from 2009 to 2011, including species in both the small and large coastal shark management units. This suggests that the estuarine waters of Cumberland and Nassau sounds support a wide variety of shark species. Although there are no studies from northeast Florida with which we can compare our results, our results are similar to those of previous studies from South Carolina (Ulrich et al. 2007) and, in particular, Georgia (Belcher and Jennings 2010). The shark species composition identified in this study was similar to that in estuarine waters of Georgia (Belcher and Jennings 2010), with Atlantic Sharpnose and Blacktip sharks and Bonnetheads comprising the majority of the catch.

The presence and abundance of sharks in Cumberland and Nassau sounds were affected most by site, bottom temperature, and month. The higher probability of catching a shark and overall greater abundance of sharks in Cumberland Sound suggest that there are differences in the abundance and distribution of sharks between these two regions. This is not unexpected, as previous studies have also shown regional differences in shark abundance in nearshore ecosystems in southwest Florida (Simpfendorfer et al. 2005), Florida Bay (Torres et al. 2006), and the Indian River Lagoon system (Curtis 2008). Since sampling effort between the two sites was comparable, this difference is not likely the result of sampling effort bias. Also, environmental conditions were very similar between the two regions and likely did not have a great influence in regional differences in shark abundance. It is possible that Cumberland Sound ($\sim$41.3 km^2) offers more potential habitat for sharks, particularly juvenile sharks, given its larger area in comparison with Nassau Sound ($\sim$30.1 km^2). It should also be noted that the entrance to Cumberland Sound is a deep dredged channel, while the entrance to Nassau Sound is a shallow, natural inlet with continuously changing sandbars (McCallister, personal observations). Thus, it is also possible that the constantly changing nature of the entrance to Nassau Sound limits the movement of sharks into the sound.

The significance of month and bottom temperature in the models for presence and abundance indicate that use of northeast Florida estuaries by sharks is seasonal. Although sharks were caught in all months of the survey, sets that caught sharks were in warmer waters (mean = 27.2°C) than sets that did not (mean = 25.6°C). Since no sharks were caught in waters below 19°C, it is likely that the movement of sharks into northeast Florida estuaries requires a minimum, or threshold, water temperature, which is consistent with the findings for other coastal estuaries. Temperature was the driving factor for the movement of Sandbar Sharks into nurseries in both Delaware (Merson and Pratt 2001) and Chesapeake bays (Grubbs et al. 2007). Similarly, Castro (1993) and Ulrich et al. (2007) documented the presence of sharks in South Carolina estuaries after water temperatures reached $\sim$19–20°C. Increasing shark abundance at higher temperatures is also expected. In the coastal waters of Texas, Froeschke et al. (2010) showed that shark catch rates increased as temperatures increased between 20°C and 30°C, a trend also seen in the present study. Also, coastal waters tend to be warmest during summer months when parturition for species like Atlantic Sharpnose and Blacktip sharks occurs (Castro 2011:509–513), resulting in increased shark catches, particularly of age-0 individuals (Parsons and Hoffmayer 2007). Catches of such sharks in this study were highest during summer months.

The results from this survey suggest that the estuarine waters of Cumberland and Nassau sounds serve as nursery habitat for Atlantic Sharpnose and Blacktip sharks. High catches of age-0 Atlantic Sharpnose Sharks with healing and healed umbilical scars in summer months, particularly July and August, suggest that this area serves as a primary nursery, with immigration into the nursery occurring in early summer. This is consistent with findings from the coastal waters of South Carolina, where neonate and age-0 individuals are captured beginning in late May (Ulrich et al. 2007). Similar patterns of nursery habitat use have also been observed for age-0 Atlantic Sharpnose Sharks in the northeast Gulf of Mexico (Carlson and Brusher 1999; Drymon et al. 2010). The lack of mature female Atlantic Sharpnose Sharks in this survey is consistent with the results of studies in the nearshore waters of the north-central Gulf of Mexico (Parsons and Hoffmayer 2005; Drymon et al. 2010). In those studies mature females were caught almost exclusively in offshore waters, and Parsons and Hoffmayer (2005) suggested that gravid females only move inshore to give birth during a very brief time interval. This could explain the capture of only one gravid female in this study.

The high abundance of age-0 Blacktip Sharks with visible umbilical scars and juveniles suggests that these waters act as both primary and secondary nursery areas during the summer months. The appearance of older juveniles in late spring and age-0 individuals in early summer (after females give birth) is consistent with the occurrence of Blacktip Sharks in nurseries in both the northwest Atlantic (Castro 1996) and northeast and north-central Gulf of Mexico (Bethea et al. 2004; Parsons and Hoffmayer 2007). Also, limited tag–return data suggest that age-0 and juvenile Blacktip Sharks use these estuaries throughout the summer months, before moving offshore in the fall. This is similar to the movement patterns of juvenile Blacktip Sharks in Terra Ceia Bay, Florida identified by Heupel and Hueter (2001, 2002).

The overall low abundance of Bonnetheads during this survey can likely be attributed to gear bias. This is not surprising, as other studies of shark nurseries that have used longline

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

gear also reported low Bonnethead catches (e.g., Belcher and Jennings 2010), while studies that have used nets reported much higher catches (e.g., Ulrich et al. 2007). Indeed, on the few occasions when a gill net was used in the present survey, the catch consisted almost completely of Bonnetheads (McCallister et al., unpublished data). Despite these low catches, the presence of gravid females and a few age-0 individuals with healed umbilical scars suggest that these waters serve as nursery habitat for Bonnetheads in some respect.

It is important to note that the gear bias associated with using longlines instead of gill nets is not limited to the ability to catch Bonnetheads and likely influenced the overall catch composition of this survey. Ulrich et al. (2007) found significant differences in relative abundance and size at capture for Finetooth and Atlantic Sharpnose sharks as well as Bonnetheads when using both longlines and gill nets to survey sharks in the estuarine waters of South Carolina. Gill nets caught both greater numbers of Finetooth and Atlantic Sharpnose sharks as well as smaller individuals. This is not surprising, as Carlson and Cortes (2003) showed that gill nets have high selectivity for these species. Unfortunately, the ability to consistently and effectively use a gill net in our survey was limited because of environmental constraints, specifically, strong tidal currents and sudden changes in depth over very short distances. Despite this, it is apparent that the use of a gill net would expand on this survey, and methods for sampling using both longlines and gill nets are currently being considered.

It has been suggested that the mere presence of gravid females and/or the high abundance of age-0 and juvenile sharks in an area does not mean that the area is a nursery or that it functions as critical habitat (Heithaus 2007). Instead, Heupel et al. (2007) proposed using well-defined criteria to quantitatively assess whether an area serves as nursery habitat. Though this issue was not directly examined in this study, our data suggest that Cumberland and Nassau sounds satisfy two of these criteria: (1) juvenile sharks remain there for extended periods of time and (2) the area is used repeatedly across years. Tag–return data from four Blacktip Sharks tagged in Cumberland Sound and recaptured less than 7 km from their initial location after 1–2 months at liberty suggest that sharks remain in that area for extended periods of time. Also, the fact that age-0 and juvenile individuals of the four most abundant species were caught in each year of the survey suggests that Cumberland and Nassau sounds are used repeatedly across multiple years. Continued sampling within these regions, along with expanding the survey to surrounding areas, will enable further testing of these criteria.

Given the current need to identify EFH and incorporate this information into fishery management plans (NMFS 1996), studies that identify and describe shark nursery habitat are increasing. Although nursery grounds have already been identified and studied extensively for some of the species caught in this survey (see McCandless et al. 2007), many of the species are highly migratory, so identifying potential nursery habitat throughout their range will provide a more detailed account of the location of EFH. Given the lack of information on shark habitat use in these waters, it is important that these areas be described. Further research will provide more species-specific data on nursery habitat use in this region, including predator–prey relationships, movement patterns within nurseries, and species interactions.

ACKNOWLEDGMENTS

This work was funded by a grant to J.G. from the National Oceanic and Atmospheric Association, National Marine Fisheries Service (NOAA–NMFS), Cooperative Atlantic States Shark Pupping and Nursery Survey Program. Additional financial support was provided by two Graduate Scholar Grants to M.M. by the University of North Florida (UNF) Graduate Program and a Faculty Summer Scholarship Grant to J.G. from the UNF Department of Academic Affairs. The UNF Biology Department provided the vessels and vehicles used during this study. Tags and tagging equipment were provided by NOAA–NMFS, Division of Highly Migratory Species. M. Heithaus, E. Johnson, and A. Piercy provided valuable help with the statistical analyses in this paper. Special thanks are extended to other UNF students who contributed significantly to this survey, especially B. Anderson, A. Breakey, A. Leary, R. Smith, and C. Walker, without whom it would have been impossible to complete this study. This research was conducted under the authorization of the Florida Fish and Wildlife Conservation Commission (Special Activity License SAL-09-1136A-SR) and the UNF Institutional Animal Care and Use Committee.

REFERENCES

Aubrey, C. W., and F. F. Snelson Jr. 2007. Early life history of the Spinner Shark in a Florida nursery. Pages 175–189 *in* C. T. McCandless, N. E. Kohler, and H. L. Pratt Jr., editors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Bass, A. J. 1978. Problems in the studies of sharks in the southwest Indian Ocean. Pages 545–594 *in* E. S. Hodgson and R. F. Matthews, editors. Sensory biology of sharks, skates, and rays. Department of Navy, Office of Naval Research, Arlington, Virginia.

Belcher, C. N., and C. A. Jennings. 2010. Utility of mesohabitat features for determining habitat associations of subadult sharks in Georgia's estuaries. Environmental Biology of Fisheries 88:349–359.

Bethea, D. M., J. A. Buckel, and J. K. Carlson. 2004. Foraging ecology of the early life stages of four sympatric shark species. Marine Ecology Progress Series 268:245–264.

Branstetter, S. 1990. Early life history implications of selected carcharhinoid and lamnoid sharks of the northwest Atlantic. NOAA Technical Report NMFS 90:17–28.

Carlson, J. K., and J. H. Brusher. 1999. An index of abundance for coastal species of juvenile sharks from the northeast Gulf of Mexico. Marine Fisheries Review 61:37–45.

Carlson, J. K., and E. Cortes. 2003. Gillnet selectivity of small coastal sharks off the southeastern United States. Fisheries Research 50:405–414.

Castro, J. I. 1993. The shark nursery of Bulls Bay, South Carolina, with a review of the shark nurseries of the southeastern coast of the United States. Environmental Biology of Fishes 38:37–48.

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use

Castro, J. I. 1996. Biology of the Blacktip Shark, *Carcharhinus limbatus*, off the southeastern United States. Bulletin of Marine Science 59:508–522.

Castro, J. I. 2011. The sharks of North America. Oxford University Press, New York.

Curtis, T. H. 2008. Distribution, movements, and habitat use of Bull Sharks (*Carcharhinus leucas*, Muller and Henle 1839) in the Indian River Lagoon system, Florida. Master's thesis, University of Florida, Gainesville.

Drymon, J. M., S. P. Powers, J. Dindo, B. Dzwonkowski, and T. A. Henwood. 2010. Distributions of sharks across a continental shelf in the northern Gulf of Mexico. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science [online serial] 2:440–450.

FAO (Food and Agriculture Organization of the United Nations). 2000. Conservation and management of sharks. FAO, Technical Guidelines for Responsible Fisheries 4, supplement 1, Rome.

FLDEP (Florida Department of Environmental Protection). 2007. Water quality assessment report Nassau–St. Mary's. Division of Water Resource Management, Tallahassee, Florida.

Froeschke, J., G. W. Stunz, and M. L. Wildhaber. 2010. Environmental influences on the occurrence of coastal sharks in estuarine waters. Marine Ecology Progress Series 407:279–292.

Grubbs, R. D., J. A. Musick, C. L. Conrath, and J. R. Romine. 2007. Long-term movements, migration, and temporal delineation of a summer nursery for juvenile Sandbar Sharks in the Chesepeake Bay region. Pages 87–107 *in* C. T. McCandless, N. E. Kohler, and H. L. Pratt Jr., editors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Heithaus, M. R. 2007. Nursery areas as essential shark habitats: a theoretical perspective. Pages 3–13 *in* C. T. McCandless, N. E. Kohler, and H. L. Pratt, Jr. editors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Heupel, M. R., J. K. Carlson, and C. A. Simpfendorfer. 2007. Shark nursery areas: concepts, definition, characterization, and assumptions. Marine Ecology Press Series 337:287–297.

Heupel, M. R., and R. E. Hueter. 2001. Use of an automated acoustic telemetry system to passively track juvenile Blacktip Shark movements. Pages 217–236 *in* J. R. Sibert and J. L. Nielsen, editors. Electronic tagging and tracking in marine fisheries. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Heupel, M. R., and R. E. Hueter. 2002. The importance of prey density in relation to the movement patterns of juvenile sharks within a coastal nursery area. Marine and Freshwater Research 53:543–550.

Magnuson–Stevens Fishery Conservation and Management Act. 1996. U.S. Code, volume 16, sections 1801–1883.

McCandless, C. T., N. E. Kohler, and H. L. Pratt Jr., editors. 2007. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Merson, R. R., and H. L. Pratt Jr. 2001. Distribution, movements, and growth of young Sandbar Sharks, *Carcharhinus plumbeus*, in the nursery grounds of Delaware Bay. Environmental Biology of Fishes 61:13–24.

NMFS (National Marine Fisheries Service). 1996. Report on the 1996 shark evaluation workshop. National Oceanic and Atmospheric Administration, NMFS, Southeast Fisheries Science Center, Miami.

NMFS (National Marine Fisheries Service). 1999. Final fishery management plan for Atlantic tunas, Swordfish, and sharks. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2003. Final amendment 1 to the fishery management plan for Atlantic tunas, Swordfish, and sharks. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2006. Final consolidated Atlantic highly migratory species fishery management plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, Maryland.

Parsons, G. R., and E. R. Hoffmayer. 2005. Seasonal changes in the distribution and relative abundance of the Atlantic Sharpnose Shark *Rhizoprionodon terraenovae* in the north central Gulf of Mexico. Copeia 2005:914–920.

Parsons, G. R., and E. R. Hoffmayer. 2007. Identification and characterization of shark nursery grounds along the Mississippi and Alabama Gulf coasts. Pages 301–316 *in* C. T. McCandless, N. E. Kohler, and H. L. Pratt Jr., editors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Simpfendorfer, C. A., G. G. Freitas, T. R. Wiley, and M. R. Heupel. 2005. Distribution and habitat partitioning of immature Bull Sharks (*Carcharhinus leucas*) in a southwest Florida estuary. Estuaries 28:78–85.

Springer, S. 1967. Social organization of shark populations. Pages 149–174 *in* P. W. Gilbert, R. F. Mathewson, and D. P. Rall, editors. Sharks, skates, and rays. Johns Hopkins Press, Baltimore, Maryland.

Torres, L. G., M. R. Heithaus, and B. Delius. 2006. Influence of teleost abundance on the distribution and abundance of sharks in Florida Bay, USA. Hydrobiologia 569:449–455.

Ulrich, G. F., C. M. Jones, W. B. Driggers III, J. M. Drymon, D. Oakley, and C. Riley. 2007. Habitat utilization, relative abundance, and seasonality of sharks in the estuarine and nearshore waters of South Carolina. Pages 125–139 *in* C. T. McCandless, N. E. Kohler, and H. L. Pratt Jr., editors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Downloaded From: https://complete.bioone.org/journals/Marine-and-Coastal-Fisheries:-Dynamics,-Management,-and-Ecosystem-Science on 30 Mar 2023
Terms of Use: https://complete.bioone.org/terms-of-use