Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States: an overview

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NMFS INTERNAL REPORT TO NOAA'S HIGHLY MIGRATORY SPECIES OFFICE

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TABLE OF CONTENTS

INTRODUCTION

Shark nursery areas can be separated into primary nursery habitat, where parturition and young-of-the-year occur, and secondary nursery habitat, which is utilized by age 1+ juveniles (Bass 1978). Evidence supporting the use of nursery areas by juvenile sharks can be traced back 320 million years in the fossil record (Lund 1990). The use of shallow waters, such as those found in our coastal environments, as shark nursery habitat was first reported by Meek (1916) in reference to observations of pupping by two carcharhiniform sharks (*Galeorhinus* and *Mustelus* species). Shark nursery areas are frequently located in highly productive coastal or estuarine waters (Castro 1987). Studies suggest that these inshore nursery areas provide the advantages of low predation (Branstetter 1990) and high forage abundance (Rountree and Able 1996).

Springer (1967) hypothesized that a limiting factor on shark populations is the amount of suitable nursery habitat available. The importance of coastal and inshore nursery habitat to the productivity of many shark species has been recognized by fisheries management agencies in recent years (NMFS 1989, 1994, 1996, 1998). The Final Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks identifies the need for further delineation of these shark nursery areas and the determination of habitat relationships, such as temperature and salinity, between juvenile sharks and their nursery environment (NMFS 1999). Such information is vital to understanding and managing sharks at this vulnerable stage where many sharks come closest to man's influence (Casey and Taniuchi 1990, Pratt and Otake 1990).

Until recent years, detailed reports of the shark nursery grounds off the U.S. East Coast and the Gulf of Mexico have been nonexistent. The first report by Castro (1993) described the species that utilize Bulls Bay, South Carolina as a nursery, which included a review of the shark nurseries of the southeastern coast of the U.S. In the mid to late 1990's, the need for a better understanding of shark nursery habitat in U.S. coastal waters prompted the initiation of several detailed studies of U.S. coastal shark nursery grounds in almost all of the coastal states from New England to Texas. Rather than duplicate the efforts of these studies, an overarching document that provided a summary of their findings was a logical undertaking.

Fifteen chapters were contributed to this report by researchers from universities and state and federal agencies in twelve U.S. states bordering the northwestern Atlantic Ocean and the Gulf of Mexico from Massachusetts to Texas. The contributed data from these nursery studies were gathered using a variety of different methods including longline, gillnet and trawl surveys. Due to the differences in fishing effort, along with the variety in tidal currents and coastline configuration in the areas sampled, a cross comparison of catch rates between studies is impossible.

Participants were requested to supply a chapter for this report summarizing the findings for their study area. In addition to the chapters, raw data on juvenile shark catch and environmental parameters associated with the shark catches were supplied from each study for the synthesis of individual species summary tables and maps, found at the end of this report.

The purpose of this report is to provide managing agencies with a better understanding of contemporary shark nursery habitats. Cooperation between federal and state governments in developing coordinated conservation measures is critical to successful domestic management of coastal shark species because range, migrations and mating and pupping areas overlap some state and even federal jurisdictions (NMFS 1999).

I would like to thank my co-editors for their help and support during this project and NOAA's Highly Migratory Species Management Division for funding. I thank Pearse Webster of the South Carolina Department of Natural Resources (SCDNR) for providing the Southern Atlantic SEAMAP Shallow Water Trawl Survey data and to Doug

Adams of the Florida Fish and Wildlife Conservation Commission (FWC) for providing data from the Fisheries-Independent Monitoring Program (FIM) in Indian River Lagoon through the Florida Department of Environmental Protection. I especially thank the participating authors for sharing the results of their nursery research. The chapters and data provided by the authors are important contributions that will help develop a better understanding of how juvenile sharks utilize the Gulf of Mexico and Atlantic states coastal shark nurseries.

Camilla McCandless, Senior Editor
Narragansett, October 1, 2002

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Shark Nursery Areas in Massachusetts State Waters

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Scope

The Massachusetts Division of Marine Fisheries has been collecting data on the relative abundance and ecology of sharks in state waters through the Massachusetts Shark Research Program (MSRP) since 1990. To gather information on the inshore occurrence and ecology of shark species in Massachusetts waters, angler and longline surveys are conducted annually from June through September. Opportunistic samples are provided by recreational fishermen who commonly target sharks and by tournament anglers through the Massachusetts Sportfishing Tournament Monitoring Program. Biological parameters including age structure, feeding ecology, local movements, and reproductive status are examined through dissection and tagging of shark specimens.

Sampling Materials and Methods

Longline Survey

MSRP longlines were set from mid June through mid September of each year in two standard areas of Chappaquiddick Island: inside Cape Poge Bay and along the eastern coastline. These areas were established to standardize sampling at sites where recreational fishermen routinely target sharks. In some years, exploratory sets were deployed in other areas in Nantucket Sound.

Longline sets were typically 0.8 km in length consisting of 6.3 mm braided nylon mainline and 40-60 #40 Japanese tuna hooks on 1.5 m stainless cable gangions. Longlines were baited with menhaden, squid, or mackerel from 1990 to 1994 and American eel from 1995 to 1999. Longline sets were typically allowed to fish for 10-12 hrs. Sharks caught on longlines were measured (FL) and either tagged with standard NMFS tags ('M' tags or blue Rototags) or retained for dissection. The latter involved the determination of stomach contents and reproductive condition. Relative abundance indices (CPUE, sharks/100 hooks) were calculated and stratified by species, area, month, water temperature, and depth.

Recreational Angler Survey

Since 1989, recreational surf anglers who routinely target coastal sharks were asked to report catch information on a standardized survey form. This information included area of capture, date and time of capture, disposition of catch, fork length, sex, and bait. The majority of this effort was collected from anglers that fish sharks along the eastern shore of Chappaquiddick Island, Martha's Vineyard, but additional data were provided by Cape Cod and Nantucket fishermen.

Opportunistic Samples

Over the last decade, coastal sharks have been incidentally captured throughout the state and reported to the MSRP by recreational and commercial fishermen. In some cases, these sharks were provided to the MSRP for examination.

Description of Study Areas

The Massachusetts coastline can be divided into two general areas relative to shark nursery habitat. The Cape Cod landmass represents the northern geographic limit to the range of the smooth dogfish, *Mustelus canis*, sandbar shark, *Carcharhinus plumbeus*, and dusky shark, *Carcharhinus obscurus*, in the western North Atlantic. The major coastal areas south of the Cape comprise Buzzards Bay, Vineyard Sound, and Nantucket Sound. However, the sand tiger shark, *Carcharias taurus*, is known to occur both north and south of Cape Cod. The former includes Cape Cod Bay and Massachusetts Bay. Within these larger areas, the coastline is peppered with hundreds of bays and estuaries.

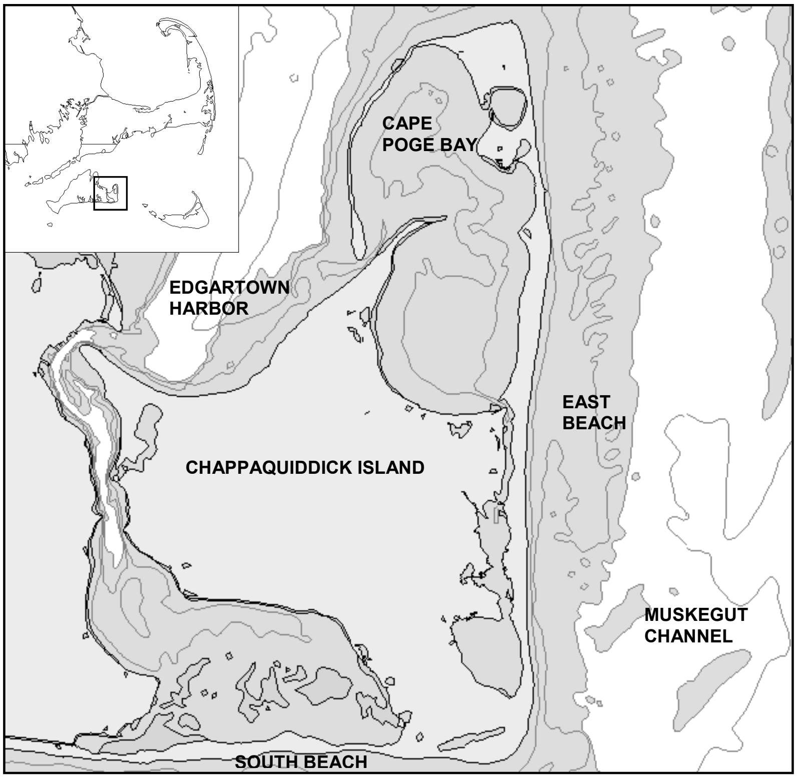

Figure 1. Chappaquiddick Island and Cape Poge Bay study area.

Although sharks were provided to the MSRP from coastal waters throughout the state, longline and recreational surveys were conducted in Nantucket Sound and, more specifically, off the eastern part of Martha's Vineyard Island (Chappaquiddick). Therefore, this report will primarily focus on these areas.

Vineyard and Nantucket Sounds

Vineyard Sound is bordered to the east by Martha's Vineyard Island, to the west by the Elizabeth Islands, and to the north by Nantucket Sound. The latter has Martha's Vineyard and Nantucket Islands to the south and Cape Cod to the north. The Sounds flood to the east, ebb to the west, and have an average tidal range of 0.3-1.0 m, depending on geographic location. Both water bodies are characterized by significant shoaling, broad areas less than 20 m deep, and deep pockets up to 28 m.

Vineyard and Nantucket Sounds feed water to several coastal bays and estuaries on Cape Cod and on the Elizabeth, Martha's Vineyard, and Nantucket Islands. Water temperatures in the Sounds and their associated estuaries fluctuate from year to year, but range from freezing in the winter months to 28 °C in the summer, depending on location. The coastal beaches, bays and estuaries associated with Nantucket and Vineyard Sounds are affected to varying degrees by anthropogenic activities including boating activities, marinas, mooring fields, private docks and piers, road runoff, and fishing.

Chappaquiddick Island

Chappaquiddick Island is connected to the eastern part of Martha's Vineyard Island by a thin barrier beach along its southern side. This approximately 8.3 x 5.0 km island has the Cape Poge Wildlife Refuge along most of its northern, eastern, and southern shorelines; it’s bordered by Edgartown Harbor on its west side (Figure 1). The eastern and southern sides of the island (East and South Beaches, respectively) support seasonal recreational surf fishing activities that catch sharks. The neritic waters of East Beach are part of Muskegut Channel, a major connection between the Atlantic Ocean and

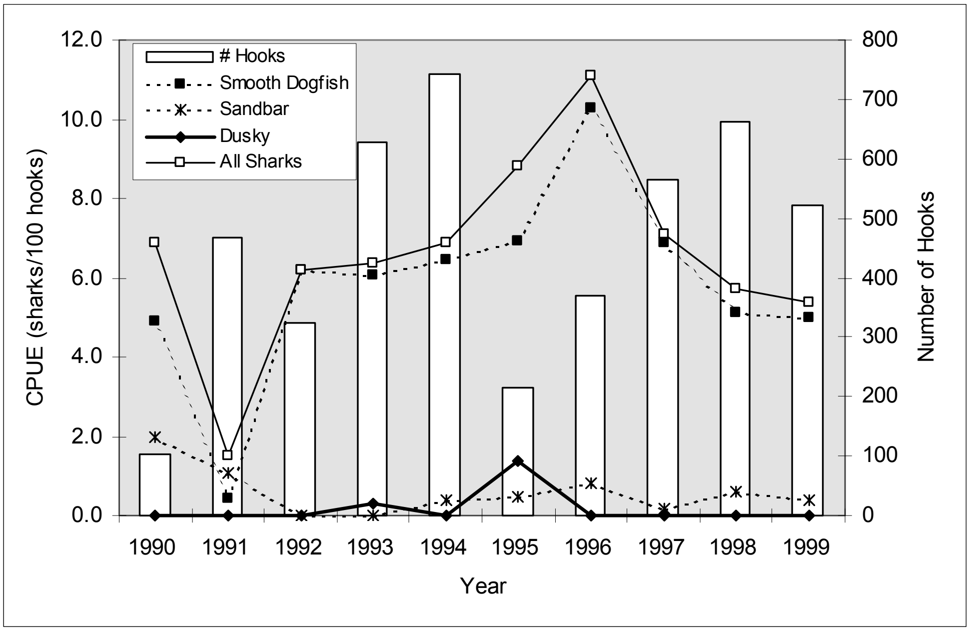

Figure 2. **Annual longline effort and shark CPUE, 1989-1999.**

Nantucket Sound. South Beach, however, has direct exposure to the Atlantic Ocean.

Cape Poge Bay is a large pristine estuary occupying the northern half of Chappaquiddick Island. The estuary is a productive homogeneous water mass with high tidal exchange through an inlet connected to the outer Edgartown Harbor on its western side (Figure 1). Water temperature and salinity (30-32 ppt) do not differ from the surrounding coastal waters of Nantucket Sound. Cape Poge Bay supports substantial fisheries for a number of species of shellfish and finfish. Although often used as an anchorage, Cape Poge Bay is a relative shallow water body (<4 m) and remains a town-protected resource with minimal anthropogenic disturbances.

Relative Abundance and Distribution____

From 1990 to 1999, 291 coastal sharks were caught by the MSRP longline survey, primarily in the region of Chappaquiddick Island. Of these, 265 (91%) were smooth dogfish (*Mustelus canis*), 21 (7%) were sandbar sharks (*C. plumbeus*), and 5 (2%) were dusky sharks (*C. obscurus*). Smooth dogfish were captured off East (72%) and South (4%) beaches as well as in Cape Poge Bay (22%). Although most of the sandbar sharks were taken off East Beach, 43% were captured in Cape Poge Bay. Four of the dusky sharks were taken off East Beach and one was taken off South Beach. All sharks were taken between mid-June and late September. Relative abundance indices for sharks caught by the MSRP longline survey are summarized in Figure 2.

From 1989 to 1999, 206 sandbar sharks were reported to the MSRP by recreational anglers (Figure 3). Although most were taken off East Beach (87%), others were caught off South Beach (5%), in Cape Poge Bay (3%), and off the south shore of Cape Cod (5%). The proportional catch of sandbar sharks from these areas is indicative of survey effort and not relative abundance. Fishing reports of sandbar sharks being caught along the south side of Cape Cod and off Nantucket Island provide anecdotal evidence that the distribution of this species is probably more widespread in Nantucket Sound than this survey may indicate. All the sandbar sharks reported to the MSRP were caught between June 21 and October 2.

Nine sand tiger sharks have been reported to the MSRP since 1989. With the exception of one entrained by a power plant, all were captured by recreational fishermen. Three were taken south of Cape Cod off Chappaquiddick Island and the balance were captured in bays north of the Cape from Quincy to Salem.

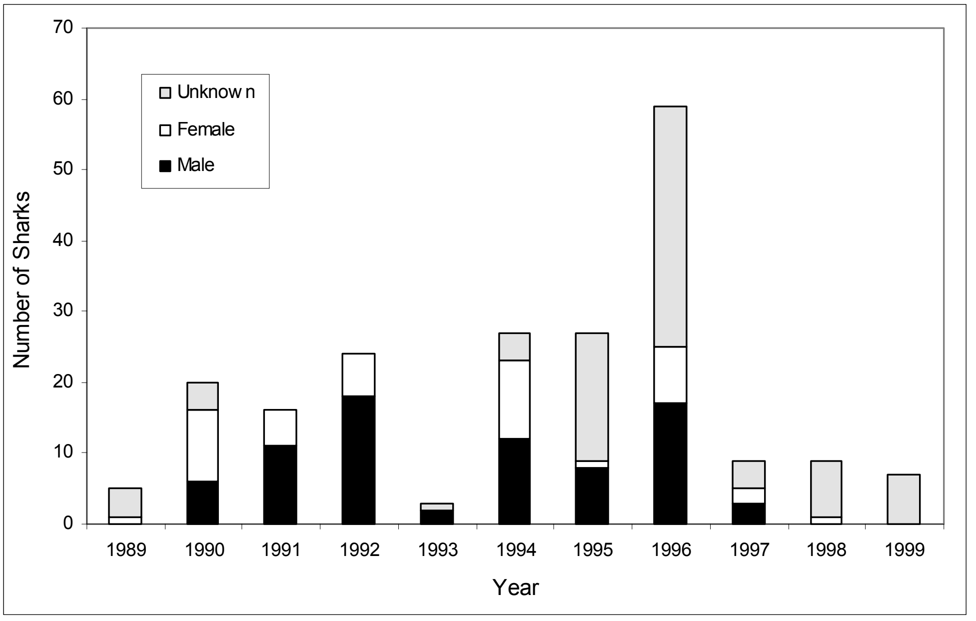

Figure 3. **Number and sex ratio of sandbar sharks reported to the MSRP by anglers, 1989-1999.**

Species Profiles

Smooth dogfish, *Mustelus canis*

A monthly analysis of smooth dogfish CPUE (1990-1999) shows that June produces the highest relative abundance index (8.2 fish/100 hooks) relative to July, August, and September (4.6, 6.2, 6.4, respectively). With the exception of the low year of 1991 and peak year of 1996, CPUE for smooth dogfish has ranged 4.9-6.9 sharks/100 hooks over the time series (Figure 2). Smooth dogfish were taken when the water temperature ranged 16-27°C, but CPUE was highest between 19 and 25°C. The MSRP has examined 433 smooth dogfish, mostly sampled from the neritic waters of Chappaquiddick Island and Cape Poge Bay. The 328 fish measured and sexed comprised adults and neonates (Table 1)(Rountree and Able, 1996). Of the adults, 97% were females ranging 83-121 cm FL and the balance were males ranging 73-93 cm FL. The neonates ranged 27.5-41.9 cm FL and comprised a more even sex ratio of 48% females.

This small shark moves into the neritic waters of Nantucket Sound, Vineyard Sound, and Buzzards Bay in late May and early June to give birth and to mate. The presence of neonatal dogfish confirms the former. However, the virtual absence of adult males in longline catches provides little evidence for inshore mating. Nonetheless, previous observations by the MSRP in 1993 and 1994 confirm that mating does occur in estuaries like Cape Poge Bay. Moreover, commercial trawl catches from Nantucket and Vineyard Sounds are known to contain adult males. Buzzards Bay, Nantucket Sound, Vineyard Sound, and their associated bays and estuaries provide important primary nursery habitat for young-of-the-year smooth dogfish.

Mustelus canis generally remains inshore until October when it moves offshore and south. To investigate these migratory patterns and growth rate in this species, 90 adult smooth dogfish have been tagged by the MSRP since 1996. Only a single recapture southeast of Pt. Judith has been reported to date.

Sandbar shark, *Carcharhinus plumbeus*

Longline CPUE indices for this species have ranged 0.0-2.0 sharks/100 hooks over the ten-year period (Figure 2). However, so few sandbars were taken each year that a single fish could significantly alter this index. When one considers the number of variables that can influence the presence of a species in a particular area, this index must be viewed with caution. Nonetheless, the data does have some ecological implications. All of the

Table 1. Summary of sharks sampled by the MSRP, 1989-1999.

Species	Catch		Size Range (cmFL)	Number			
	Total	Tagged		Neonates	Juveniles	Adults	Unknown
Smooth dogfish, *Mustelus canis*	433	90	27.5 – 121.0	69	0	328	36
Sandbar shark, *Carcharhinus plumbeus*	227	31	61.0 – 157.0	0	138	5	84
Sand tiger shark, *Carcharias taurus*	9	0	87.4 – 132.0	5	4	0	0
Dusky shark, *Carcharhinus obscurus*	5	2	175.0 – 254.0	0	3	1	1
Total	674	123		74	145	334	121

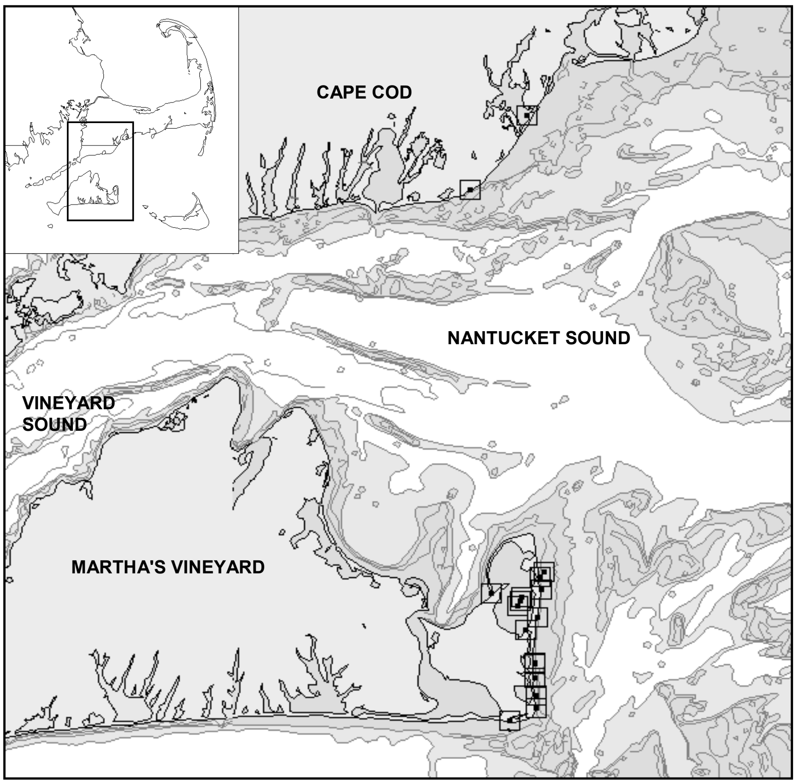

Figure 4. Locations where sandbar sharks (*C. plumbeus*) have been reported to the MSRP (n=227).

sandbar sharks taken on longline were caught in water temperatures between 20 and 24°C and depths of 2.4-6.4 m. The fact that 43% of these fish were taken in Cape Poge Bay indicates the relative importance of this area.

In total, 227 (86 males, 57 females, 84 unknown) sandbar sharks have been examined or reported to the MSRP since 1989 (Table 1, Figure 4). Although sandbar sharks were taken between June 21 and October 2, the species was most abundant in July (Figure 5). The overall size range of both sexes was 61-157cm FL and a length frequency distribution is shown in Figure 6. If size at maturity is 143cm FL and 149cm FL for males and females, respectively (Sminkey and Musick, 1995), then 5% of the males and 2% of the females sampled over the eleven-year period were mature. Clearly, the majority of sandbar sharks occurring inshore are juveniles utilizing these areas as secondary nurseries.

Age and growth estimates supporting two different age scenarios for this species come from three sources. Two studies support an age at maturity of 15 yr and longevity of 35 yr (Casey et al., 1985; Sminkey and Musick, 1995), while another provides estimates roughly twice this

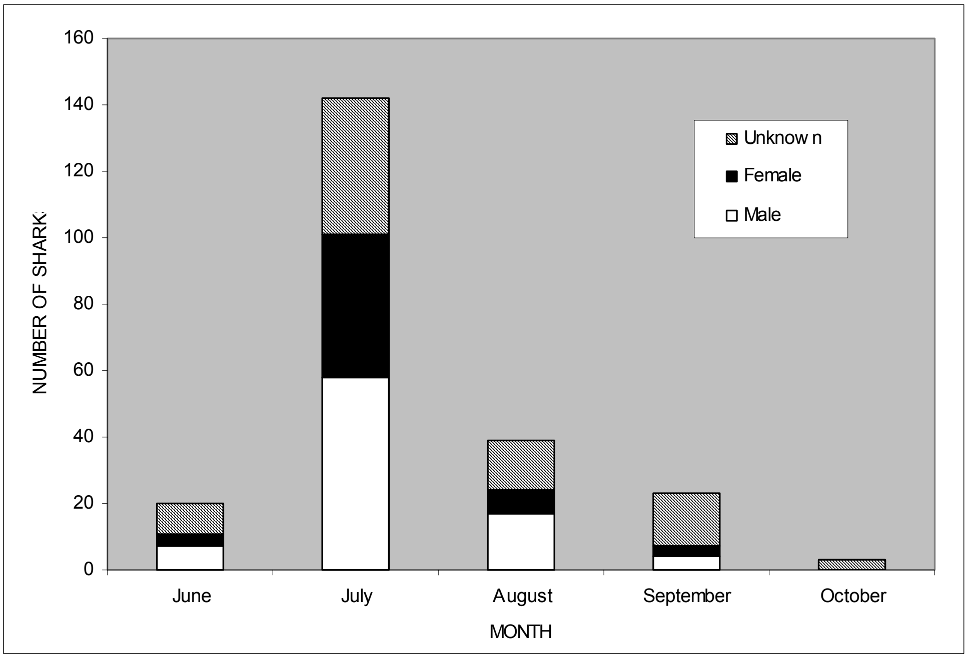

Figure 5. **Monthly distribution of sandbar sharks (*C. plumbeus*) sampled by the MSRP, 1989-1999.**

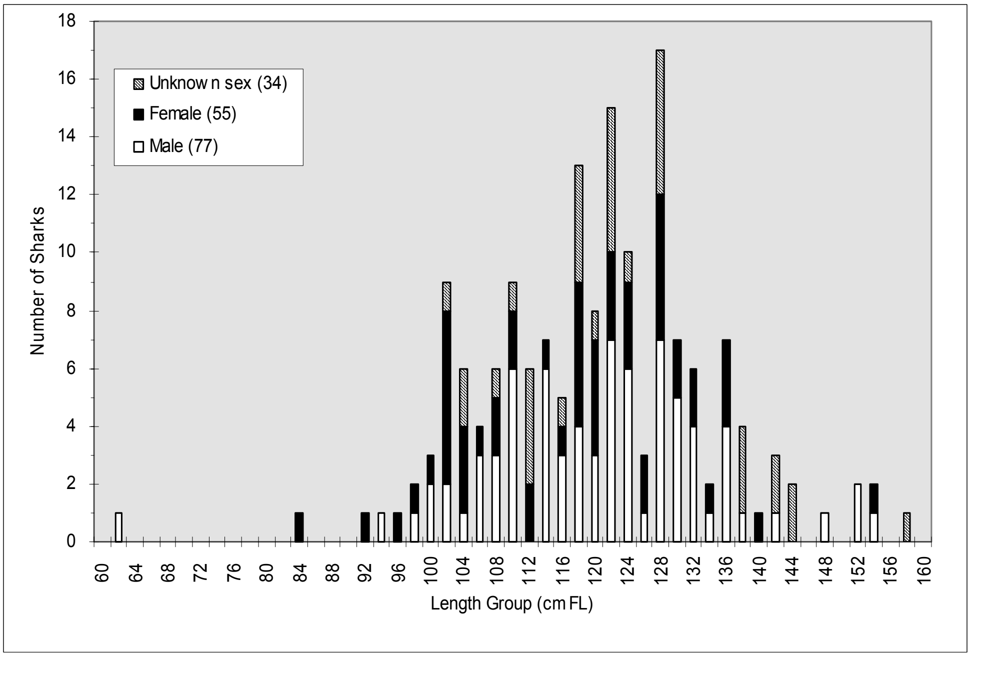

Figure 6. **Length frequency distribution of sandbar sharks, *C. plumbeus*, sampled by the MSRP, 1989-1999.**

(30/60) (Casey and Natanson, 1992). For stock assessment purposes, the 1998 Shark Evaluation Workshop considered the former scenario to be more likely (NMFS, 1998). Using Casey et al. (1985), the age structure of the sandbar sharks sampled over the eleven-year period ranged from 2 to 15 years.

Sand tiger shark, *Carcharias taurus*

This species was once considered the most abundant shark in Massachusetts along with the dogfishes. In the 1920's, *Carcharias taurus* supported a commercial fishery in Nantucket Sound until it was thought to be locally exhausted (Bigelow and Schroeder, 1953). Photographs that were provided to the MSRP by the Nantucket Historical Society confirmed that this fishery landed large adult fish. Although considered "the most common of the large sharks" by Andrews (1973), not a single adult sand tiger shark has been reported to the program since its inception in 1989, despite the extensive commercial and recreational fisheries (for other species) in Nantucket Sound. This provides evidence to support the notion that intensive commercial fisheries can lead to the long-term depletion of local shark populations.

However, nine juvenile sand tiger sharks have been reported to the MSRP from two general locations in coastal Massachusetts (Table 1, Figure 7): south of Cape Cod in coastal waters off East Beach, Chappaquiddick Island and bays north of the Cape from Quincy to Salem. All of these were small immature sand tigers in the size range of 87-132 cm FL; the five sexed were all female. According to Branstetter and Musick (1994), these fish ranged in age from neonate to two, with most being the former (Table 1). The lack of adult sand tigers in Massachusetts waters provides evidence that these fish migrated north from southeastern pupping grounds (Gilmore et al., 1983).

Dusky shark, *Carcharhinus obscurus*

Only five dusky sharks have been sampled by the MSRP and these were taken by longline (Table 1, Figure 8). These sharks were caught in water temperatures ranging 17-24°C and depths ranging 4.8-19.2 m. Four were captured along East Beach and one was taken off South Beach in deeper water (Figure 8). Of the four reliably measured, three (2 females, 1 male) were in the size range of 173-183 cm FL and one female was 254 cm FL. According to Springer (1960), the smaller duskies were immature and the larger female had reached maturity; dissection of these fish confirmed this.

Preliminary Findings

The neritic waters of Massachusetts provide nursery habitat for smooth dogfish, sandbar sharks, and dusky sharks at the northern limit of their geographic range. Moreover, the occurrence of neonatal and juvenile sand tiger sharks in some areas of Massachusetts is indicative of nursery habitat for this species. The following preliminary findings are presented for each species.

Smooth dogfish: The presence of adult and neonatal smooth dogfish in Nantucket Sound and its associated bays and estuaries suggests that these areas provide important primary nursery habitat. The known occurrence of this species in Buzzards Bay and Vineyard Sound indicates that these areas may serve a similar role as nursery habitat.

Sandbar shark: The seasonal occurrence of juvenile sandbar sharks off Chappaquiddick Island, in Cape Poge Bay, and off Cape Cod and Nantucket Beaches suggests that the neritic waters of Nantucket Sound and its associated bays and estuaries provide secondary nursery habitat for this species. Although the lack of angler reports from Buzzards Bay and Vineyard Sound indicates that these water bodies do not play a similar role, this cannot be said with certainty without an expansion of the survey. In addition, the apparent higher relative abundance of juvenile sandbar sharks in the coastal waters of Chappaquiddick Island may be a function of effort or may be related to the nature of this area, which is pristine. The extent to which the southern beaches and bays of Cape Cod contribute to the ecology of this species is not fully understood. These areas are known to suffer from more anthropogenic effects than Chappaquiddick Island and this may influence the relative abundance of sandbar sharks in these areas. Great South Bay (Long Island, NY) was once a primary nursery for the sandbar shark (Nichols, 1916; Thorne, 1916), but the species is no longer found in this well-developed embayment (H.L. Pratt, Jr., personal communication). Future MSRP efforts should be directed at expanding both the longline

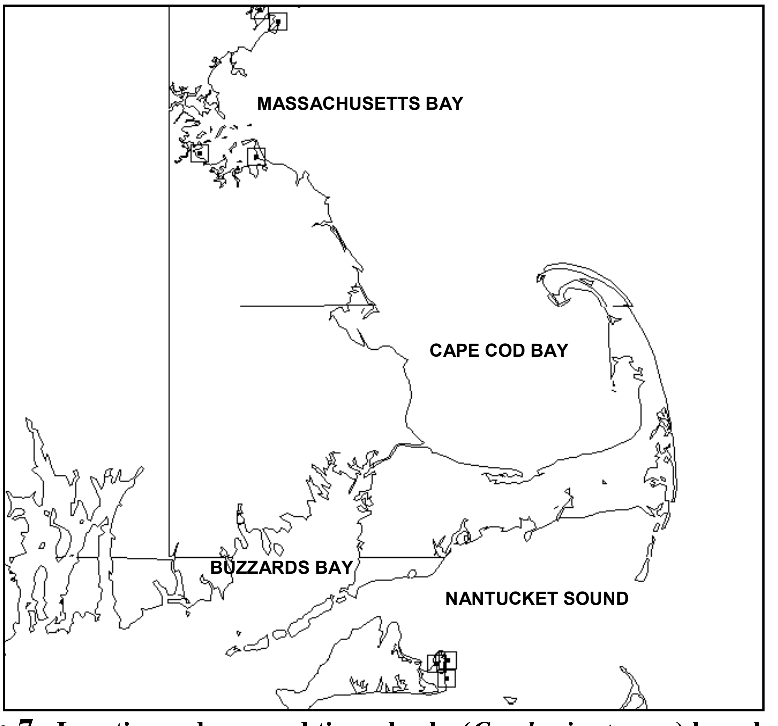

Figure 7. **Locations where sand tiger sharks (*Carcharias taurus*) have been sampled by the MSRP (n=9).**

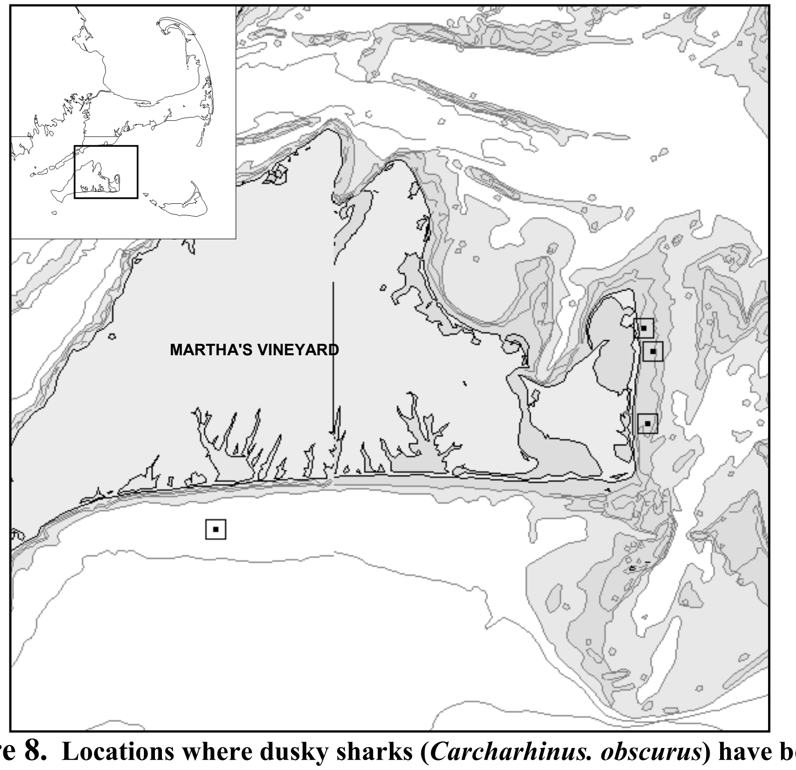

Figure 8. **Locations where dusky sharks (*Carcharhinus. obscurus*) have been sampled by the MSRP (n=5).**

and angler surveys to other areas within the Sound to more fully describe the extent to which it contributes to the life history of this species.

Sand tiger shark: The occurrence of neonatal and juvenile sand tiger sharks in coastal areas of Massachusetts indicates that these areas may act as primary and secondary nursery habitat for this species. If age and growth estimates by Branstetter and Musick (1994) are valid, then this study documents the northernmost existence of primary nursery habitat. However, its extremely low occurrence in these areas indicates that their relative importance is low.

Dusky shark: This is the first report to document the nearshore occurrence of the dusky shark in Massachusetts. Although rare, the preponderance of juveniles suggests that the near coastal eastern and southern waters of Martha's Vineyard Island provide suitable secondary nursery habitat for this species. More effort is needed in these and other areas to further investigate this.

Acknowledgements

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Shark Nursery Areas in Coastal New Jersey and Long Island, New York

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Scope

A preliminary investigation of the bays of New Jersey and Long Island, New York was conducted in 1996 as part of the National Marine Fisheries Service (NMFS) sandbar shark nursery ground survey funded by NOAA/NMFS Highly Migratory Species, Silver Spring, Maryland through the Integrated Shark Research and Management Program (ISHARK).

Historically, pupping grounds of the sandbar shark, *Carcharhinus plumbeus*, on the United States east coast extended as far north as Great South Bay, Long Island, New York, but there are no recent reports of pupping in these northern bays. Gillnet and hook and line surveys were conducted in Peconic Bay, Shinnecock Bay and Great South Bay, NY, and in Barnegat Bay and Great Bay, NJ during July and August 1996 to determine the current northern extent of sandbar shark pupping grounds along the US east coast. No sandbar sharks were caught in Great South Bay, Shinnecock Bay or Peconic Bay, NY, or in Barnegat Bay, NJ. Seventeen neonate sandbar sharks were captured in Great Bay, NJ. All sharks were tagged and released and three sharks were recaptured.

Sampling Materials and Methods

In 1996, sampling was conducted at 9 stations from 6 to 11 July in New Jersey, and 12 stations from 15 to 22 August in New York (Figure 1). Station locations were based on published historical capture locations of sandbar sharks, personal communication with state and federal fisheries biologists, and commercial and recreational fishers with local knowledge. Sampling locations were spaced to maximize sampling coverage of the study areas.

Daytime gillnet sets were made with a bottom-set nylon monofilament gillnet (length 233 m, height 3.1 m, 10.6 cm stretch mesh) set across the tidal current in 1.5 m to 4.3 m of water depth. Once the net was set, air temperature, sea surface temperature, salinity, wave height, and depth were logged. To minimize mortality and ensure the best condition for tag and release, the net was continually tended by under running the net with the boat, removing all animals, algae and debris. Set duration was a minimum of 2.1 hours to a maximum of 5.0 hours (mean 3.1 hours).

Baited hook sampling was conducted in New York where the gillnet could not be deployed due to local conditions (heavy boat traffic, extreme current velocity or dense macroalgae). Rods (4/0 and 5/0) were outfitted with 4/0 reels carrying 50 lb. monofilament line attached to nylon coated steel leaders. In addition, at all but one station, a handline made of 4 mm braided nylon with a nylon coated steel leader was used. Straight shank hooks (6/0) were baited with menhaden (*Brevoortia tyrannus*), bluefish (*Pomatomus saltatrix*), or weakfish (*Cynoscion regalis*). Ground menhaden chum was used when available. All together, 2-3 hooks were simultaneously set for 1-2 hours during

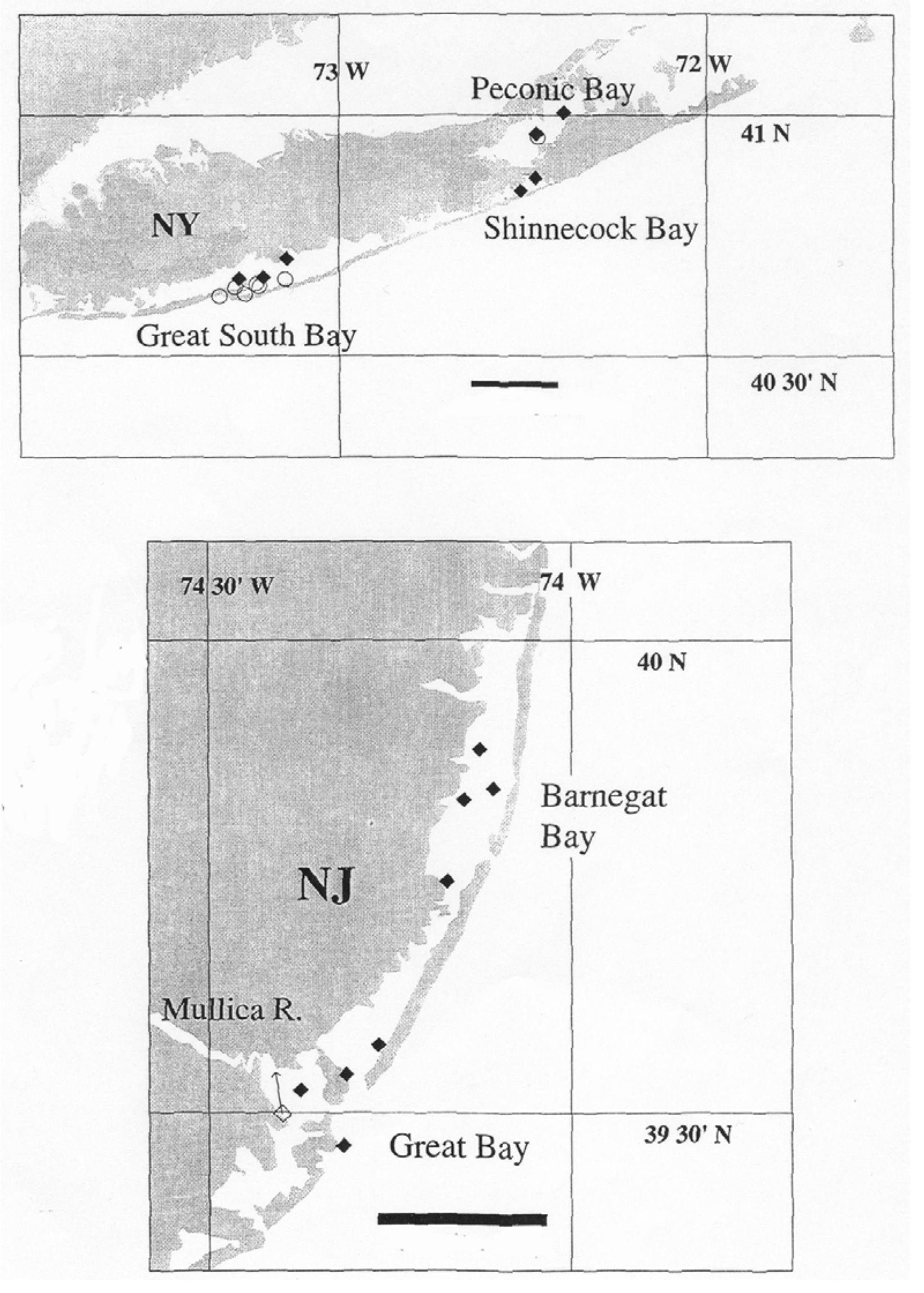

Figure 1. **Sampling station locations in New York (top panel) and New Jersey (bottom panel). Gear type is indicated by symbol; closed diamonds are gillnet stations, open circles are hook and line stations, scale bars are 20 kilometers. Open diamonds indicate locations where sandbar sharks were captured and arrowed line indicates recapture location.**

Table 1. Summary of sampling effort in New York and New Jersey

State	Area	Gillnet set hours	Hook and line set hours	Number of hooks
New York	Great South Bay	9.3	10	3
	Shinnecock Bay	6.2	-	-
	Peconic Bay	6.9	2	2
	Total	**22.4**	**12**	
New Jersey	Great Bay	16.6	-	-
	Barnegat Bay	11.4	-	-
	Total	**28.0**		

seven sampling periods (Table 1) in water 0.9 m to 8.6 m deep (mean 4.3 m).

Fork length (FL) and total length (TL) of each shark were measured to the nearest centimeter and body weight was measured to the nearest 0.1 kg. Sharks were sexed and neonate (newborn) sandbar sharks were distinguished from juvenile sandbar sharks (age one and older) by the presence of an open umbilical scar. Live sharks were tagged with either a small, yellow plastic dart tag (Hallprint) or National Marine Fisheries Service M-type capsule tag with reduced dart tip which were uniquely numbered and inscribed with a request for information about shark length, fishing gear and location of capture.

Description of Study Areas

Great South Bay is located along the south shore of Long Island, New York. Formed by a barrier island (Fire Island), the bay is 76 km long and has an area of 238 km^2 with depths averaging 1.3 m and a tidal range of 0.2 to 1.25 m (Hair and Buckner, 1973; Wilson et al., 1991). Salinity ranges from 25 to 27 ppt and summer surface temperatures range from 21° to 25° C. The main inlet connecting the Atlantic Ocean to the Bay is located on the western end of Fire Island. The other source of seawater exchange is via channels running from Moriches Bay to the east of Great South Bay. Restricted exchange of seawater reduces the tidal exchange volume (Wilson et al., 1991) thereby reducing water quality by concentrating nutrients and contaminants (Dennison et al., 1991). Freshwater input is minimal, originating from stream flow, groundwater and land run-off (Wilson et al., 1991).

New Jersey's coastal bays are similar to Great South Bay, New York, with barrier islands and inlet systems separating bay waters from the Atlantic Ocean. Barnegat Bay is a shallow lagoon type estuary, 48 km long, 2 to 6 km wide with a total area of 193 km^2 (Chizmadia et al., 1984). Salinity ranges from 19 to 30 ppt and summer sea surface temperatures range 23° to 28° C (Chizmadia et al., 1984). Freshwater input comes primarily from the Toms River at the north end of the Bay and seawater exchange occurs through Barnegat and Manasquan Inlets. Except for the Intracoastal Waterway, depths in Barnegat Bay are very shallow (range 0.3 to 4 m) with 73% of the Bay less than 2 m deep at mean low water (Chizmadia et al., 1984). Tides range 0.15 to 1.2 m in Barnegat Bay (Chizmadia et al., 1984; Rogers, Golden and Halpern, Inc., 1990). Nutrients and coliform bacteria from nonpoint sources have degraded water quality in Barnegat Bay (Rogers, Golden and Halpern, Inc., 1990).

The Mullica River-Great Bay estuary comprised of several shallow bays connected by creeks and the Intracoastal Waterway encompassing 276 km^2 is a pristine system receiving freshwater from the New Jersey Pinelands Land Management Area (Able et al., 1996). Salinity ranges 13 to 31 ppt and summer sea surface temperatures range from 18° to 35 ° C (Thomas et al., 1974). Tidal range is 0.9 to 1.0 m (National Oceanic and Atmospheric Administration, 1985). Freshwater input to Great Bay is mainly from the Mullica River and seawater exchange occurs at Little Egg and Brigantine Inlets.

Sea temperatures were similar in the sampling areas, but salinity was lower in New Jersey (t-test, $p<0.05$). Sea surface temperature ranged from 21.5° to 26.0° C (mean 23.9° C) in New Jersey and 21.8° to 28.0 °C (mean 24.6° C) in New York. Salinity was 19.6 to 29.7 ppt and was variable (mean ± one standard error 25.0 ± 1.1 ppt) in New Jersey and in New York salinity was relatively constant with a range of 26.0 ppt to 30.0 ppt (mean 28.0 ± 0.4 ppt). The two lowest salinity measurements were 19.6 ppt and 21.7 ppt in upper Barnegat Bay, New Jersey.

Species Profile

Sandbar shark, *Carcharhinus plumbeus*

No sandbar sharks were captured at any of our New York stations or in Barnegat Bay, New Jersey. Seventeen young of the year sandbar sharks were captured over mud bottom at the Landing Creek station in Great Bay, New Jersey (Figure 1) in 2.4 m water depth. Salinity and temperature were 26.5 ppt and 23.8 °C, respectively, at the station where sandbar sharks were captured. Lengths ranged from 42 to 52 cm FL (47 to 62 cm TL). The mean FL (± 95% confidence interval) was 47.4 ± 1.6 cm (56.3 ± 2.3 cm TL). Body weight ranged from 0.3 to 1.5 kg (mean 1.1 ± 0.2 kg).

All sandbar sharks captured were neonates with open umbilical scars and were released in fair to excellent condition. Six of these sandbar sharks had pieces of umbilical cord attached to the umbilical scar.

Tag and Recapture of Sandbar Sharks

One sandbar shark, tagged July 8, 1996 at the Landing Creek Station, was recaptured 25 days later (August 8) in Great Bay 3.7 km from the tagging location (Figure 1). Two sharks were recaptured in March 1997 off Cape Hatteras, North Carolina by commercial fishermen in the same gillnet set.

Preliminary Findings

In 1996 Great South Bay, New York, and Barnegat Bay, NJ did not appear to be active pupping grounds for the sandbar shark. Raritan Bay, NJ and adjacent waters have been sampled for decades by the staff of the NEFSC Sandy Hook Laboratory using gillnets and otter trawls. No sandbar sharks have ever been recorded in these bays in over 30 years of sampling (Wilk et al., 1996; S. Wilk, personal communication, August, 1996).

Reports indicate that the Great Bay, New Jersey area has served as a nursery of the sandbar shark and our results indicate it was an active pupping ground in 1996. Small juvenile sandbar sharks (mean length 597 mm TL) have been captured in Great Bay (Thomas et al., 1974) and larger juveniles (940-2300 mm TL, 3.6-114 kg) were reported in the vicinity of Little Egg Inlet (Milstein, 1978). The lengths of the small juvenile sandbar sharks reported by Thomas et al. (1974) are consistent with the lengths of young of the year sandbar sharks that we report here and in Delaware Bay (Merson and Pratt, 2001).

The recapture of a sandbar shark after 25 days-at-liberty, 3.7 km from the tagging location, in Great Bay suggests that the young of the year remain in the natal nursery for a period of time after their birth. This is consistent with findings from Delaware Bay where tagged young of the year sandbar sharks were recaptured up to 62 days after release and most were captured less than 5 km from the release location (Merson and Pratt, 2001). The two sandbar sharks recaptured off Cape Hatteras, North Carolina in March is evidence that sandbar sharks migrate long distances probably in aggregations from their pupping grounds to overwintering areas. The existence of a southern overwintering area is discussed by Springer (1960) and McCandless et al. (2002).

In conclusion, the results from this study indicate that Great Bay, NJ was the northern limit of sandbar shark pupping grounds in 1996. Young of the year sandbar sharks have been reported recently from the Long Island, NY area, outside of Great South Bay (J. Morrissey, personal communication July, 2001). This may indicate that sandbar sharks use areas outside of bays as pupping grounds or that there has been a recent northward expansion of sandbar shark pupping grounds. Further quantitative sampling should be conducted in Great Bay, NJ to describe the density of sandbar sharks in this essential habitat and areas north of NJ should be investigated on a more spatial and temporally extensive basis to assess the importance of New York State waters as shark nurseries and to gauge the relative contribution of areas outside of coastal embayments to sandbar shark pupping grounds.

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Shark Nursery Areas in Delaware and New Jersey State Waters

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Scope

The National Marine Fisheries Service (NMFS) Apex Predators Program staff have been conducting gillnet surveys for juvenile sandbar sharks (*Carcharhinus plumbeus*) in Delaware and New Jersey state waters since 1995 as part of the Sandbar Shark Nursery Grounds Project funded by the NMFS Highly Migratory Species Office. Longline surveys were added to the sampling protocol in 1997. The Sandbar Shark Nursery Grounds Project has been a part of the Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) survey since 1998. The COASTSPAN survey is an ongoing investigation of shark nursery grounds along the East Coast of the United States. A total of 2080 sharks were caught in Delaware Bay from 1995 to 2000, of which 2066 were juvenile sandbar sharks, 11 were juvenile sand tiger sharks (*Carcharias taurus*), two were juvenile smooth hammerhead sharks (*Sphyrna zygaena*) and one was a mature Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) (Table 1). One thousand eight hundred and two (87%) of the sharks sampled were tagged and released (Table 1).

Sampling Materials and Methods

Stations were chosen both randomly and based on NMFS historical data. An attempt was made to sample at the majority of the sites on a monthly basis from May to October, weather and current conditions permitting. Sampling was conducted during daylight hours. The sampling protocol was designed without consideration for tidal influences. Sampling included both gillnet and longline gear.

A 213 m (700 ft) long by 3 m (10 ft) deep sinking gillnet comprised of 10.6 cm (4 in) stretch mesh made of #177 (20 lb test) nylon monofilament was used. Each end of the net was flagged, buoyed, and anchored. The net was set downwind, generally perpendicular to the shore and across the tidal current, in 1-10 m of water. Net sampling began approximately 20 minutes after setting the gear. The net was continuously sampled by under running it, pulling it across the boat while leaving the net ends anchored. All animals, algae, and other objects were removed with each pass as the net was reset into the water. This practice maximized survival, minimized bycatch mortality, and ensured the best shark condition for tagging. If after the first two passes there were no sharks in the net, the net was left to soak for the time remaining until retrieval. Total net soak time averaged three hours.

A 50-hook bottom longline was used in areas of high current, deep water, and/or heavy boat traffic. The mainline consisted of 1000 ft of 1/4 in braided nylon mainline, and 50 gangions comprised of 12/0 Mustad circle hooks with barbs depressed, 50 cm of 1/16 stainless cable, and 100 cm of 1/4 in braided nylon line with 4/0 longline snaps. Bait was fresh menhaden and other local fish species taken

Table 1. **1995 - 2000 Delaware Bay shark catch summary**

Species	Total catch	Total tagged	Size range (cm FL)	Neonates	Juveniles (age 1+)	Adults	Maturity not determined
Carcharhinus plumbeus	2066	1790	40 - 140	1648	401	0	17
Carcharias taurus	11	11	92 - 177.8	0	11	0	0
Sphyrna zygaena	2	0	49	2	0	0	0
Rhizoprionodon terraenovae	1	1	79	0	0	1	0
Totals	**2080**	**1802**	**-**	**1650**	**412**	**1**	**17**

from the gillnet, or strips of previously frozen menhaden or mackerel

Station location (GPS), surface water and air temperatures, depth, salinity, and time were recorded for each set. When possible, bottom type was determined by observing sediment on the anchor. Bycatch was recorded to the lowest possible taxon. The sex, weight, fork length and total length (disc width for skates and rays) of all elasmobranchs were recorded. All live sharks, except *Mustelus canis*, were tagged with a Hallprint dart tag (1995-1997) in the musculature of the base of the first dorsal fin or a blue rototag (1997 - 2000) in the first dorsal fin and released. Umbilical scar condition was recorded in six categories: "umbilical remains," "fresh open," "partially healed," "mostly healed," "well healed," and none.

Description of Study Area

Delaware Bay is a temperate coastal plain estuarine system located in the Mid Atlantic Bight. The total area of the Bay is 1989 km^2 with an average depth of 7.4 m. Extensive shoals are major features in Delaware Bay (Figure 1) where depths range from one to four meters (National Oceanographic and Atmospheric Association (NOAA) 1985). Sloughs and channels (5 to 9 m deep) run from these shoals into the main shipping channel (9 to 46 m deep) (National Ocean Service 2000). The main shipping channel extends from the mouth of the Bay near Cape Henlopen into the center of the Bay and then up the Delaware River.

The tides in Delaware Bay are semidiurnal and range on average 1.4 m. Strong tidal currents are the primary source of circulation within the Bay. These strong currents cause the circulation of large amounts of suspended sediment in the water column, frequently reducing the visibility to less than 0.5 m (Sharp 1988). The Bay is well mixed and water temperature is relatively uniform throughout the water column ranging from 20 to 28 ºC in the summer months (Michels 1996). Salinity ranges from 8 ppt at the mouth of the Delaware River to 33 ppt at the mouth of Delaware Bay (Michels 1996).

Relative Abundance and Distribution of Juvenile Sandbar Shark

Catch per unit effort (CPUE) was measured as sharks per hour for both gillnet and longline sets. From 1995 - 2000 neonate and juvenile sandbar sharks were most abundant along the Delaware coast in the bay from Port Mahon to Broadkill Beach with lower more localized abundance on the New Jersey side off Villas and on Deadman and Crow shoals (Figures 1 and 2). When looking at neonates and juveniles separately, neonates appear to be much more abundant than the juveniles (Figures 3 and 4). This can be partially explained by the selectivity of our gear towards the smaller sharks. The neonates appear to be most abundant in the protected (lower current) areas of the Bay and the juveniles appear to be more evenly dispersed throughout their range in the Bay. Neither neonates nor juveniles seem to be abundant throughout the center of the Bay where the shipping channel lies (Figures 2, 3 and 4). Sharks that were caught near the mouth of the Bay were only captured in late September and were most likely nearing time for their migration south to their overwintering nursery grounds.

Tag and Recapture Data on Juvenile Sandbar Sharks

From 1995 to 2000, 1790 sharks were tagged and

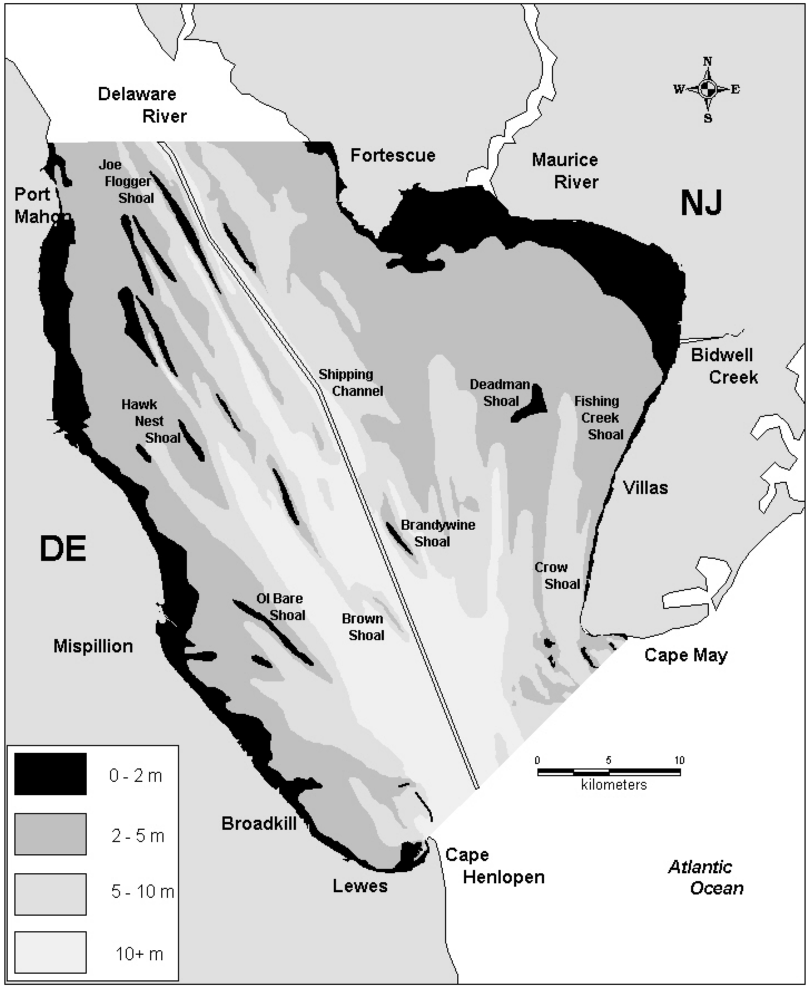

Figure 1. **Map of Delaware Bay showing four depth strata: 0-2 m, 2-5 m, 5-10 m, and 10+ m.**

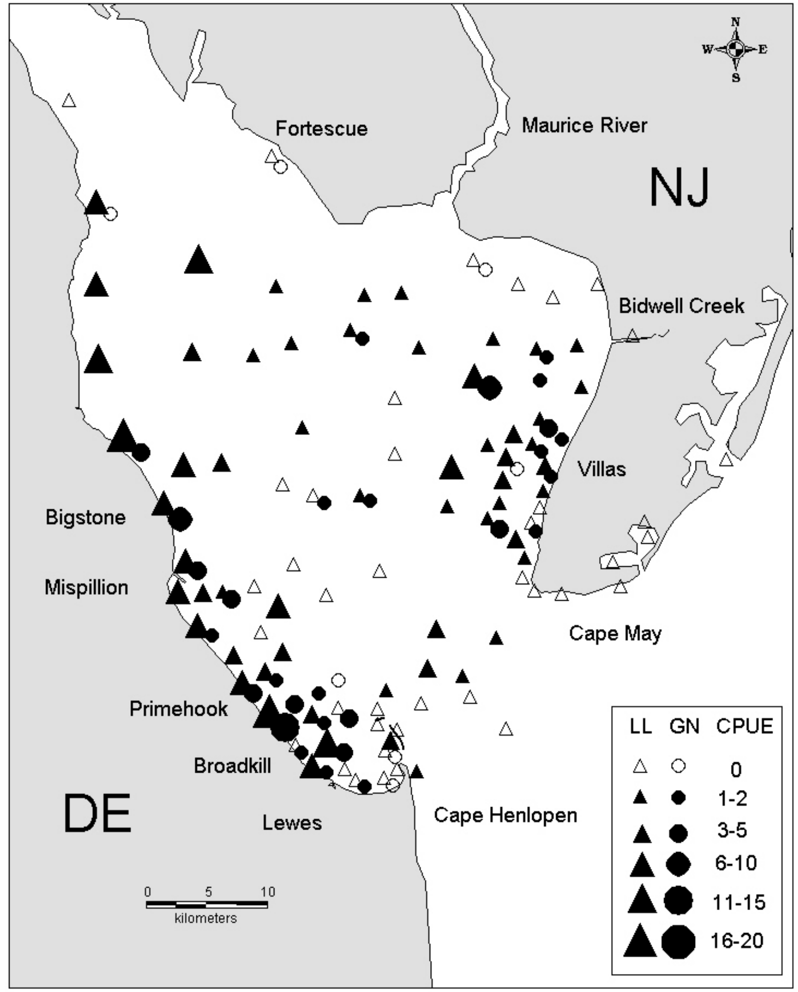

Figure 2. **1995 - 2000 CPUE (sharks/hour) for neonate and juvenile (age 1+) sandbar sharks caught by longline or gillnet in Delaware Bay**

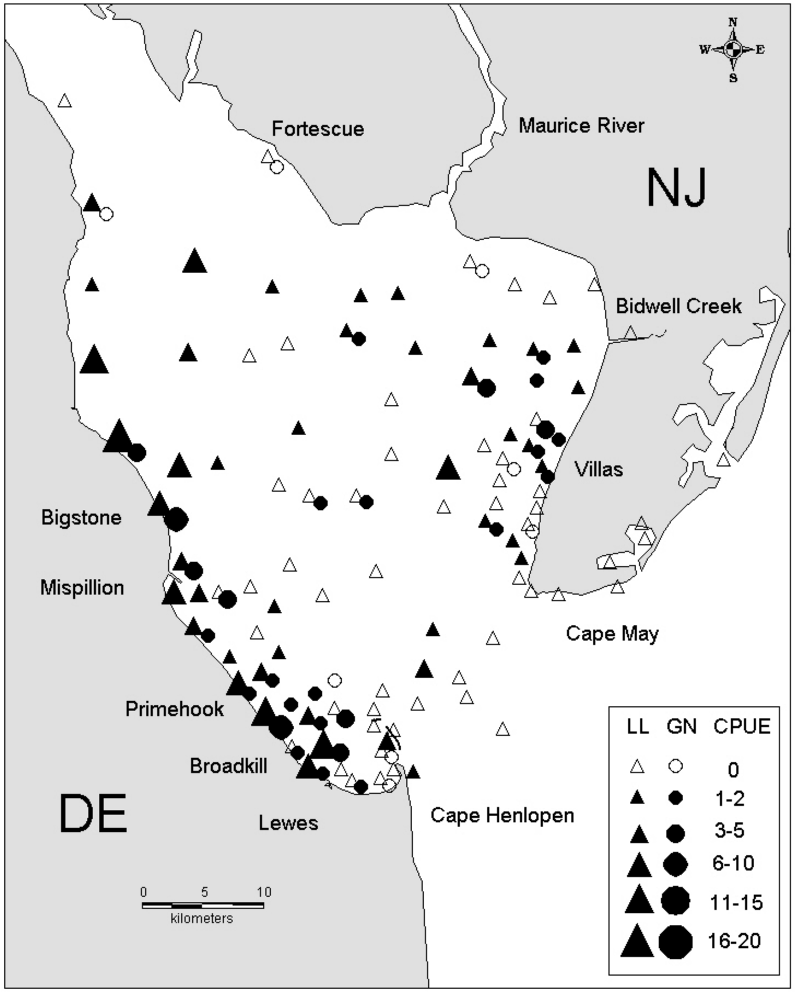

Figure 3. **1995 - 2000 CPUE (sharks/hour) for neonate sandbar sharks caught by longline or gillnet in Delaware Bay**

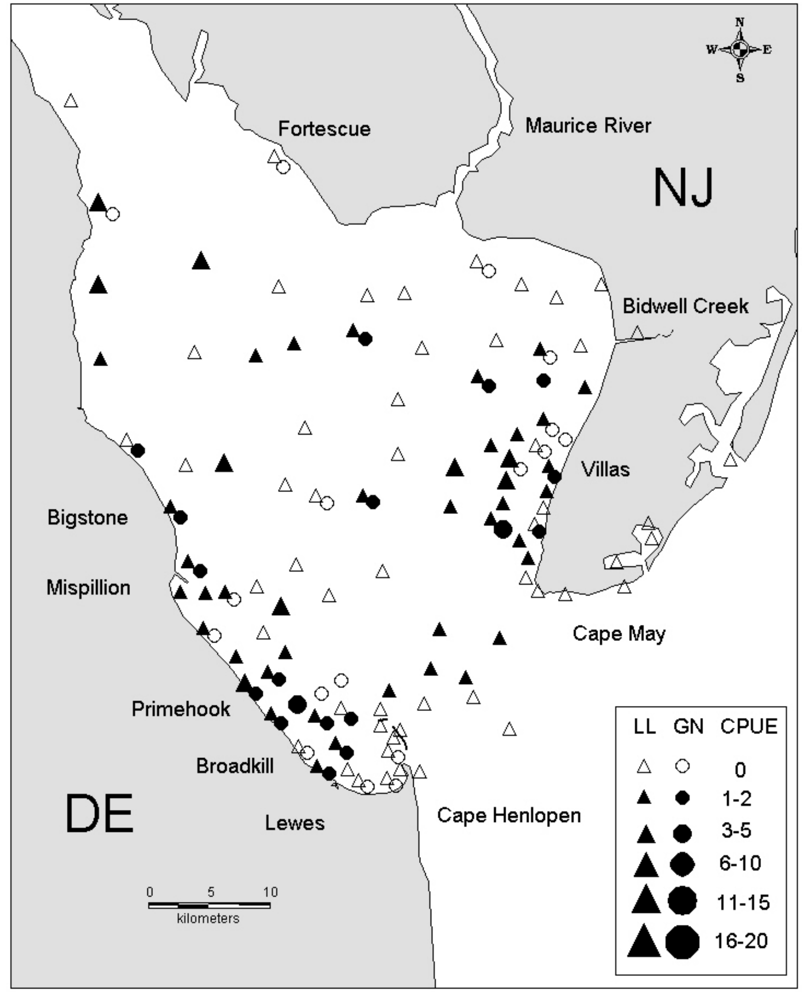

Figure 4. **1995 - 2000 CPUE (sharks/hour) for juvenile (age 1+) sandbar sharks caught by longline or gillnet in Delaware Bay**

Table 2. **Range of environmental parameters at time of capture for juvenile sharks captured in Delaware Bay from 1995 - 2000**

Species	Temperature (ºC)	Salinity (ppt)	Depth (m)
Carcharhinus plumbeus	15.5 - 30.0	18.3 - 31.0	0.8 - 23.0
Carcharias taurus	19.0 - 25.0	23.1 - 29.8	2.8 - 7.0
Sphyrna zygaena	25.5	30.3	3.6

released in Delaware Bay and 149 (8%) of these sharks have been recaptured to date (Table 1). One hundred and five (70%) of the recaptures were made within the same year they were tagged (Figures 5 and 6). All but one of these sharks were neonates. The tag recapture data indicates that neonate movements within the Bay are local within the first two months of their primary nursery season (June and July) and then disperse out into the Bay towards the end of the summer (August and September). This precedes their migration south to overwintering nursery grounds (Figure 5). Many neonates tagged within Delaware Bay were recaptured outside of the Bay towards the end of the summer and into the fall of the same year (Figure 6). These sharks were captured off the Delaware, Maryland, Virginia, and North Carolina coasts, presumably on route to their overwintering nursery grounds (Figure 6). Captures in North Carolina waters during the winter months indicate that these waters serve as overwintering grounds for young of the year sandbar sharks born in Delaware Bay (Figure 6).

Forty-four (30%) of the sharks recaptured were at liberty for one or more years. All of the sharks recaptured one or more years later were neonates at the time of release except for three juvenile (age 1+) sharks (Figures 7 and 8). Nineteen of these sharks were recaptured within Delaware Bay indicating that some neonate sandbar sharks return to their natal nursery grounds for at least two years after birth (Figure 7). Tag recaptures outside Delaware Bay one or more years after release in the Bay indicate that juvenile sandbar sharks migrate down the U.S. East Coast in late summer to early fall and overwinter off of North Carolina, South Carolina and Georgia, before migrating back north to their summer nursery grounds (Figure 8). Two neonates tagged in Delaware Bay in the summer of 1998 were recaptured the following summer, one in Bulls Bay, SC and one off Longbeach Island, NJ indicating that not all juvenile sandbar sharks return to their natal nursery grounds.

Species Profiles

Sandbar shark, *Carcharhinus plumbeus*

Sandbar sharks were captured in water temperatures ranging from 15.5 - 30.0 ºC, salinity from 18.3 - 31.0 ppt, and depths ranging from 0.8 to 23.0 m (Table 2). Captured sandbar sharks ranged in size from 40 to 140 cm FL (Table 1). The largest sandbar shark exhibiting a partially healed umbilical scar, indicative of recent birth, was 61 cm FL.

Sand tiger shark, *Carcharias taurus*

Sand tiger sharks were captured in water temperatures ranging from 19 to 25 ºC, salinity from 23.1 to 29.8 ppt, and a depth range from 2.8 m to 7.0 m (Table 2). Captured sand tiger sharks ranged in size from 92 cm to 177.8 cm FL (112 - 208.3 cm TL) (Table 1). Based on size all ten of the sand tiger sharks captured were juveniles and one (92 cm FL/ 112 cm TL) was a possible young of the year juvenile.

Smooth hammerhead shark, *Sphyrna zygaena*

Two neonate smooth hammerhead sharks (49 cm FL with fresh open umbilical scars) were caught by gillnet on July 13, 1995 in 3.6 m of water (Table 1 and 2). The temperature and salinity at time of capture was 25.5 ºC and 30.3 ppt (Table 2).

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

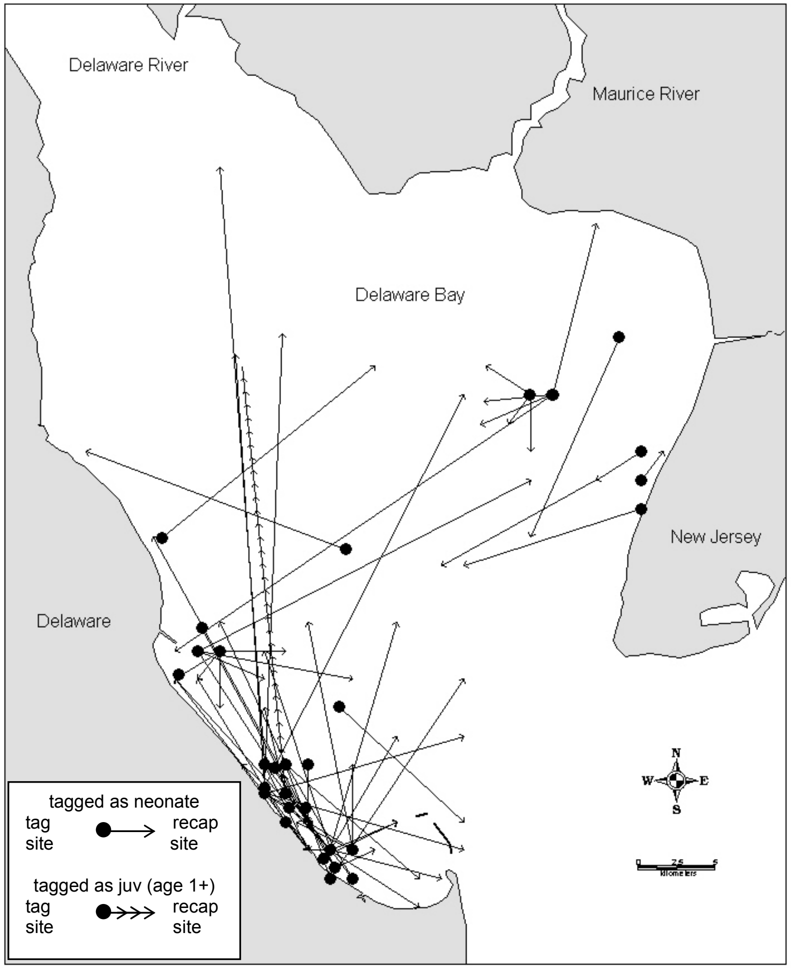

Figure 5. **Juvenile sandbar sharks tagged in Delaware Bay from 1995 to 2000 and recaptured in Delaware Bay within the same year tagged**

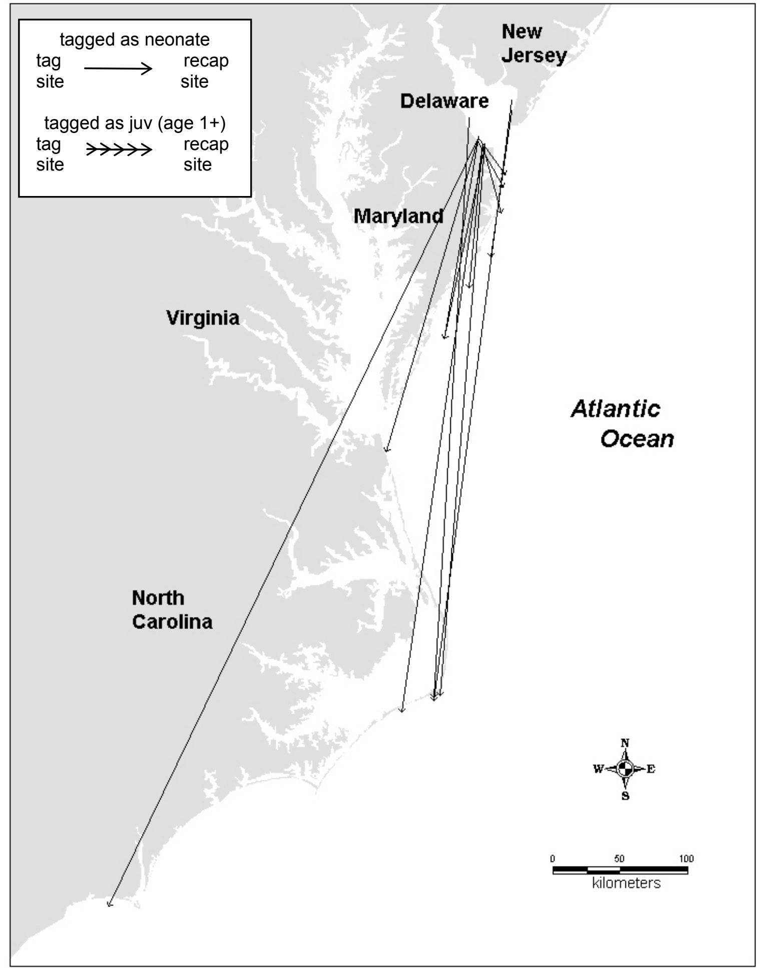

Figure 6. **Juvenile sandbar sharks tagged in Delaware Bay from 1995 to 2000 and recaptured outside Delaware Bay within the same year tagged**

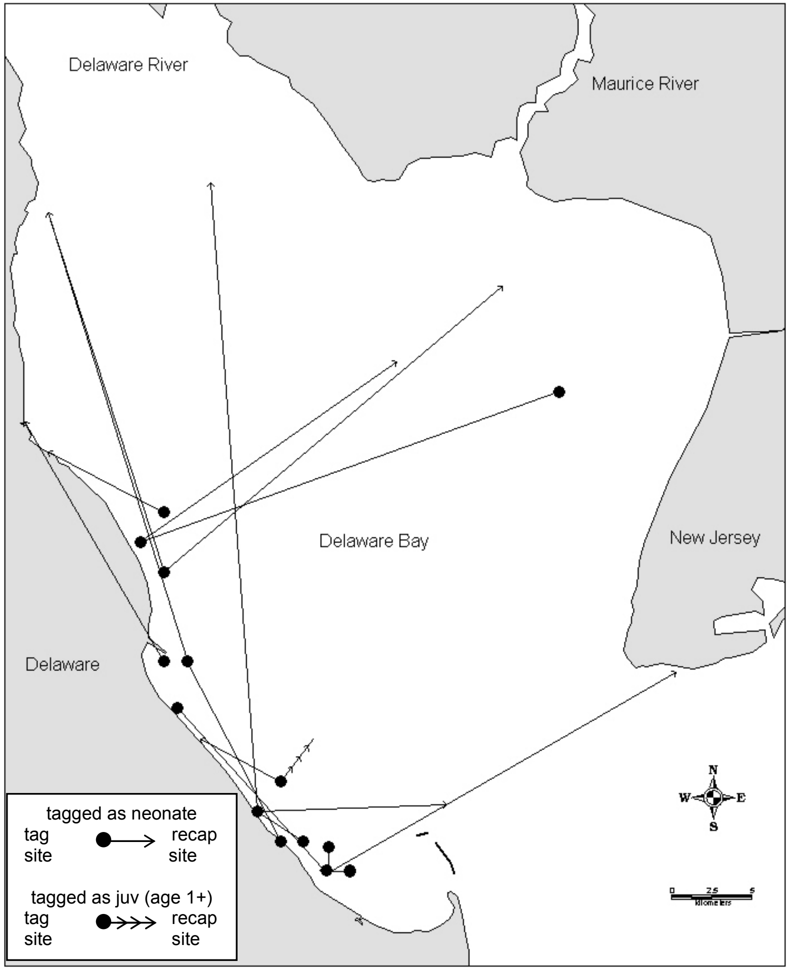

Figure 7. **Juvenile sandbar sharks tagged in Delaware Bay from 1995 to 2000 and recaptured in Delaware Bay one or more years later.**

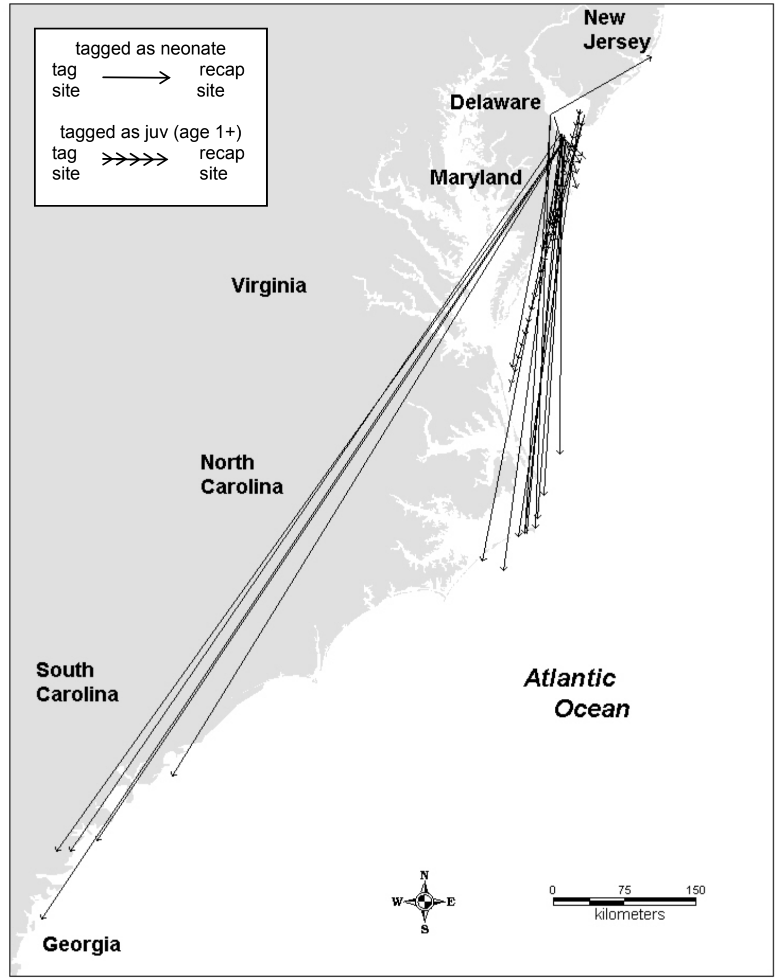

Figure 8. **Juvenile sandbar sharks tagged in Delaware Bay from 1995 to 2000 and recaptured outside Delaware Bay one or more years later.**

One mature male Atlantic sharpnose shark was tagged and released on August 23, 1999 in 4 m of water (Table 1). This shark was 79 cm FL and weighed 3.7 kg (Table 1). The temperature and salinity at time of capture was 26 ºC and 27 ppt. This shark is rarely found north of North Carolina, but it occurs as a stray as far north as the Bay of Fundy, ME.

Preliminary Findings

The results of this study show the importance of Delaware Bay as a pupping and nursery ground for sandbar sharks. Delaware Bay is essential habitat for juvenile sandbar sharks (Merson and Pratt 2001) as evidenced by their extensive use of the Bay during the summer months. The presence of juvenile sand tiger sharks in Delaware Bay suggests that the Bay may be a secondary nursery ground for this species. More extensive sampling of the bay with gear targeting larger sharks will be needed to evaluate the use of Delaware Bay by sand tiger sharks. The presence of neonate smooth hammerhead sharks in Delaware Bay indicate that the Bay may be used as a nursery ground for this species; although, no smooth hammerheads have been caught since 1995.

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Shark Nurseries of Virginia: Spatial and Temporal Delineation, Migratory Patterns, and Habitat Selection; a Case Study

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Scope

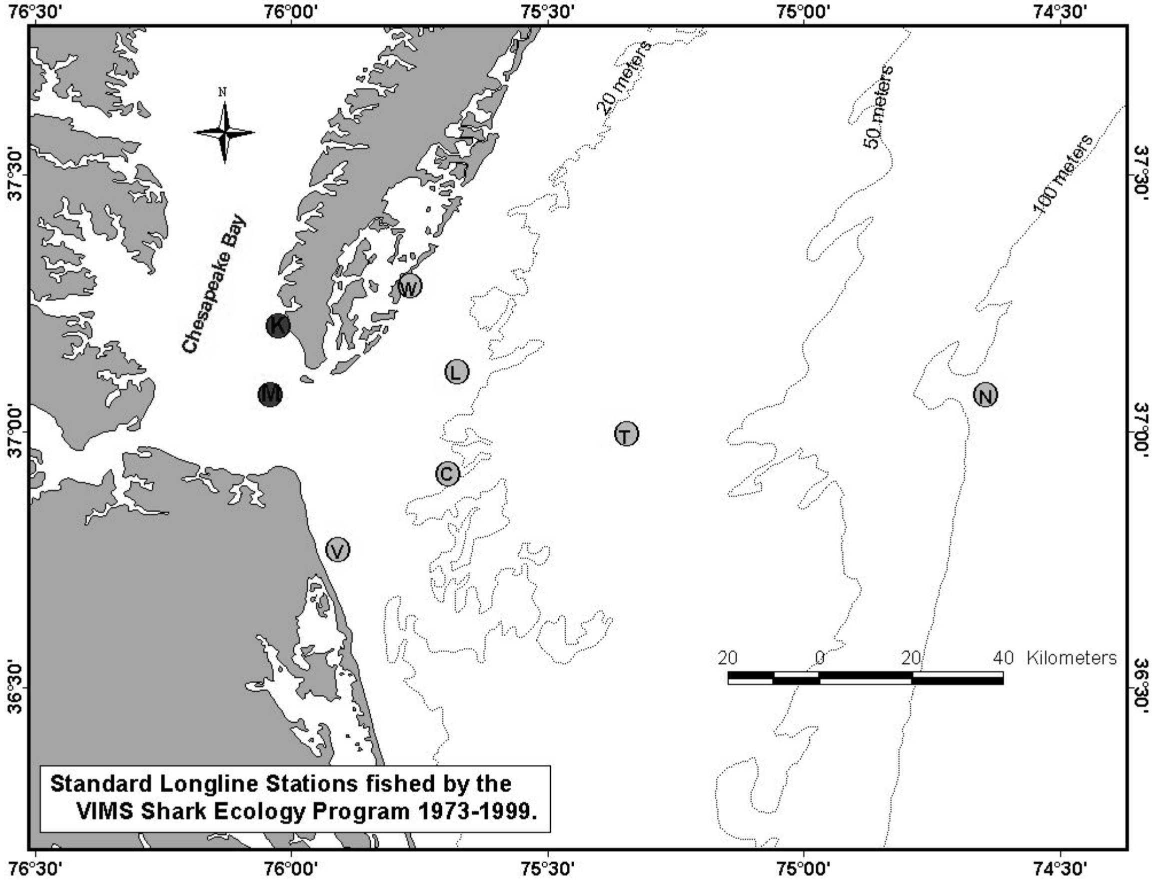
The Virginia Institute of Marine Science has carried out a longline sampling program since 1973 to study the distribution, abundance and biology of sharks and large pelagic teleosts from Cape Hatteras, NC to Cape Henlopen, DE. The VIMS longline survey is a depth-stratified station-oriented field survey of the Chesapeake Bay and Virginia coastal waters. Greater detail on this program is given in Musick et al (1993) as well as an analysis of historical trends in species composition, abundance and distribution with season and depth.

A detailed investigation of the ecological function of Chesapeake Bay as a summer nursery for juvenile sandbar sharks, *Carcharhinus plumbeus* was completed in spring 2001. The results are summarized in this chapter, while complete description, analysis, and statistical explanation may be found in Grubbs (2001). This chapter concludes with a brief section describing the utilization of Virginia waters as nurseries by other shark species.

Sampling Materials and Methods

Since its inception in 1974, the VIMS longline survey has routinely included stations in Chesapeake Bay. Two locations in the lower eastern Bay, Kiptopeke (37^{0}10' N, 76^{0} 00' W) and Middleground (37^{0} 06' N, 76^{0} 03' W), have been standard stations since 1980 (Figure 1). The survey was expanded in 1993 to include additional ancillary sampling in the Bay in an effort to delineate the summer nursery. These preliminary data indicated the primary nursery was indeed concentrated in the lower eastern part of the Bay where salinity is highest. Based on these preliminary sets, continued sampling to delineate the nursery was limited to the Virginia portion of the Bay south of 37^{o} 50' N, an area of approximately 4000km^{2}. Logistical constraints made random sampling of this area impractical, therefore, selection of sampling sites were chosen haphazardly to maximize coverage. In the ten-year span from 1990 to 1999, 174 longline sets were made in Chesapeake Bay. Temporal nursery delineation work (discussed below) indicated that utilization of the primary nursery occurs from early June through September. Therefore, only sets made in these months were used for spatial delineation. This reduced the number of sets to 147. Of these, 73 were standard sets made at Kiptopeke and Middleground, and 74 were ancillary sets sampled to delineate the nursery. Twenty of these ancillary sets were made during the years 1990-1994, while 54 were made during the period 1995-1999. To minimize sampling bias toward stations K and M, mean CPUE was calculated for each of these stations over two-year periods. This provided four CPUE estimates for station M and five for station K. These were combined with the ancillary stations giving a total of 83 stations used for the spatial

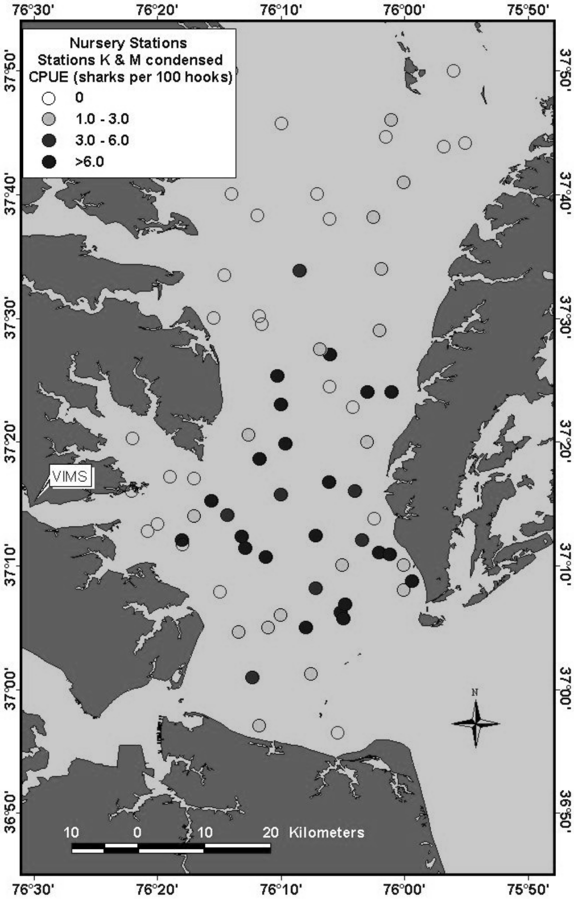
Figure 1. **Locations of standard stations sampled by the VIMS longline survey from 1973-1999 including stations K (Kiptopeke) and M (Middleground) in the lower Chesapeake Bay.**



delineation of the nursery (Figure 2). Catch per unit effort (CPUE) data from these stations were analyzed as a function of nine physical and environmental variables. Spearman's rank correlation was used to determine which variables would be included in the models. Tree-based regression models determined threshold values of the variables that were most influential and best discriminated between stations with high and low CPUE. Minimum cost-complexity pruning and cross-validation of the pruned tree models were used to develop optimal trees. Grids were interpolated for bottom salinity, dissolved oxygen, and temperature, using data collected by the VIMS Trawl Survey (Figure 3). These grids represent the mean distribution for each variable during summer months calculated using data collected from 1995 through 1999. These grids were used to develop response surfaces that mapped suitable nursery areas according to the regression tree models. Logistic regression was used as a means of validating the nursery habitat models and several indices of classification were used to test their accuracy.

Another objective of this study was to delineate temporally the migration patterns of juvenile sandbar sharks in Chesapeake Bay, to determine the location of wintering areas, and to determine if philopatry or homing to natal summer nurseries in subsequent years occurs. Monthly data collected at the two lower eastern Bay stations, Kiptopeke ($37^0$10' N, 76^0 00' W) and Middleground (37^0 06' N, 76^0 03' W), during the ten-year period from 1990 to 1999, 100 sets in total, were used to delineate migration patterns and nursery usage temporally in Chesapeake Bay.

Figure 2. Distribution of longline stations used to delineate the *Carcharhinus plumbeus* nursery spatially in Chesapeake Bay. Darker circles represent higher CPUE (sharks per 100 hooks).

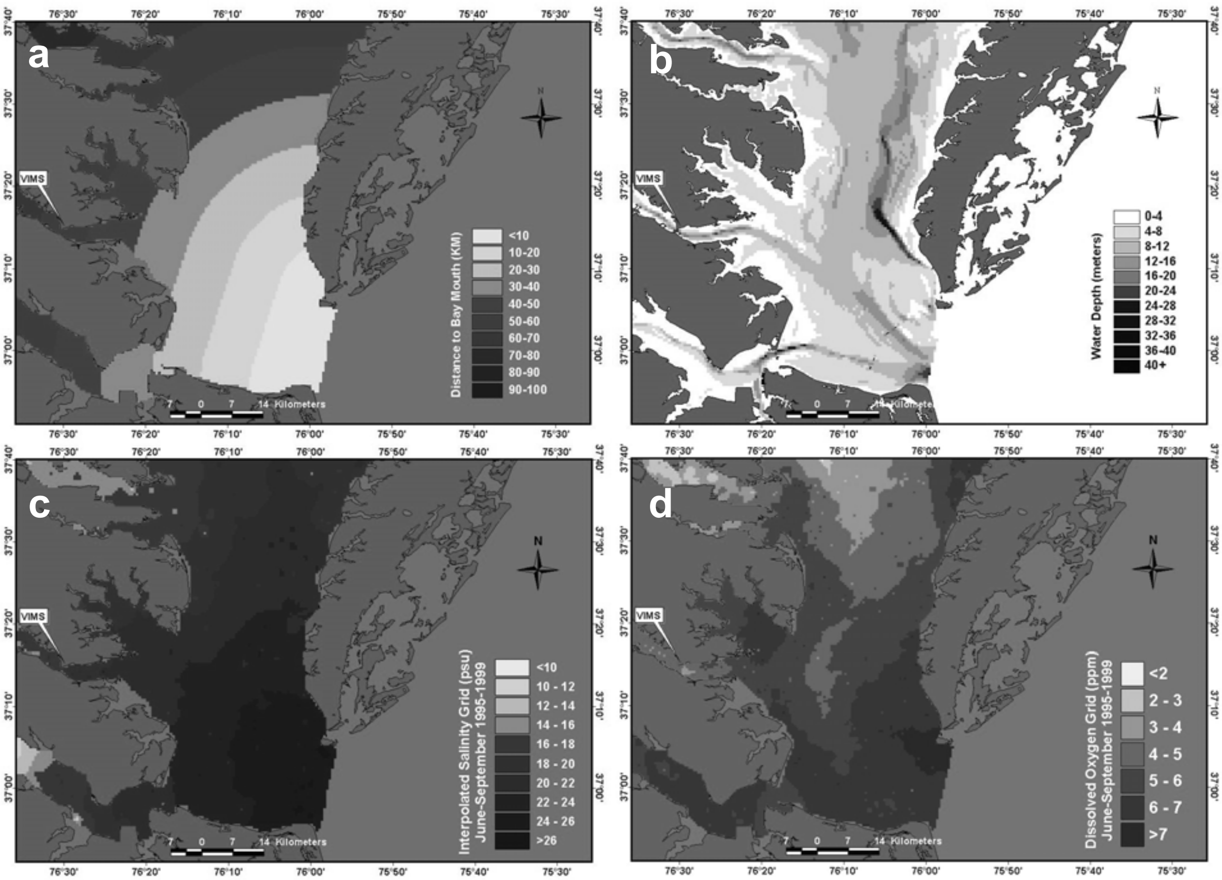


The sampling period for temporal delineation was May 1 to October 15 of each year. This period was divided into eleven semimonthly intervals. Mean CPUE was calculated for each interval and plotted to determine the timing of the summer immigration to Chesapeake Bay and the fall emigration from the Bay. Temporal trends in CPUE were compared to surface temperature, surface salinity, day length, and lunar phase to investigate potential stimuli for migration. The influence of these environmental factors (independent variables) on CPUE (dependent variable) was investigated using linear regression over immigration and emigration periods independently.

Tag-return data were also used to investigate the timing of summer and fall migrations for juvenile sandbar sharks. All recaptures were mapped using ArcView 3.1 GIS. Distance from tagging location and recapture location was measured as the shortest distance between the two points without crossing land. Data from tag recaptures made in Chesapeake Bay were used to estimate when sharks first arrive to the estuary in the summer and when they leave the estuary in the fall. Recaptures made during the winter and spring were used to determine the general location of the primary wintering grounds for the juvenile sharks. In addition, these data were used to determine the timing of their arrival to and departure from the wintering grounds. Finally, recaptures made in subsequent summers, those having gone through at least one winter prior to recapture, were used to determine whether or not these juvenile sharks return to their natal estuary as a summer nursery (i.e. evidence of philopatry) or move to new areas in subsequent years.

Collections for these studies were made with a commercial-style longline consisting of 3/16-inch tarred, hard-laid nylon main line, which is anchored at each end and marked by a hi-flier marker buoy. Three-meter gangions are spaced approximately 18 meters apart along the main line and a large inflatable float is attached to the main line following every 20th gangion. Each gangion is composed of a stainless steel tuna clip attached to a 2-meter section of 1/8-inch tarred nylon trawl line the end of which is attached to a large barrel swivel. A 1-meter section of 1/16 inch galvanized aircraft cable is crimped to the swivel and the other end is crimped to a Mustad 9/0 stainless steel shark hook. Bait consists mostly of *Brevoortia tyrannus*, Atlantic menhaden, and *Scomber scombrus*, Boston mackerel. A standard set consists of 100 hooks covering approximately two kilometers soaked for four hours. The statistical unit is catch per unit effort (CPUE) defined as the number of sharks per 100 hooks. Eight standard stations (Figure 1) plus ancillary localities are fished each month (May or June through September or October). Sampling for each month is completed within four days to reduce between-station variability. Each fish is measured and sexed and biological samples are taken as needed for genetic, age/growth, and reproduction analyses. Healthy specimens not needed for sampling are tagged and released for long-term studies on migration, habitat utilization, and age and growth.

Figure 3. Examples of interpolated variable grids used to display response surfaces for nursery-delineation models. a) Distance to Bay Mouth, b) Depth, c) Bottom salinity, d) Bottom dissolved-oxygen. Depth data are from EPA, Chesapeake Bay Program. Salinity and dissolved-oxygen grids are interpreted from data collected by the trawl survey combined over the period June - September, 1995-1999



Spatial Nursery Delineation of Juvenile Sandbar Sharks

Results

Abundance of juvenile *C. plumbeus*, based on CPUE data from longline sampling, was positively correlated with bottom salinity, depth, dissolved oxygen, and longitude and negatively correlated with distance to the mouth of the Bay, bottom temperature and latitude (Table 1, Figure 4). As expected, latitude and longitude were highly correlated with many of the other variables and were therefore dropped from the analysis (Table 2). Distance to the mouth of the Bay was introduced as a surrogate for salinity in order to make the models more applicable for management purposes. This will be discussed in more detail below. These two variables were highly correlated, as expected, and therefore, were not included together in the tree models. The initial regression tree models using salinity, depth, dissolved oxygen, and bottom temperature as predictor variables overfit the data, producing trees with 22 terminal nodes. Cost-complexity pruning indicated the variance was reduced by more than 50% at six terminal nodes. The full tree was pruned accordingly. This tree (Figure 5) indicated salinity was the most important environmental variable influencing the distribution of juvenile sharks in the estuary and suggested a

Table 1. Spearman's Rank Correlation (rho) for CPUE (sharks per 100 hooks) versus potential predictor variables.

SPEARMAN'S NONPARAMETRIC CORRELATION (rho)

VARIABLE	Correlation Coefficient	Significance	N
Distance to Bay Mouth	-0.535**	<0.001	83
Bottom Salinity	0.447**	<0.001	83
Bottom Temperature	-0.351**	<0.001	83
Bottom Dissolved Oxygen	0.232*	0.034	83
Minimum Set-Depth	0.265*	0.016	83
Maximum Set-Depth	0.177	0.109	83
Latitude	-0.401**	<0.001	83
Longitude	0.248*	0.024	83
Year	-0.047	0.676	83

**Correlation is significant at the .01 level (2-tailed)

*Correlation is significant at the .05 level (2-tailed)

Figure 4. Matrix plot of CPUE plus five independent variables (distance to mouth, salinity, minimum set depth, dissolved oxygen, temperature)

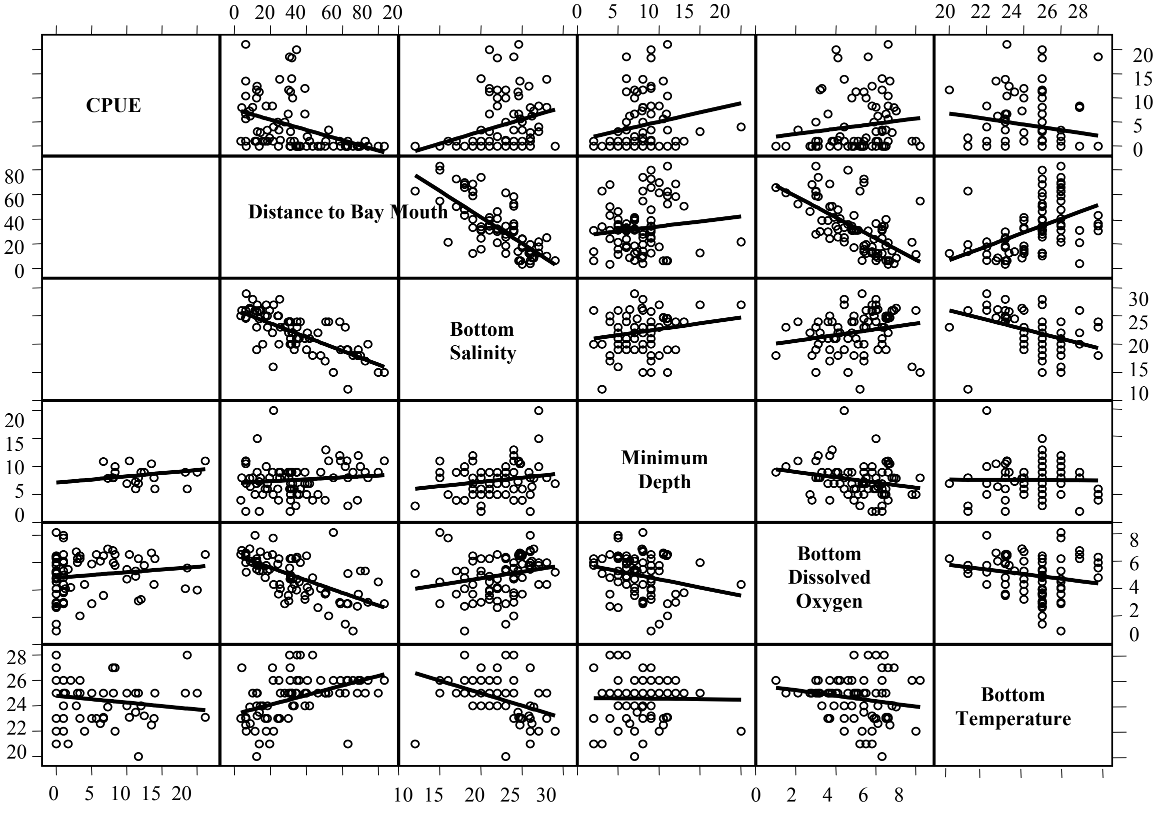


Table 2. **Spearman's Rank Correlation (rho) for predictor variables. Only significantly correlated predictor variables are shown.**

SPEARMAN'S NONPARAMETRIC CORRELATION (rho)

FACTOR COMBINATION	Correlation Coefficient (rho)	Sign. (2-tailed)	N
Latitude vs. Bottom Temperature	0.483**	<0.001	83
Latitude vs. Bottom Salinity	-0.613**	<0.001	83
Latitude vs. Bottom Dissolved-Oxygen	-0.685**	<0.001	83
Latitude vs. Distance to Bay Mouth	0.900**	<0.001	83
Latitude vs. Minimum Set-Depth	0.314**	0.004	83
Latitude vs. Maximum Set-Depth	0.296**	0.007	83
Longitude vs. Bottom Salinity	0.347**	0.001	83
Longitude vs. Minimum Set-Depth	0.389**	<0.001	83
Longitude vs. Maximum Set-Depth	0.512**	<0.001	83
Bottom Salinity vs. Bottom Temperature	-0550**	<0.001	83
Bottom Salinity vs. Bottom Dissolved-Oxygen	0.302**	0.006	83
Distance to Bay Mouth vs. Bottom Temperature	0.563**	<0.001	83
Distance to Bay Mouth vs. Bottom Salinity	-0.737**	<0.001	83
Distance to Bay Mouth vs. Bottom D. Oxygen	-0.652**	<0.001	83
Bottom Dissolved-Oxygen vs. Minimum Set-Depth	-0.223*	0.043	83
Minimum Set-Depth vs. Maximum Set-Depth	0.721**	<0.001	83

**Correlation is significant at the .01 level (2-tailed)
*Correlation is significant at the .05 level (2-tailed)

preference for areas where salinity is greater than 20.5. The model selected depths greater than 5.5 meters as the second most important variable defining nursery habitat and also suggested a preference, perhaps tolerance-based, for areas with dissolved oxygen concentrations greater than 5.35 ppm. Areas within Chesapeake Bay that correspond to these variable levels are shown by the response surface in Figure 6. This model is referred to as Ecological Model I. Cross-validation of the regression tree model indicated truncation of the model to three terminal nodes, which corresponded to station splits based on salinity and depth only, was sufficient to explain the data. This model is referred to as Ecological Model II (Figure 7) and the corresponding response surface map (Figure 8) indicated that suitable nursery habitat encompasses most of the lower Bay south of 37^0 20' N latitude and extends as far as 37^0 40' N on the eastern side of the Bay. This reflects the haloclinal tilting typical of the estuary due to freshwater riverine influx from the western side of the Bay coupled with tidal influx of high-salinity oceanic water from the south. One major criticism of this model, however, is that whereas depth is a relatively stable variable, salinity is extremely dynamic seasonally and annually, not fixed in space and time. To illustrate the effect of annual variability on the response surface, salinity and dissolved oxygen grid coverages were interpolated for data from July 1996, representing a very wet year, and July 1999 representing a drought year. Figure 9 shows the response surfaces for the two models applied to these two months. According to Ecological Model I, the amount of suitable habitat in 1999 (794 km^2) was 50% greater than that of 1996 (524 km^2). According to Ecological Model II, only using salinity and depth, the discrepancy was even greater. The amount of suitable habitat in July 1999 (2134 km^2) was more than 180% greater than that in July 1996 (741 km^2). This is supported by anecdotal evidence of sharks being caught by recreational fishers as far up the York River as VIMS in 1999. Schwartz (1960) reported juvenile *C. plumbeus* as far north as Flag Pond in Calvert County (four specimens, 1958) and the West River

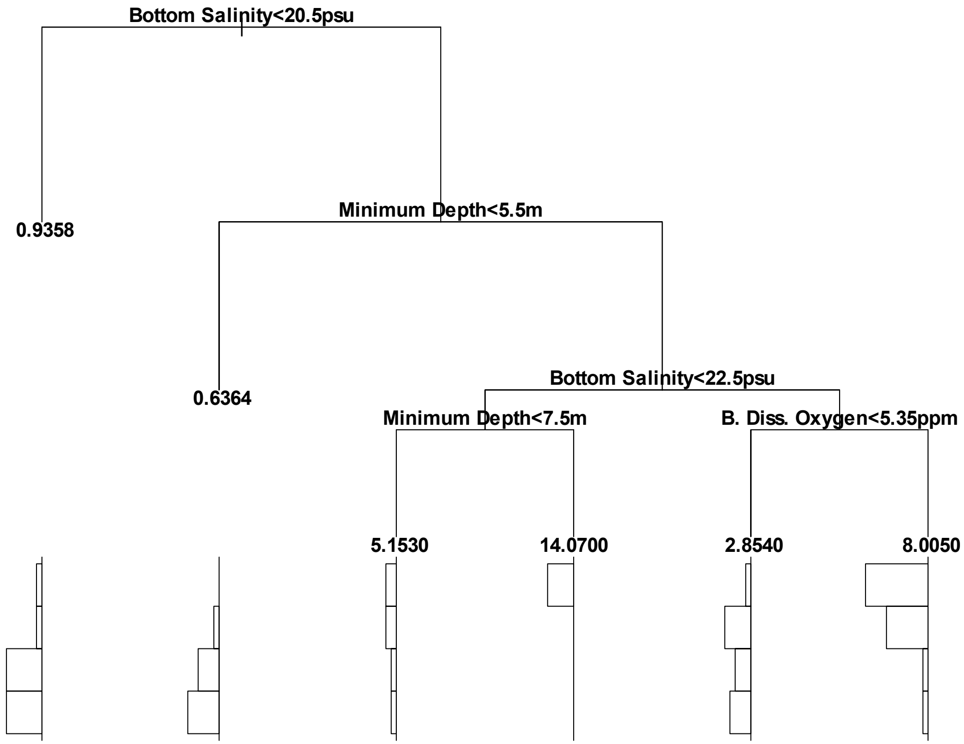


Figure 5. Categorical regression tree modeling (CART). Ecological Model with tree pruned to six terminal nodes with predicted CPUE below each node.

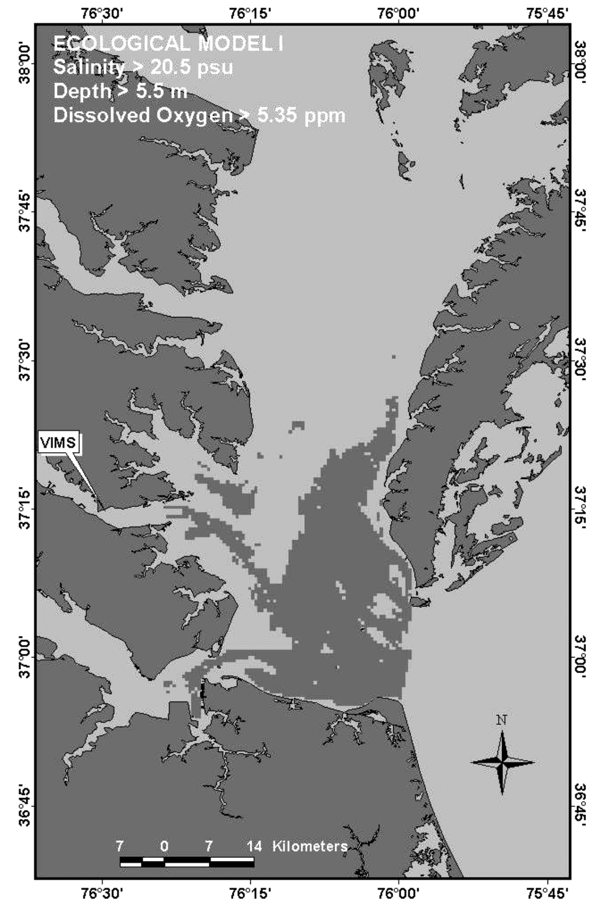


Figure 6. Response surface for Ecological Model I. Shaded area is portion of Chesapeake Bay with average summer salinity greater than 20.5, depth greater than 5.5 meters, and dissolved oxygen concentration greater than 5.35 ppm. This area is interpreted to represent suitable nursery habitat according to the model.

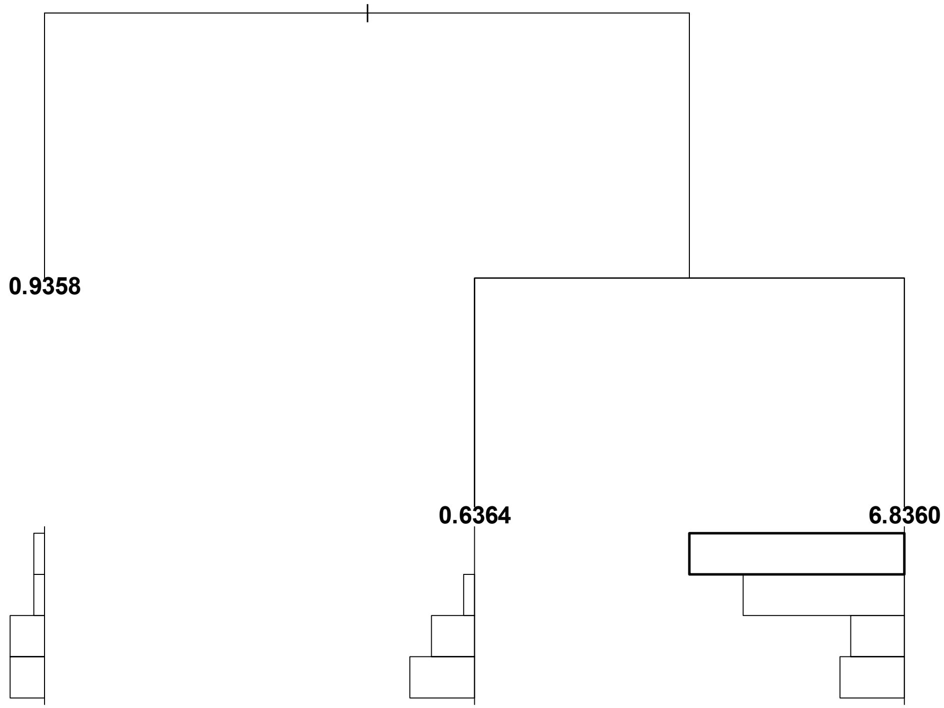


Figure 7. **Categorical regression tree modeling (CART). Final tree of the Ecological Model pruned to three terminal nodes. Predicted CPUE and histogram shown below each terminal node. Histograms show distribution of CPUE values among the observations in each node.**

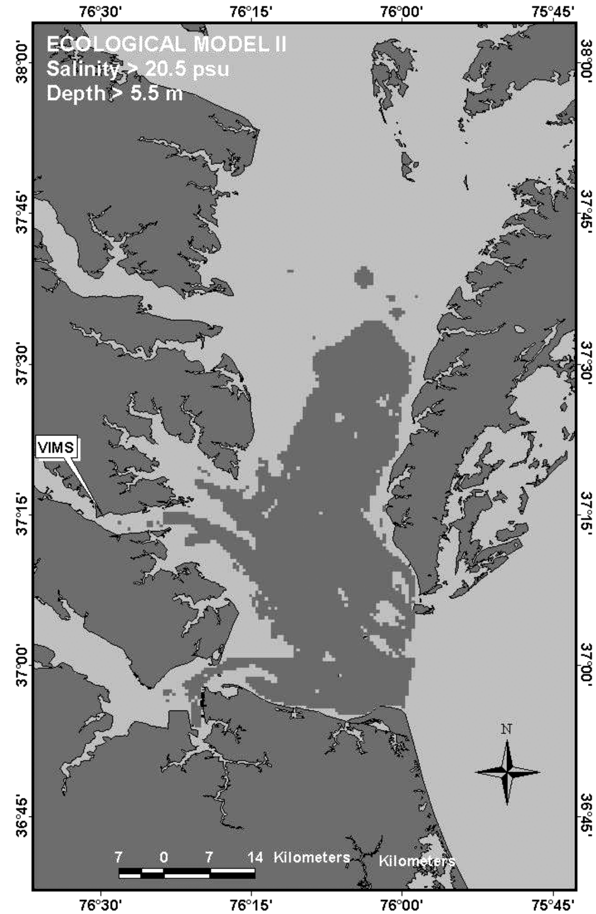
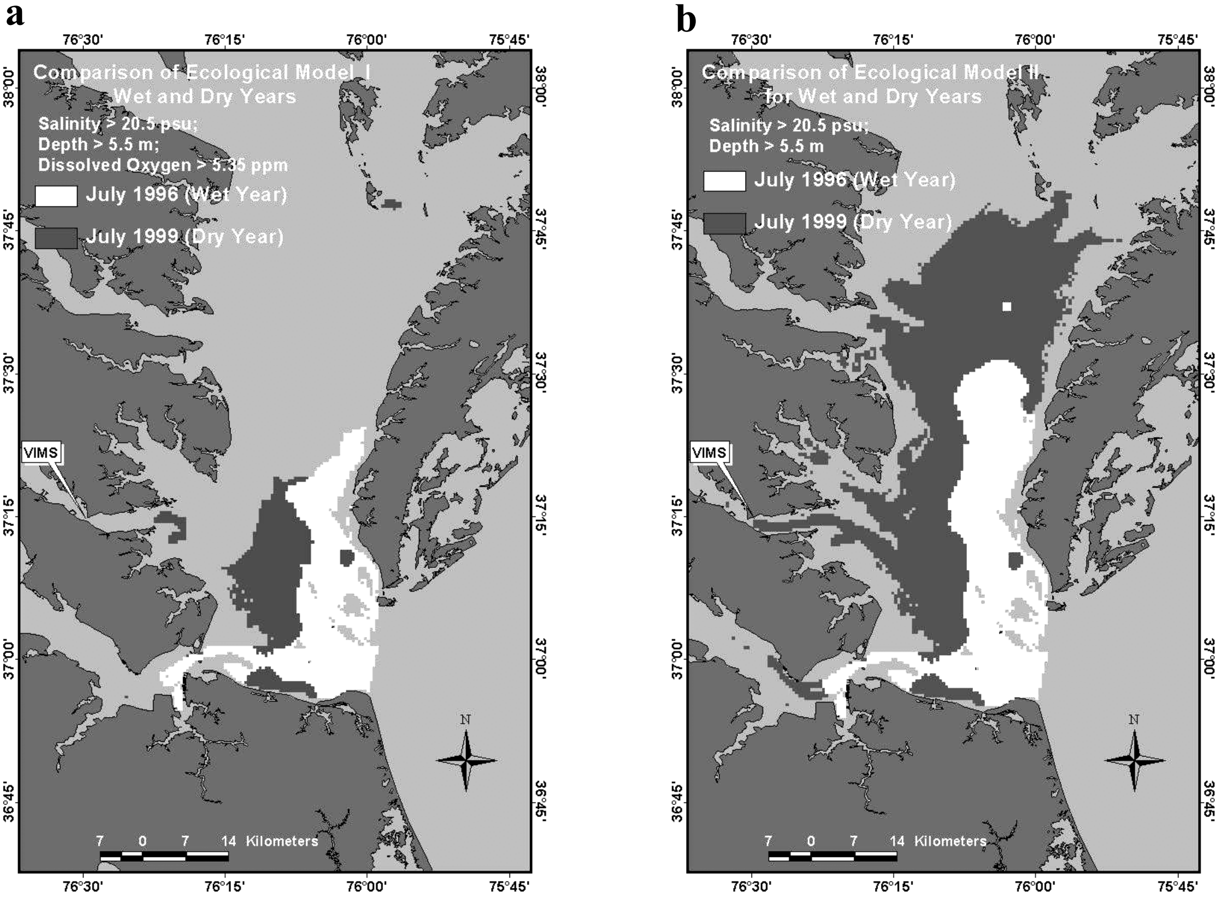


Figure 8. Response surface for Ecological Model II. Shaded area is portion of Chesapeake Bay wit average summer salinity greater than 20.5 and depth greater than 5.5 meters. This area is interpreted to represent suitable nursery habitat according to the reduced Ecological Model.

Figure 9. Comparison of suitable nursery habitat defined by a) CART Ecological Model I and b) CART Ecological Model II for a wet year (low salinity) and a drought year (high salinity).



in Anne Arundel County (one specimen, 1959) in the Maryland portion of the Bay. Perhaps these were rare forays into marginal habitats or perhaps salinity was anomalously high during this period. This was prior to the development of any directed shark fisheries along the East Coast, however. Therefore abundance may have been much higher and competition may have forced the utilization of these areas.

The ecological models delineated nursery EFH for juvenile *C. plumbeus* in Chesapeake Bay according to the environmental parameters sampled. These models were very simple to understand ecologically and were based primarily on selection for high salinity regions. A second goal of this study, however, was to develop an EFH model that would be of use for management of the population through the establishment of regulations limiting exploitation within the nursery. Protecting or regulating geographic areas based on dynamic variables such as salinity are difficult at best, even during periods of stability. Annual and seasonal variability render management impossible based on salinity. Salinity is highly correlated with distance to the mouth in Chesapeake Bay; therefore distance was introduced as a surrogate variable for salinity in a second model. Again, the initial trees overfit the data but cost-complexity pruning and cross-validation suggested only three terminal nodes were needed to explain the data. The regression tree (Figure 10) indicated distance to mouth was the most important variable influencing shark distribution in the Bay, and predicted presence at stations less than 34.5 km from the Bay mouth. This model also indicated higher abundance of sharks at depths greater than 5.5 meters. Because

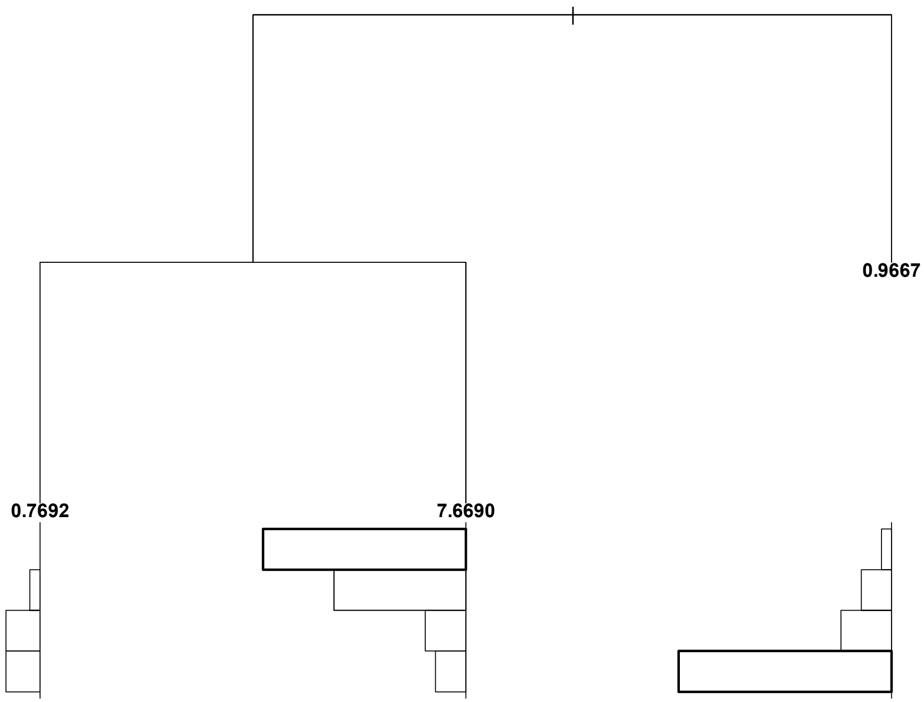


Figure 10. **Categorical regression tree modeling (CART). Final tree of the Management Model pruned to three terminal nodes. Predicted CPUE and histogram shown below each terminal node. Histograms show distribution of CPUE values among the observations in each node.**

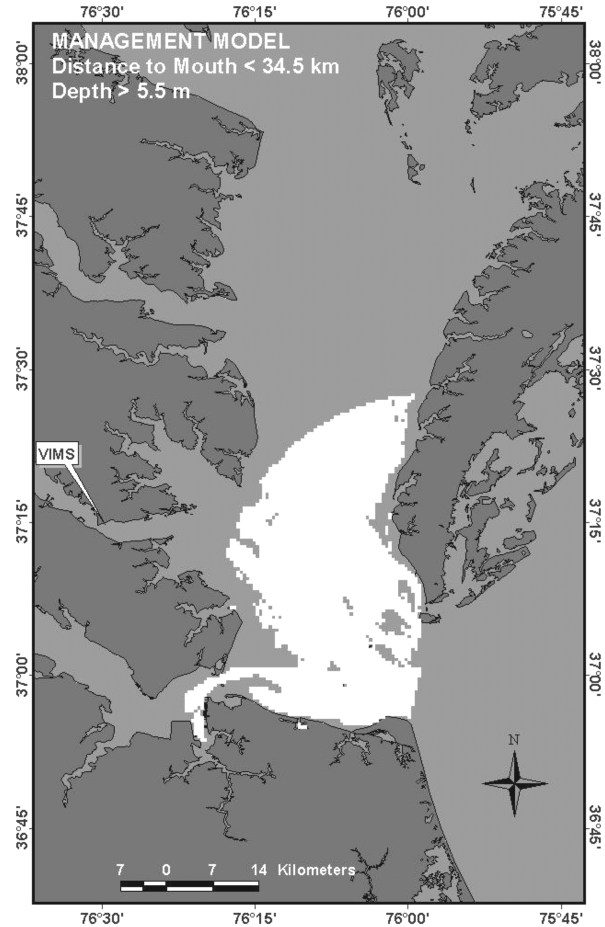


Figure 11. **Response surface for the Management Model. Shaded area is portion of Chesapeake Bay less than 34.5 km from the mouth of the Bay and depth greater than 5.5 meters. This area is interpreted to represent suitable nursery habitat according to the reduced Management Model.**

Table 3. **Classification ability of reduced ecological and management tree models. Each model was pruned to three terminal nodes. Classification is measured by the proportion of each estimation parameter is included in the terminal node possessing the highest shark CPUE.**

Estimation Parameter (% encompassed by model)	Ecological (S, Z, T, DO) Salinity/Min. Depth (3)	Management (D, Z, T, DO) Distance/ Min. Depth (3)
Sets where CPUE>1.0	74.1% (40/54)	81.5% (44/54)
Sets where CPUE>3.0	91.2% (31/34)	97.1% (33/34)
Total Sharks Caught	90.1%	88.7%
Tag Recaptures	86.4% (19/22)	81.8% (18/22)
Telemetry Fixes	100% (67/67)	100% (67/67)

both variables used in this Management Model are stagnant; the response area from this model (Figure 11) is stable. Though distance to mouth may have no direct ecological significance or influence, the resulting response surface encompasses most of the suitable habitat from the initial models but does not fluctuate due to dynamic influential variables. This model provides a much more functional management tool for regulating the nursery.

Both of these very simple spatial models performed very well in all post-hoc measures of classification (Table 3). The terminal node predicting highest shark abundance in Ecological Model II contained 74.1% of all sets with CPUE >1.0 and 91.2% of all sets with CPUE >3.0. That of the Management Model performed even better, with 81.5% of all sets with CPUE >1.0 and 97.1% of all sets with CPUE >3.0. Of the total number of sharks caught, 90.1% were in the high abundance terminal node of Ecological Model II and 88.7% were in that of the Management Model.

The ability of these models to classify and delineate the nursery correctly was assessed by two independent data sources, tag-recapture data and telemetry data. Nineteen of 22 (86.4%) tag recaptures from the Bay were within the response surface for Ecological Model II whereas 20 of these 22 (81.8%) were within the response surface of the Management Model (Figure 12). A total of nine sharks manually tracked for a cumulative 350 hours generated 67 location fixes temporally separated by at least six hours. All 67 (100%) of these location fixes were within the response surfaces for both models (Figure 13).

As a means of validating these models, logistic regression modeling was performed on the data. Presence/absence was substituted for CPUE as the response variable. Univariate logistic regressions were performed using each independent variable and CPUE as the dependent or response variable. All five continuous predictor variables used in the CART models were interval coded to increase model stability. The -2 log-likelihood statistic (G) was significant ($p<0.05$) for all univariate models except that for minimum set depth ($p=0.059$). The percent correct classification for the univariate regressions ranged from 69 and 77% (Table 4a). In all cases, the univariate models were more successful in predicting presence than absence. Overall model significance was greatest for distance to Bay mouth ($G=27.7$, $p<0.0001$) and bottom salinity ($G=16.4$, $p<0.0001$), comparable to the results of the tree models. Pearson, Deviance, and Hosmer-Lemeshow goodness-of-fit tests were insignificant for all univariate models except bottom temperature (Table 4b). The tests were all highly significant ($p<0.001$) for temperature indicating this univariate model fit the data very poorly. Insignificant test statistics for all other variables indicated these models adequately fit the data.

Multivariate regressions were performed using the same combinations of variables as in the

Figure 12. **Tag recaptures for juvenile *C. plumbeus* recaptured in Chesapeake Bay during the same year and subsequent years compared to CART models of nursery habitat. a) Recaptures compared with Ecological Model II, b) Recaptures compared with the Management Model**

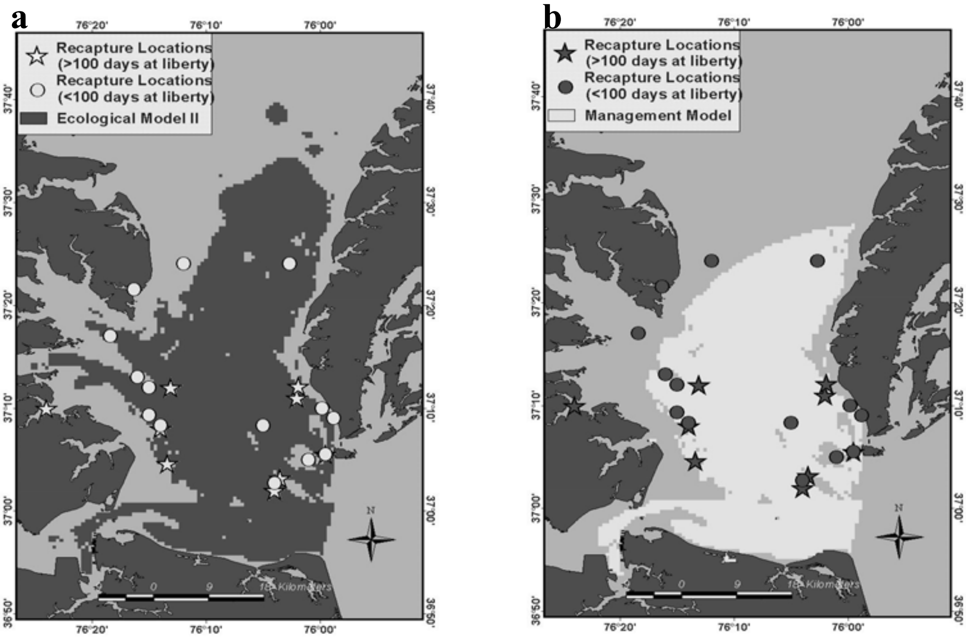


Figure 13. **Telemetry fixes for nine juvenile *C. plumbeus* manually tracked for 11 to 64 hours (cumulative 350 hours) from 1996 through 1999 compared to CART models of nursery habitat. The minimum interval between fixes was six hours to avoid autocorrelation. a) Telemetry fixes compared with Ecological Model II, b) Telemetry fixes compared with the Management Model.**

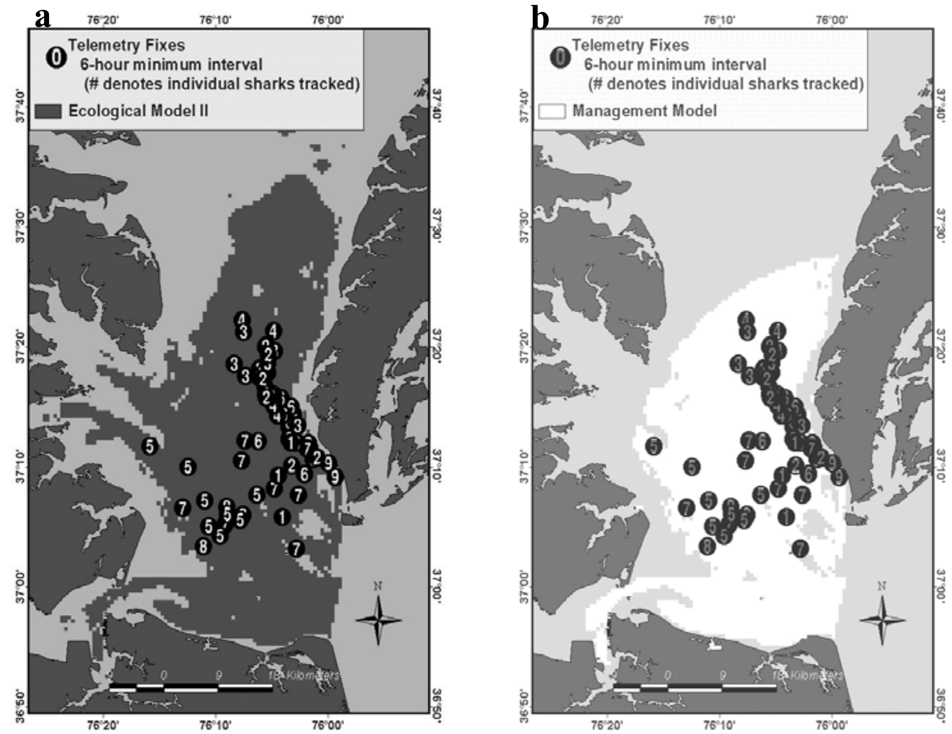


Table 4. **Results of univariate logistic regressions. a) Model significance, classification, Somer's D measure of model predictive ability; b) Goodness-of-Fit tests for each univariate model (significance indicates lack of fit)**

a.

Variable	G	df	Sign.	Classification % Correct			Somer's D
				Pres	Abs	Overall	
Bottom Salinity (≤16;17-19; 20-22;23-25; ≥26psu)	16.398	1	<0.0001	90.74	48.28	75.90	0.49
Distance from Bay Mouth (<15km; 15-30km; 30-45km; 45-60km; >60km)	27.721	1	<0.0001	90.74	51.72	77.11	0.64
Minimum Set-Depth (1m intervals; 2-20m)	3.551	1	0.059	98.15	13.79	68.67	0.20
Bottom Dissolved-Oxygen (≤2;3;4;5;≥6 ppm)	4.823	1	0.028	98.15	13.79	68.67	0.26
Bottom Temperature (1^0C intervals; 20-28^0C)	10.540	1	0.001	87.04	55.17	75.90	0.48

b.

Variable	Goodness-of-Fit Tests (probabilities)		
	Pearson	Deviance	Hosmer-Lemeshow
Bottom Salinity	0.722	0.716	0.545
Distance from Bay Mouth	0.593	0.536	0.593
Minimum Set-Depth	0.395	0.285	0.110
Bottom Dissolved-Oxygen	0.658	0.637	0.779
Bottom Temperature	0.001	0.005	0.009

Ecological and Management models from the regression tree analyses. The most significant multivariate logistic models are summarized in Table 5. The logistic regression of Ecological Model I including salinity, depth, and dissolved oxygen (dropping temperature) predicted presence of juvenile *C. plumbeus* best (Table 5), as in the tree models. The overall model was highly significant (G=23.102, df=3, p<0.0001) and all goodness-of-fit tests suggested the model adequately fit the data. The model had 78.31% correct classification, but predicted presence (88.89%) much better than absence (58.62%). This model had a Somer's D estimate of model predictive ability of 0.61. The scale of Somer's D ranges from zero for a model with no predictive ability to one for a perfect predictive model. The model including temperature was also highly significant (G=27.925, df=4, p<0.0001) but the Pearson goodness-of-fit chi-square (p=0.08) suggested this model did not fit the data as well as the model without temperature. The model including only salinity and depth was also highly significant (G=19.329, df=2, p=0.0001) and the goodness-of-fit statistics suggested this model adequately fit the data as well. Model classification (74.70%) and Somer's D (0.56) were slightly lower than the model that included dissolved oxygen. Significance of individual variable coefficients was determined by the Wald statistic evaluated at 0.05. Salinity was the most significant factor in all three of these models and the odds ratio ranged from1.32 to 1.35 indicating an increased likelihood of shark presence with increased salinity. Minimum set depth was also a significant factor in the models that included dissolved oxygen and/or temperature but was insignificant in the reduced model that included only salinity and depth. Its odds ratio ranged from 1.19 to 1.28 indicating an increased likelihood of shark presence with increased depth.

The logistic regression of the Management Model using all four variables used in the CART model was highly significant (G=38.876, df=4,

Table 5. **Summary of overall logistic-regression statistics for full and reduced Ecological and Management Models a) overall model significance (-2 log likelihood = G), classification, Somer's D measure of model predictive ability b) Goodness-of-Fit tests (p<0.05 indicates lack of fit)**

a.

Model	**G**	**df**	**Sign.**	Classification % Correct			**Somer's D**
				Pres	Abs	Overall	
Ecological Model 1 (S, Z, DO, T)	27.925	4	<0.0001	83.33	62.07	75.90	0.66
Ecological Model 2 (S, Z, DO)	23.102	3	<0.0001	88.89	58.62	78.31	0.61
Ecological Model 3 (S, Z)	19.329	2	0.0001	85.19	55.17	74.70	0.56
Management Model 1 (Dist, Z, DO, T)	38.876	4	<0.0001	88.89	75.86	84.34	0.76
Management Model 2 (Dist, Z)	38.300	2	<0.0001	90.74	72.41	84.34	0.75

b.

Model	Goodness-of-Fit Tests (probabilities)		
	Pearson	Deviance	Hosmer-Lemeshow
Ecological Model 1 (S, Z, DO, T)	0.088	0.244	0.345
Ecological Model 2 (S, Z, DO)	0.291	0.116	0.158
Ecological Model 3 (S, Z)	0.143	0.102	0.305
Management Model 1 (Dist, Z, DO, T)	0.046	0.683	0.767
Management Model 2 (Dist, Z)	0.962	0.937	0.476

p<0.0001) and all goodness-of-fit tests suggested the model adequately fit the data (Table 5). The model had 84.34% correct classification (88.89% for presence; 75.86% for absence) and a Somer's D of 0.76. The coefficients for dissolved oxygen and temperature were insignificant; therefore they were dropped from the model. The reduced Management Model including only distance to mouth and minimum set depth was also highly significant (G=38.300, df=2, p<0.0001), and the percentage of correct classification and Somer's D were virtually unchanged from the full model (Table 5). Distance to mouth was the most significant variable (p<0.001) and its odds ratio was 0.91 in both models indicating a decrease in likelihood of shark presence with increased distance from the mouth of the Bay. Minimum set depth was also highly significant in both models (p<0.01) and its odds ratio was 1.48 in the full model and 1.50 in the reduced model indicating and increased likelihood of shark presence with increased depth.

These results were in close agreement with the regression-tree models. In the Ecological Models, salinity and depth were the most important variables influencing the distribution of juvenile *C. plumbeus* using regression trees and logistic regression. For the Management Models, distance to Bay mouth and depth were the most important variables influencing distribution using both techniques. Both methods also suggested that bottom temperature and dissolved oxygen concentration may also influence this distribution, though less than salinity and depth. Dissolved oxygen concentration in Chesapeake Bay is extremely dynamic. Large hypoxic areas are established in late summer. Most of these areas are in deeper water north of the EFH area delineated in this study. It is hypothesized, however, that in certain summers this hypoxic zone may indeed cause constriction of the summer nursery just as low salinity (wet years) did in 1996.

Using both regression-tree modeling and multivariate logistic regression, it was found that complex habitat selection patterns could be adequately modeled with only two variables. To examine potential differences in the response surfaces delineated using each technique, the selection functions, $w^*(\chi)$, were plotted for each influential variables using the coefficients from their univariate models (Figure 14). Values of the selection function, $w^*(\chi)$, greater than 0.5 predict shark presence and values less than 0.5 predict shark absence. The value of the independent variable as it crosses this threshold can be compared with the splitting-rule value of the variable in the regression-tree models. Differences in actual variable reference points were probably simply a function of the use of a continuous response variable, CPUE, in the tree models and the use of a binary response variable, presence/absence, in the logistic models. The selection function for distance to bay mouth started at a value greater than 0.9 at zero kilometers and gradually declined. The curve predicted shark presence when distance to mouth is less than 44.5 km compared to a value of 34.5 km selected by the tree models (Figure 14a). The selection function for salinity indicated that shark presence was predicted when salinity is greater than 19.7 (Figure 14b). This corresponded very closely with the value 20.5 from the regression-tree models. Three selection functions were plotted for the minimum set depth variable. The univariate regression model (G=3.551, p=0.59) for this variable and the corresponding coefficient (Wald=3.22, p=0.0729) were not significant. This model, however, included all stations whereas the tree models first divided the stations based on salinity or distance to bay mouth. It then used only those stations with salinity greater than 20.5 in the Ecological Model and those stations less than 34.5 km from the mouth in the Management Model to make a second split based on the depth parameter. Based on this fact, two additional univariate logistic regressions were performed. The first used only stations where distance to mouth was less than 44.5 km, the reference from the univariate selection function using distance to mouth as the predictor. This model was highly significant as was the model coefficient for depth (Wald chi-square = 8.35, p=0.0039). The second used only stations where salinity was greater than 19.7, the reference from the univariate selection function using salinity as the predictor. This model was also highly significant as was the model coefficient for depth (Wald chi-square = 6.63, p = 0.01). When plotted, the selection functions for these two models predicted presence of *C. plumbeus* ($w^*(\chi)$ > 0.5) in water deeper than 3.9 and 3.65 meters, respectively (Figure 14c), compared with 5.5 meters selected by the tree models.

Though the models appeared to be in close agreement, small differences in salinity, distance to mouth, and depth correspond to large differences in area defined. The area delineated by the regression-tree Ecological Model (salinity >20.5, depth >5.5 m) was layered over that delineated by the logistic regression (salinity >19.7, depth >3.65 m) in Figure 15a. In this case, the area defined by the logistic model was 39% greater than that defined by the tree model. The area delineated by the regression-tree Management Model (distance to mouth <34.5 km, depth >5.5 m) was layered over that delineated by the logistic regression (distance to mouth <44.5 km, depth >3.9 m) in Figure 15b. The area defined by the logistic model was 51% greater than that defined by the tree model.

Discussion

This study represents the first attempt to quantify habitat selection spatially and delineate the corresponding nursery to define essential fish habitat for an elasmobranch. The statistical procedures used in this study have been used on a number of teleost species. Regression tree modeling was used to determine important habitat variables in nursery areas for several species of flatfishes in Alaskan waters (Norcross et al. 1995, 1997). Multivariate logistic regression has been used to investigate habitat preference by juvenile flatfishes around Kodiak Island, Alaska (Norcross et al. 1999) and by juvenile *Paralichthys dentatus* in Chesapeake Bay (Kraus and Musick in prep). This is the first time these techniques have been used for elasmobranchs.

The results of this study provide a framework for delineating EFH for shark nursery grounds. Nursery EFH for most shark species occurs in state-controlled waters. The spatial models resulting from this methodology can be used by state and regional regulatory agencies to limit harvest in areas determined to constitute essential nursery habitat. In the summer of 1996, a directed commercial fishery developed in Chesapeake Bay, targeting juvenile *Carcharhinus plumbeus*. About 20,000 kg of juvenile sharks were landed, mostly in three-week period from mid-June to the beginning of July. All of the sharks landed came from the area delineated as EFH in this study. As discussed, the amount of suitable habitat according to these

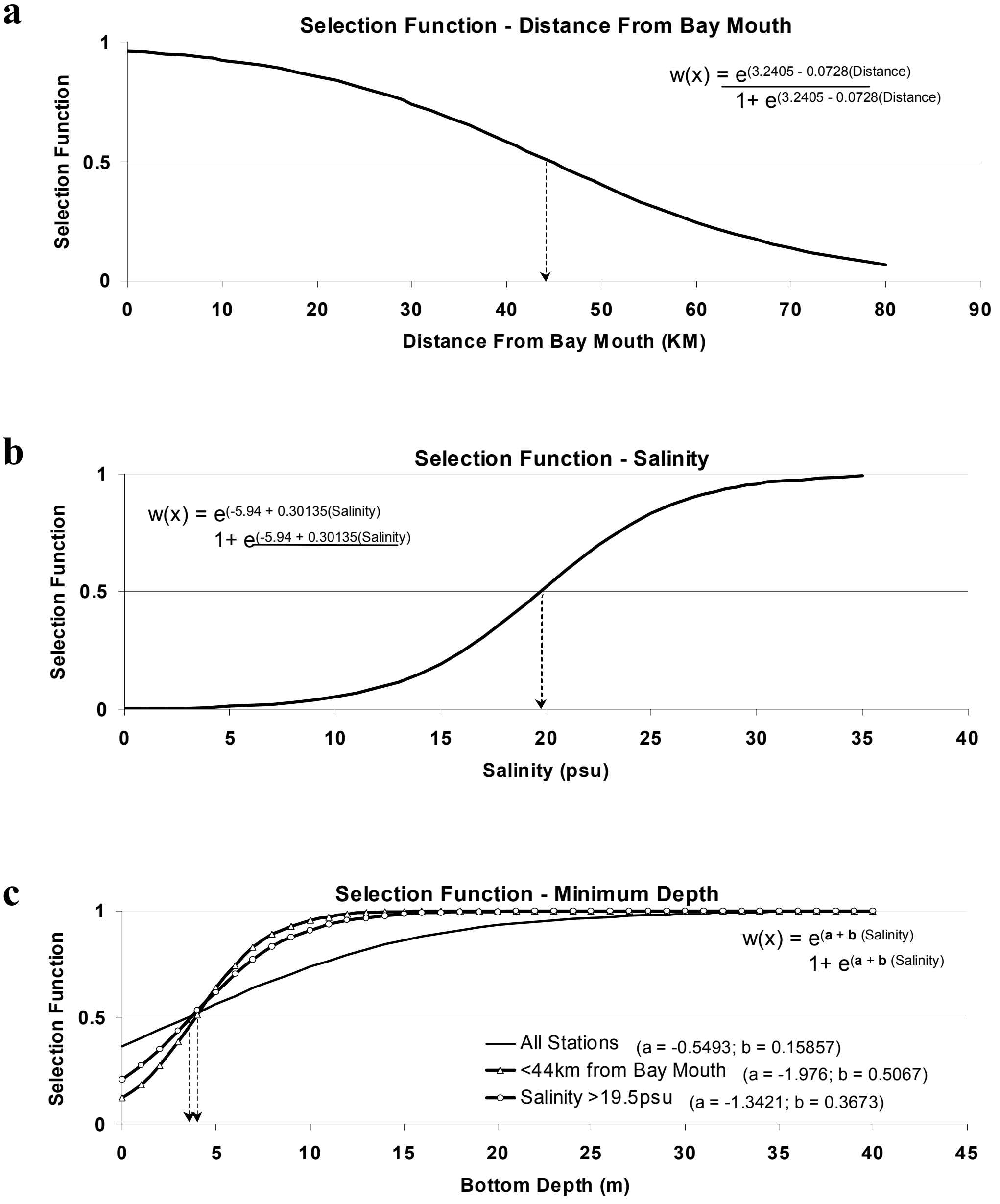


Figure 14. **Plot of univariate selection functions (w(x). Parameter estimates from univariate logistic regressions for distance from mouth (a), salinity (b), depth (c), depth adjusted for distance (c), and depth adjusted for salinity (c).**

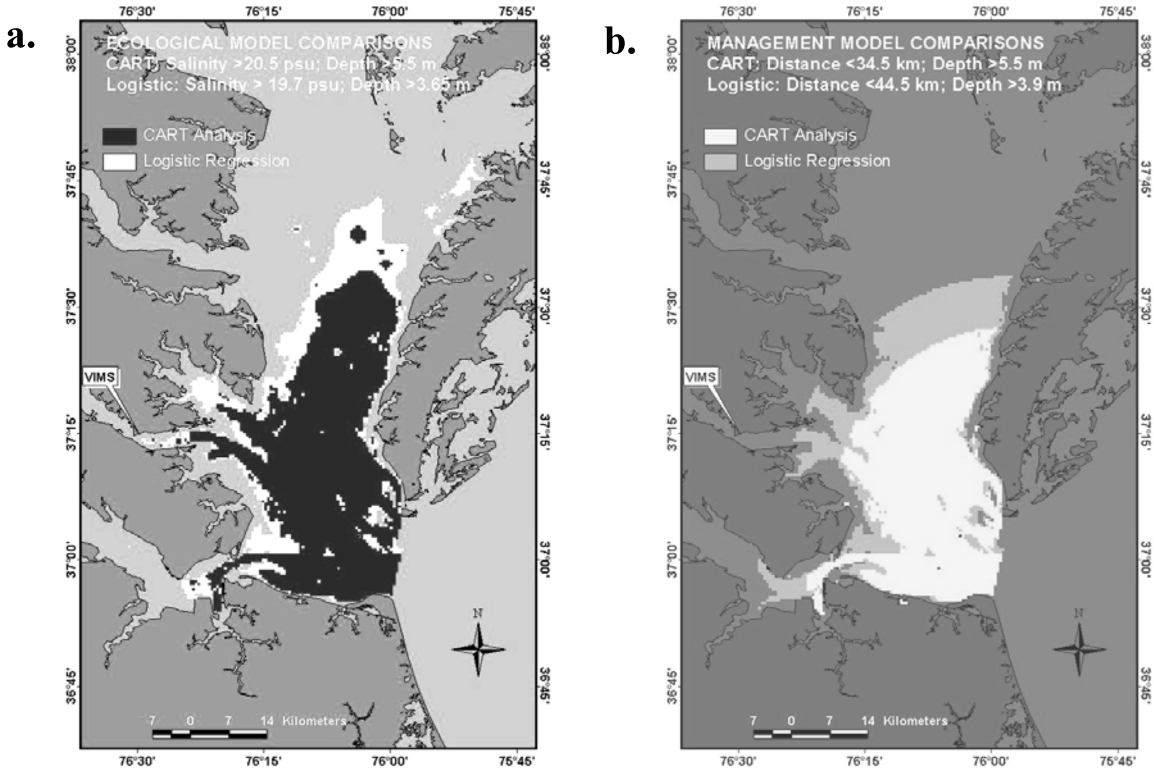


Figure 15. **Maps comparing suitable nursery habitat defined by regression tree (CART) models and logistic regression models: a) Ecological Model, b) Management Model.**

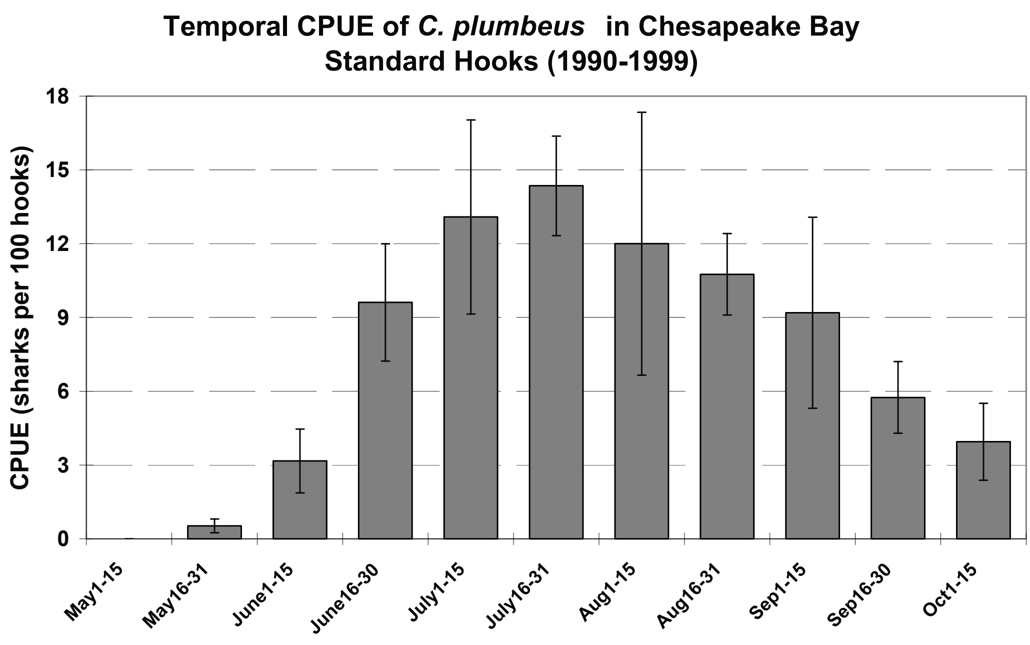


Figure 16. **Mean semi-monthly CPUE (*C. plumbeus* per 100 hooks) for Middleground and Kiptopeke stations combined using Standard 9/0 hooks - 1990 to 1999**

models was severely constricted in 1996 due to low overall estuarine salinity. This may have concentrated the juvenile sharks making them particularly vulnerable to the gillnet fishery. VIMS CPUE data indicated this may have equated to the harvest of as much as 75% of the Chesapeake Bay nursery population and resulted in severe juvenescence of that portion of the Atlantic stock (Grubbs and Musick in prep a). Minimum size limit regulations have recently been established, however the development of a temporary no-take zones during the summer months, as determined by EFH modeling, may be a better method for preventing such destructive fishing practices from resurfacing.

Future research directions with these EFH models will involve including water quality and other potentially influential anthropogenic variables. Interestingly, all of the models in this study identified the lower western portion of Chesapeake Bay as suitable nursery habitat, yet the CPUE data indicated very low abundance of juvenile *C. plumbeus* in this region. This is the most urbanized region of the lower estuary and is subject to intense urban and agricultural run-off through the James River. It is hypothesized that these factors have severely degraded otherwise suitable nursery habitat in the region.

Temporal Nursery Delineation of Juvenile Sandbar Sharks

Results

The results of this study indicated that Chesapeake Bay is utilized as a summer nursery for *C. plumbeus* primarily from mid-May to mid-October (Figure 16). The CPUE data indicated that juvenile sharks began immigrating to the Bay after May 15 with the majority of sharks entering the estuary after June 15. The CPUE peaked in late July indicating full recruitment to the estuary by this time. Mean CPUE began to decline in August, particularly later in the month. We hypothesize that this CPUE decline in August represents dispersal throughout the nursery rather than the beginning of the emigration period. Similar dispersal trends have been observed in the movement patterns of other fishes such as *Morone saxatilis* in Chesapeake Bay (Moore and Burton 1975). The CPUE data suggested emigration from the estuary in preparation for the fall migration to wintering grounds occurred in late September and early October. Migration to and from the Bay was not significantly correlated with salinity, day length, or lunar phase. Significant correlations were observed, however, between migration patterns and surface temperature, as hypothesized previously by Musick and Colvocoresses (1986), as well as day length.

Mean surface temperature from data collected *in situ* mirrored the temporal trend in CPUE very closely, particularly during the immigration period (Figure 17). No sharks were caught when temperatures were below 18^0C and sets with CPUE>2.0 were observed only when temperature was greater than 21^0C. Peak shark CPUE was observed when temperature was approximately 26^0C. Linear regression using mean surface temperature as the independent variable and mean CPUE as the dependent variable for the immigration period only was highly significant ($p<0.001$, $r^2=0.98$) indicating temperature may act as a factor triggering immigration to Chesapeake Bay (Figure 18a). During the emigration period, mean surface temperature also mirrored CPUE, though there appeared to be a temperature lag (Figure 17b). CPUE began to decline a full month prior to significant declines in temperature, which never cooled below 21^0C during the emigration phase. Linear regression indicated that CPUE is significantly correlated with surface temperature during the emigration period ($p=0.02$, $r^2=0.77$), and the intercept of the fitted line suggested all sharks leave the Bay prior to the water cooling to 20^0C (Figure 18b). The relationship, however, was not as strong as during the immigration period and the observed time lag suggested that temperature may not be the environmental trigger for these sharks to leave the estuary and begin the fall migration.

Day length was defined as the time between sunrise and sunset. These data were calculated for each set using data supplied by the United States Naval Observatory Astronomical Applications Department. This variable is annually conservative; therefore means for the time intervals were calculated for one year only. Day length changed little during the May 1 to July 31 period, varying by only 42 minutes (Figure 17b). Linear regression analysis of CPUE as a function of day length for the immigration period was insignificant ($p>0.001$, $r^2=0.15$) (Figure 19a). Day length declined continuously during the emigration period,

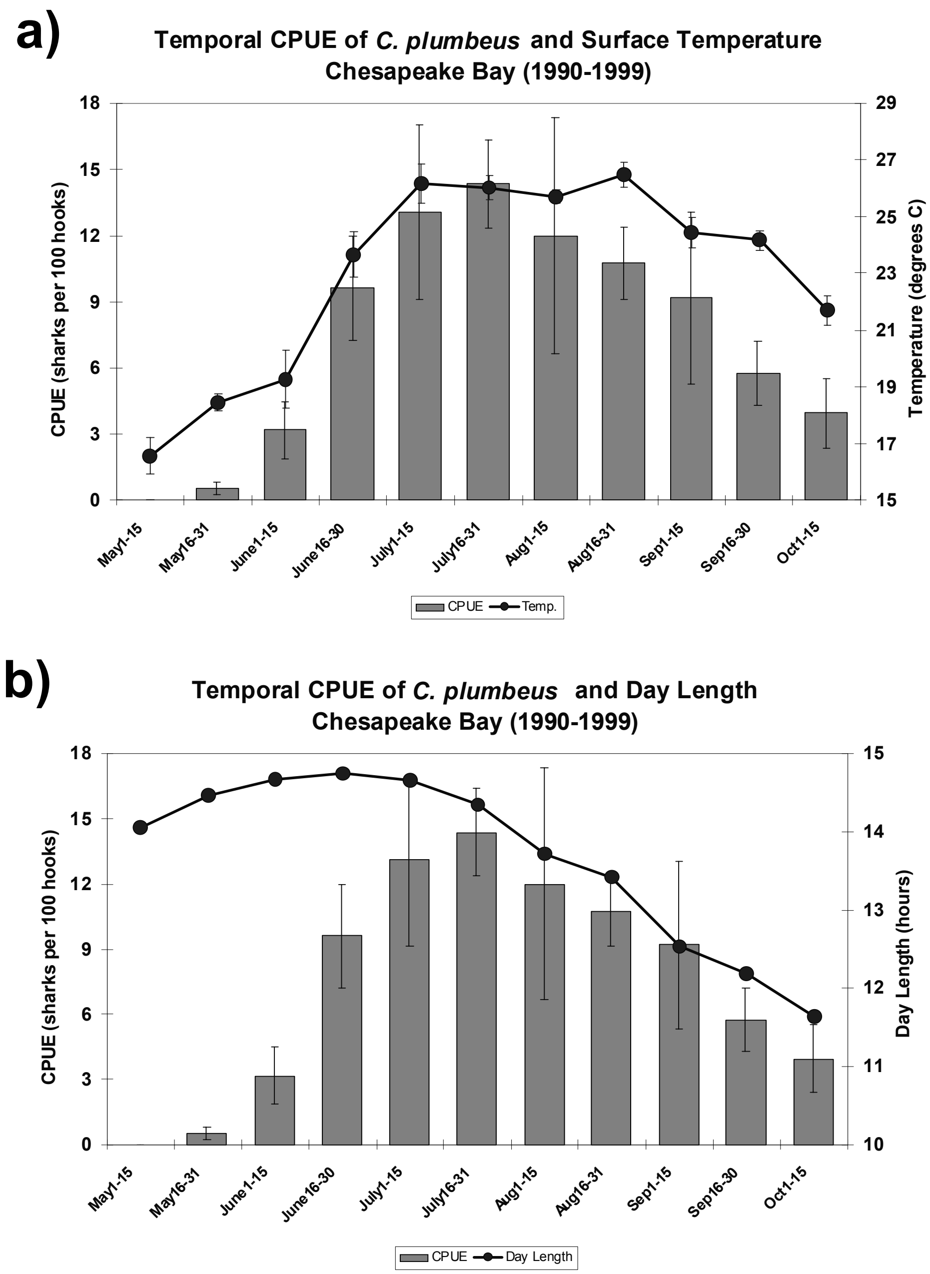


Figure 17. **Mean semi-monthly CPUE (*C. plumbeus* per 100 hooks) and a) surface temperature (^{0}C) and b) day length for Middleground and Kiptopeke stations combined for the years 1990-1999 (standard 9/0 hooks only).**

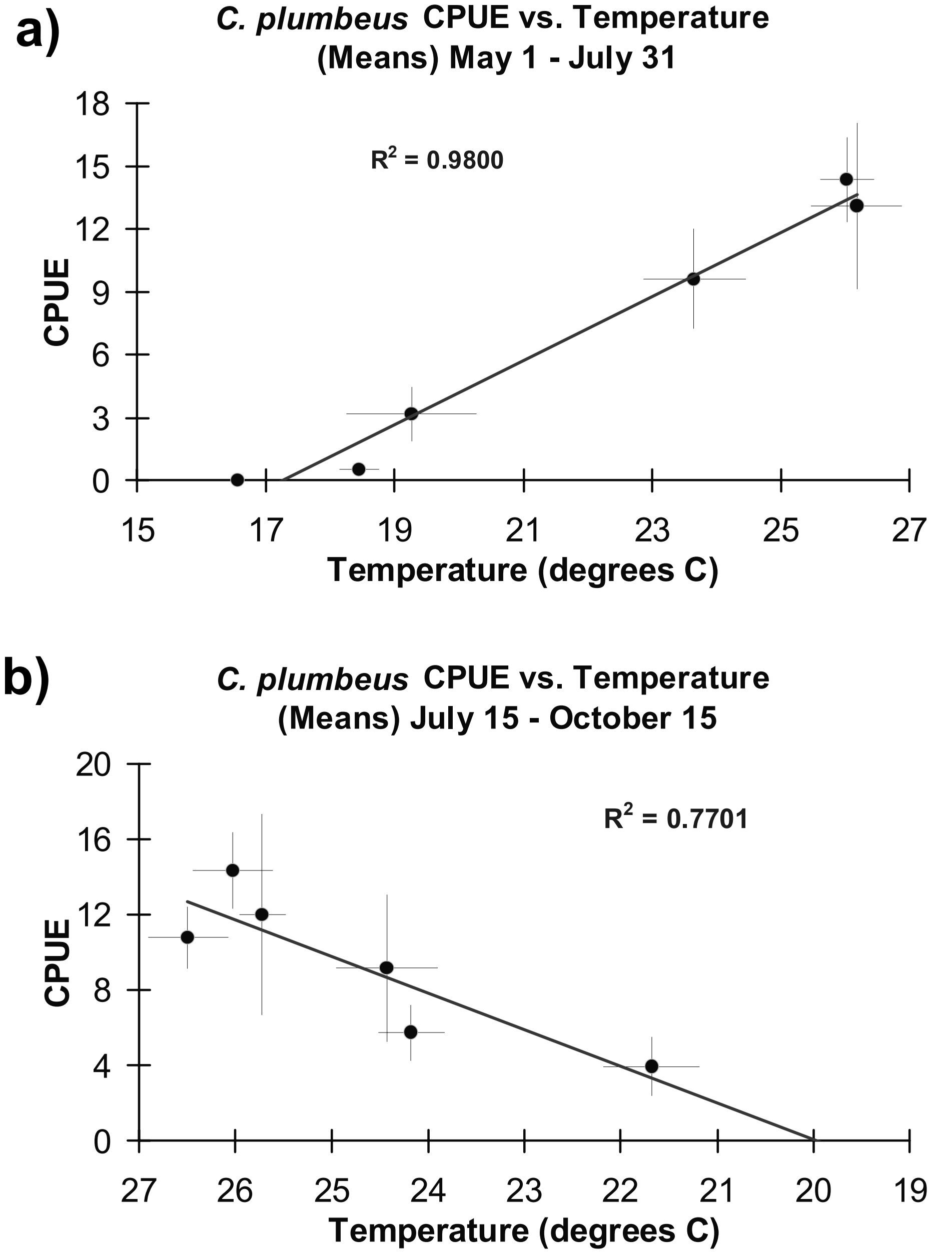
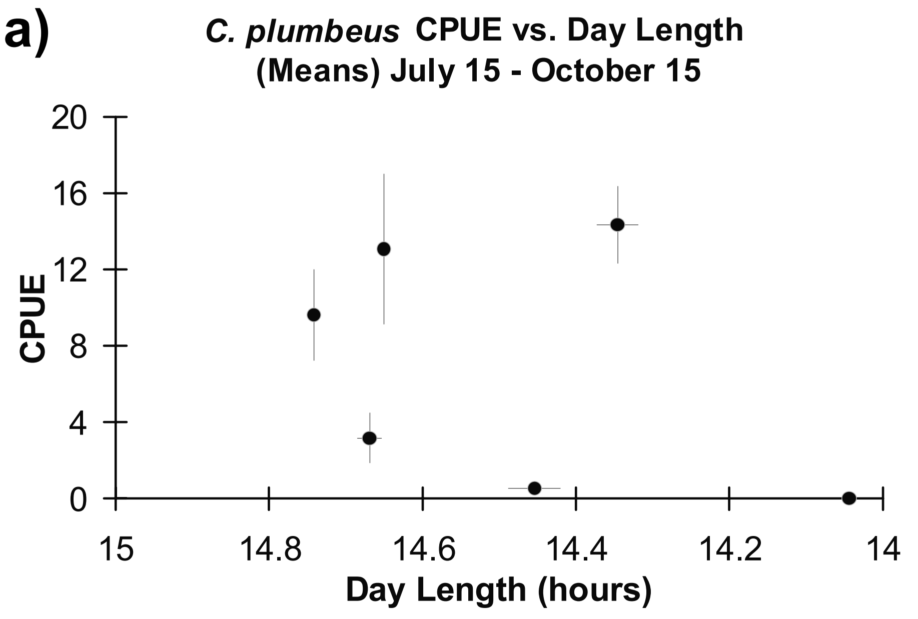


Figure 18. **Fitted line plots from linear regression of mean CPUE (*C. plumbeus* per 100 hooks) vs. mean surface temperature. Means are for semimonthly intervals. (error bars = SEM) a) Immigration period: May 1 - July 31; b) Emigration period: July 15 - October 15.**



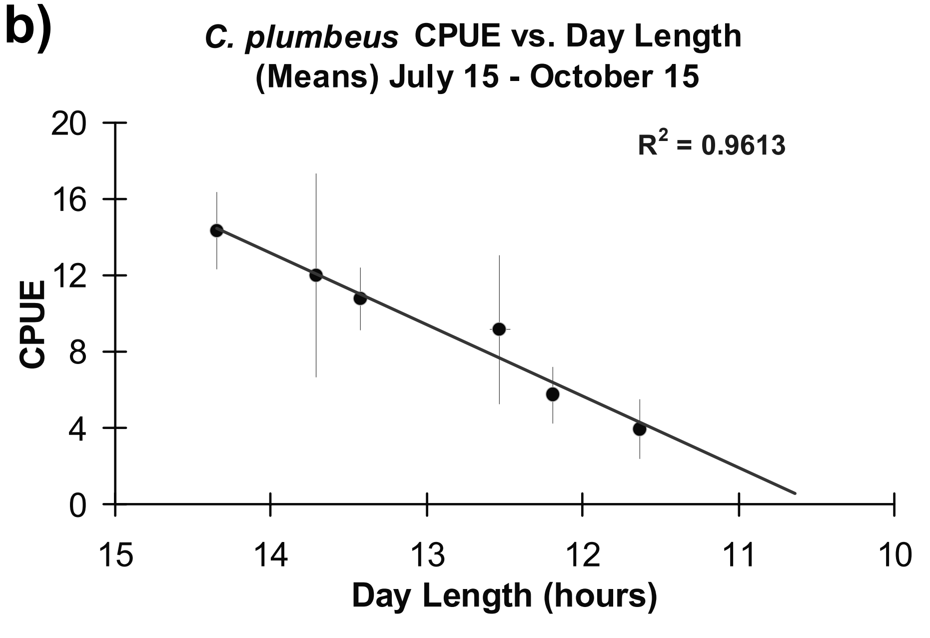
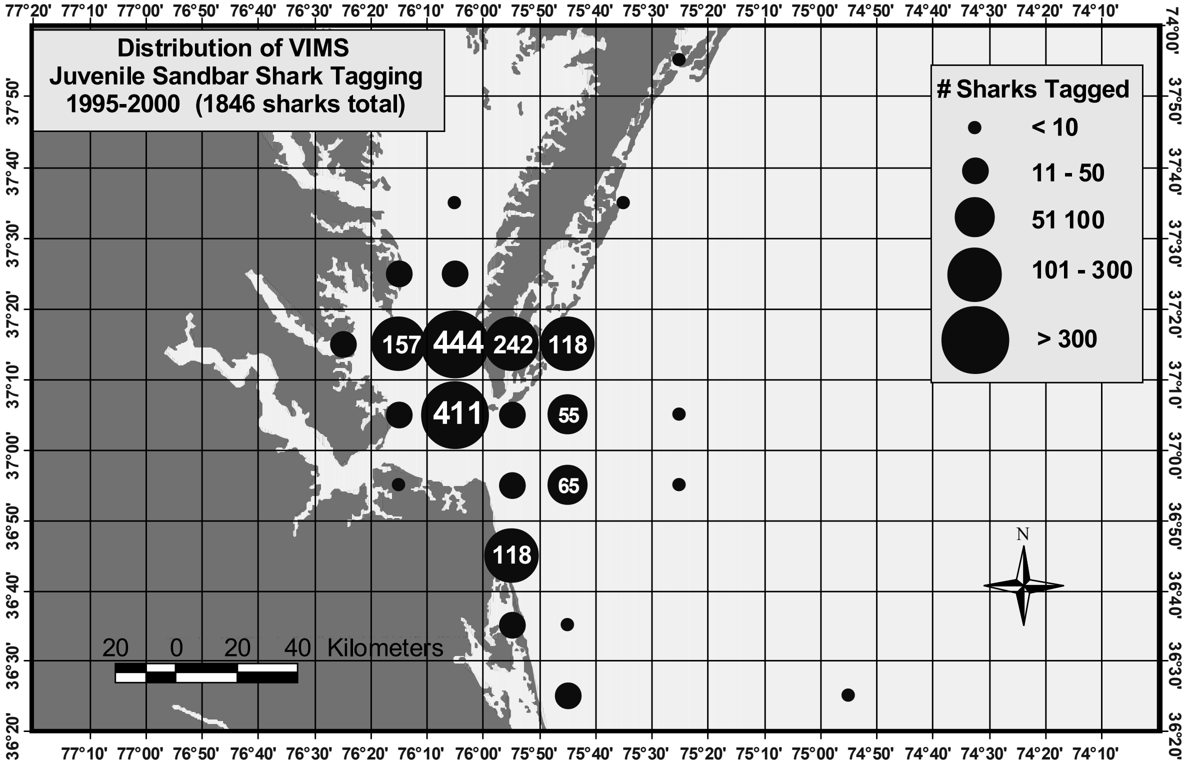


Figure 19. **Plots from linear regression of mean CPUE (*C. plumbeus* per 100 hooks) vs. day length. Means are for semimonthly intervals. (error bars = SEM) a) Immigration period: May 1 - July 31; b) Emigration period: July 15 - October 15.**

Figure 20. **Distribution of juvenile *C. plumbeus* tagging by VIMS during summers of 1995 to 2000.**



dropping by approximately 2.6 hours, and mirrored CPUE remarkably well during this period (Figure 17b). The linear-regression analysis was highly significant ($p<0.001$, $r^2=0.96$), suggesting day length may be a significant cue triggering emigration from the estuary (Figure 19b). Day length has been shown to initiate migration in birds (Berthold 1975) and Aidley (1981) suggested it might be a possible trigger for fishes. The data presented in this study indicate that temperature serves as a migratory catalyst for juvenile *C.plumbeus* to enter Chesapeake Bay and day length serves as the stimulus to emigrate from the Bay in fall. It is possible that day length also serves as the stimulus to begin spring migrations from wintering grounds. In other words, day length may signal juvenile sharks to begin migrating north, yet they remain in coastal waters until temperature stimulates a movement into the estuarine nursery. Additional data from the wintering grounds are needed to test this hypothesis.

Mark and Recapture

A total of 1,846 juvenile *C. plumbeus* were tagged in Virginia waters from 1995 through 2000 (Figure 20). More sharks were tagged in 1999 than any other year (n=439, 23.4% of total), followed closely by 1998 (n=416, 22.5% of total). Sampling and tagging only occurred during the months of May through October. The fewest sharks were tagged in May (n=51, 2.8%) and the most were tagged in July (n=550, 29.8%). Approximately 61.3% (n=1131) of the sharks were tagged inside Chesapeake Bay whereas 14.3% (n=264) were tagged in seaside lagoons and tidal creeks along Virginia's Eastern Shore, and 24.4% (n=451) were tagged in Virginia coastal waters. To date, 45 shark recaptures have been reported giving an overall recapture rate of only 2.4%, which is less than half of that reported for juvenile *C. plumbeus* in Delaware Bay (Merson 1998). It is believed that the low recovery rate is due to severe under-reporting by commercial gillnet fishers in the summer nursery and winter longline and drop-net fishers in North Carolina waters. Four of the reported recaptures were discarded due to incomplete data, leaving 41 that were used in the analysis.

Recreational fishers returned more tags than any other group (n=25). Commercial vessels accounted for ten of the reported recaptures. Six of the commercial recaptures were reported by independent fisheries observers on commercial vessels whereas only four were reported by the commercial fishers themselves. These results coupled with the overall low coverage of commercial vessels by observers indicate that under-reporting in the commercial sector was extreme. In fact, four of six winter recaptures by commercial vessels in North Carolina waters were reported by a single observer, Mr. Chris Jensen, formerly of the Gulf & South Atlantic Fisheries Development Foundation. In addition to fishery recaptures, five of the tag returns were recaptured by the VIMS longline survey and researchers from the North Carolina Aquarium returned one tag. Recapture data also were obtained for two sharks tagged by the VIMS shark-ecology program using tags supplied by the National Marine Fisheries Service prior to the inception of the VIMS tagging program bringing the total returns used in the analysis to 43.

Sharks tagged with VIMS dart tags were recaptured after a mean of 267 days and ranged between 4 and 1,109 days at liberty. Distance between tag and recapture locations was calculated as the shortest distance between the points using land as a bounding graphic in ArcView 3.2 GIS. In other words, sharks were not allowed to cross over land to reach the recapture location giving a conservative but realistic point-to-point distance measure. The mean distance between tag and recapture locations was 104 kilometers and ranged from 0 to 830 kilometers. In addition, the two recaptured sharks tagged by VIMS using NMFS tags were recaptured after 2,049 and 561 days at liberty and were 300 and 560 kilometers from the tagging location, respectively.

Of the 43 tag returns, 31 (72%) were recaptured less than 50 km from the tagging location (Figure 21). Twenty-five of these were recaptured in the Chesapeake Bay nursery and six were in nurseries on Virginia's Eastern Shore. The earliest of these recaptures occurred on May 28 and the latest return was on October 15 (Figure 21) suggesting that these summer nursery areas are utilized from late May to mid-October. These results are in perfect agreement with the temporal delineation pattern of the summer nursery interpreted using the longline CPUE data (Figure 16).

All of the remaining 12 recaptures were more than 200 kilometers (mean=384 km) from the tagging location following a mean of 550 days at liberty. Eleven of these were recaptured south of the tagging location whereas only one was recaptured north of its tagging origin (Figure 22, 23). With only one exception, all southern recaptures occurred during the winter and spring when they are suspected to be in winter nursery areas. These data indicate that the primary winter nurseries are located in near shore areas along the Outer Banks of North Carolina between 34^0 30' N and 35^0 30' N latitude (Figure 22, 23). The shark tagged with NMFS tag R9670 was approximately age two when tagged and was recaptured in this region more than 5.5 years later. This suggests that this region is used as a wintering area for at least the first seven years of life. These wintering areas may extend much farther south, however. One shark tagged as a neonate was recaptured the following May in the Inter-coastal Waterway in Hilton Head, South Carolina (32^0 9' N, 80^0 50' W), 830 km from the tagging location. A shark tagged with NMFS tag 211102 was recaptured 1.5 years later in of January and was nearly 200 km off the coast of Charleston, South Carolina (32^0 50' N, 77^0 50' W). This shark was at least seven years old when tagged; suggesting older juveniles may utilize deeper, offshore southern regions as wintering areas.

These data also provide information concerning the timing of these migratory movements. Sharks were recaptured in the wintering areas as early in the fall as October 25 and as late in the spring as May 23 (Figure 22). This corresponds remarkably well with the timing of the immigration and emigration from the summer nursery in Chesapeake Bay. These data indicate that Chesapeake Bay and lagoons along Virginia's Eastern Shore act as a summer nursery from late May to mid-October and coastal areas of North Carolina and South Carolina provide important winter habitat from late October to late May. These areas may provide important refuge habitat from predation. The only natural predators of juvenile sandbar sharks are larger sharks. Most large sharks found in Virginia remain in coastal waters during the summer. Very few enter the bays and lagoons. During the winter, most of these larger sharks have

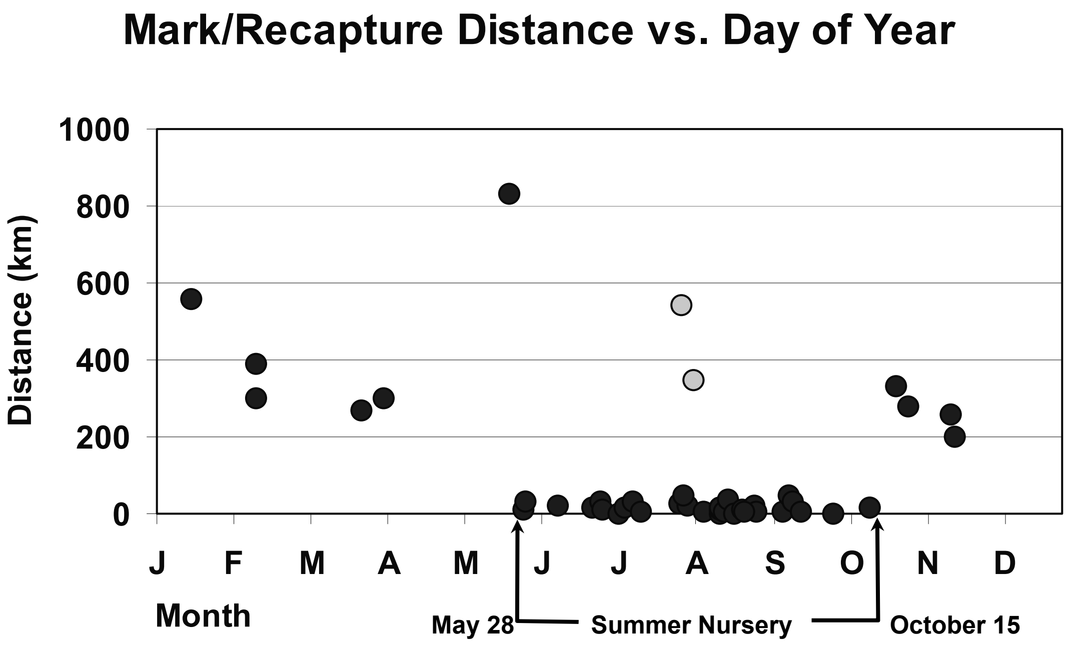


Figure 21. **Temporal delineation of summer nursery of *C. plumbeus* using tag recapture data. Distance between tag and recapture location vs. day of year of recapture.**

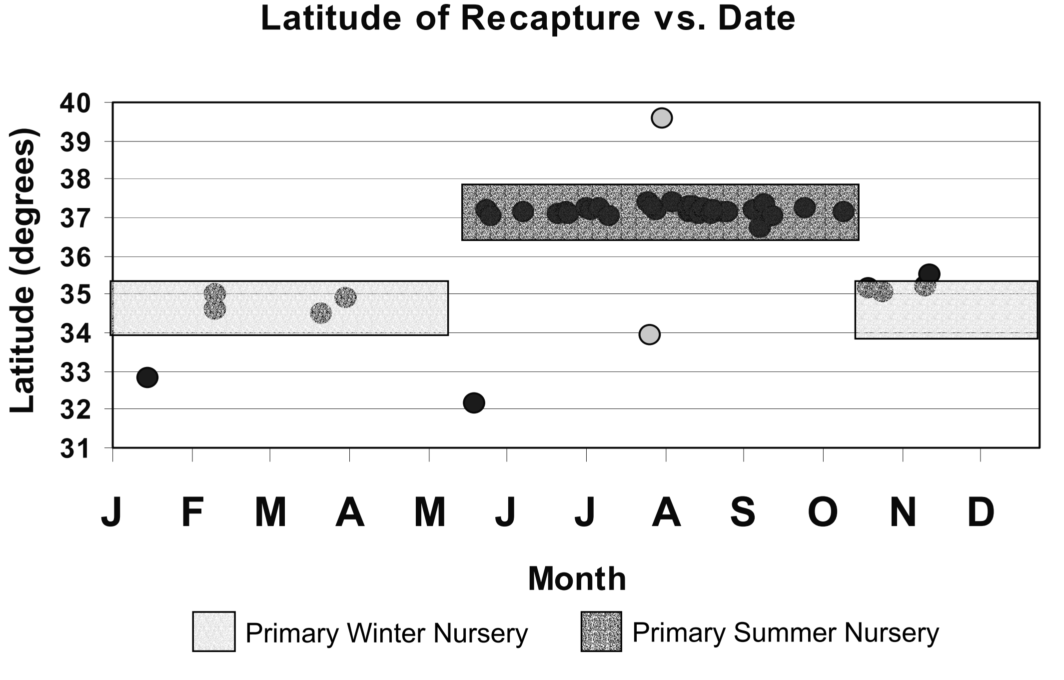
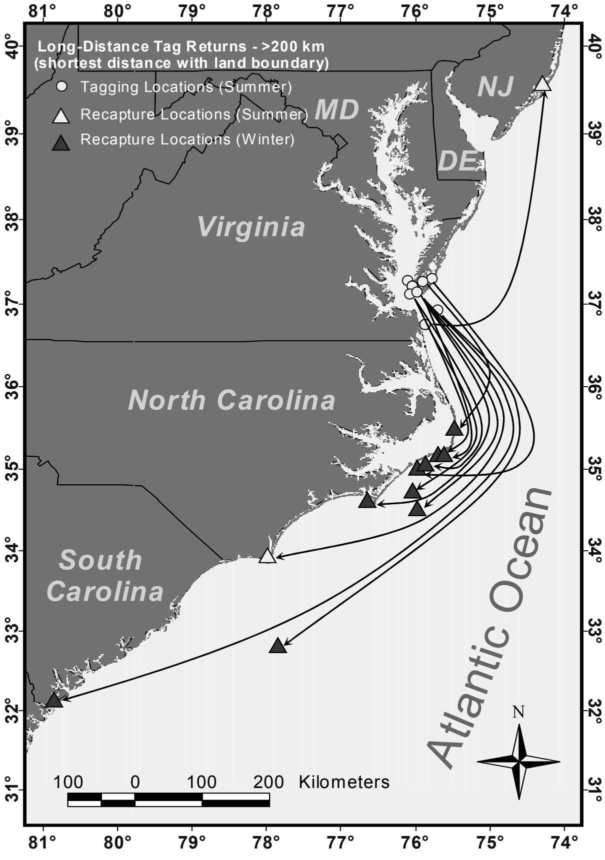


Figure 22. **Location and temporal delineation of winter nursery of *C. plumbeus* using tag recapture data. Latitude of recapture location vs. day of year of recapture.**

Figure 23. **Long-distance tag returns. All recaptures made >200 kilometers from tagging location, seasons combined.**



migrated well south or offshore of the areas used by the juvenile sandbar sharks.

Thirty-three of the 43 recaptured juvenile sharks were caught between May 28 and October 15. Of these, 17 were recaptured the same year they were tagged (Figure 24) after a mean of 30 days at liberty (range = 4-82 days). The mean distance between tag and recapture locations was 15 km (range = 0-37 km). These recaptures indicate that the sharks do not leave the protective nursery during this period, but actively move throughout the estuary. For instance, one shark was recaptured approximately 32 kilometers from its tagging location only four days later whereas another was recaptured within one kilometer of the tagging location after 44 days. These findings agree with those obtained using ultrasonic telemetry (Grubbs and Musick, in prep. b). Ten juvenile sandbar sharks were continuously tracked for periods of 10 to 50 hours. Although none of the tracked sharks moved out of the estuary, their daily straight-line movements averaged 34 kilometers per day and activity spaces ranged from 39 to 275 square kilometers.

Gerking (1959) defined homing as "going to a place formerly occupied instead of equally probable places." Fourteen recaptured sharks were caught in the Chesapeake region but in subsequent summers (Figure 25) after a mean of 461 days at liberty (range = 225-1,109). The mean tag-recapture distance for this group was 17 kilometers (range 0-48 km). Ten were recaptured after approximately one year at liberty, three after two years at liberty, and one after three years at liberty (Figure 26). The age at recapture based on age at tagging estimated from length-at-age data from Sminkey (1994) ranged from one to four years.

Two sharks recaptured during the summer months were not recaptured in Virginia waters, shown as lighter circles in Figures 21 and 22. One of these was tagged in Virginia coastal waters along Virginia Beach in October 1999. These near-shore waters are part of the migration route for sharks from nurseries north of Chesapeake Bay. This shark was recaptured the following August in Little Egg Harbor, part of Barnegat Bay, in New Jersey (Figure 23). This animal was probably tagged during its fall migration to southern wintering grounds, then returned the following summer to its natal summer nursery in New Jersey. Therefore, this does not indicate a departure from natal homing. The same cannot be said for the second shark, which was recaptured in the Cape Fear River in North Carolina in July 1998, one year after being tagged in Chesapeake Bay (Figure 23). This animal may have migrated to this region the previous fall as a wintering area but migrated inshore to the river the following summer rather than returning to its natal nursery to the north. Therefore, in this data set, 14 of 15 recaptures (93%) returned to their natal summer nursery in subsequent years. These data provide the first strong evidence for philopatry or natal homing in this species. Additional data are needed to examine the duration of this philopatric behavior and determine if females maintain this bond to adulthood, returning when mature at about 15 years old (Sminkey and Musick 1995) to deliver their own pups. In addition, future research directions should focus on determining what environmental cues the juvenile sharks use to discern their natal nursery. Olfaction has been well

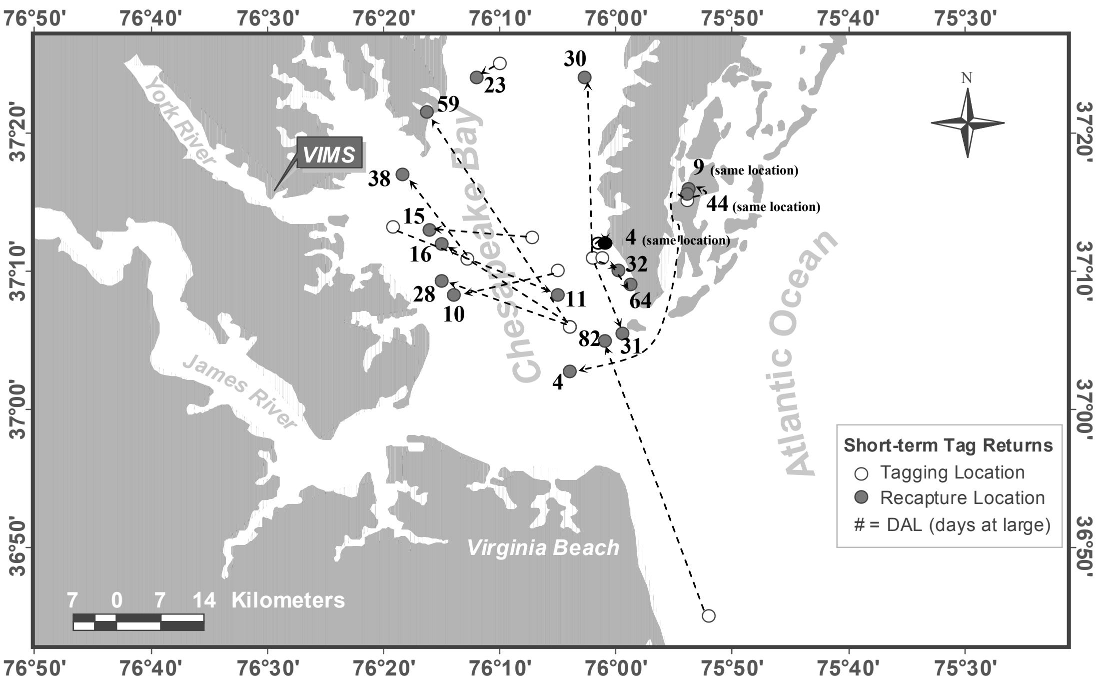


Figure 24. **Short-term tag recaptures. All sharks recaptured the same summer in which they were tagged.**

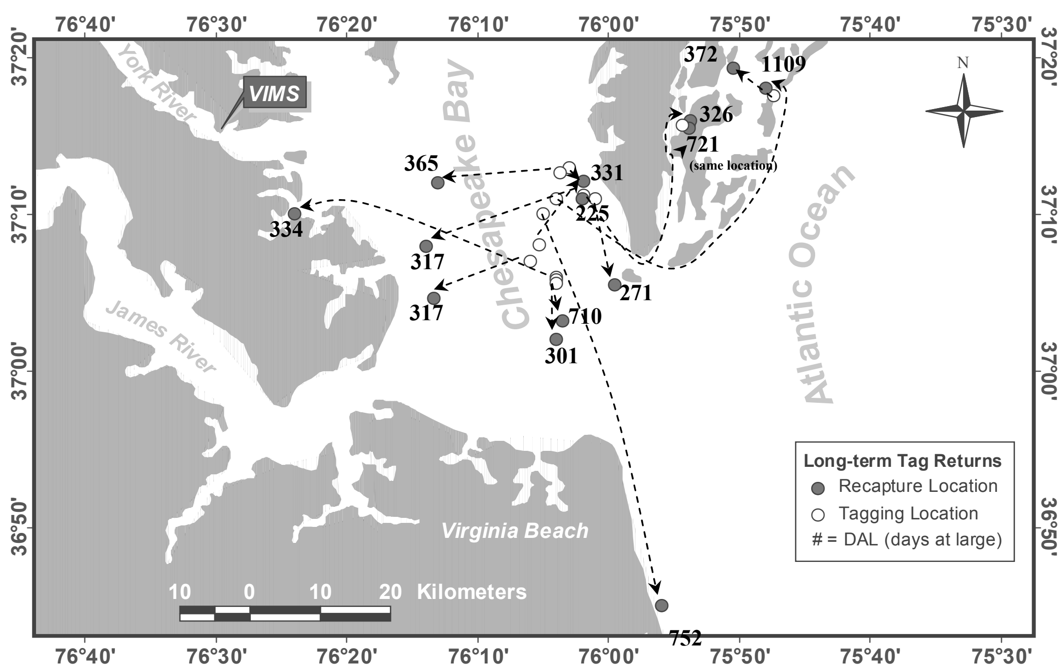


Figure 25. **Evidence of natal homing. Tag recaptures made < 50 kilometers from tagging location in summers following at least one winter migration.**

Table 6. **Minimum Convex Polygon (MCP) and Kernal activity space, mean swimming speed, and mean swimming rate for all ten juvenile *C. plumbeus* tracked. Grand means only include tracks of greater than 24 hours in duration. Italicized activity-space estimates were not included in calculation of mean activity spaces. (S.D. = standard deviation)**

Shark #	Duration (hours)	MCP (km^2)	50% Kernal (km^2)	75% Kernal (km^2)	95% Kernal (km^2)	Mean Speed km / hr	Swimming Rate body lengths / sec
9634	*10*	*4.20*	*1.58*	*3.66*	*7.23*	*not calculated*	*not calculated*
5375	*11*	*23.73*	*4.77*	*19.02*	*42.80*	*not calculated*	*not calculated*
9633	*13*	*24.49*	*15.63*	*34.68*	*69.43*	*not calculated*	*not calculated*
9630	25	74.45	10.59	30.91	103.56	not calculated	not calculated
9635	43	96.38	10.12	47.76	116.10	1.39	0.553
9639	44	97.94	16.60	47.64	102.03	1.53	0.719
9631	50	65.96	10.39	25.79	78.35	1.48	0.535
9637	50	275.84	64.01	290.63	382.66	1.71	0.779
5285	50	39.59	12.36	33.77	62.28	1.00	0.327
9632	49 + 15	121.64	7.95	52.21	135.74	1.55	0.652
MEAN tracks>24hrs	**46.57**	**110.26**	**18.86**	**75.53**	**140.10**	**1.44**	**0.594**
S.D.	**11.71**	**77.60**	**7.59**	**95.37**	**109.61**	**0.24**	**0.161**

documented as the principal stimulus for homing in diadromous fishes (Hasler and Scholz 1980). Harden Jones (1968) suggested marine fishes also might use olfactory cues from groundwater seepage to locate home habitats.

These data elucidate the importance of defining seasonal essential fish habitat for the various life stages of highly migratory species. These estuarine areas are highly susceptible to anthropogenic degradation and must be afforded some level of protection. Fishing regulations have been implemented to protect these juvenile sharks in Virginia summer nursery habitats. No regulations exist, however, on the wintering grounds, which are just beginning to be investigated. Sharks appear to be densely aggregated in these regions and are therefore highly susceptible to commercial fishing gear and can easily be over-exploited. Protection of juvenile sandbar sharks while in crucial summer habitats may prove fruitless unless protection in winter and migratory habitats is implemented as well.

Telemetry

Manual telemetry was used in investigate the diel activity patterns of juvenile *Carcharhinus plumbeus* (sandbar sharks) in Chesapeake Bay. Ultrasonic transmitters equipped with depth sensors were attached externally to ten sharks ranging from 59 to 85 centimeters in total length and sharks were tracked manually for 10 to 50 consecutive hours. Mean activity space (minimum convex polygons) was conservatively estimated to be 110 km^2 (Figure 27, Table 6) based on tracks of 40 hours or more and ranged from 39.6 to 275.8 km^2. This mean estimate is two orders of magnitude greater than that reported for other carcharhiniform species (Morrissey and Gruber 1993, Holland et al. 1993, McKibben and Nelson 1986).

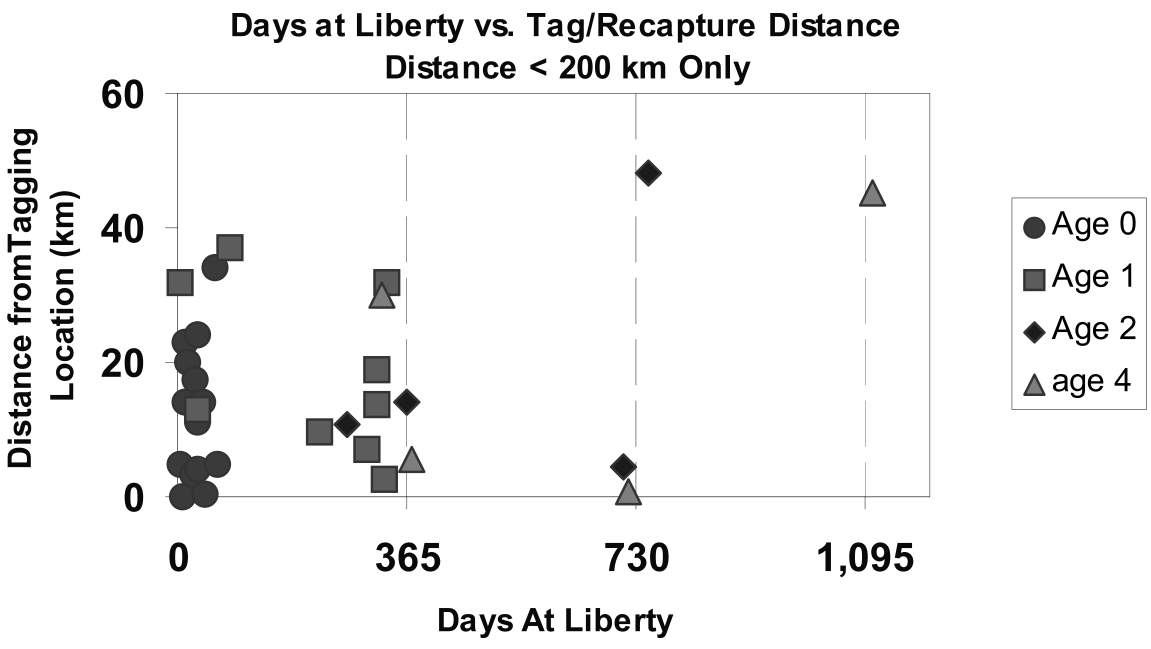


Figure 26. **Evidence of natal homing from tag recaptures. Distance from tagging location versus days at liberty for all sharks recaptured less than 200 kilometers from the tagging location.**

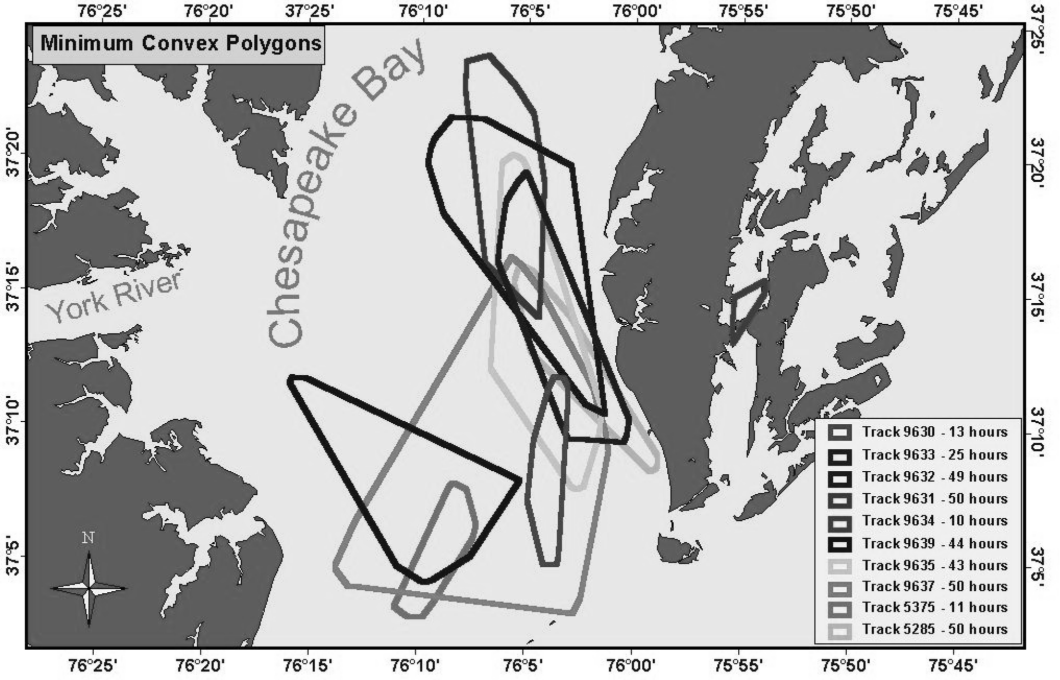


Figure 27. **Minimum Convex Polygons for all ten juvenile *Carcharhinus plumbeus* tracked. The area calculations associated with polygons can be seen in Table 6.**

Table 7. **Results of t-tests for difference between mean swimming depth (meters) during day and night based on time of nautical twilight. Means are given with standard deviation in parentheses. Results of t-tests using raw depth data for each track are followed by t-test results using overall mean for each track as a replicate. (* indicates T statistic is significant at = 0.05.)**

Shark #	**Twilight Day** N	Mean (S.D.)	**Twilight Night** N	Mean (S.D.)	**T statistic** $\mu_1 \neq \mu_2$	**Δ (sign.)**
9630	89	16.93 (7.08) m	28	7.74 (4.58) m	8.03*	<0.0001
9631	180	17.84 (7.89) m	97	11.23 (4.39) m	8.97*	<0.0001
9632	171	16.73 (9.38) m	86	6.84 (5.67) m	10.49*	<0.0001
9635	168	8.31 (6.53) m	79	7.16 (2.39) m	2.03*	0.044
9637	198	8.55 (7.65) m	77	4.83 (2.26) m	6.18*	<0.0001
9639	136	7.57 (2.60) m	86	8.18 (2.95) m	-1.57	0.12
ALL means	**6**	**12.66 (4.97) m**	**6**	**7.66 (2.10) m**	**2.85***	**0.036**

Transmitters were equipped with depth sensors. The track of shark 9631 is shown in Figure 28 as an example. The corresponding depth record is shown in Figure 29. Swimming depth ranged from surface to 40 meters. Depths of more than 40 meters were common during daylight hours whereas depths greater than 20 meters were rare during the night (Figure 30a). A transmitter malfunction resulted in the loss of depth data for shark 5285. The results from the remaining six sharks tracked for more than 24 continuous hours indicated that mean daytime swimming depth was 12.7 meters whereas mean nighttime swimming depth was 7.7 meters. This difference was statistically significant (Table 7). Swimming depth was significantly deeper during the day for five of the six sharks (Table 7, Figure 31). The activity spaces of nearly every shark were centered over one of the three deep channels in the lower Chesapeake Bay (Figure 32). Most sharks tracked remained in the deep channels during the day but ventured out of the channels to shallower waters during the night. This diel activity pattern and large activity space is hypothesized to be an adaptation for foraging on patchy prey in a highly productive, but highly seasonal, temperate estuary.

These data also challenge the demersal classification of the species because the sharks were at least three meters from the bottom more than 50% of the tracking duration and at least six meters from the bottom more than 35% of the duration. In fact, sharks were observed swimming near the surface in water greater than forty meter in depth. The example for shark 9631 is shown in Figure 30b.

Swimming direction was also analyzed and was highly correlated with mean direction of tidal current for all sharks. Figure 33 uses shark 9631 as an example. For this shark 81.6% of fixes were in the general direction of the current. The mean for all sharks analyzed was 75.8% of fixes in the general direction of the mean current. Mean swimming direction and mean current direction were statistically similar. Angular dispersion was estimated at 56.8^0 relative to the tidal-current direction.

Species Profiles

Sandbar shark, *Carcharhinus plumbeus*

From 1973 to 1999, VIMS caught 2,306 sandbar sharks in Chesapeake Bay and the lagoons on Virginia's eastern shore. Water temperature was between 17^0C and 28^0C. Ninety-seven percent were caught when water temperature was at least 21^0C and 85% when at least 24^0C. Fifty-four percent were female. None were mature males while 64 mature females were captured. Seventy percent of the mature females were caught in Magothy Bay on Virginia's Eastern Shore between the years 1982 and 1987. Only six mature females were captured between 1990 and 1999. All mature females were caught when water temperature was between 18^0C and 26^0C. Immature females ranged from 37 to 129 centimeters pre-caudal length (PCL) and males ranged from 39 to 96 centimeters PCL. Only seven males (0.7%) were 90 centimeters or more while 81 immature females (6.8%) were at least this large.

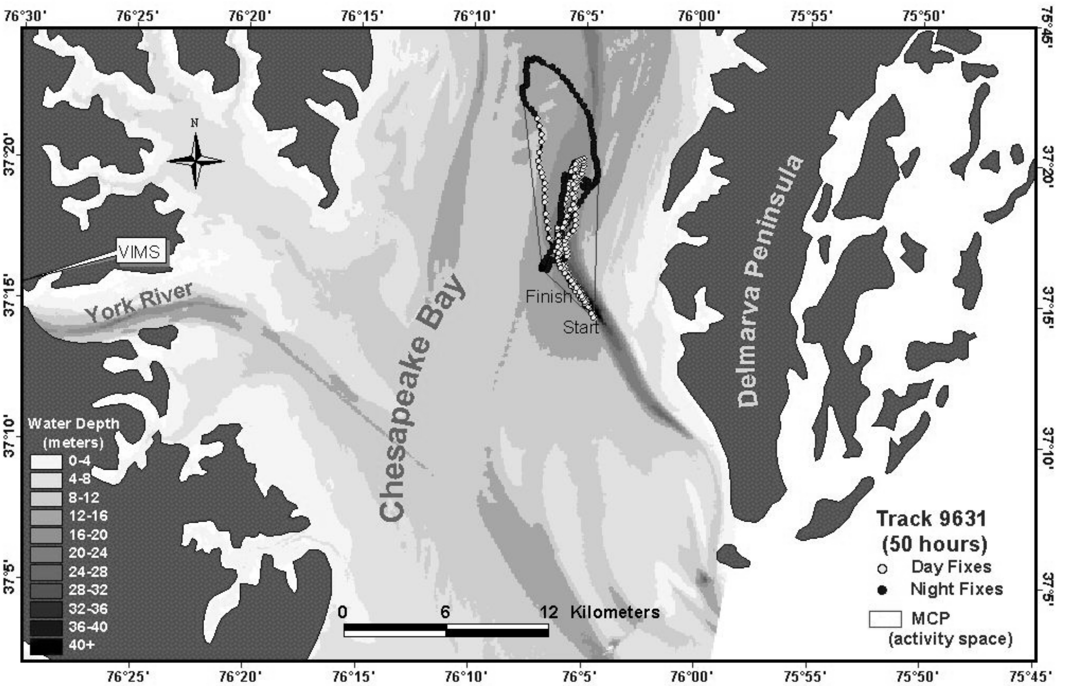


Figure 28. **Movements of shark 9631 tracked for 50 consecutive hours (August 26-28, 1997). Light circles are location fixes recorded during the day and dark circle are location fixes recorded at night. The track is outlined by the Minimum Convex Polygon of activity space.**

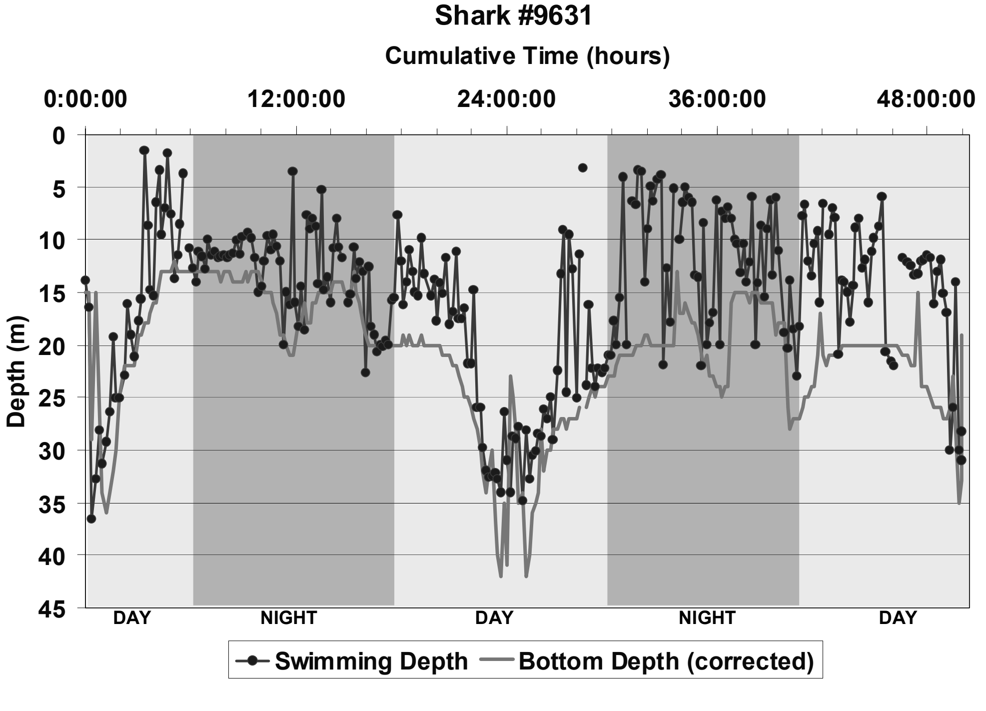


Figure 29. **Swimming depth and bottom depth recordings for Shark 9631 tracked for 50 consecutive hours. (Bottom depths were interpolated from a bathymetry grid using corrected fix locations in ArcView GIS)**

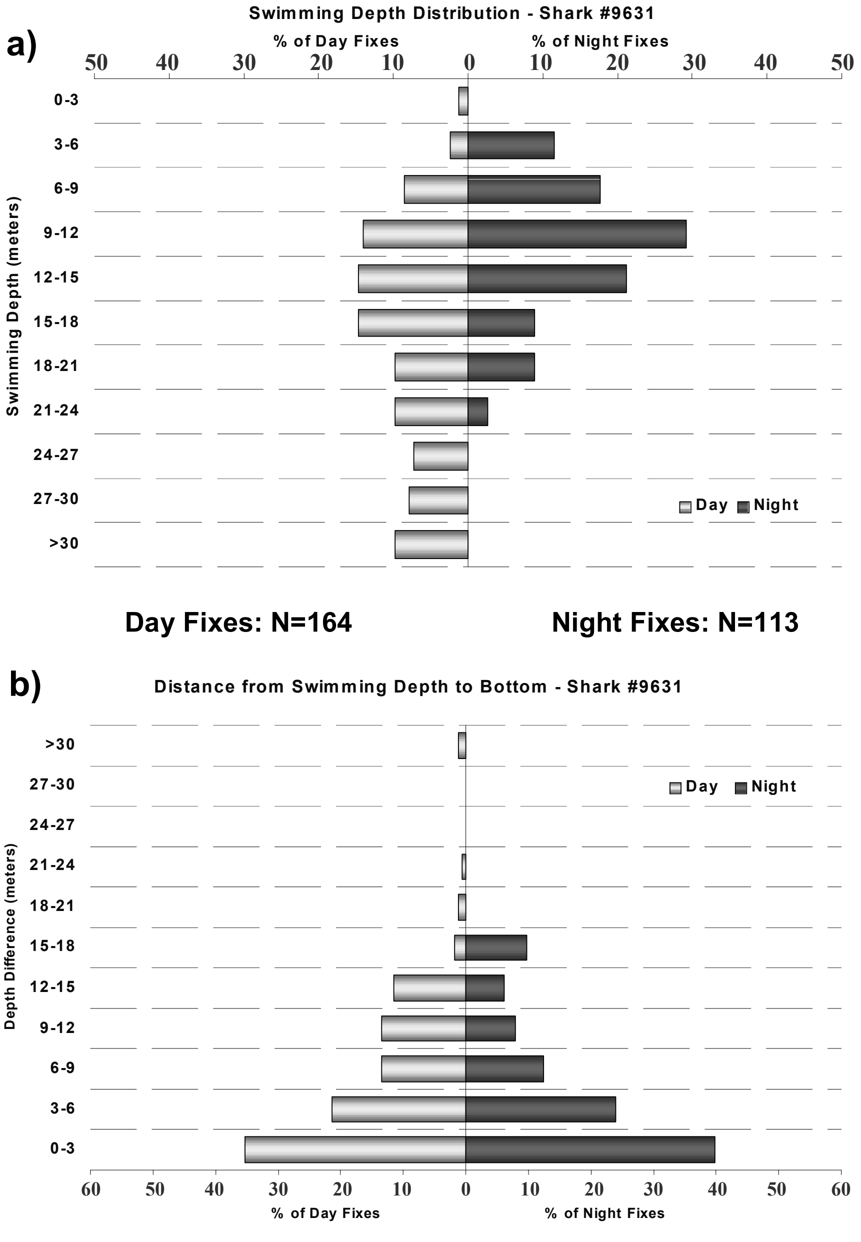


Figure 30. **Shark 9631 swimming-depth dynamics. a) Comparison of the distributions of swimming depth during day and night. b) Distribution of the distance from swimming depth to bottom of estuary during day and night.**

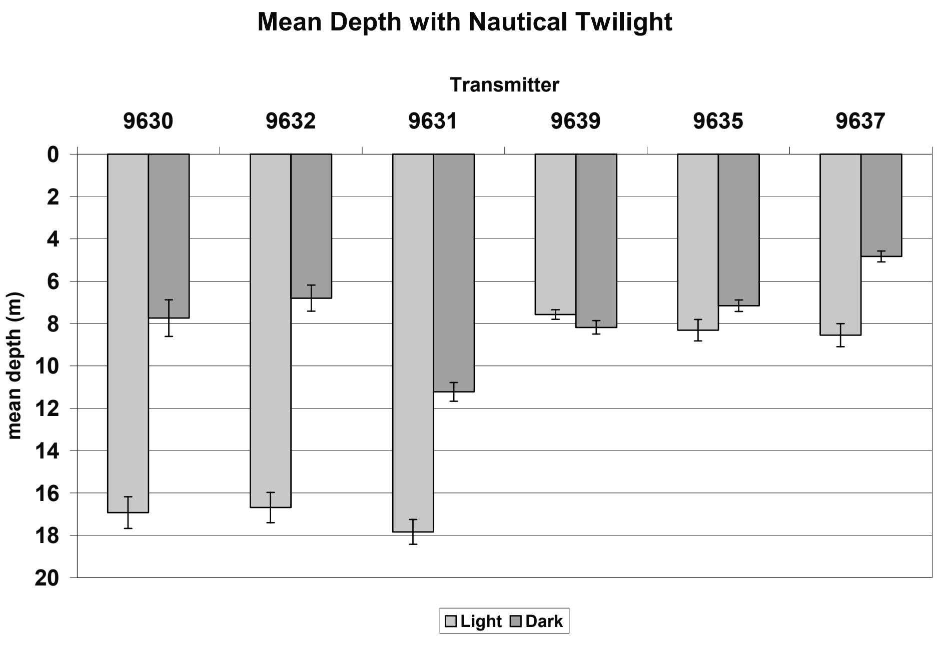


Figure 31. **Mean swimming depth during Light and Dark based on timing of nautical twilight for sharks 9630, 9631, 9632, 9635, 9637, and 9639. An asterisk (*) indicates a significant difference according to individual t-tests. Overall mean swimming depth during light was significantly deeper than mean swimming depth during dark (t-test, T = 2.85, Δ=0.036). Error bars are standard error of the mean.**

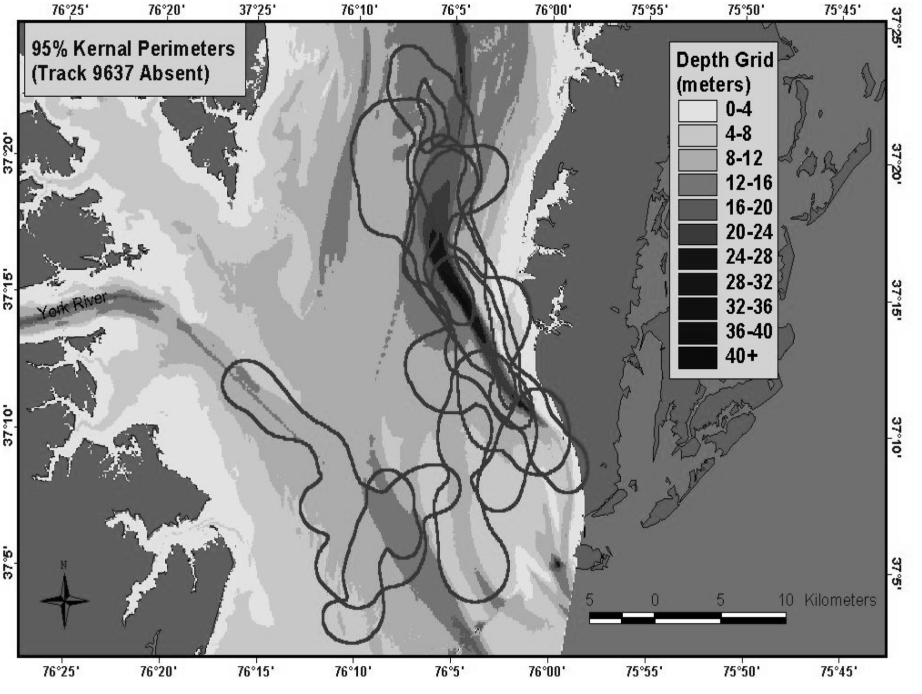


Figure 32. **Perimeters of 95-percent Kernals for eight (9637 excluded) Chesapeake Bay tracks combined over bathymetry grid. Kernals are centered over deep channels throughout the lower estuary.**

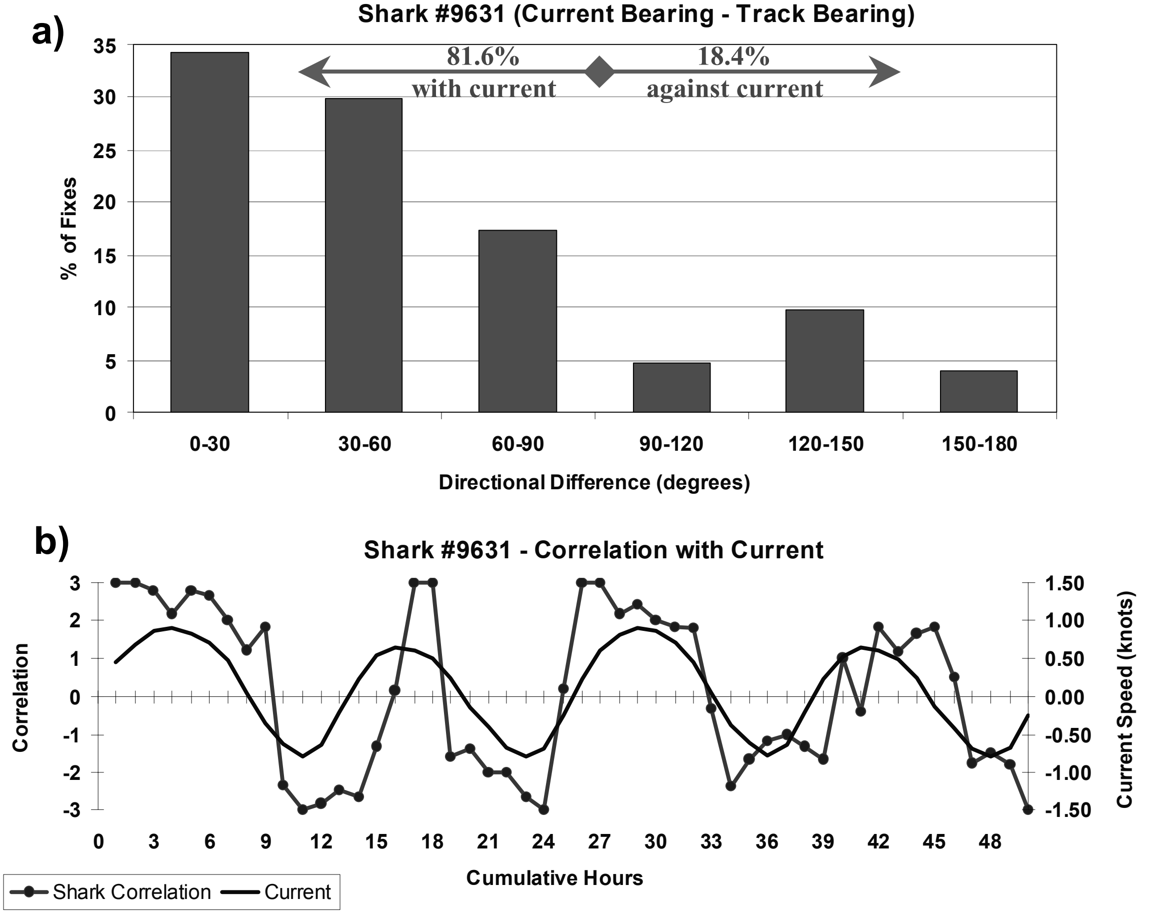


Figure 33: **Shark 9631 Directional-Swimming Data. a) Frequency histogram of deviation of swimming direction from tidal-current direction. b) Shark/Current correlation index plotted with tidal-current amplitude.**

Smooth dogfish, *Mustelus canis*

Forty-three mature female *Mustelus canis* (68 to 101 cm PCL) were caught in the extreme lower Chesapeake Bay and the tidal creeks and lagoons along Virginia's Eastern Shore between 1980 and 1999. Water temperature was between 16^{0}C and 28^{0}C. Most were carrying term embryos or were postpartum. Most pregnant females were caught in May and early June. Juveniles are commonly caught in these areas during summer months using recreational fishing gear as well as scientific trawling gear indicating these areas act as primary nursery habitat for this species.

Blacktip shark, *Carcharhinus limbatus*

Virginia waters are not pupping or nursery areas for blacktip sharks. Older juveniles, sub-adults, and occasionally adults are transient in Virginia coastal waters during the summer months but rarely enter the estuaries. Many blacktip sharks have been caught at coastal sampling stations, but only two have been caught in the estuaries. A male (93cm PCL) was caught in the lower Chesapeake Bay in August of 1990 (27^{0}C surface water temperature) and a female (88cm PCL) was caught in Magothy Bay in July 1992 (29^{0}C surface water temperature).

Spinner shark, *Carcharhinus brevipinna*

Virginia waters are not pupping or nursery areas for spinner sharks. Older juveniles, sub-adults, and occasionally adults are transient in Virginia coastal waters during the summer months but rarely enter the estuaries. These are infrequently caught at coastal sampling stations, but only one has been caught in the estuaries. A juvenile male (48cm PCL) was caught in the lower Chesapeake Bay in August of 1998 (27^{0}C surface water temperature).

Dusky shark, *Carcharhinus obscurus*

Historically, this species was second most common large coastal species caught by the VIMS longline survey, behind *C. plumbeus*. In recent years, it has become rare in the survey. Dusky sharks use exposed nearshore waters in Virginia as nursery areas but rarely enter the estuaries. One juvenile female (79cm PCL) was caught in the lower Chesapeake Bay in August of 1990. The surface water temperature was 27^{0}C.

Scalloped hammerhead shark, *Sphyrna lewini*

Scalloped hammerhead sharks use nearshore coastal waters as well as high-salinity estuaries as pupping and nursery habitats. Most pupping is south of Virginia. Occasionally, females pup along the coast of Virginia and offspring move into adjacent estuaries. One juvenile female (62cm PCL) was caught by this survey in July of 1991. The water temperature was 27^{0}C. In July of 1994, the first author caught one juvenile while recreational fishing in Chincoteague Bay (Virginia's Eastern Shore) and observed several others caught by a local recreational charter boat. It is clear that Virginia waters are not primary nursery habitat for this species.

Sand tiger shark, *Carcharias taurus*

This species is primarily transient in Virginia coastal waters. Occasionally pupping takes place in Virginia estuaries however. Single juvenile males were caught in the lower Chesapeake Bay in July of 1990 (76cm PCL, 27^{0}C) and in October of 1998 (91cm PCL, 24^{0}C). In September of 1995, a single female (104cm PCL) was caught in Magothy Bay. Virginia waters clearly are not primary nurseries for this species.

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Shark Nursery Areas in North Carolina State Waters

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Scope

Shark nursery grounds data was collected during nine separate projects in the state of North Carolina extending from Holden Beach in the southeast region to Oregon Inlet in the northeast region between 1996 and 2001 (Figure 1). This included one fishery dependent study, seven fishery independent studies, and fisheries dependent sampling by North Carolina Division of Marine Fisheries (NCDMF) during 2001. Shark reproductive condition, pupping, and nursery grounds data were collected during the following projects:

1) Jensen, C. F. and G. A. Hopkins. 2001. Evaluation of bycatch in the North Carolina Spanish and King mackerel sinknet fishery with emphasis on sharks during October and November 1998 and 2000 including historical data from 1996-1997 - North Carolina Sea Grant, Fisheries Resource Grant #98FEG-47.

2) Thorpe, T., M. L. Moser, D. Beresoff, and C. F. Jensen. 1999. Sinking gillnet selectivity for sharks in coastal waters from Long Beach to Shallotte Inlet, southeastern North Carolina

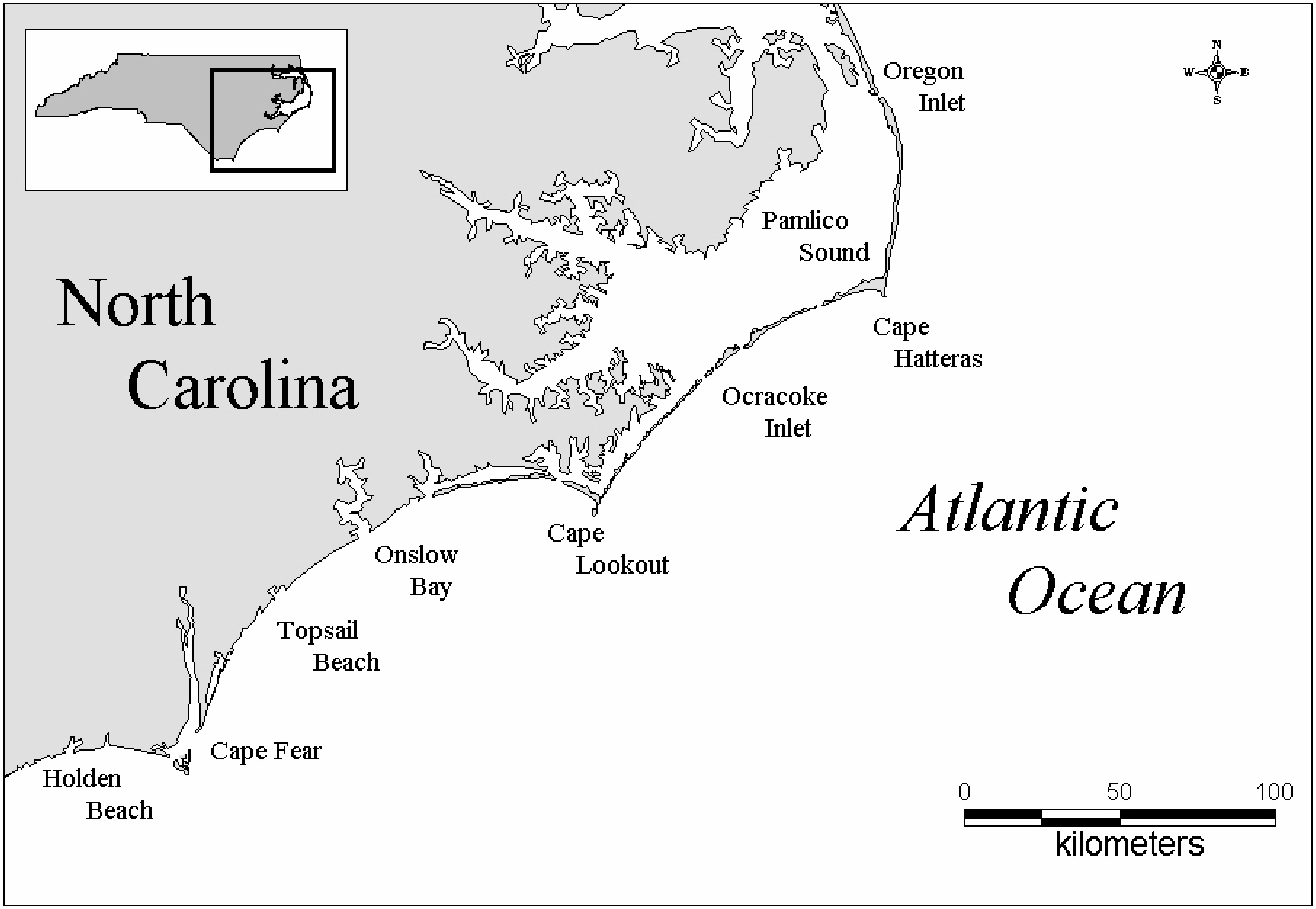

Figure 1. **Coastal North Carolina from Oregon Inlet to Holden Beach**

1997-1998 - North Carolina Sea Grant, Fisheries Resource Grant #97FEG-10.

3) Jensen, C. F. 1998. Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) Survey in North Carolina May - November 1998. Report to Apex Predators Program, National Marine Fisheries Service (NMFS) Narragansett, RI. Contract #M-9001. North Carolina Division of Marine Fisheries and NMFS Highly Migratory Species Management Division, Silver Spring, MD.

4) Jensen, C. F. 2001. Unpublished COASTSPAN data from June - July 2000 in North Carolina. Apex Predators Program, NMFS, Narragansett, RI and NMFS Highly Migratory Species Office and Essential Fish Habitat, Silver Spring, MD.

5) Thorpe, T. and D Beresoff. 2000. Determination of gillnet bycatch potential of spiny dogfish (*Squalus acanthias* L.) in southeastern North Carolina coastal waters. North Carolina Sea Grant, Fisheries Resource Grant #99-FEG-47.

6) Pabst, A. and T. Thorpe. In progress. Assessment of modified gillnets as a means to reduce bycatch in southeastern North Carolina coastal waters. 2001. North Carolina Sea Grant, Fisheries Resource Grant #00-FEG-09.

7) Thorpe, T., D. Beresoff, and K. Cannady. 2001. Gillnet bycatch potential, discard mortality and condition of red drum (*Sciaenops ocellatus*) in southeastern North Carolina. North Carolina Sea Grant, Fisheries Resource Grant #00-FEG-14.

8) North Carolina Division of Marine Fisheries sampling of, shrimp trawls, flounder gillnets, long haul seines, and stop nets during 2001.

9) Grabowski, J. H., M. A. Dolan, A. R. Hughes, and D. L. Kimbro. 2001. The biological and economic impacts of restored intertidal oyster reef habitat to the nursery function of the estuary. Fisheries Resource Grant Project #: 98 - EP - 16.

A total of 11,069 sharks (excluding the spiny dogfish, *Squalus acanthias*, caught during the gillnet bycatch study) representing six families and 18 species were caught from 1996 - 2001 (Table 1).

Table 1. Shark composition of North Carolina sampling from 1996 – 2001, including one fisheries dependent study, seven fisheries independent studies, and North Carolina Division of Marine Fisheries sampling.

Common Name	Species	Family	Total N
Spiny dogfish	*Squalus acanthias*	Squalidae	6
Atlantic angel shark	*Squatina dumerili*	Squatinidae	28
Sand tiger shark	*Carcharias taurus*	Odontaspidae	11
Thresher shark	*Alopias vulpinus*	Alopiidae	23
Smooth dogfish	*Mustelus canis*	Carcharhinidae	2231
Blacknose shark	*Carcharhinus acronotus*	Carcharhinidae	124
Spinner shark	*C. brevipinna*	Carcharhinidae	216
Finetooth shark	*C. isodon*	Carcharhinidae	79
Bull shark	*C. leucas*	Carcharhinidae	5
Blacktip shark	*C. limbatus*	Carcharhinidae	99
Dusky shark	*C. obscurus*	Carcharhinidae	52
Sandbar shark	*C. plumbeus*	Carcharhinidae	1735
Tiger shark	*Galeocerdo cuvier*	Carcharhinidae	4
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	Carcharhinidae	5828
Scalloped hammerhead shark	*Sphyrna lewini*	Sphyrnidae	45
Great hammerhead shark	*S. mokarran*	Sphyrnidae	2
Bonnethead shark	*S. tiburo*	Sphyrnidae	575
Smooth hammerhead shark	*S. zygaena*	Sphyrnidae	6

Sampling Methods and Materials

All studies were conducted in nearshore and inshore state waters. Nearshore waters are defined as state waters out to 3 NM. Inshore waters are defined as protected waters inside coastal inlets. Sinking gillnets were used in all studies. Longlines and hook and line were used in high current areas, high vessel traffic, commercial trawling areas, or to supplement trawling areas, or to supplement trawling areas, or to supplement gillnet catches in studies (Jensen 1998, Thorpe et al. in review). Bait used for all longline and hook and line consisted of frozen squid and fresh fish captured in the gillnet (bluefish, Spanish mackerel, menhaden, ladyfish, etc). Gillnet stretch mesh size over all studies ranged from 6.35 cm to 15.24 cm (2.5 - 6"). Soak times ranged from 0.32 - 23 hours. Nets were under run at intervals during COASTSPAN sampling in 1998 and 2000, while most nets from other studies were generally set once and retrieved at the end of the set. Environmental data included water depth, temperature, salinity, tide, bottom type, wave height, and weather conditions. Environmental data was not obtained for all sets.

Biological data for elasmobranchs included pre-caudal (PCL), fork (FL), total (TL), and stretch total length (TLs) in centimeters, weight (kg), sex, and maturity. Shark reproductive parameters were standardized during all studies using methods from Branstetter and Burgess (1997, 1998), and Pratt, et al. (1998). Neonatal or young-of-the-year (YOY) sharks were defined as sharks born during the year of capture (age 1), determined by a combination of umbilical scar condition (Pratt et. al 1998) and lengths from other studies. Extrapolated mean monthly growth rates and length frequencies were occasionally used to separate neonate from juvenile (age1+) specimens in which umbilical scars were either not observed or were well healed, but the specimen appeared to be within the size range of neonates or YOY for that species. Maturity estimates were assigned to female sharks that were not dissected based on documented size at maturity from the literature. Subadult males and females were categorized as juveniles; therefore, only juveniles and adults are used to reduce confusion. Sharks were tagged between 1996 - 2001 with National Marine Fisheries Service (NMFS) Hallprint dart tags and blue rototags (sharks ~≤ 70cm FL), and NMFS M-type dart tags (sharks ~≥ 70 cm FL). Occasionally larger sharks were tagged with Hallprint and blue rototags when M tags were exhausted. Many sharks were injected with oxytetracycline for on-going age and growth studies by the Apex Predators Program, NMFS, Narragansett Lab. Release condition was noted following Pratt, et al. (1998).

Description of Study Area

Coastal North Carolina is an area with diverse habitats that includes large estuaries, lagoons, salt marshes, and tidal creeks bordered by barrier islands. Submerged aquatic vegetation is dominated by eelgrass (*Zostera marina*) and, to a lesser extent, shoalgrass (*Halodule wrightii*) and widgeon-grass (*Ruppia maritima*) (Mallin et al. 2001). The Albermarle-Pamlico estuary is the largest enclosed sound in North Carolina encompassing approximately 7530 km^2 and is the second largest estuary in the United States (Mallin et al. 2000).

Traveling seaward from the barrier islands is a gently sloping sandy plain with isolated areas of rock-reef structures (Mallin et al. 2000). These rock-reef structures support a variety of algae, invertebrate, and fish communities (Cahoon et al. 1990). Maximum depths within the plains area is up to 60 m, and at the shelf break it deepens rapidly (Mallin et al. 2000). The Gulf Stream roughly marks this shelf break and is responsible, through frictional forcing, for driving the counter-current water circulation in Raleigh, Onslow, and Long Bays (Mallin et al. 2000).

Species Profiles

Neonatal sharks were identified for 12 species sampled from 1996-2001 (Table 2). A total of 1,676 sharks were tagged (16%) with 93 recaptures (Table 2). Recaptures of sandbar and other shark species, from these studies, continue to be returned. Environmental parameters are given in Table 3.

Spiny dogfish, *Squalus acanthias*

Six spiny dogfish were sampled during these studies (not including the spiny dogfish study) (Table 1 and 2). Water temperatures ranged from 17.5 °C to 20.9 °C and depths ranged from 4.3 m to 12.2m (Table 3). No neonates were caught from Cape Hatteras to

Table 2. **Summary of young-of-the-year (YOY), juvenile, and adult sharks with tagging effort during 1996 - 2001 in North Carolina. Total n includes lost or escaped sharks.**

Species	Size range (cm)	YOY	Juvenile	Adult	Total	Tag	Recapture
Spiny dogfish	68.5 - 82.5 FL	0	0	6	6	0	0
Atlantic angel shark	92.5 - 124 TL	0	4	9	28	21	0
Sand tiger shark*	100 - 244 TL	3	4	4	11	7	0
Thresher shark	73 - 128 FL	10	13	0	23	2	0
Smooth dogfish	38.5 - 115 FL	10	999	980	2231	6	0
Blacknose shark	36 - 115 FL	10	8	33	124	7	0
Spinner shark	41.9 - 141 FL	111	95	0	216	45	2
Finetooth shark	83.8 - 120.5 FL	0	28	51	79	15	0
Bull shark	66.5 - 213 FL	2	1	2	5	0	0
Blacktip shark	46.3 - 145.5 FL	4	70	20	99	3	0
Dusky shark	74.5 - 259 FL	40	9	2	52	29	0
Sandbar shark	45.5 - 145 FL	1214	489	unknown	1735	1301	85
Tiger shark	122.5 - 196.7 FL	0	4	0	4	0	0
Atlantic sharpnose shark	22.3 - 91.4 FL	910	726	4015	5828	194	7
Scalloped hammerhead shark	31.8 - 210 FL	16	23	5	45	9	1
Great hammerhead shark	236 - 258 FL	0	1	1	2	0	0
Bonnethead shark	30.5 - 92.3 FL	1	215	327	575	33	0
Smooth hammerhead shark	62 - 92.5 FL	0	6	0	6	4	0

Table 3. **Environmental parameters for sharks captured during fishery dependent and independent sampling from 1996-2001 in North Carolina**

Species	Mean surface water temperature range (°C)	Salinity range (‰)	Depth range (m)
Spiny dogfish	17.5-20.9	31.6	4.3-12.2
Atlantic angel shark	16.8-21.4	31.2-31.6	4.3 - 21.4
Sand tiger shark	19.1 - 27.2	25.8 - 31	8.2 - 14.6
Thresher shark	18.2 - 20.9	N/A	4.6 - 13.7
Smooth dogfish	16.5 - 28.3	21.9 - 35.5	1.9 - 17.7
Blacknose shark	20.3 - 33	32 - 36	3.3 - 11.9
Spinner shark	18.1 - 33	27.6 - 36	3.1 - 16.5
Finetooth shark	22 - 30.6	29.5 - 34	3.1 - 10.7
Bull shark	27	30	NA
Blacktip shark	20.3 - 33	29.7 - 36	8.5 - 12.8
Dusky shark	18.1 - 22.2	25 - 35	4.3 - 15.5
Sandbar shark	16.5 - 28.4	21.9 - 34.7	3.0 - 17.7
Tiger shark	30	36	NA
Atlantic sharpnose shark	17.4 - 33	15 - 35.9	1.4 - 16.5
Scalloped hammerhead shark	19 - 30	20 - 36	3.1 - 13.5
Great hammerhead shark	NA	NA	9.8
Bonnethead shark	19 - 33	30 - 35.3	0.6 - 11.6
Smooth hammerhead shark	17.8 - 20.2	31.5	5.1 - 15.5

Holden Beach.

During the spiny dogfish bycatch study off Holden Beach most specimens sampled were mature females (76%) of which 89.6% were either gravid or post partum (only five). Embryos measured from 6.4 to 26.4 cm TL. Parturition size has been documented at 22 to 33 cm TL (Compagno 1984a). One female aborted an embryo measuring 23.4 cm TL in a holding tank, which survived and was released to the wild alive. Based on this data, spiny dogfish parturition may occur in deeper water off southeast North Carolina possibly from late January through early April. This needs further examination. Spiny dogfish overwinter off the coast of North Carolina and make up an important commercial sinknet fishery in North Carolina.

Atlantic angel shark, *Squatina dumerili*

Twenty-eight large juvenile and adult angel sharks were sampled in November 1997, 1998, and 2000 (Tables 1, 2). Water temperature ranged from 16.8 to 21.4 ºC and depths ranged from 4.3 m to 21.4 m (Tables 3). Large juvenile and adult angel sharks occurred in the fall sinknet fishery in the vicinity of Cape Hatteras, but neonate and small juveniles were not present.

Sand tiger shark, *Carcharias taurus*

Eleven sand tigers ranging from YOY to adult were examined from Cape Hatteras to Holden Beach (Tables 1, 2). Only one sand tiger was brought aboard and measured, because the remaining sharks were too large to bring aboard or they fell out of the net. Water temperature ranged from 19.1° C to 27.2° C and depths ranged from 8.2 m to 14.6 m (Table 3). Sand tigers were caught in the vicinity of Cape Hatteras and at Holden Beach.

NCDMF report that sand tiger sharks are common on various shipwrecks and artificial reefs particularly between Cape Lookout and Cape Hatteras in Raleigh Bay. Numerous juvenile sand tiger sharks were caught in December 2001 by NCDMF staff conducting SCUBA inspections of artificial reef material near Cape Lookout. This particular artificial reef and other shipwrecks in the area provide at least secondary nursery habitat. Schwartz (1995) caught sand tigers in Pamlico Sound. These catches indicate that a broad coastal region of North Carolina is used as both a primary and secondary nursery ground for this species, corroborating observations of Gilmore, et al. (1983).

Thresher shark, *Alopias vulpinus*

A total of 23 thresher sharks were caught, most (22) during the fall sinknet fishery at Cape Hatteras (Tables 1, 2). One juvenile was caught off Holden Beach in April 1997. Ten of 23 specimens were judged to be YOY, based on size and extrapolated growth rates from other studies (Cailliet et al. 1983, Compagno 1984a). No adults were caught during these studies. Water temperature ranged from 18.2° C to 20.9° C and depths ranged from 4.6 m to 13.7 m.

The thresher shark is not commonly encountered during directed commercial shark longline operations off North Carolina, indicating that they are spatially or temporally excluded from the gear by the fishery characteristics or tend to avoid the gear (Branstetter and Burgess 1998). Occasionally, larger threshers are encountered in the sinknet fleet during the fall off Cape Hatteras. Based on these observations, coastal North Carolina is broadly used as a primary and secondary nursery for the thresher shark.

Smooth dogfish, *Mustelus canis*

During the study period 2231 smooth dogfish were caught. They are second in abundance in North Carolina only to the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. Based on growth rates (Conrath 2000) and umbilical scar condition, neonates, juveniles, and adults including pregnant females were present in nearshore and inshore waters from Oregon Inlet to Holden Beach. Most smooth dogfish were caught during May, October, and November, and they contributed to a significant fall sinknet fishery off Cape Hatteras. One neonate was caught off Oregon Inlet in July. Other than the Cape Hatteras study, smooth dogfish were scarce to absent in catch records from June to November (Jensen 1998, Thorpe et al. in review). Water temperatures ranged from 16.5° C to 28.3° C and depths ranged from 1.9 m to 17.7 m.

Smooth dogfish begin showing up in the catches off Cape Hatteras during October, probably migrating from the north (Castro 1993, Rountree and Able 1996). Schwartz (1984b), reported observing neonate and juvenile (age 1+) smooth dogfish near Cape Lookout from April to as late as September in some years. Schwartz (1995) also noted smooth dogfish in the Neuse River, Pamlico Sound, and Core Sound. Smooth dogfish occurred in the lower Cape Fear River from February to May (Schwartz 2000). North Carolina provides habitat for pupping, nursery, and overwintering grounds for the smooth dogfish.

Blacknose shark, *Carcharhinus acronotus*

One hundred twenty-four blacknose sharks ranging from neonates to adults were caught during these studies (Table 2). Water temperatures ranged from 20.3 to 33º C and depths ranged from 3.3 m to 11.9 m (Table 3). Blacknose sharks were not seen north of Cape Hatteras. Ten neonates from 36 cm to 44.5 cm FL were caught from May to July with various stages of umbilical scar healing off Holden Beach south of Cape Fear. Schwartz (1984a) caught neonate blacknose sharks in trawl surveys from June to August in the vicinity of Cape Lookout. Grabowski, et. al (2001) noted the presence of small juveniles and possibly neonatal blacknose sharks during July at Middle Marsh in Back Sound near Cape Lookout, Carteret County. Pregnant females have occurred in the commercial shark fishery off North Carolina from February to July (Branstetter and Burgess 1998). Blacknose sharks were caught during June 1973 and 1978 near the mouth of the Cape Fear River. Castro (1993) reported blacknose sharks use South Carolina as a pupping and primary nursery grounds. Southeast North Carolina may serve as the northern limit of pupping and nursery grounds for the blacknose shark.

Spinner shark, *Carcharhinus brevipinna*

Two hundred and sixteen spinner sharks were captured (Table 1). No adults were caught, although one was near maturity. Water temperatures ranged from 18.1 to 33º C and depths ranged from 3.1 m to 16.5 m (Table 3). Spinner sharks ranged in size from 41.9 to 141 cm FL. One hundred and eleven were classified by the author as neonates while the remaining were juveniles, age 1+ (Table 2). Neonates were caught from Oregon Inlet to Holden Beach from May to September with varying stages of umbilical scar healing. Neonates with umbilical remains to partially healed umbilical scars were seen from May to July, indicating that most pupping occurred at this time. North Carolina provides important pupping and nursery ground habitat for this species as it was the third most abundant in numbers of neonates caught during the six year period (Table 2).

A series of four pregnant spinner sharks was examined on 9 January 1995 during a shark observer program off Ocracoke Inlet. Sizes of embryos ranged from 50.4 to 52.6 cm TL (Gulf and South Atlantic Fisheries Development Foundation, Inc. 1996). Spinner shark birth size is 60-75 cm TL (Castro 1993). Juvenile spinner sharks approximately 1-2 yr old have been caught in the lower Cape Fear River during July and August (P. Barrington, Aquarium Curator, North Carolina Aquarium, Fort Fisher, NC, personal communication, 1998).

Finetooth shark, *Carcharhinus isodon*

A total of 79 finetooth sharks were captured by gillnet (Table 1). Water temperature ranged from 22° C to 30.6º C and depths ranged from 3.1 m to 10.7 m (Table 3). Finetooth shark sizes ranged from 83.8 to 120.5 cm FL. Large juveniles and adults were caught from Cape Hatteras to Holden Beach, while none were seen north of Cape Hatteras (Table 2). No neonates were caught. Early term gravid females were caught during the study, while no near term females were noted. F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) has not observed neonate finetooth sharks off Cape Lookout during trawl and longline surveys, although he reported seeing larger individuals during fisheries independent shark longline surveys in the vicinity of Cape Lookout. Neonatal finetooth sharks are found further south in Bulls Bay, South Carolina (Castro 1993). Further investigation is needed in extreme southeastern North Carolina to evaluate potential primary puppng and nursery habitat. These data support the use of SE North Carolina as a secondary nursery ground for the finetooth shark.

Bull shark, *Carcharhinus leucas*

Five bull sharks were observed ranging from neonate to adult (Tables 1, 2). Most environmental conditions are lacking because three specimens were not observed during the set but were supplied by another study. Although bull sharks frequent North Carolina coastal waters (Bransttetter and Burgess 1997), few were captured, possibly because of size or spatial and temporal exclusion from study sites. In this study, no gear was set in lower salinity waters characteristic of bull shark nursery grounds in other regions (Castro 1993). J. Gearhart (Fishery Biologist, NCDMF, personal observation, August 2001) reported seeing a large bull shark (~300 cm TL) at an artificial reef in Onslow Bay. The smallest specimen observed in the catches was 66.5 cm FL with a partially healed umbilical scar during October 2001 at Atlantic Beach. Birth size in the Gulf of Mexico is reported as 53.5 - 72.5 cm PCL (J. Neer, Coastal Research Fellow, Coastal Fisheries Institute, Louisiana State University, personal communication, 2001), which corresponds with the length of the two neonatal specimens from North Carolina. A second neonate 81cm FL with a mostly healed umbilical scar was observed in May of 2000 in the lower Cape Fear River estuary. This specimen was at the extreme upper limit of neonates for the northern Gulf of Mexico, and given the time (May), it may actually be a small juvenile approaching age 1. Water temperature at capture for this specimen was 27° C (Table 3). During a May 1995 commercial shark longline trip, two adult female bull sharks were examined offshore of Drum Inlet, Raleigh Bay, north of Cape Lookout (Branstetter and Burgess 1997). One female was gravid, with embryos appearing near term, while the second female contained ripe vitellogenic ova but was not gravid. This new data suggests that bull sharks use southeast North Carolina as a primary nursery ground, although the data is limited.

Southeast North Carolina may be the extreme northern limit of nursery ground habitat for the bull shark as the center of abundance for nursery grounds appears to be the estuarine waters of the Indian River lagoon system of east central Florida and the Gulf of Mexico (Castro 1993, J. Neer, Coastal Research Fellow, Coastal Fisheries Institute, Louisiana State University, personal communication, 2001). Schwartz (2000) reported bull sharks in Core Sound, the Neuse River, and the lower Cape Fear River. The three juvenile specimens from the Cape Fear River were 77 cm to 102 cm FL and were captured during September of 1973 and 1978. The 77 cm FL specimen was within the neonatal size range of bull sharks from the Gulf of Mexico. Castro (1993) reported larger juveniles but no neonates in South Carolina coastal waters. Further investigation, particularly in the Albemarle/Pamlico/Core Sound complex and adjacent river estuaries, as well as the Cape Fear River and estuary is needed.

Blacktip shark, *Carcharhinus limbatus*

Ninety-nine blacktip sharks were caught ranging in size from 46.3 to 145.5 cm FL, with neonate through adult sizes of both sexes (Tables 1, 2). Water temperatures ranged from 20.3° C to 33° C and depths ranged from 8.5 m to 12.8 m (Table 3). Blacktip sharks were observed in both nearshore and inshore waters from Cape Hatteras and Core Sound to Holden Beach. Although blacktip sharks are captured by the commercial longline shark fishery north of Cape Hatteras (Branstetter and Burgess 1998), no blacktip sharks were caught north of Cape Hatteras during this study. Four neonates were caught from Yaupon Beach to Holden Beach southwest of Cape Fear (Table 2). One of these neonates was caught in July with a partially healed umbilical scar, while the other three were captured during September with “mostly” to “well healed” umbilical scars. Post partum and early stage gravid females were caught off Holden Beach during July.

F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) has never caught neonate blacktip sharks in the vicinity of Cape Lookout during 20+ years of trawl and longline surveys. However, Grabowski et. al, (2001) reported the presence of small juvenile and possibly neonatal blacktip sharks at Middle Marsh, Back Sound in the vicinity of Cape Lookout during the months of July through September. Juvenile blacktip sharks of about 1 to 2 years old have been reported from the lower Cape Fear River in July and August (P. Barrington, Aquarium Curator, North Carolina Aquarium, Fort Fisher, NC, personal communication, 1998). Schwartz (2000) reported three neonate blacktips approximately 46.5 cm FL from the lower Cape Fear River during April and October of 1973, 1974, and 1976. These data suggest that southeast North Carolina supports habitat for primary and secondary nursery grounds for this species. This evidence indicates that southeast North Carolina may be the northern extent of nursery grounds for the blacktip shark.

Dusky shark, *Carcharhinus obscurus*

Fifty-two dusky sharks ranging in size from 74.5 cm to 259 cm FL were caught during these studies (Tables 1, 2). Neonates and juveniles dominated the catch that included only two adults (Table 2). Dusky sharks were caught from Cape Hatteras to Holden Beach. Neonatal dusky sharks were caught during April and May off Holden Beach with fresh to mostly healed umbilical scars. Neonates were caught from Bogue Banks to Cape Hatteras with partially to mostly healed umbilical scars during October and November. While most were taken in nearshore waters, two dusky sharks were captured inside the lower Cape Fear River and one inside Bardens Inlet behind the Cape Lookout lighthouse. Recorded water temperatures ranged from 18.1° C to 22.2° C and depths ranged from 4.3 m to 15.5 m (Table 3).

Neonate dusky sharks have been caught from March to April in the vicinity of Cape Lookout (F. J. Schwartz, Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001). Observations from the Commercial Shark Fishery Observer Program (CSFOP) provided evidence that at least during February through April, there was pupping and nursery ground activity in the region from Cape Hatteras to Cape Fear (Gulf and South Atlantic Fisheries Development Foundation, Inc. 1996, Branstetter and Burgess 1998). A near term dusky embryo of 76.5 cm FL was tagged on 5 January 1996, with a NMFS tag, 20 nm southeast of Ocracoke Inlet and recaptured 29 May 1997 at South Hatteras Beach, Cape Hatteras (NMFS 1998). Schwartz (2000) reported one hundred thirty five juvenile dusky sharks from the lower Cape Fear River during 1973, 1976, and 1977. Thus, a broad area of North Carolina from at least Cape Hatteras to Holden Beach and offshore waters supports primary, secondary, and overwintering nursery grounds.

Sandbar shark, *Carcharhinus plumbeus*

A total of 1,735 sandbar sharks were captured by gillnet and longline (Table 1). Size ranged from 45.5 cm to 145 cm FL (Table 2). Water temperatures ranged from 16.4° C to 28.4 ºC, while water depths at capture ranged from 3.0 m to 17.7 m (Table 3). Sandbar sharks were the third most abundant species noted. Of these, 1,214 were YOY; most of the remainder were small juveniles, a few unknowns and larger juveniles (Table 2). Neonate sandbar sharks were caught for the first time during June and July 2000 at Cape Hatteras, inside Pamlico Sound, and at Yaupon Beach. A possible neonate was caught in April 2001 in Core Sound, while a neonate with umbilical remains was caught in Core Sound in June 2001. This new information suggests that sandbar sharks are using nearshore and inshore waters of North Carolina as primary nursery grounds. These data also provide supporting evidence that sandbar sharks use North Carolina as a secondary and overwintering nursery ground (Jensen and Hopkins 2001, Jensen 1998, Pratt et al. 1998, NMFS 1998).

Sandbar sharks in general migrate to the vicinity of Cape Hatteras and south during the fall, overwinter, then migrate north in the spring (Kohler et al. 1998, Jensen and Hopkins 2001, NMFS 1998, Springer 1960). Schwartz (1995) reported juvenile sandbar sharks from Pamlico Sound, the New River, and the coastal waterway near the New River and southwest of Cape Fear. Schwartz (2000) reported the occurrence of thirty-eight sandbar sharks 50.9 cm to 110 cm FL in the lower Cape Fear River between 1974 and 1978. Jensen and Hopkins (2001) provide a detailed account of sandbar shark migration and activity at Cape Hatteras.

Tiger shark, *Galeocerdo cuvier*

Four tiger sharks were captured (Table 1). All were juveniles ranging in size from 122.5 cm to 196.7 cm FL (Table 2). Water temperature was 30° C during one capture. Tiger sharks occur commonly throughout North Carolina coastal waters. Larger numbers of juvenile through adult tiger sharks are a common bycatch of the directed commercial shark longline fishery off North Carolina (Branstetter and Burgess 1998). Although evidence suggests that North Carolina provides a primary and secondary pupping and nursery grounds further offshore, only limited data on this species was available from the nearshore waters of southeastern North Carolina.

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

Atlantic sharpnose sharks were the most commonly caught sharks in North Carolina waters (Table 1). They were encountered during each month of sampling. A total of 5,826 sharks were captured by all fishing methods and ranged in size from 22.3 cm to 91.4 cm FL (Table 2). Of these, 910 were neonates, 726 were juveniles, and 4,015 were mature (Table 2). Water temperature ranged from 17.3° C to 33º C and depths ranged from 1.4 m to 16.5 m (Table 3). Neonates were seen from Cape Hatteras to Holden Beach both nearshore and inshore with fresh to partially healed umbilical scars occurring from May - July. "Mostly healed" umbilical scars were seen from June to August. Atlantic sharpnose sharks (15 – 106 cm FL) were the most abundant shark species caught during an intensive survey of the Cape Fear River estuary between 1973 and 1978 (Schwartz 2000). The Atlantic sharpnose shark uses North Carolina nearshore and inshore waters as primary and secondary nursery ground habitat.

Scalloped hammerhead shark, *Sphyrna lewini*

A total of 45 scalloped hammerheads were caught from Oregon Inlet to Holden Beach (Table 1). Life stages of these sharks ranged from neonates to mature males and a near term gravid female, with a size range from 31.8 to 210 cm FL (Table 2). Water temperatures ranged from 19° C to 30° C and depth ranged from 3.1 m to 13.5 m (Table 3). Neonatal sharks were caught from Cape Hatteras to Holden Beach, with only smaller juveniles at Oregon Inlet. One neonate was caught at Cape Hatteras in July with a partially healed umbilical scar. Most neonates were caught from Yaupon Beach to Lockwoods Folly Inlet with partialy to well healed umbilical scars in June and July with one in September. One gravid female caught in June off Holden Beach contained 35 embryos 37 to 42 cm TL, a size close to the parturition size reported by Castro (1993) and Branstteter (1987). The coastal region from Cape Hatteras to Holden Beach is used by the scalloped hammerhead as primary and secondary nursery grounds, while the region north of Cape Hatteras seems to support only a secondary nursery ground. Sampling is needed north of Cape Hatteras to delineate the extent of the nursery range. North Carolina may be the northern range of the nursery grounds for the scalloped hammerhead, the center of abundance being further south. Most neonates were caught south of Cape Fear.

F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) reported observing only about five neonates over a 25-year period off Cape Lookout. P. Barrington (Aquarium Curator, North Carolina Aquarium, Fort Fisher, NC, personal communication, 1998) reports that 1-2 year old juveniles are taken in and around the vicinity of the Cape Fear River during the summer months. Schwartz (2000) reported 10 scalloped hammerheads ranging 32.8 cm to 59.7 cm FL from the lower Cape Fear River during June and July 1973 to 1978. Castro (1993) reported neonatal and larger juvenile scalloped hammerheads off Charleston and Bulls Bay, South Carolina during summer months.

Great hammerhead shark, *Sphyrna mokarran*

Only two great hammerheads with fork lengths of 236 cm and 258 cm were caught (Table 1). One was a juvenile while the other was an adult (Table 2). No neonates or small juveniles were caught.

Great hammerheads are captured regularly in the directed commercial shark fishery off the Carolinas particularly during summer months, although no neonates or juveniles were caught during five years of observer work in the region (Branstteter and Burgess 1997, 1998). F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) has never caught any neonates or small juveniles during over twenty-five years of shark longline and trawl net surveys off Cape Lookout. Castro (1993) found no great hammerheads during a shark nursery survey off South Carolina.

Bonnethead shark, *Sphryna tiburo*

A total of 575 bonnetheads ranging in size from 30.5 cm - 92.3 cm FL were captured (Table 1, 2). This was the fourth most abundant shark species (Table 1). Neonates through adult males and a progressive series of pregnant females were examined (Table 2). Water temperatures ranged from 19° C to 33° C and depths ranged from 0.6 m to 11.6 m (Table 3). Bonnethead sharks were caught from Cape Hatteras to Holden Beach, throughout both nearshore and inshore waters. Gravid females were caught from July to September. Embryo lengths in September were 24.7 to 29.8 cm TL, approaching or the same as the documented parturition size recorded from the Gulf coast of Florida during August and September (Parsons 1993, Carlson and Parsons 1997). These embryos had teeth beginning to protrude through the gums. Embryonic growth rates were estimated as 6 - 8 cm per month. One neonate 30.5 cm FL was caught off Holden Beach during September with a partially healed umbilical scar. Small juveniles of about 33 to 44 cm FL were caught from May to July from Cape Hatteras to Holden Beach, of which a few may have been YOY. Parturition appeared to be in the fall as in Florida. However, this issue needs further examination. Southeastern North Carolina provides both primary and secondary nursery grounds for the bonnethead, although this may be the northern extent of pupping in this species.

F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) reports the regular occurrence of bonnetheads in both nearshore and inshore waters around Cape Lookout, Core Sound and Pamlico Sound. Some neonate and small juveniles were caught on occasion over 25 years of sampling with otter trawl and longline in the region. Schwartz (2000) caught two bonnetheads 43.5 cm FL in the lower Cape Fear River in 1976 and 1977.

Smooth hammerhead shark, *Sphyrna zygaena*

Six smooth hammerhead sharks were captured in nearshore waters between Cape Hatteras and Holden Beach. They ranged in size from 62 to 92.5 cm FL (Table 1, Table 2). Water temperatures at capture ranged from 17.8° C to 20.2° C and depths ranged from 5.1 m to 15.5 m (Table 3). All six specimens were small juveniles. The smallest specimen of 62 cm FL was captured at Yaupon Beach in May. This is close to size at birth (Branstetter 1990). The five remaining specimens were caught off Cape Hatteras during October and November. F.J. Schwartz (Professor, Institute of Marine Sciences, University of North Carolina, personal communication, 2001) caught three juvenile smooth hammerheads (86, 81, and 69 cm FL) during independent shark sampling in North Carolina offshore waters in May 1989 and in inshore waters in August 1998 and in May 2000. Overall this species is more tolerant of temperate water than other hammerheads (Compagno 1984b). Thus, North Carolina is probably used as a secondary nursery ground for the smooth hammerhead, but more comprehensive data is needed to demonstrate this.

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Shark Nursery Areas in South Carolina's Estuarine and Coastal Waters

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Scope

The sampling effort reported here was directed at determining the utilization of South Carolina estuarine and near-shore coastal waters as primary pupping and nursery habitat and secondary nursery habitat for large and small coastal sharks. The Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) program is providing the funding and framework to develop this information on a regional basis. Sampling was initiated in 1998 and this report covers the period, 1998-2000. Geographical coverage within South Carolina extends from Bulls Bay southward to St. Helena Sound. There are undoubtedly other areas within the state that are important pupping and nursery habitat but logistical constraints required that sampling be confined to the above areas with the current level of support.

In addition to the COASTSPAN sampling, this report includes shark data collected from a survey to monitor adult red drum stocks in the near-shore coastal waters of South Carolina. The shark component of these longline collections often exceeded the red drum catch. This data collected aboard the R/V Anita provides a significant expansion to the shark database in South Carolina. The R/V Anita sampling occurred primarily in near-shore coastal waters (within 6-7 miles from the beach) although some exploratory directed shark trips were conducted in St. Helena Sound and the North Edisto estuary.

Data for near-shore coastal and estuarine sampling is presented separately to examine differences in species composition, catch per unit effort and species diversity.

Sampling Materials and Methods

Navigation charts were reviewed with the project coordinator, Wes Pratt, to select prospective sampling sites. Sites were selected in the lower, high salinity reaches of South Carolina estuaries with appropriate depths for gillnet deployment. Selected areas were visited to determine the actual conditions and the feasibility of successful sampling.

The gillnet gear (GN) was provided by the COASTSPAN program and is described in the Delaware Bay chapter. The only modification that we made to the net was the removal of the ½ inch nylon rope attached to top line of the gill net. We found that the removal of this line substantially reduced tangling during deployment, twisting of the net while it was fishing and reduced the weight of the net making it easier to handle. No negative effects from removing this line were noted. The net was set and under-run at approximately 20-minute intervals.

The COASTSPAN longline (CLL) gear consisted of 1000 feet of ¼ inch braided nylon mainline with 50 hook gangions. The supplied gangions were constructed of ¼ inch braided nylon and 50 cm of 1/16- inch stainless steel cable with a 12/0 tuna circle hook and a 4/0 longline snap. These gangions were utilized during the first year of the project but were somewhat unwieldy and we replaced them with the monofilament gangions that we had successfully used on other shark projects and in our red drum work. These gangions consisted of 0.5 m of 200-pound test monofilament with a 4/0 longline snap and a 12/0 tuna circle hook. These gangions were stored in shallow wooden boxes with strips of hard rubber attached to the edges of the boxes. The gangions are inserted in slits cut in the rubber which holds them securely and prevents tangling. Each box holds 60 gangions. The hooks are baited while the gangions are secured in the boxes. This system is easily deployed from a small boat and speeds up the setting and haul back procedure. When the gear is being hauled back the gangions are re-racked in their boxes ready for the next set.

Prior to the 2000 sampling year the longline was set, allowed to soak for 45-60 minutes and then retrieved and either reset or moved to a new location. Very high bait loss was noted on most sets attributed primarily to blue crabs, *Callinectes sapidus*, and neonate Atlantic sharpnose sharks, *Rhizoprionodon terraenovae*. As a result much of the time the gear was deployed it wasn't actually fishing because of the lack of bait. In response to this the sampling strategy was modified and longline sets were conducted much like the gillnet sets with the longline under-run at 15-20 minute intervals with sharks removed and baits replaced. This procedure worked well and seemed to produce larger numbers of sharks in excellent condition for tagging.

A different longline gear was used on the R/V Anita; a 15.2 m shallow draft research vessel equipped with two, small hydraulic longline reels each having a capacity of about 7000 feet of 600-pound test monofilament. The R/V Anita longline gear (ALL) consisted of a mainline that was 6000 feet long with 100 foot buoy lines attached at each end. The mainline was equipped with stop sleeves at 100-foot intervals to keep the gangions from sliding together when a large shark or red drum was captured. The gangions are as described for the CLL with the exception that the hooks employed were 14/0 and 15/0 tuna circle hooks. A full set consisted of 120 hooks although when sampling in estuarine areas we sometimes utilized a half set (60 hooks on 3000' mainline). Soak time for this gear averaged 0.75 hours.

Latitude and longitude (GPS) for the beginning and end of each set was recorded along with start and end time of deployment and retrieval and water temperature. Sharks not required for life history studies that were in good condition were measured and tagged. Atlantic sharpnose, smooth dogfish and spiny dogfish were the only species not tagged. The only nurse sharks tagged were those small enough to bring on deck where a pilot hole for the tag could be made with a sharp heavy bladed knife. Several attempts to tag large nurse sharks in the water left us with a bent or broken tagging needle due to this species' extremely tough skin. Sharks less than 1 m FL were tagged with the COASTSPAN rototags and larger sharks with the "M" tags.

Sharks from all gear types were measured (FL and TL mm). Sharks were examined to determine the condition of the umbilicus to classify the sharks as neonates or juveniles. The condition of the claspers on larger sharks was examined to determine if they were mature. Some of the Atlantic sharpnose sharks and the majority of blacknose sharks, *Carcharhinus acronotus*, were sacrificed for life history studies being conducted by graduate students from the College of Charleston and University of South Carolina.

Catch per unit effort (CPUE) was calculated for estuarine and near-shore coastal areas and by gear type. Prior COASTSPAN work uses catch per hour as the unit of CPUE for the gill net and CLL. In order to make the Anita longline (ALL) effort comparable, a conversion to "equivalent hours" was made on the catch per set data from this gear. Equivalent hours were computed as follows: (each ALL set was multiplied by 2.4; the ratio of ALL hooks to CLL hooks) and this product was multiplied by 0.75 (average hours per ALL set).

Description of Shark Nursery Areas

The estuarine and coastal waters of South Carolina provide pupping and nursery habitat for several species of sharks. The estuarine areas that we have sampled to date where neonate and juvenile sharks were common were characterized by relatively high salinity ranging from 24-37 ppt. The coastal sampling sites were 3-5 miles offshore and the salinities ranged from 31-35 ppt. Estuarine sampling sites were characterized by tidal amplitudes averaging almost 2 m with strong currents in the proximity of channels. There were high amounts of suspended sediments particularly during ebb tides. The amount of turbidity generated by wave action appeared to reduce the abundance or catchability of sharks, as catch rates were generally low when winds were blowing onto the shoreline adjacent to the sampling area. Bottom types were primarily mud although sand was predominant in some sampling areas, particularly near the mouths of inlets. A number of the sites were in close proximity to extensive oyster reefs. These bottom types support a rich fauna of fish and invertebrates that serve as forage for the neonate and juvenile sharks.

Water temperature is a major determinant of the occurrence of sharks in the coastal and estuarine waters. Appearance of large and small coastal species within the estuaries occurs at about 19 °C, with juvenile sandbar, *Carcharhinus plumbeus*, adult male Atlantic sharpnose and bonnethead, *Sphyrna tiburo*, sharks encountered at this temperature in mid-April. Sharks start to leave estuarine areas and move into coastal waters when there is a decreasing trend in water temperature with many leaving while estuarine temperatures are around 26- 28 °C. Although our coastal waters sampling coverage is incomplete during the spring months it appears that large and small coastal species move into South Carolina waters at temperatures as low as 17 C. In the fall we have encountered large and small coastal sharks at temperatures as low as 14.0 C although the catches drop substantially when temperatures drop below 19-20 C.

The smooth and spiny dogfish (*Mustelus canis* and *Squalus acanthias*, respectively) exhibit the opposite type of response to temperature in South Carolina waters, appearing in the late fall when temperatures drop to 18-19 C (smooth dogfish) and 13 C (spiny dogfish) and remaining in coastal waters until late winter or early spring when temperatures rise above 19 C.

A more detailed description of temperature preferences is given in the individual species reports later in this report.

Description of Study Areas

Estuarine Sampling Locations

The locations of estuarine sampling areas are shown in Figure 1. The following areas were selected and sampled from June 1998 through September 2000. Site characteristics such as bottom type and other significant features are described.

Bulls Bay (mouth of Five Fathom Creek, BB-FFC)- This site is located near the ocean in the northern end of Bulls Bay with a mud /shell bottom with set depths from < 1 m to 4.5 m. This has been a productive site and we have sampled it during all 3 years.

Charleston Harbor (southeast side of Castle Pinckney, CH-CP)- This site is located near the center of Charleston Harbor with a sand/shell hash bottom and depths of 1-4 m. This site was only sampled with the longline (CLL) one time, and not on an optimum tide stage. Catches were low and bait loss from blue crabs was very high. Additional survey work to identify productive sampling areas is needed to characterize the shark populations in Charleston Harbor. This area has become a high salinity estuary since the completion of the Santee re-diversion project and should constitute good shark habitat.

Stono River Estuary (STO)- Several stations within the Stono estuarine system were sampled on one occasion with rod and reel and longline (CLL) gear. Bottom types were mud/shell and sand and catches were limited to neonate Atlantic sharpnose. Prior sampling in this area has shown it to be highly dominated in the summer months by neonate sharpnose and it is apparently an important primary nursery habitat for this species. Given the limited amount of sampling time available and higher interest in other species, sampling in this area was discontinued.

St. Helena Sound-Rock Creek (SHS-RC)- This is the only site in St. Helena Sound that has been routinely fished with the gill net and COASTSPAN longline (CLL). Several other exploratory stations in St. Helena Sound have been made using the R/V Anita longline gear.

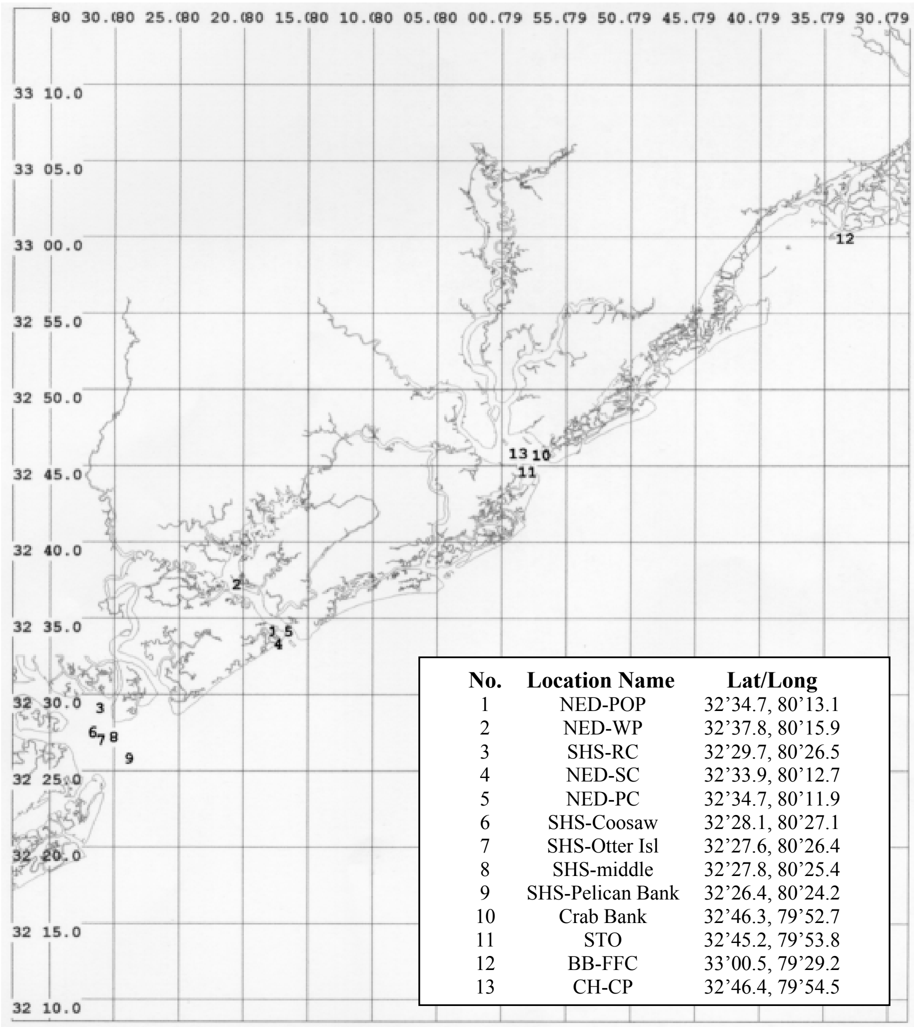
North Edisto River Estuary: The following estuarine sampling sites have been established within the North Edisto estuarine system:

North Edisto-South Creek (NED-SC)- This is the nearest site to the ocean in the North Edisto system and bottom type is mud/shell with a relatively uniform depth of about 16 m. This location was sampled with two types of longline gear but is not suitable for gillnet sampling.

North Edisto-Point of Pines (NED-POP)- The bottom in this area is sand/mud/shell hash and is a gradually sloping bar adjacent to a deep channel. Gillnet sets are made on the bar in depths ranging from 1-6 m and longline sets are generally deployed extending into the adjacent channel.

North Edisto-Wadmalaw Point (NED-WP)-This has been one of our most productive sites for both longline and gillnet gear. The site is located on the

Figure 1. **Estuarine Sampling Locations**



No.	Location Name	Lat/Long
1	NED-POP	32'34.7, 80'13.1
2	NED-WP	32'37.8, 80'15.9
3	SHS-RC	32'29.7, 80'26.5
4	NED-SC	32'33.9, 80'12.7
5	NED-PC	32'34.7, 80'11.9
6	SHS-Coosaw	32'28.1, 80'27.1
7	SHS-Otter Isl	32'27.6, 80'26.4
8	SHS-middle	32'27.8, 80'25.4
9	SHS-Pelican Bank	32'26.4, 80'24.2
10	Crab Bank	32'46.3, 79'52.7
11	STO	32'45.2, 79'53.8
12	BB-FFC	33'00.5, 79'29.2
13	CH-CP	32'46.4, 79'54.5

riverside of a large shallow embayment with extensive oyster reefs that are exposed at low tide. The bottom is predominantly mud and shell with scattered small patches of live oysters. Gillnet sets extend to the marsh edge at the shallow end and to 3-5 m on the offshore end.

North Edisto-Privateer Creek (NED-PC)- There is an extensive tidal flat area adjacent to a deep hole at the confluence of Privateer creek and the North Edisto. This area with a sand/mud/shell bottom was sampled with the CLL, Depths ranged from 1.5 –6 m and this area would probably be suitable as a gillnet station in the future.

Near-shore Coastal Sampling Locations

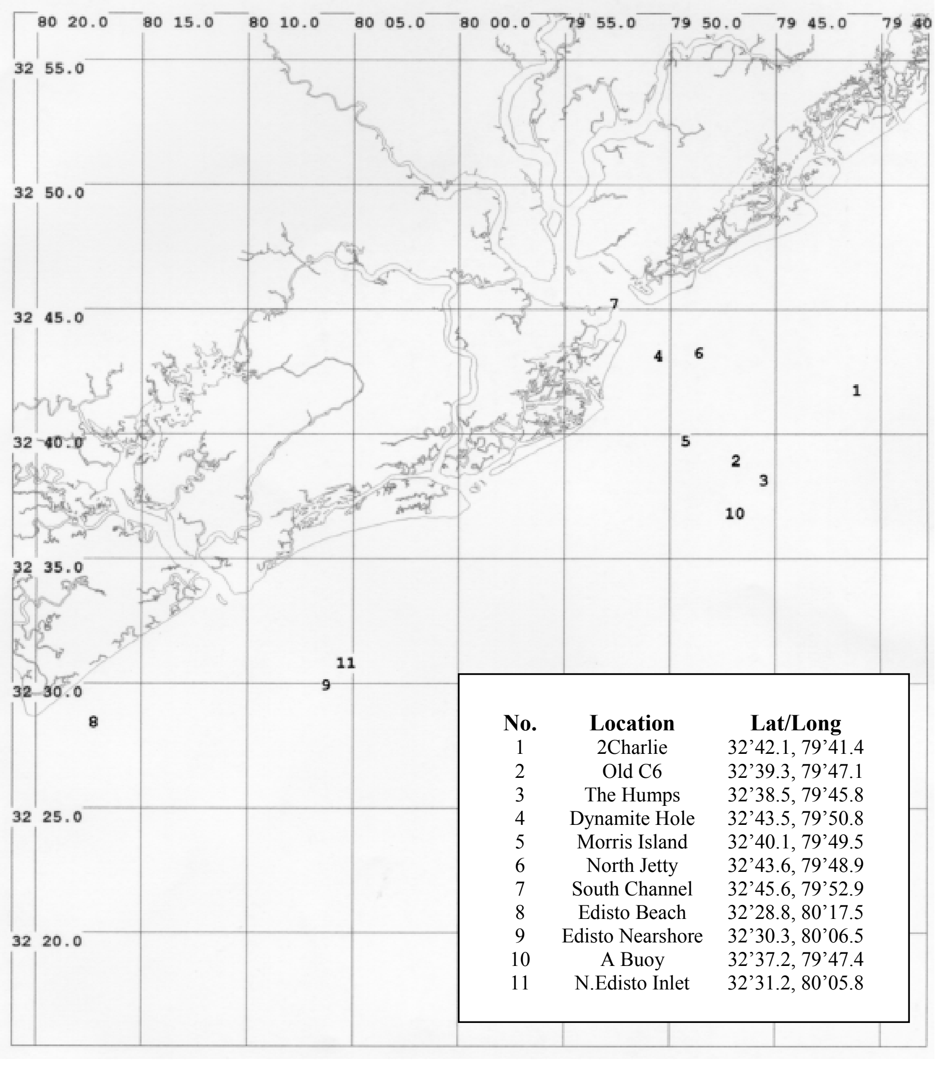
The following locations were sampled using the R/V Anita on trips primarily directed at adult red drum population studies. The locations of these sites are shown in Figure 2.The majority of these sites were live-bottom; areas of low relief rock outcrops encrusted with various invertebrates such as sponge and gorgonians. These areas are productive for a variety of shark species.

Live bottom Sites:

Old C-6 – This is a live bottom site with an average depth of 11 m.

The Humps – This is an area of "created" live bottom consisting of 1-2 m high chunks of marl that were dumped in a spoil disposal site during the last

Figure 2. **Near-shore Sampling Locations**



No.	Location	Lat/Long
1	2Charlie	32’42.1, 79’41.4
2	Old C6	32’39.3, 79’47.1
3	The Humps	32’38.5, 79’45.8
4	Dynamite Hole	32’43.5, 79’50.8
5	Morris Island	32’40.1, 79’49.5
6	North Jetty	32’43.6, 79’48.9
7	South Channel	32’45.6, 79’52.9
8	Edisto Beach	32’28.8, 80’17.5
9	Edisto Nearshore	32’30.3, 80’06.5
10	A Buoy	32’37.2, 79’47.4
11	N.Edisto Inlet	32’31.2, 80’05.8

Charleston Harbor deepening project. This bottom has been colonized primarily by anemones. In addition there is a rich invertebrate fauna of crabs and worms associated with this bottom. The average depth is 12 m.

2 Charlie – Live bottom with an average depth of 13 m.

A Buoy – This area has a 0.5-1 m rocky ledge with an average depth of 14 m.

North Jetties – This area has patchy live bottom and is located inside the north Charleston Harbor jetty at the offshore end of the jetty. The average depth is 8 m.

Edisto Beach – Located within one mile of the south end of Edisto Beach this area has extensive live-bottom coverage and an average depth of 5 m.

Other Near-shore Coastal Sites:

Dynamite Hole – This area is a channel through a break in the south Charleston Harbor jetty with an average depth of 6 m. Bottom type is sand and mud.

Morris Island – The bottom in this area is mud/sand with an average depth of 8 m.

North Edisto Inlet and Vicinity – Several stations were sampled in this area, which has sand/mud bottom and an average depth of 9 m.

Results and Discussion

Species Composition

A total of 4,284 sharks were caught during sampling conducted from March 1998 through November 2000. The majority of the sampling effort was expended in the near-shore coastal environment using the previously described longline gear on the R/V Anita. The total shark catch in the near-shore coastal area was 3,368 sharks represented by 15 species (Table 1).

Table 1. Species Composition by Area Fished (Near-shore Coastal)

Species	No.	%
Atlantic sharpnose shark	2281	67.7
Smooth dogfish	493	14.6
Blacknose shark	252	7.5
Sandbar shark	95	2.8
Spiny dogfish	83	2.5
Blacktip shark	45	1.3
Spinner shark	26	0.8
Tiger shark	22	0.7
Finetooth shark	21	0.6
Nurse shark	20	0.6
Scalloped hammerhead shark	14	0.4
Dusky shark	9	0.3
Bonnethead shark	4	0.1
Sand tiger shark	2	0.1
Thresher shark	1	0.0
Total	**3368**	

The Atlantic sharpnose was the strongly dominant species making up 67.7 % of the catch. The smooth dogfish and spiny dogfish together comprised 17.5 % of the catch but only occurred from November to March when most other species of sharks had left coastal waters in response to low temperatures. The small coastal blacknose was third in abundance in the near-shore waters at 7.5 % of the catch. Sandbar sharks made up 2.8 % of the catch and blacktip sharks, *Carcharhinus limbatus*, 1.3 %. Spinner (*C. brevipinna*), tiger (*Galeocerdo cuvier*), finetooth (*C. isodon*), nurse (*Ginglymostoma cirratum*), scalloped hammerhead (*Sphyrna lewini*), dusky (*C. obscurus*), bonnethead, sand tiger (*Carcharias taurus*), and thresher (*Alopias vulpinus*) sharks made up the remaining 3.2 % of the catch with individual species contributions of less the 1.0 %.

Table 2. Species Composition by Area Fished (Estuarine)

Species	No.	%
Atlantic sharpnose shark	458	50.0
Bonnethead shark	189	20.6
Finetooth shark	161	17.6
Sandbar shark	57	6.2
Scalloped hammerhead shark	23	2.5
Blacktip shark	16	1.7
Spinner shark	4	0.4
Lemon shark	3	0.3
Blacknose shark	2	0.2
Smooth dogfish	2	0.2
Bull shark	1	0.1
Total	**916**	

The Atlantic sharpnose was also the dominant species in the estuarine samples, making up 50.0 % of the catch (Table 2). Estuarine catches of Atlantic sharpnose were heavily dominated by neonates, whereas the near-shore coastal catches were predominantly adults and juveniles. More information on size distribution is presented later in this report in individual species descriptions. Second and third in abundance were the bonnethead and finetooth at 20.6 and 17.6 % respectively of the estuarine catch. The bonnethead ranked thirteenth and the finetooth ninth in abundance in the coastal samples, however this may not be an accurate reflection of these species actual abundance outside of the estuaries. We were unable to conduct sampling close to the beaches due to the operation of the shrimp trawl fishery during periods when these sharks could have been abundant in these areas. Castro (1993) reported that most of his samples in the Bulls Bay, SC area came from the seaward sides of the barrier islands, 1-4.5 km from the beach and he found the finetooth to be abundant in such waters but makes no mention of the bonnethead. Sandbar sharks ranked fourth in abundance in both areas. The catches in the estuarine areas were dominated by neonates and small juveniles, with the dominant size group in the coastal waters consisting of large juveniles. Scalloped hammerhead and blacktip sharks ranked fifth and sixth in the estuarine samples, at 2.5 and 1.7 % of the catch respectively. In order of abundance the following species made up the rest of the estuarine catch with each contributing less than 0.5 % of the total: spinner, lemon (*Negaprion brevirostris*), blacknose, smooth dogfish and bull sharks.

Sampling in the estuarine areas was conducted primarily with the COASTSPAN gillnet (GN) and longline (CLL) with some exploratory effort in St. Helena Sound, North Edisto estuary and Charleston Harbor using the R/V Anita. Species diversity was lower in the estuarine areas with catches comprised of 11 versus 15 species in the coastal waters. This difference represents habitat preferences to some degree but was probably also influenced by the temporal distribution of sampling effort. Estuarine sampling was restricted to April to September, which would effectively preclude catching the smooth dogfish and spiny dogfish that only occur in our area when temperatures are at their seasonal minimums. An additional factor that may have contributed to the greater number of species in the coastal sampling was the preponderance of sampling effort during the fall when sharks are leaving estuarine areas and migrating from more northern areas to their over-wintering grounds. This may have increased the probabilities of catching more of the relatively uncommon species. Species encountered in the coastal waters but not in estuarine areas include: spiny dogfish, tiger, nurse, dusky, sand tiger, and thresher. Of these species we believe that the tiger, nurse and thresher do not utilize estuarine areas to any significant degree. Further sampling is needed to determine whether the other species utilize estuarine areas during any part of the life cycle. Lemon and bull sharks were captured in estuarine sampling but not in the coastal waters. This probably represents a sampling artifact, as there is substantial anecdotal evidence of the occurrence of both species in the near-shore coastal waters.

There was a substantial difference in the species composition for the various gear types utilized (Tables 3, 4 and 5). Some of the differences are attributable to spatial and temporal differences in sampling effort as previously discussed for the smooth and spiny dogfish. The species selectivity of the Anita longline (ALL) and the COASTSPAN longline (CLL) appear to be comparable. The Atlantic sharpnose ranked number one for both ALL and CLL and second behind bonnethead for the COASTSPAN gillnet (GN). Sandbar sharks ranked fourth for the ALL and CLL

Table 3. Species Composition by Gear (Anita Longline)

Species	No.	%
Atlantic sharpnose shark	2456	68.4
Smooth dogfish	495	13.8
Blacknose shark	254	7.1
Sandbar shark	134	3.7
Spiny dogfish	83	2.3
Blacktip shark	48	1.3
Spinner shark	26	0.7
Tiger shark	22	0.6
Finetooth shark	21	0.6
Nurse shark	20	0.6
Scalloped hammerhead shark	14	0.4
Dusky shark	9	0.3
Bonnethead shark	5	0.1
Sand tiger shark	2	0.1
Bull shark	1	0.0
Lemon shark	1	0.0
Thresher shark	1	0.0
Total	**3592**	

Table 4. Species Composition by Gear (COASTSPAN Longline)

Species	No.	%
Atlantic sharpnose shark	124	53.0
Finetooth shark	64	27.4
Scalloped hammerhead shark	17	7.3
Sandbar shark	13	5.6
Bonnethead shark	6	2.6
Blacktip shark	5	2.1
Spinner shark	3	1.3
Lemon shark	2	0.9
Total	**234**	

Table 5. Species Composition by Gear (Gillnet)

Species	No.	%
Bonnethead shark	182	39.7
Atlantic sharpnose shark	159	34.7
Finetooth shark	97	21.2
Blacktip shark	8	1.7
Scalloped hammerhead shark	6	1.3
Sandbar shark	5	1.1
Spinner shark	1	0.2
Total	**458**	

and sixth for the GN. Of most interest were the differences demonstrated for the CLL and GN, which were utilized in the same areas and in many cases the set locations were virtually identical for the two gear types. Bonnetheads were the dominant species in the gillnet catches (34.7 %) but only ranked fifth (2.6 %) in the CLL samples. This may be attributable to differences in feeding behavior of the bonnethead that makes it less susceptible to hook and line capture. Finetooth, scalloped hammerhead, and sandbar sharks appear to be more vulnerable to the longline than gillnet.

Catch per unit effort (CPUE)

The overall CPUE for 1998-2000 combined gears was 5.81 sharks per hour. The annual combined CPUE was relatively stable at 6.29, 5.03, and 5.98 sharks/hour for 1998, 1999, and 2000 respectively.

The annual CPUE for the Anita longline (ALL) is shown in Table 6. CPUE was originally recorded as catch per set but in order to allow comparison with the other gear types and COASTSPAN protocol where the CPUE unit is sharks/hour we converted the ALL effort as described in the Methods section. Shark CPUE was highest in 1998 at 6.48 sharks/hour and lowest in 1999 at 4.83 sharks/hour. Given the short time series available there is no indication of any shark abundance related trends in CPUE.

Table 6. Catch per Unit Effort (CPUE) for Anita Longline

Year	Sharks	**Sets**	**CPUE Sharks/Set**	**Equivalent Sharks/Hour**
1998	1551	122	11.66	6.48
1999	1005	115.5	8.70	4.83
2000	1036	99	10.46	5.81.
Total	**3592**	**347.5**	**10.34**	**5.74**

COASTSPAN longline (CLL) annual CPUE (Table 7) showed an increasing trend from 2.15 sharks/hour (1998) to 4.83 in 2000. The increase in annual CPUE is probably more reflective of improving techniques and knowledge of where and when to sample than relative shark abundance. CPUEs for this gear were lower than those for the other gear types but it was an effective gear for sampling in estuarine areas and produced low levels of mortality with most sharks in excellent condition for tagging.

Table 7. Catch per Unit Effort, COASTSPAN Longline (CLL)

Year	Sharks	Hours	CPUE Sharks/Hour
1998	35	16.25	2.15
1999	8	2.5	3.20
2000	192	39.75	4.83
TOTAL	235	58.5	4.02

The COASTSPAN gillnet (GN) had the highest CPUE for any gear type and an increasing trend in CPUE for 1998-2000 (Table 8). Sharks/hour were 7.48, 8.73, and 9.36 in 1998, 1999, and 2000 respectively. The increasing trend in CPUE from 1998-2000 has undoubtedly been influenced by our “learning curve” in net placement and sampling techniques. CPUE figures for all gear types will be a more useful tool to assess trends in shark abundance as we develop a longer time series and standardize techniques and sampling stations. There is an apparent, high temporal variability in the availability of sharks at the same sampling station, which necessitates caution in interpreting trends in CPUE and increased sampling effort to reduce variance.

Table 8. Catch per Unit Effort, COASTSPAN Gillnet

Year	Sharks	Hours	CPUE Sharks/Hour
1998	144	19.25	7.48
1999	107	12.25	8.73
2000	206	22.0	9.36
TOTAL	457	53.5	8.54

Mortality and Tagging

The overall mortality rate for combined gears was 4.5 % (Table 9). The gillnet had the highest rate of mortality (21.6 %) and the two longline gears produced substantially lower rates at 3.8 % (CLL) and 2.3 % (ALL). The slightly higher mortality rate for the CLL is attributed to higher average water temperatures during the months that this gear was employed (May-September) whereas many of the ALL sets were made during March/April and October/November. Additionally the estuarine sets produced higher numbers of neonates, particularly Atlantic sharpnose, which seem particularly susceptible to gear induced mortality. The gillnet

Table 9. **Mortality and Disposition of Sharks by Gear Type**

Gear	Tagged No.	Tagged %	Rel. w/o tag No.	Rel. w/o tag %	Sac. No.	Sac. %	DOA No.	DOA %	Total
ALL	774	21.6	2063	57.4	672	18.7	83	2.3	**3592**
CLL	116	49.6	104	44.4	5	2.1	9	3.8	**234**
GN	244	53.3	111	24.2	4	0.9	99	21.6	**458**
Total	**1134**	**26.5**	**2278**	**53.2**	**681**	**15.9**	**191**	**4.5**	**4284**

Table 10. **Recapture Data**

Species	Life Stage	Time at Liberty Days	Time at Liberty Years	Distance and Direction Traveled	Growth (in)
Sandbar shark	Juvenile	596	1.6	216mi.S	?
	Neonate	59	0.16	<1mi.	?
	Juvenile*	629	1.72	25mi.W	4.2”TL (1410TL-1516TL)
	Juvenile	70	0.2	6mi.S	?
	Juvenile	631	1.7	111mi.NE	?
Bonnethead shark	Juvenile	59	0.16	23mi.SW	?
	Neonate	43	0.12	4mi.S	?
	Adult**	329	0.90	1mi.W	3.3”TL (1160TL-1243TL)
	Juvenile**	383	1.05	1mi E	2.6”TL (996TL-1062TL)
	Juvenile	13	0.04	0	0”TL (865TL-865TL)
Finetooth shark	Neonate***	19	0.05	0	?
	Neonate	4	0.01	12mi.NE	1”TL
	Juvenile	56	0.15	0	1.6”TL (609TL-651TL)
Blacknose shark	Juvenile	1512	4.14	120mi.NE	?
	Adult	443	1.2	170mi.NE	5.3”TL
Tiger shark	Juvenile	1873	5.1	621mi.NE	?
	Juvenile	674	1.85	160mi.SSW	32.0”TL (106TL-1890TL)
Scalloped hammerhead shark	Neonate	38	0.10	78mi.SW	?
Nurse shark	Juvenile	324	0.89	0	6.7”TL (1131TL-1502TL)
Blacktip shark	Juvenile	62	0.17	25mi.SW	? (Archival tag released)

* Captured in fall in near-shore coastal waters and recaptured in estuarine waters 1.72 years later

** Adult and juvenile recaptured within 1 mile of original tagging location approximately 1 year later. Evidence of juvenile site fidelity.

*** Neonate with a fresh open umbilical scar gear was utilized during the same months as the CLL but the major contributor to the higher mortality rate of this gear, was repeat captures of the same individuals. When under-running an anchored net, captured sharks had to be tagged and released in close proximity to the net. It was not unusual to catch the same shark up to three times during a gillnet deployment. Sharks often survived an initial recapture although in weakened condition but subsequent recaptures were often fatal. This was the major disadvantage of the gillnet gear in our area. It was disheartening to kill animals that had been tagged less than an hour before.

Mortality rates also varied considerably between species; ranging from zero for blacknose, dusky, lemon, nurse, sand tiger, sandbar, smooth dogfish, spiny dogfish and tiger to a high of 27.0 % for gillnet caught sharpnose (primarily neonates). Other species with high mortality rates in the gillnet were bonnethead (21.4 %), finetooth (16.5 %), and blacktip (12.5 %).

The percentage of sharks tagged from the combined sampling efforts was 26.5 % (Table 9). Only 21.6 % of the ALL caught sharks were tagged due to the large number of Atlantic sharpnose, smooth dogfish and spiny dogfish. Additionally a large percentage of the blacknose (84.6 %) were sacrificed for life history studies being conducted by Trey Driggers, a University of South Carolina graduate student. Atlantic sharpnose (15.4 %) were also sacrificed for life history studies but they would not have been tagged anyway. About half of the sharks captured by CLL (49.6 %) and GN (53.3 %) were tagged. The higher percentage of tagged sharks was due to the lesser contribution of Atlantic sharpnose to the catch and the lack of smooth and spiny dogfish in the estuarine areas. A total of 1,134 sharks were tagged during the 1998-2000 sampling years.

Tag Recaptures

Twenty recaptures have been reported to date. Thirteen tags were returned by recreational fishermen, shrimp trawlers or commercial longliners. The remaining seven were recaptured by this project or other biologists. With one exception, a tiger shark recaptured by a commercial shark longliner, the latter recaptures were the only ones that provided reliable growth data. The majority of recreational and trawler recaptures only provide an estimate of length or weight, in many cases less than the initial size at tagging. The reputed tendency of fishermen to exaggerate the length of a fish doesn't appear to be evident with sharks. Recapture data is shown in Table 10.

A sandbar shark that was tagged in the near-shore coastal waters adjacent to Charleston harbor during the fall was recaptured after 1.72 years at liberty inside the North Edisto estuary. McCandless and Pratt (2001) noted that juvenile sandbars move back into Delaware Bay in the spring and early summer, and many of these sharks exhibit site fidelity, returning to the same estuary and even the same location within that estuary from one year to the next. This sandbar, which was recaptured inside the North Edisto estuary, was tagged only 25 miles from the recapture location at a time of year when sharks would have been leaving the estuary with dropping water temperatures. This shark had grown from 1410 mm to 1516 mm TL, an increase of 10.6 cm (4.2 inches).

Two bonnethead recaptures provided convincing evidence of estuarine site fidelity, returning to within 1 mile of where they were originally captured after one year at liberty. We are awaiting the recapture of a shark tagged as a neonate to provide insight on whether sharks return to the estuary that they utilized as a neonate. The adult recapture was at liberty 329 days and was recaptured within 1 mile of the tagging location. This shark had grown from 1160 to 1243 mm TL an increase of 8.3 cm (3.3 inches) in slightly less than a year. The juvenile bonnethead was at liberty 382 days and was recaptured within 1 mile of the tagging site. This shark increased from 996 to 1062 mm TL, growing 6.6 cm (2.6 inches).

Three finetooth recaptures were made, two in the same location as the individuals were tagged and one that had moved 12 miles to the northeast. A project recapture at liberty for 56 days had grown 1.6 inches TL.

Two blacknose recaptures demonstrated movements to the northeast of 120 and 170 miles. Time at liberty ranged from 1512 days (4.14 years) to 443 days (1.2 years). The adult at liberty 443 days had reportedly grown 5.3 inches TL.

A juvenile tiger shark at liberty for 1873 days (5.1 years) was recaptured off Montauk Point, New York, 621 miles northeast of the tagging location. No growth data was available for this specimen. A small juvenile (presumably a neonate) tagged off Charleston was recaptured after 674 days (1.85 years) at liberty. Reliable growth data was obtained for this specimen because it was recaptured by a commercial longline fisherman (Eric Sanders), with prior experience in cooperative shark research. The tiger shark had grown 32.0 inches almost doubling its' length.

Only one scalloped hammerhead (neonate) was recaptured and it had moved 78 miles to the southwest after 38 days at liberty. This shark was recaptured in late summer and was apparently starting a southern migration.

Nurse sharks may exhibit site fidelity if the one recapture that we made is indicative of their general behavior. This individual was at liberty almost one year and was recaptured by this project in essentially the same location where the shark was tagged. Growth was 6.7 inches TL for this juvenile specimen.

Only one tagged blacktip was recaptured. This shark had been tagged in the vicinity of Bulls Bay by investigators from Mote Marine Laboratory. The shark had been marked with a Hallprint dart, an "M" tag and an archival tag. We did not see the dart tag. We were unsure what the archival tag was and whether we should sacrifice the shark to retrieve the tag. The shark was in good condition and the shark was released.

Nursery Utilization of South Carolina's Estuarine and Near-shore Coastal Waters

Castro (1993) reported on the shark nurseries of Bulls Bay, South Carolina and vicinity and reviewed the existing literature on southeastern United States shark nursery utilization. Castro determined that Bulls Bay is a nursery for blacknose, spinner, finetooth, blacktip, sandbar, dusky, Atlantic sharpnose, scalloped hammerhead, and smooth dogfish sharks. The results from this study corroborate much of his Bulls Bay observations and extend the known nursery areas southward as far as St. Helena Sound. We found no appreciable differences between the shark fauna of Bulls Bay, the North Edisto and St. Helena Sound, which are also high salinity estuaries. In this report we have classified the estuarine environment somewhat differently than Castro in that our estuarine stations were restricted to areas inside the barrier islands and he includes the near-shore coastal waters out to approximately 4.5 km from the beach as part of the Bulls Bay estuarine system. Our results to date indicate that the following species (based on the presence of neonates) utilize the estuarine areas of Bulls Bay, North Edisto and St. Helena Sound as primary nursery habitat: Atlantic sharpnose, bonnethead, finetooth, sandbar, blacktip, scalloped hammerhead, spinner, and possibly the lemon shark. South Carolina's estuarine areas also serve as secondary nursery habitat (presence of juveniles) for the same list of species with the definite addition of the lemon shark.

Near-shore coastal waters show much the same picture, with the addition of the tiger shark to the species utilizing these areas for primary nursery habitat. The blacknose is reported by Schwartz (1984) and Castro (1993) to utilize near-shore waters in the Carolinas as pupping and nursery ground habitat but to date we have not captured a neonate in either our estuarine or near-shore coastal sampling. This may be a function of the spatial and temporal distribution of our sampling and additional stations near the beaches in May and June are needed to resolve this question. The dusky is another species for which we have found no evidence of the presence of neonates in estuarine areas but have limited evidence that the near-shore waters are utilized by this species as primary and secondary nursery habitat. Castro (1993) stated that pregnant dusky sharks dropped their pups early in the spring and that the neonates also left the estuarine waters in early summer moving to cooler water. Our sampling in the early spring has been somewhat limited to date and determining the current status of dusky pupping and nursery utilization in South Carolina will require further samples. A more detailed account of the occurrence and associated environmental parameters of neonate sharks follows in the individual species summaries.

Species Profiles

The following species profiles are presented in the order of the species' relative abundance from our 1998-2000 sampling. Whenever possible we have provided temperature ranges for each species and the earliest and latest occurrence of the species from our samples. This will generally correspond to the time of occurrence in South Carolina waters but in some cases a species may occur earlier or later in the year but sampling efforts did not extend throughout the period of occurrence. The sand tiger, bull and thresher sharks were represented by only one or two specimens and are not covered in this section.

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

The Atlantic sharpnose occurred at all of the estuarine sampling stations and were the most abundant species in these areas, making up 50 % of the estuarine catch.

The earliest estuarine capture of a neonate sharpnose with an open umbilicus (FR) was on 5/12/99. No sharpnose with umbilical remains were captured which is consistent with birthing of the pups outside the estuaries. No adult females have been captured with any of the gear types within the estuarine areas. It is conceivable that they do not feed during this period but gillnet sampling should have taken some gravid or post-partum females if they entered the estuarine areas. We also caught a gravid full term female on the Anita longline gear on 6/2/00 near the inlet at Edisto Beach, which produced pups on deck. These pups were released and appeared to be in excellent condition. We believe this female was either in the process of delivering pups or within a few hours of doing so when she was caught. The latest capture of a neonate with FR umbilicus was on 6/5 /98. Water temperatures during this period ranged from 21-29 °C. Salinities in areas where we captured neonate and adult males ranged from 24- 37 ppt. Castro (1993) found that parturition in the Bulls Bay area occurred in shallow coastal waters at depths of 9 m or less in late May to early June. Our observations indicate that parturition may occur as early as the first week of May and continues into June. The actual timing may be variable depending on the speed with which the near-shore coastal waters warm in the spring. By mid July most of the neonates have a well healed (WH) umbilicus, which corresponds to Castro's observation that the umbilical scar persists for 4- 6 weeks.

Adult male sharpnose move into estuarine areas as early as mid-April, when temperatures are about 19 °C. These adult males are the only sharpnose in the estuarine areas until the pups enter the estuaries in mid May. It is assumed that they are utilizing the abundant food in the estuaries prior to the mating season. Their departure from the estuarine areas corresponds to the end of parturition. The latest catch of a mature male was on 6/17/98 at a water temperature of 28 °C. It seems probable that they leave the estuaries when postpartum females will be ready to mate. Juvenile sharpnose other than the neonates apparently don't use the estuarine areas as nursery habitat. All of the non-adult sharpnose that we have caught in our estuarine sampling have been within the size range for young of the year (YOY). We did not sample the estuarine areas later than mid September and there were still some neonates present at this time. Water temperatures were still high at 28 °C.

The near-shore coastal waters are important nursery habitat for juvenile and neonate Atlantic sharpnose. Adult male and female sharpnose are also very common in the coastal waters from late March through mid December. The Atlantic sharpnose dominated the catch in the coastal waters at 67.7 %.

The earliest occurrence of an Atlantic sharpnose in our samples was an adult male taken on 3/26/98; water temperature 14 °C. Adult males dominated catches until early June when juveniles and neonates began to appear in the catches. Water temperatures had risen to 24-25 °C by this time. Throughout the summer, catches contained all groups; neonates, juveniles and both male and female adults. With the onset of decreasing water temperatures in October, (range 18-24 C), the catches became heavily dominated by adult males. The catches in November and December when temperatures had dropped to between 14 and 20 had a more equal representation of adults of both sexes. The neonates and juveniles had largely moved out of the coastal waters when temperatures had dropped to 18-19 C by mid November in most years. The latest occurrence of adult males and females at any of our stations was on 12/18/98 at a temperature of 15 °C. The lowest temperature occurrence for male and female adults was 14 °C on 11/29/00.

The length frequency distribution for Atlantic sharpnose captured from 1998-2000 (Figure 3) indicates that adult fish (850-1200 mm TL) made up 78.3 % of the combined catch. Neonates/YOY (300-450 mm TL intervals) were second in abundance at 11.3 %. Intermediate size/age groups comprising the 500-800 mm TL intervals made up only 10.7 % of the catch. The preponderance of adults in our samples is explainable by the majority of our sampling effort occurring in the coastal waters during the fall when most of the neonates and juveniles had migrated to

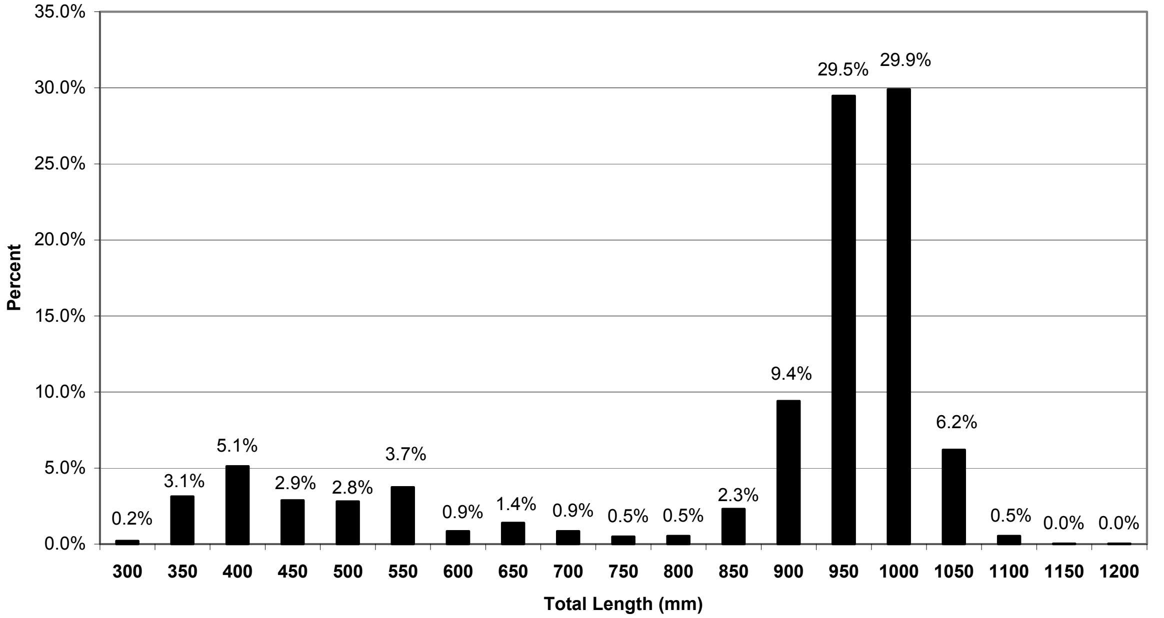


Figure 3. **Atlantic Sharpnose Shark Length Frequency Distribution, n=2819**

the south or offshore. The relative scarcity of the intermediate size groups is indicative that our sampling areas did not encompass the major habitat for these size groups. Anecdotal evidence indicates that these size groups may be more abundant in deeper water of 15-20 m.

Smooth dogfish, *Mustelus canis*

Smooth dogfish appear in South Carolina coastal waters in mid to late fall when water temperatures drop to 18-19 °C. The latest capture in the winter was on 01/21/99 at a temperature of 12.8 °C. Smooth dogfish may stay in SC coastal waters throughout the winter but may move out to deeper water if water temperatures get too low. We caught large quantities of this species in 21 m at a temperature of 17 °C on 01/20/99. We did not sample during February and March so it is currently impossible to confirm their occurrence in shallow coastal waters or their relative abundance in more offshore waters during late winter and early spring In the spring when water temperatures reached 18 to 19 °C, catch rates dropped to very low levels and smooth dogfish were not encountered with any gear type after mid April.

Castro (1993) found gravid females and neonates with fresh umbilical scars to be common off South Carolina in late April and May and also found that juveniles were occasionally caught throughout the summer. Limited sampling during this time period in near-shore and estuarine areas did not produce any neonate smooth dogfish. The incidence of pupping in South Carolina near-shore waters may be highly variable from year to year; occurring more frequently if waters warm slowly in the spring. In years when we have an early spring the gravid females may have already moved back to the north before parturition.

Gravid females were encountered until mid April at a water temperature of 19 °C. The overwhelming majority of smooth dogfish were captured in the near-shore coastal waters, with only two captures in estuarine areas (1 adult female and 1 juvenile female in lower St. Helena Sound on 04/14/99).

The sex ratio in our samples was highly skewed toward females (98 % of the catch). The catches also consisted almost solely of adults as demonstrated in the length frequency distribution (Figure 4). Only 3 juveniles (0.6 %) were caught.

Blacknose shark, *Carcharhinus acronotus*

The blacknose was the second most abundant carcharhinid in our samples. Catches of blacknose were restricted to near-shore coastal waters and dominated by late juveniles and adults (Figure 5).

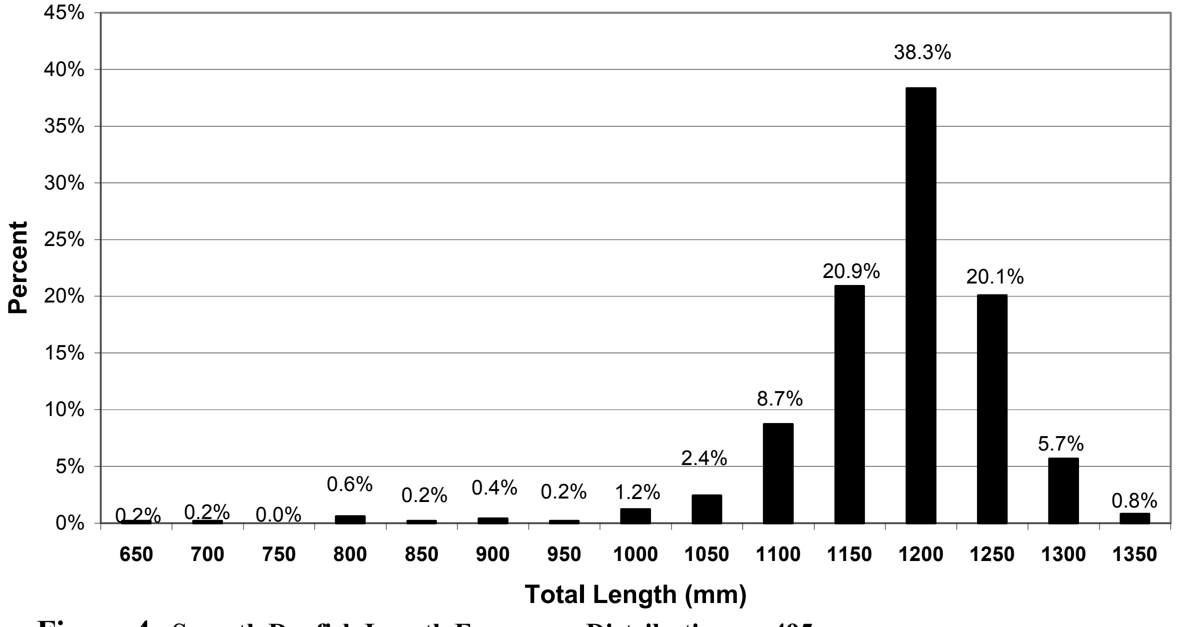


Figure 4. **Smooth Dogfish Length Frequency Distribution, n=495**

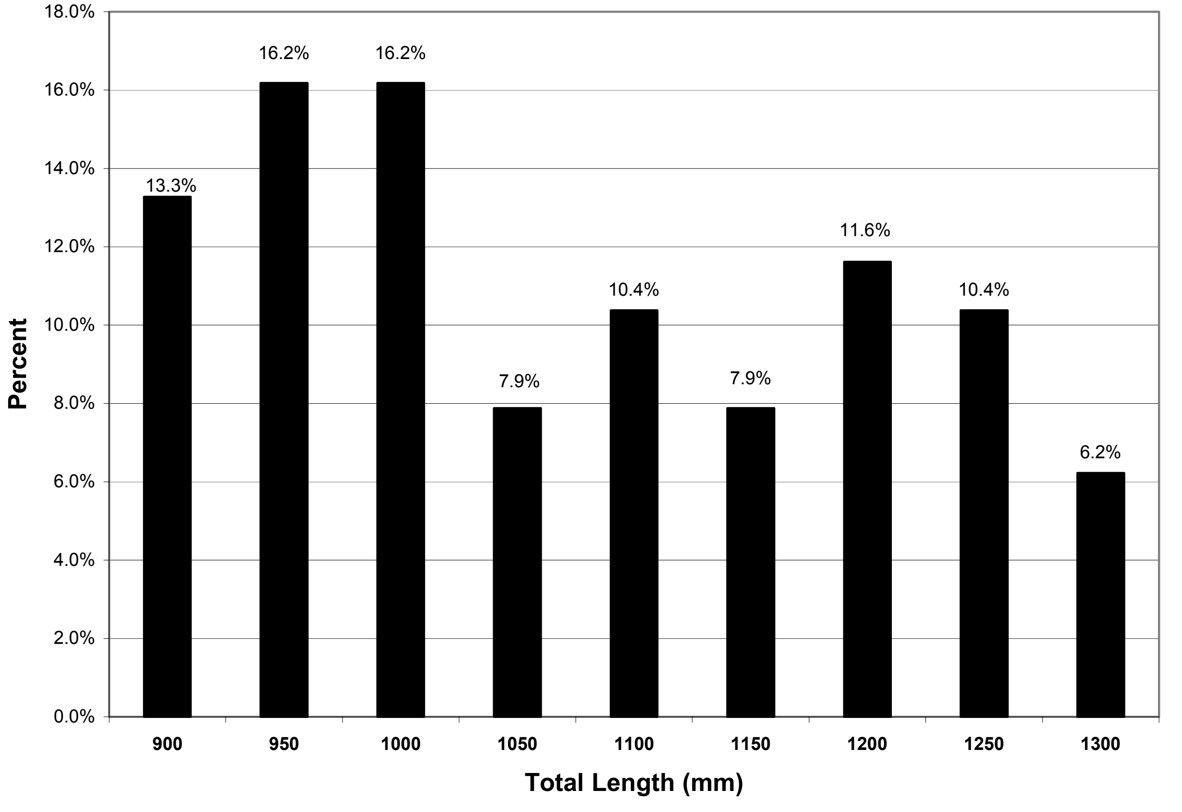


Figure 5. **Blacknose Shark Length Frequency Distribution, n=254**

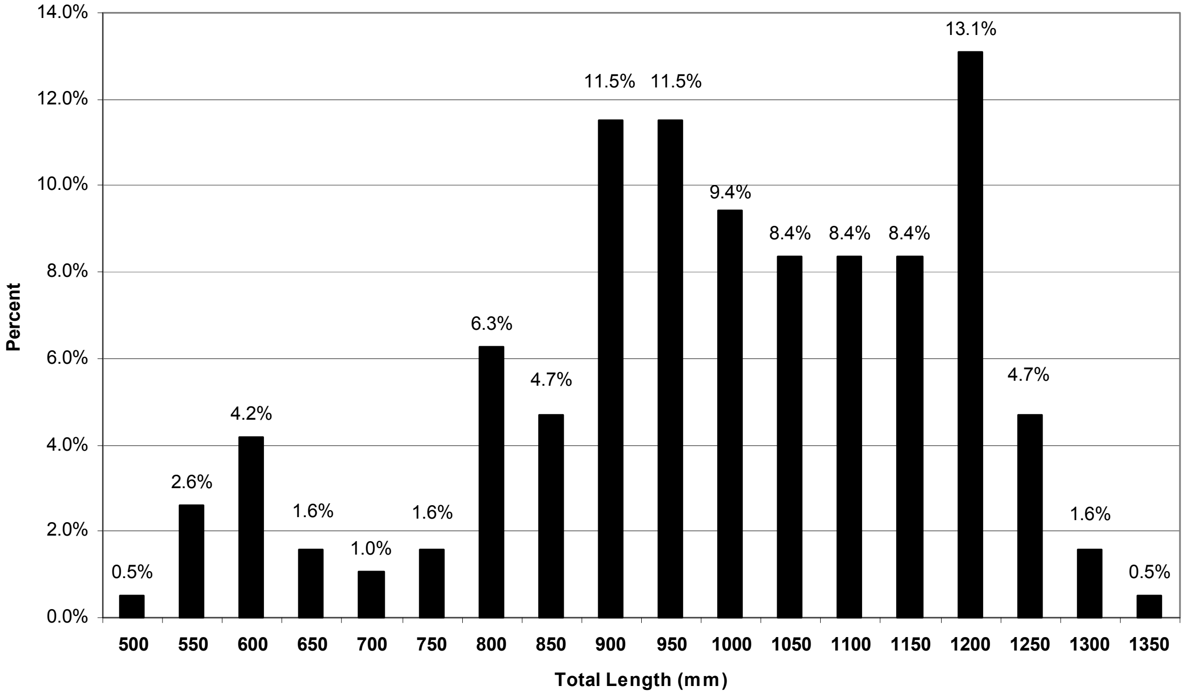


Figure 6. Bonnethead Shark Length Frequency Distribution, n=192

Castro (1983) states that maturity is reached at about 100 cm TL. The sex ratio of blacknose in our samples was close to 1:1. Our earliest capture of a blacknose was in mid May at a water temperature of 22 °C. Blacknose were caught as late as early December when water temperatures were 18-19 °C.

Castro (1993) considered the Bulls Bay area to be a pupping ground for the blacknose based on the capture of gravid females with near full term young. The smallest free-swimming pup that he encountered was 512 mm TL caught in late July. Our sampling gave no indication of pupping in South Carolina waters and it appears that blacknose make minimal if any utilization of estuarine waters. Juveniles may be more abundant in close proximity of the beaches; areas that we have not sampled to date.

Bonnethead shark, *Sphyrna tiburo*

The bonnethead was much more abundant in estuarine areas with only 1.5 % of the catch from near-shore coastal areas. It is possible that this species was more abundant in the areas closer to the beaches during the summer months but we were unable to sample these areas due to potential conflicts with commercial shrimping. The earliest estuarine capture of a bonnethead was an adult male on 04/14/99 at a water temperature of 19 °C. The latest estuarine capture occurred on 09/08/00 at a water temperature of 26 °C.

In his 1993 assessment of South Carolina nursery grounds Castro made no mention of the bonnethead's utilization of our waters as nursery habitat. Our samples indicate that South Carolina estuaries serve as secondary nursery habitat for bonnethead juveniles and feeding habitat for gravid females. Castro (1983) states that pups are born in late summer and early fall at a length of about 32 cm TL. They apparently don't give birth in South Carolina waters as we did not encounter any neonates; pups with UR, FR or PH umbilical scars. The umbilical scars seem to be persistent in this species as we found MH and WH umbilical scars as late as July, which would have been almost 10 months after birth. The smallest juvenile with a recognizable umbilical scar in our samples was 493 mm TL.

Maturity in this species is reached at about 75 cm TL (Castro 1983) and Figure 6 shows the dominance of adult bonnetheads in our samples. The percentage of bonnetheads in the adult category

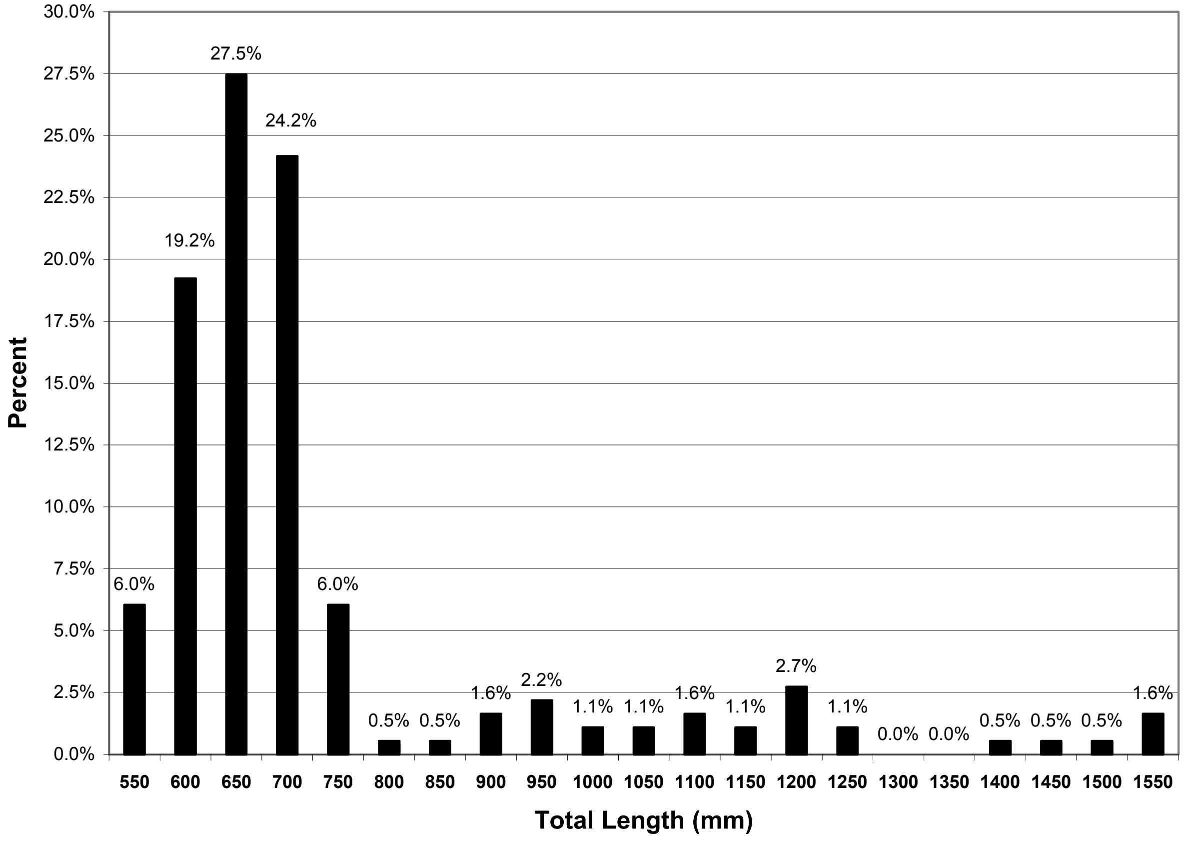


Figure 7. Finetooth Shark Length Frequency Distribution, n=182

was 88.5. The sex ratio in our samples was strongly skewed toward females at 77.2 % of the catch.

Finetooth shark, *Carcharhinus isodon*

South Carolina estuarine waters are important nursery grounds for finetooth neonates. Our samples indicate that adult finetooths make minimal utilization of estuarine waters with only one adult male caught (0.6 % of the estuarine catch). Estuarine catches were strongly dominated by neonates, which made up 83.2 % of the catch (Figure 7). The remainder of the estuarine catch (16.1 %) was juveniles.

Only 11.5 % of the finetooth catch was taken in near-shore coastal waters. The majority of specimens from this area were late juveniles (66.7 %) with the remainder adults. The earliest capture of a finetooth in near-shore coastal waters was in mid May at a water temperature of 22 °C. The latest captures were in late October when water temperatures ranged from 20-23 °C. This species apparently initiates offshore or southerly migrations earlier than the blacknose, sandbar and Atlantic sharpnose.

Pupping occurs from early to mid June according to our captures of neonates with umbilical remains (UR) on 6/5/98 and PH umbilical scars on 6/20/00. The UR neonates were 554 and 556 mm TL. The neonate with an FR umbilicus was 566 mm TL. Neonates with MH scars taken on 8/19/98 and 8/24/99 were 595 and 694 mm TL respectively. Pupping apparently occurs in the near-shore coastal waters rather than inside the estuary, as we have never encountered a gravid or adult female in our estuarine sampling. The latest capture of a finetooth in estuarine waters was in mid September at a temperature of 28 °C. Finetooth may have persisted in the estuaries later than mid September but declining catch rates in September indicated that the majority of finetooths had left by this time. Our findings on the pupping time and size of neonates corresponds closely with that presented by Castro (1993) for the Bulls Bay area.

Sandbar shark, *Carcharhinus plumbeus*

South Carolina estuarine and coastal waters are an important nursery ground for neonate and juvenile sandbar sharks. Juveniles enter the coastal and estuarine areas earlier than the gravid females. In this study the earliest samples that produced juvenile sandbars was 4/14/99 at a water temperature of 19 °C. Castro (1993) found juvenile sandbars to be abundant in coastal waters adjacent to Bulls Bay as early as late March. The latest capture of a juvenile was in mid September when water temperatures were still as high as 28 °C. Sandbar juveniles may stay in the estuaries longer but by this time we had shifted our sampling effort to the near-shore coastal waters. We caught juvenile sandbars in our coastal sampling as late as early December when water temperatures had dropped to 15 °C. Sandbars seem to be one of the most tolerant carcharhinids to low water temperatures.

Neonates with FR umbilical scars were taken on 6/4/98 and 5/31/00 at water temperatures of 29 and 25 °C respectively. Neonates with MH umbilical scars were taken as late as early September. The majority of neonates had WH umbilical scars by mid August. The smallest sandbar with an FR umbilicus was 607mm TL taken on 5/31/00.

Maturity in this species is reached at approximately 183 cm TL (Castro 1983), and according to this standard only 4 of 92 specimens caught in near-shore coastal waters were mature. Mature animals made up only 3.1 % of the overall sandbar catch (Figure 8). Castro (1993) stated that mature males did not occur close to shore in summer and our mature sharks were all females. None of the 57 sandbars caught in estuarine sampling were mature. The first mode in Figure 8 (600-850mm TL) included a mixture of neonates and sharks in or approaching their second year. The overall sex ratio for sandbars in our samples was close to 1:1; 59.0 % females and 41.0 % males.

Spiny dogfish, *Squalus acanthias*

Spiny dogfish are winter visitors to our area and are most abundant during colder winters. Water temperature preferences for this species are 6-11 °C (Castro 1983). We conducted very limited sampling during winter months but did collect spiny dogfish in late January at a water temperature of 12.8 °C. Large catches of this species were made in late March when water temperatures were 14 °C. They were not encountered later in the year and we assume that they were in the process of beginning their northward migration at about this time.

Castro (1983) states that sexual maturity in this species is reached at about 80 cm TL for males and 100 cm TL for females. Our length frequency distribution (Figure 9) shows that 98.8 % of the catch was 950 mm TL or less. Sub-adult females made up 92.8 % of the catch. Five sub-adult males (6.0 %) and only one adult male (1.2 %) comprised the remainder of the spiny dogfish catch.

Blacktip shark, *Carcharhinus limbatus*

The blacktip shark utilizes South Carolina near-shore coastal and estuarine waters for pupping and nursery habitat. The earliest appearance of blacktips in our catches was in mid May at water temperatures of 22-24 °C. The latest captures occurred in late November to early December when temperatures had declined to 18-19 °C. Juvenile and adult blacktips apparently do not utilize estuarine waters to any appreciable degree. We caught only one sub adult; a 1295 mm TL male on 7/1/99.

The remaining estuarine captures were all neonates, ranging from 695-834 mm TL. The earliest appearance of a blacktip with FR umbilicus was on 6/27/00. This individual was 635 mm TL. Another individual with FR umbilicus was taken on 7/8/88. on the same date a specimen (691 mm TL) with no discernible umbilical scar was captured. If the umbilical scar persists for 4-6 weeks (Castro 1993), it would indicate that pupping starts as early as late May or early June. Castro (1993) noted the capture of a specimen 653 mm TL with an open umbilicus on 6/15/90. All of the specimens that we captured after mid July had MH, WH or N umbilical scars. Three specimens captured on 8/23/00 had WH umbilical scars and ranged from 703-834 mm TL.

The length frequency distribution for blacktips taken in our sampling is shown in Figure 10. Castro (1983) states that the blacktip reaches sexual maturity at 135 and 155 cm TL for males and females respectively. Mature males made up 14.9 % and females 6.4 % of the near-shore coastal catch. One neonate was captured in this area (MH umbilicus, 687 mm TL) on 6/21/00. The remainder

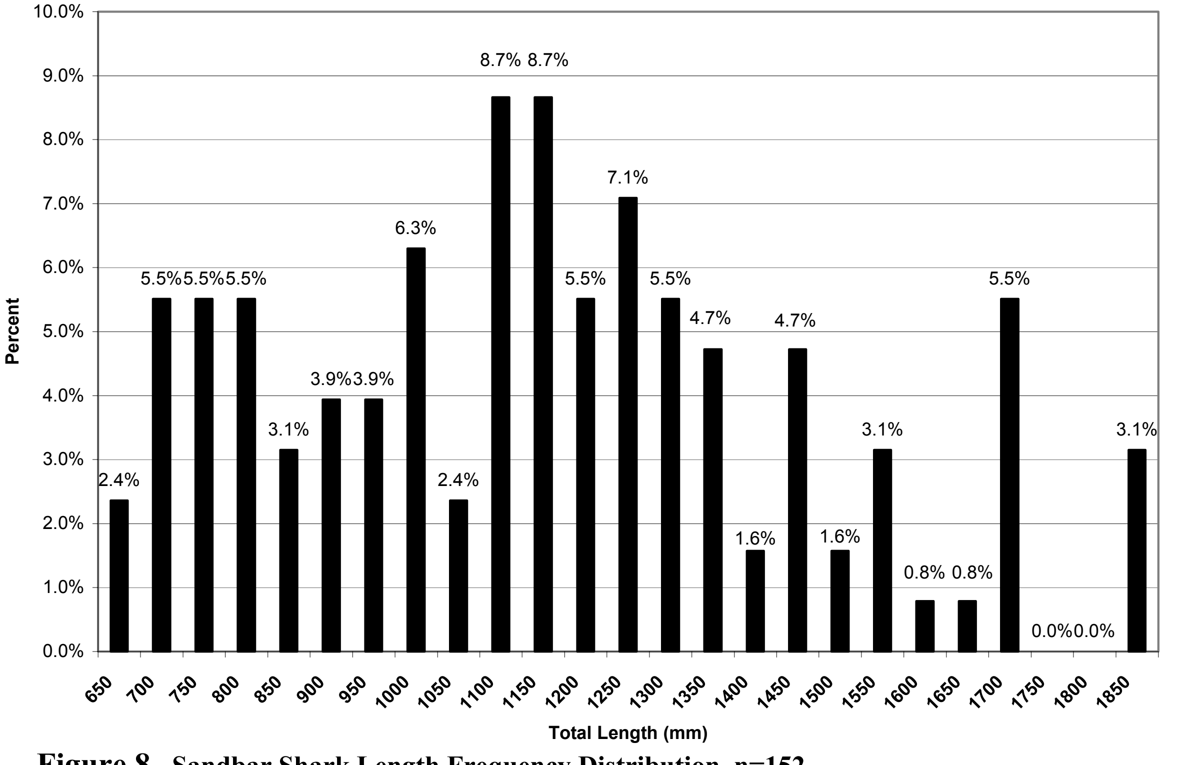


Figure 8. **Sandbar Shark Length Frequency Distribution, n=152**

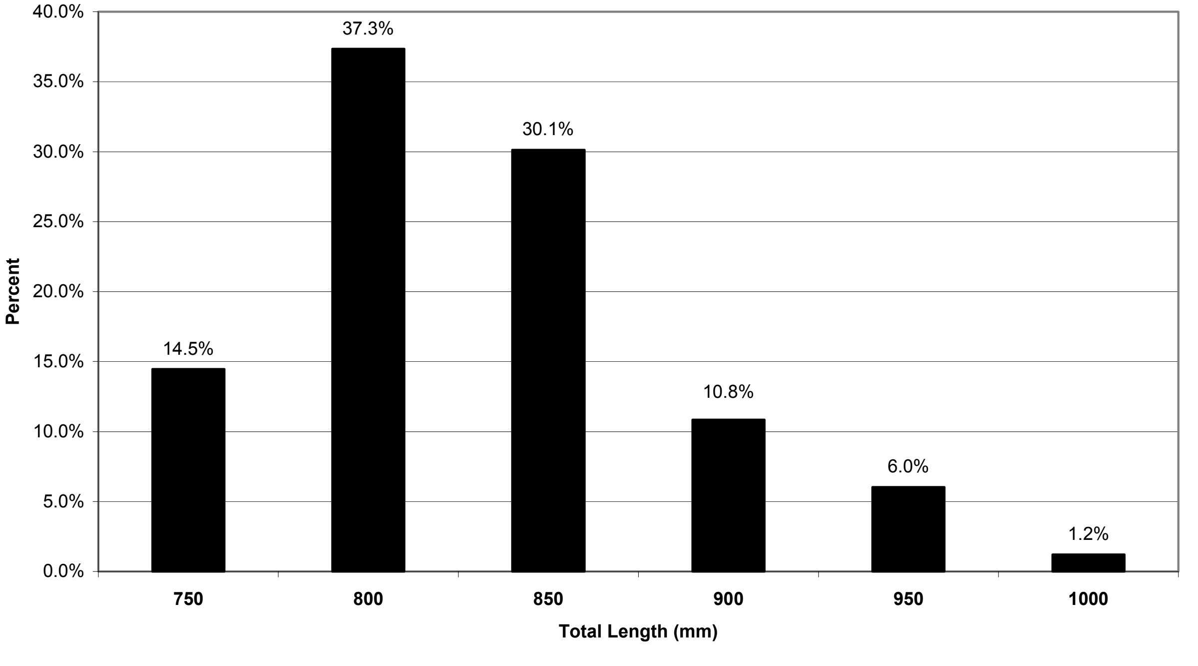


Figure 9. **Spiny Dogfish Length Frequency Distribution, n=83**

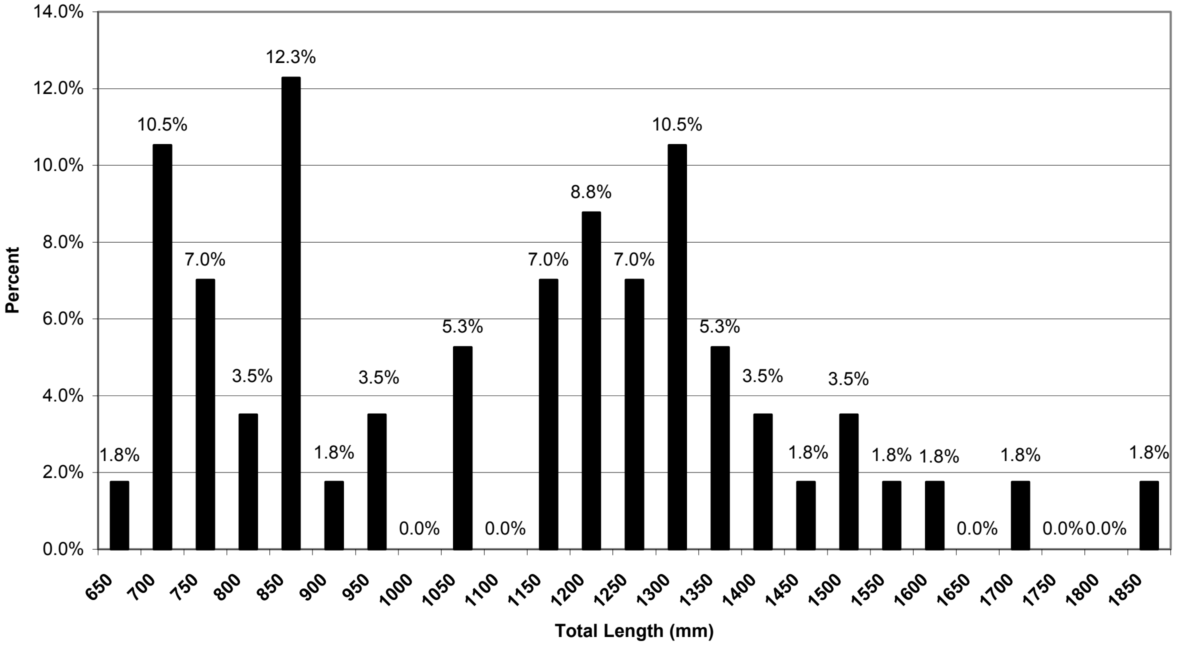


Figure 10. **Blacktip Shark Length Frequency Distribution, n=62**

of the coastal catch was comprised of advanced juveniles.

Scalloped hammerhead shark, *Sphyrna lewini*

Castro (1983) states that the scalloped hammerhead is seldom found in water cooler than 22 °C. The earliest captures of scalloped hammerheads in our sampling occurred in near-shore coastal waters in mid April at temperatures of 17 °C. These specimens were juvenile males 1036 and 1046 mm TL. The latest captures that we recorded were in mid November when water temperatures had declined to 19 °C. Four specimens were taken with a TL range of 675-816 mm, none of which had a visible umbilical scar. The only obvious neonate that we caught in the near-shore coastal waters was a 568 mm TL specimen with a WH umbilical scar taken on 9/29/99.

Castro (1993) noted the occurrence of scalloped hammerhead pupping in South Carolina near-shore coastal waters. He recorded numerous neonates taken in shrimp trawls in the Charleston vicinity. Neonates with open umbilical scars were taken as early as mid May. Our sampling did not produce any neonate hammerheads until mid July; one specimen with a MH umbilicus (500 mm TL) and four specimens with WH umbilical scars (TL range 439-480). Pupping is apparently restricted to coastal waters and there may be a delay of up to 2 months before the neonates enter estuarine areas.

The latest capture of neonate, scalloped hammerheads occurred on 8/29/00. This 615 mm TL specimen did not have a discernible umbilical scar.

Spinner shark, *Carcharhinus brevipinna*

Castro (1993) observed numerous neonates in gill net and shrimp trawl catches in South Carolina waters. We did not find this species to be abundant in the areas that we have sampled to date. Most of our specimens were taken in near-shore coastal waters (26) with only four captures in estuarine waters. One neonate with WH umbilical scar taken on 9/9/99 was 823 mm TL. Another neonate taken on 8/18/99 was slightly smaller (773) and did not have a visible umbilical scar. This was thought to be a neonate born earlier in the year. The latest capture of a neonate spinner in estuarine waters occurred on 9/14/00. This specimen had a WH umbilicus and was 810 mm TL. The length range of spinner sharks from coastal waters was 734-1318 mm TL. None of the observed spinners were large enough to be sexually mature.

Tiger shark, *Galeocerdo cuvier*

Captures of tiger sharks were restricted to the near-shore coastal waters. Only one sexually mature individual was caught; a female with an estimated TL of 3.0 m. Thirty- six percent of the tiger sharks observed were thought to be neonates (TL less than 1000 mm) with the remainder juveniles ranging from 1017-2438 TL. The earliest capture of a tiger shark occurred on 7/23/98 (29 °C). Tiger sharks were captured as late as mid December and at water temperatures as low as 14 °C. The coastal waters of South Carolina are utilized by this species as nursery ground habitat but estuarine areas inside the barrier islands don't appear to be used by this species.

Nurse shark, *Ginglymostoma cirratum*

Nurse sharks are considered to be a more tropical species but our sampling regularly encountered this species associated with live bottom (low relief rock outcrops encrusted with sponge and gorgonians). Fifteen of the 20 nurse sharks captured were considered to be sexually mature using Castro's (1983) criteria of 150 cm TL. The earliest capture of a nurse shark was on 7/23/98 at a temperature of 29 °C. The latest capture was on 10/26/99 when the temperature was 20 °C. This species appears to be less tolerant of low water temperatures that many of the other species. No neonates or young juveniles were observed.

Dusky shark, *Carcharhinus obscurus*

Dusky shark gravid females and pups were reported to be common in the vicinity of Bulls Bay in late April and early May (Castro 1993). We did not encounter any adult dusky sharks in our sampling and all of our captures were restricted to November in coastal waters. This restricted temporal availability was suggestive of a migration through our area from cooler waters to the north. This species was caught at a temperature of 18 °C. The size range for this species was 922-1213 mm TL. Six of the nine dusky sharks captured were considered to be neonates based on their length (922-1099 mm TL) and the dates of capture. Additional sampling in late April and May is needed to determine current utilization of South Carolina waters as pupping and nursery grounds by this species.

Lemon shark, *Negaprion brevirostris*

Castro (1993) observed gravid female lemon sharks on two occasions in South Carolina waters and thought that parturition was likely to occur in this area. However he did not observe any neonates; the smallest lemon shark that he observed measured 1023 mm TL. He concluded based on the lack of smaller individuals that the known nursery grounds of the lemon shark were confined to South Florida and the Bahamas until evidence of parturition in our area was obtained. We observed an 823 mm TL specimen with a WH umbilicus on 8/23/00. A second individual taken in the same area (North Edisto estuary) on 9/8/00 was 832 mm TL and lacked a discernible umbilical scar. Although far from conclusive, given questions of how long the umbilical scar persists in this species, there is at least an indication of some nursery utilization of South Carolina waters by this species.

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Preliminary Findings for Georgia's Shark Nursery Study, a Part of the Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) Survey

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Scope

Savannah State University began sampling for various species of shark in 1998 to identify shark species that utilize Georgia's estuarine and offshore waters as nursery and pupping grounds. This project is part of the Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) survey and was funded through the National Marine Fisheries Service's (NMFS) Highly Migratory Species (HMS) Office. Due to logistical constraints sampling did not continue in 1999. In 2000 the University of Georgia's Marine Extension Service (UGA MAREX) took over the sampling responsibilities and were funded through Savannah State University by NMFS. A total of 292 sharks were captured using longline, hook and line, and trawl methods of which 168 were tagged and released in 1998 and 2000. The species composition for the combined catches was 63.0% Atlantic sharpnose, 18.8% bonnethead, 8.9% blacktip, 5.5% sandbar, 1.7% scalloped hammerhead, 1.4% finetooth, and less than 1% lemon and spinner sharks.

Sampling Materials and Methods

Sampling effort was primarily focused in Wassaw Sound in 1998 with sets also in St Andrew Sound, Cumberland Sound and off of Jekyll and St. Simons islands. St. Andrew, St. Simons, and Altamaha sound systems were the focus of sampling effort in 2000. The Altamaha system also included sets made in the Hampton River area, which is located north of St. Simons Island. A total of 37 sets (3 longline, 14 hook and line, and 20 trawls) were conducted from May through September 1998 and a total of 110 sets (92 longline and 18 hook and line) were conducted from May through September 2000. A 50 hook bottom longline was used with 1000 ft of 1/4 in braided nylon mainline, and 50 gangions comprised of 12/0 Mustad circle hooks with barbs depressed, 50 cm of 1/16 stainless cable, and 100 cm of 1/4 in braided nylon line with 4/0 longline snaps. Longline soaks were approximately 1 hour in duration. Hook and line methods were used in high current and/or areas with heavy boat traffic and were often paired with longline sets. The sharks caught by hook and line were recorded independently of the longline catch. Fishing usually consisted of bottom rigs baited similarly to the longline while drifting over the sample sites. Sampling was also conducted on board the R/V Anna and the R/V Bluefin during the Georgia Department of Natural Resources (GADNR) monthly trawl surveys, using a 12.2 m (40 ft) otter trawl. Sharks captured using all methods were identified, measured, weighed and examined for umbilical scar condition. Once the biological data were collected the sharks were tagged and returned to the water. Environmental data was only collected in 2000.

Description of Georgia's Estuaries

Georgia's coast is comprised of thirteen barrier islands, which are separated from the mainland by approximately 400,000 acres of marshlands as well as tidal creeks and sounds. The Golden Isles, the common name for this island chain, form 8 sound systems between islands contained within the state boundaries with one other system marked by Georgia's southern most island, Cumberland and Florida's northernmost island, Amelia (Figure 1). Georgia's marshlands are dominated by *Spartina alterniflora*, or smooth cordgrass, which varies in

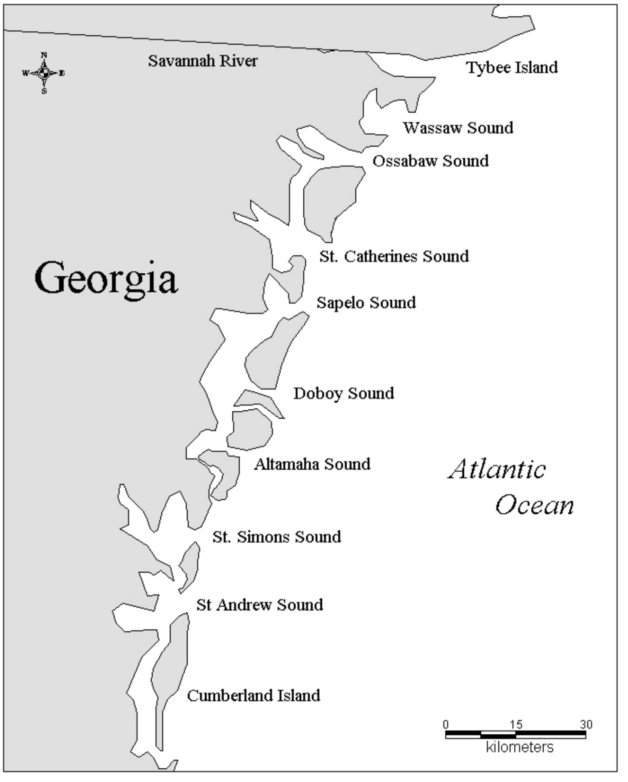

Figure 1. **Map of Georgia's coastline showing the eight major sound systems.**

height and density according to tidal height. Five major rivers flow into the sounds diluting the saltwater and adding to the level of turbidity, while forming highly productive marine communities. Of the five, Savannah, Ogeechee, Altamaha, Satilla and St. Marys (ordered from north to south respectively) the Altamaha is the freshest of the systems. (Johnson et al., 1974) The other systems, formed by the other four rivers, are well mixed estuaries with average salinities ranging from 21.8 to 28.8 ppt (Music et al., 1997).

Species Profiles

The following species profiles are presented in the order of species catch abundance from the combined 1998 and 2000 sampling (Table 1). The species composition for the combined catches was 63.0% Atlantic sharpnose, 18.8% bonnethead, 8.9% blacktip, 5.5% sandbar, 1.7% scalloped hammerhead, 1.4% finetooth, and less than 1% lemon and spinner sharks. The range of environmental parameters at time of capture for each species is listed in Table 2 for the year 2000. No environmental parameters were recorded in 1998.

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

Atlantic sharpnose sharks were the most prevalent species found in Georgia waters in 1998 and 2000. Sharpnose sharks were collected during all sampling months and were found in all areas sampled. A total of 91 sharpnose sharks (17-82 cm FL) were caught in 1998. The majority of these (80%) were neonates, with 16 juveniles and two adults. A total of 93 sharks were captured using longline (85) and rod and reel (8) methods in 2000. Sizes of Atlantic sharpnose sharks sampled in 2000 ranged from 26.6 to 43.5 cm FL. The corresponding environmental parameters for the sharks captured during longline sets in 2000 were: salinities ranging from 21.6 to 36.4 ppt., dissolved oxygen levels ranging from 4.30 to 7.40 mg/l, water temperatures ranging from 26.4 to 30.8 °C and at depths ranging from 2.7 to 13.1 m.

Table 1. **1998 and 2000 COASTSPAN catch summary**

Species	Size Range FL cm	Number of Neonates	Number of Juveniles	Adults	Total Number Caught	Number Tagged
Atlantic Sharpnose	17.0 - 82.0	73	48	63	184	78
Blacktip	43.7 - 113.6	18	5	3	26	19
Bonnethead	31.0 - 90.0	0	50	5	55	47
Finetooth	45.5 - 51.0	1	3	0	4	3
Lemon	120.0	0	1	0	1	1
Scalloped Hammerhead	36.0 - 52.0	0	5	0	5	4
Sandbar	47.0 - 94.0	8	8	0	16	16
Spinner	65.4	1	0	0	1	1

Table 2. **Range of environmental parameters at time of capture for 2000* sampling**

Species	Temperature (ºC)	Salinity (ppt)	Dissolved oxygen (mg/l)	Depth (m)
Atlantic Sharpnose	26.4 - 30.8	21.6 - 36.4	4.30 - 7.40	2.7 - 13.1
Blacktip	28.1 - 30.4	22.9 - 36.1	4.35 - 6.08	2.4 - 11.6
Bonnethead	27.7 - 30.1	30.6 - 36.6	4.23 - 6.85	2.4 - 13.1
Finetooth	28.2	32.1	6.21	3.8 - 4.3
Lemon	27.6	32.9	4.70	13.0
Scalloped Hammerhead	28.7	36.4	5.30	7.6
Sandbar	26.9 - 30.1	29.6 - 35.0	4.00 - 5.90	3.7 - 13.1
Spinner	28.2	32.1	4.70	3.8

*environmental parameters not measured in 1998

Bonnethead shark, *Sphyrna tiburo*

Bonnethead sharks were the second most abundant species found in Georgia waters in 1998 and 2000. A total of 15 bonnethead sharks (31 to 76 cm FL) were caught from June to September 1998 in St Andrews, Cumberland and Wassaw Sounds. Bonnetheads were collected during all sampling months and in all three sound systems in 2000. A total of 40 sharks were captured using longline (26) as well as rod and reel (14) in 2000. Sizes for bonnetheads sampled in 2000 ranged from 38.2 to 90.0 cm FL. The corresponding environmental parameters for the sharks captured during longline sets in 2000 were: salinities ranging from 30.6 to 36.6 ppt., dissolved oxygen levels ranging from 4.23 to 6.85 mg/l, water temperatures ranging from 27.7 to 30.1 °C and at depths ranging from 2.4 to 13.1 m.

Blacktip shark, *Carcharhinus limbatus*

Blacktip sharks ranked third for abundance in Georgia waters in 2000. No blacktip sharks were caught in 1998. Blacktip sharks were found from June through September and in all three sound systems in 2000. A total of 26 sharks were captured using longline (22) and rod and reel (four) methods. The corresponding environmental parameters for the sharks captured during longline sets in 2000 were: salinities ranging from 22.9 to 36.1 ppt., dissolved oxygen levels ranging from 4.35 to 6.08 mg/l, water temperatures ranging from 28.1 to 30.4 °C and at depths ranging from 2.4 to 11.6 m. Blacktip sharks captured during the 2000 sampling season ranged in size from 43.7 to 113.6 cm FL. The majority of those captured were neonates.

Sandbar shark, *Carcharhinus plumbeus*

A total of 16 sandbar sharks were captured using longline (11) and rod and reel (five) methods in 2000. No sandbar sharks were captured in 1998. Sandbar sharks were collected during the months of

June through September and in all three sound systems, but occurred with the highest frequency in St. Simons sound. The corresponding environmental parameters for the sharks captured during longline sets in 2000 were: salinities ranging from 29.6 to 35.0 ppt., dissolved oxygen levels ranging from 4.00 to 5.90 mg/l, water temperatures ranging from 26.9 to 30.1 °C and at depths ranging from 3.7 to 13.1 m. Sandbar sharks caught during this study ranged in size from 47.0 to 94.0 cm FL and equally represented neonates as well as juveniles.

Scalloped hammerhead shark, *Sphyrna lewini*

One juvenile scalloped hammerhead (52 cm FL) was caught off Jekyll Island in July 1998 by trawl. A total of 4 scalloped hammerheads were captured using longline (one) and rod and reel (three) methods in 2000. Scalloped hammerheads were collected during all sampling months except for August in 2000. One shark was collected from each St. Simons and St. Andrew sounds, with the remaining two captured in St. Andrew sound. The corresponding environmental parameters for the one scalloped hammerhead captured during a longline set in 2000 were: salinity of 36.4 ppt, dissolved oxygen level of 5.30 mg/l, water temperature of 28.7 °C and at a depth of 7.6 m. Scalloped hammerheads sampled during the 2000 season ranged in size from 36.0 to 50.5 cm FL.

Finetooth shark, *Carcharhinus isodon*

One juvenile finetooth shark (45.5 cm FL) was caught off St. Simons Island in July 1998 by trawl. A total of three finetooth sharks were captured using longline (two) and rod and reel (one) methods in 2000. Finetooths were found during the months of July and September and occurred in St. Andrew and St. Simons systems in 2000. The sharks sampled in 2000 ranged in size from 46.5 to 51.0 cm FL. The corresponding environmental parameters for the sharks captured during longline sets in 2000 were: salinity of 32.1 ppt., dissolved oxygen level of 6.21 mg/l, water temperature of 28.2 °C and at depths ranging from 3.8 to 4.3 m.

Lemon shark, *Negaprion brevirostris*

One lemon shark was caught during a longline set in St. Andrew sound in September 2000. This juvenile (120.0 cm FL) was caught at a temperature of 27.6 ^{o}C, salinity of 32.9 ppt, depth of approximately 13.0 m and a dissolved oxygen level of 4.70 mg/l.

Spinner Shark, *Carcharhinus brevipinna*

One spinner shark was caught during a longline set in St. Andrew sound in September 2000. This neonate (65.4 cm FL) was caught at a temperature of 28.2 ^{o}C, salinity of 32.1 ppt, depth of approximately 3.8 m and a dissolved oxygen level of 6.21 mg/l.

Preliminary Findings

To date, the results of this study show the importance of Georgia's coastal estuaries as pupping and nursery grounds for various species of sharks. The presence of large numbers of neonate Atlantic sharpnose, bonnethead and blacktip sharks as compared to juveniles of the same species may indicate the importance of these areas as pupping grounds for these species. The presence of juvenile bull, finetooth, scalloped hammerhead, lemon and spinner sharks may indicate secondary nursery grounds for these species. Neonate and juvenile sandbar sharks exhibit a similar catch ratio, indicating that Georgia estuaries may serve as both primary and secondary nursery grounds for this species. Further sampling, employing various gear types, will be beneficial in determining whether species with low catch numbers, such as spinner, lemon and bull sharks, are truly utilizing Georgia's waters or just "passing through".

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Shark Nursery Grounds in Sapelo Island National Estuarine Reserve, Georgia and Coastal Alabama

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Scope

This study evaluates the importance of the estuarine reserve of Sapelo Island, Georgia as a nursery habitat for sharks and examines post-release survival and movements of juvenile sharks off Alabama. Sampling in the Sapelo Island National Estuarine Reserve in Georgia was funded by a Saltonstall-Kennedy Grant and the University of Georgia Marine Institute at Sapelo Island. A total of 424 sharks were caught using a trammel net in the estuarine system of Sapelo Island, Georgia in 1997. The data from coastal Alabama was collected from June through October 1999 for the author's thesis research (Gurshin 2000) and was funded in part by the Department of Fisheries and Allied Aquacultures of Auburn University. Seventeen sharks were caught using hook and line and tracked off Alabama in 1999.

Sampling Materials and Methods

Sapelo island, Georgia

Twelve Duplin River field stations and three Doboy Sound stations were sampled two or three times a week using a stratified sampling design (Figure 1). A monofilament trammel net that measured 183 m long, 3.0 m high, 6.35 cm stretched mesh on inner panel, and 35.6 cm stretched mesh on outer panels was used to sample at the last 2 h of ebb tide. For each sample, bottom and surface salinity, bottom and surface temperature, tide, lunar phase, and depth were recorded. Apparently healthy specimens were identified, sexed, measured and released. Those that died were placed on ice for further analysis of morphological characteristics and stomach contents. Due to limited manpower, some specimens in large catches were not measured or sexed. Sharks were staged as neonates, juveniles or adults based on the size ranges reported in the literature (Clark and von Schmidt 1965, Branstetter 1981, 1987, Branstetter and Shipp 1980, Castro 1993a, 1993b, 1996, Compagno 1984, Parsons 1983, 1985).

Stomach contents were removed from the anterior end of the rugae of the stomach to the anterior end of the pyloris, weighed, and prey items were identified to the lowest taxon possible. Stomach contents were reported as percentage frequency of occurrence (O) (% O was estimated as the proportion of stomachs that contain a specific prey type), percentage by number (N) (% N was estimated as the proportion of the number within a prey category of the total number of prey items found in the stomachs), and percentage by weight (W) (% W was estimated as the proportion of a prey type that appears in the stomachs according to weight). Index of relative importance (IRI) was calculated following the formula given by Pinkas, et al. (1971). The percentage index of relative importance (%IRI) was calculated using the following equation as given by Cortés (1997):

$$\%IRI = (100)IRI_i / {}^{n}\sum_{i=1} IRI_i$$

For analyzing trends in abundance, catch-per-unit-effort (sharks per net hour) was measured as number of sharks caught per net hour of soak time. A two-way analysis of variance ($\alpha = 0.05$) was used to test for differences in CPUE among upper, middle, lower Duplin River and Doboy Sound for early June, late June, early July, late July, and early August (Sokal and Rohlf 1995). Differences were separated with Tukey's studentized range test ($\alpha = 0.05$, Sokal and Rohlf 1995).

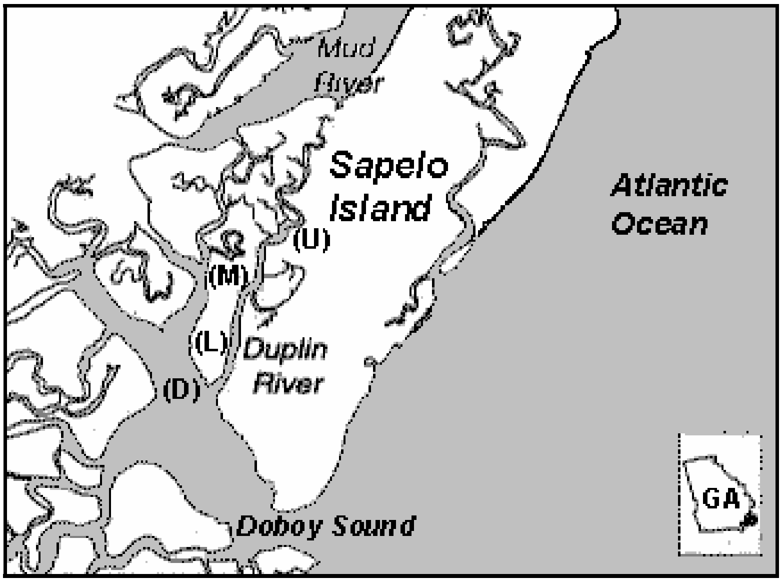


Figure 1. **Sapelo Island, Georgia is shown with upper (U), middle (M), lower (L) Duplin River and Doboy Sound (D) marked as sampling areas, each with three sampling stations.**

Coastal Alabama

Ultrasonic telemetry was used to estimate post-release survival of juvenile and small adult sharks. Sharks were caught between 0700 and 1600 h from June through October 1999 with hook-and-line: 13.6-kg test monofilament line, 68-kg barrel swivel, 39-kg steel leader, and 9/0 bronze hook. Condition of each shark at release was ranked from 0 (poor) to 5 (good). One point was given for each of the following observations: no bleeding, swimming away, not sinking, no external injury, and not hooked in stomach or gills. Table 1, shows the times and conditions of each shark during capture. Chum was used to attract sharks to the fishing area with the assumption it did not alter behavior during telemetry (Sciarrotta and Nelson 1977; Holts and Bedford 1993). Sand trout *Cynoscion arenarius* and mackerel scad *Decapterus macarellus* were used as bait for all fishing.

Hook location, total length (TL), retrieval and handling time, sex, location, and condition were recorded for each released shark. Environmental depth profiles (temperature, salinity and dissolved oxygen) at the site of fishing were taken with a YSI probe.

Tonic immobility was used throughout the study to sedate sharks for measurement and tag attachment (Gruber and Zlotkin 1982; Henningsen 1994). Tonic immobility is a state of animal hypnosis when some elasmobranchs are inverted in a horizontal position. Complete immobility was achieved by turning the shark upside down with one hand forward of the dorsal fin and the other hand around the caudal peduncle. Individually coded ultrasonic transmitters (18 x 70 mm, model CT-82-3, Sonotronics, Tucson, Arizona) were attached to a plastic sheep tag (Allflex, Dallas, Texas) with a magnesium self-release mechanism (0.5 - 6 h). Details on the float tag assembly is described by Gurshin (2000).

A portable directional hydrophone and receiver (model USR-4D, Sonotronics) were used to continuously track each shark for 0.5 to 5.9 h (mean = 2.5 ± 1.8 SD h). Shark positions were recorded with Loran C and latitude-longitude coordinates, when the strongest transmitter signal was detected with the hydrophone pointed straight down. Depth was also recorded at each position. Mortality was assumed if the shark stopped moving because these species are obligate ram ventilators (Roberts and Rowell 1988; Parsons and Carlson 1998).

Distances and bearings between positional fixes were calculated with Positioning Aid 2.1 software (U.S. Coast Guard Research and Development Center, 1995). Net distance was the distance between the release position and the last position recorded. The total distance moved was

Table 1. Total abundance and CPUE (no. h^{-1} soak time) of four shark species during 1 June - 9 August 1997. * indicates significance at $\alpha = 0.05$.

	Rhizoprionodon terraenovae		*Carcharhinus limbatus*		*C. isodon*		*Sphyrna tiburo*	
	No.	**CPUE**	**No.**	**CPUE**	**No.**	**CPUE**	**No.**	**CPUE**
Early June	6	3.6	4	2.4	1	0.6	2	1.2
Late June	43	18.6	7	3.0	0	0.0	3	1.3
Early July*	162	81.8*	27	13.6	28	14.4	4	2.0
Late July	82	24.9	17	5.2	3	0.9	0	0.0
Early August	12	5.2	10	4.3	6	2.6	7	3.0
Total	305	134.1	65	28.5	38	18.5	16	7.5
	No.	**CPUE**	**No.**	**CPUE**	**No.**	**CPUE**	**No.**	**CPUE**
Upper Duplin River	13	13.1	0	0.0	0	0.0	1	1.0
Middle Duplin River	15	11.4	12	9.1	0	0.0	2	1.5
Lower Duplin River	206	39.6	22	4.4	19	4.4	13	2.3
Doboy Sound	71	17.2	31	7.6	19	3.8	0	0.3
Total	305	81.3	65	21.1	38	8.2	16	5.1

the sum of the distances between each position. Rate of movement for a shark was the distance between two successive locations divided by the track time for the time interval. Net direction was the bearing from the release position to the last recorded position.

Description of Study Areas

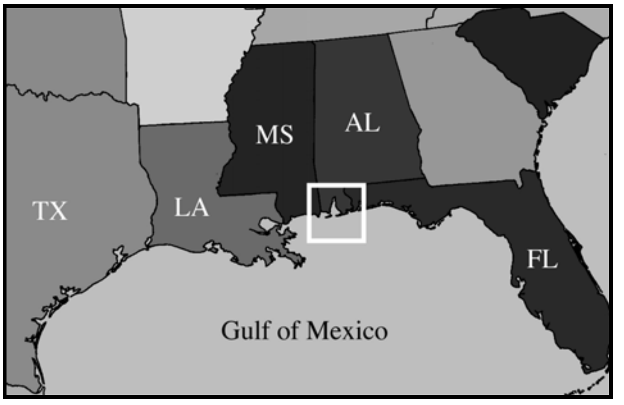
Sapelo Island, Georgia

The Sapelo Island National Estuarine Reserve is an estuarine system dominated by *Spartina alterniflora* marshes, protected by a barrier island (figure 1). The reserve covers 6,111 acres of marsh and land. This barrier island, fourth largest in Georgia, has a 12 km long tidal creek called Duplin River. Average tidal range is about 2.3 m with tidal fluctuations greatly affected by wind direction and intensity. The channel of Duplin River is approximately 4 to 5 m in depth with a couple of areas deeper than 10 to 20 m. The Doboy Sound is approximately 7 to 10 m deep. Freshwater input is from runoff and the Altamaha River. During the study, water temperatures ranged from 21.8 to 31.8°c and salinity ranged from 22.5 to 31°c. The marsh soil is composed of alkaline clay with thin sand layers. The Duplin River has an estuary of 3,296 acres. The Duplin River's mouth is connected to the Atlantic Ocean by Doboy Sound.

Coastal Alabama

The study area was in coastal waters off Alabama in the northeast Gulf of Mexico (Figure 2). Sharks were caught, released, and tracked at three sites: (1) a barrier island, (2) a sandbar, and (3) a gas platform. The barrier island was approximately 2 km long and located approximately 1 km south of Dauphin Island, Alabama. All sharks caught at this site were at least 100 m off the west side of the island "Sand Island" in 4 to 8 m depth. The sandbar "Dixie Bar" site paralleled the east side of the Mobile Bay ship channel south of the Bay mouth for approximately 7.7 km with depths of 1-6 m. The gas platform (Exxon-MO-MO-823-A) was located about 5.5 km south of Dauphin Island in depths of 12 to 14 m. Water temperatures during the study ranged from 24.5 to 28.9 °C at depth and 29.1 to 31.5 °C at the surface. Dissolved oxygen ranged from 0.3 to 7.0 mg/L at depth and 4.3 to 7.4 mg/L at the surface. Bottom salinity ranged from 31.4 to 36.3 ppt and surface salinity ranged from 23.5 to 30.7 ppt.

A



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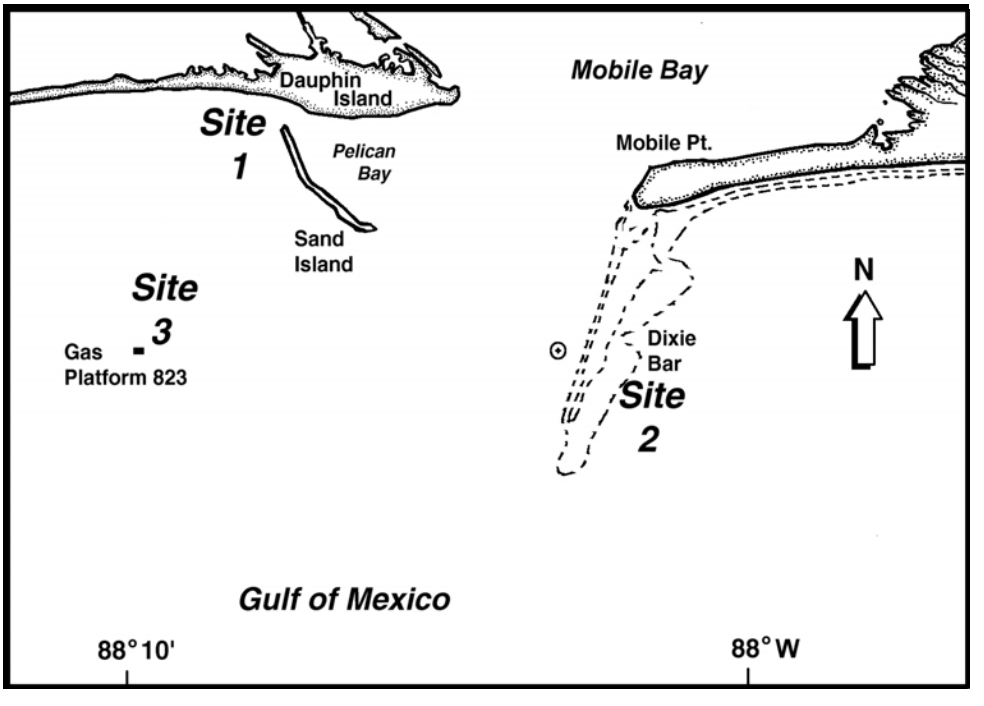


Figure 2. (A) The study area is shown within the box in the northern Gulf of Mexico. (B) An enlarged map of the study area showing the catch-and-release sites: (1) a barrier island called Sand Island; (2) a sandbar called "Dixie Bar;" and (3) a gas platform (Exxon MO-MO-823-A rig).

Species Profiles

Sapelo Island, Georgia

Atlantic sharpnose, *Rhizoprionodon terraenovae* (N = 305); blacktip, *Carcharhinus limbatus* (N = 65); finetooth, *C. isodon* (N = 38); and bonnethead, *Sphyrna tiburo* (N = 16) sharks were collected in 35 trammel net (183 m x 2.4 m) collections from 6 June 1997 to 10 August 1997 in the Duplin River and Doboy Sound of Sapelo Island National Estuarine Research Reserve. Neonate Atlantic sharpnose were the most abundant followed by blacktip and finetooth pups. Juvenile and adult bonnethead sharks also occurred in the estuary.

Atlantic Sharpnose Shark, *Rhizoprionodon terraenovae*

Atlantic sharpnose sharks were found in all parts of the sample area with the majority in the lower Duplin River and Doboy Sound. A total of 305 specimens were caught in the estuary throughout the summer season (Table 1). This species was significantly more abundant (26.4 CPUE) compared to blacktip (5.6 CPUE), finetooth (3.3 CPUE), and bonnethead (1.4 CPUE) sharks ($p < 0.05$). Catch-per-unit-effort was significantly higher (81.8) in early July compared to late July (24.9), late June (18.6), early August (5.2) and early June (3.6) in 1997 ($p < 0.05$). This species was caught in the estuary system in bottom water temperatures of 25 to 31 °C, bottom salinities of 22 to 30 ppt, and all depths sampled (0 to 5 m). There was no distinct pattern associated with these habitat conditions.

The mean total length (TL) was 395 mm (± 83.7 SD) and median was 387 mm (N = 169) indicating the majority of the specimens caught were either neonates or young-of-the-year (Figure 3A). Specimens ranged from 258 mm to 970 mm TL. Only two specimens were greater than 900 mm TL.

According to all five indices of stomach content analyses, bony fishes were the most important food items followed by penaeid shrimps (Table 2). In these samples, bony fishes included menhaden, anchovies, blennies, and other unidentified teleosts. However, Atlantic sharpnose sharks foraged on a variety of prey species as evidenced by occasional squid, caridean shrimp, mantis shrimp, and crabs found in their stomachs.

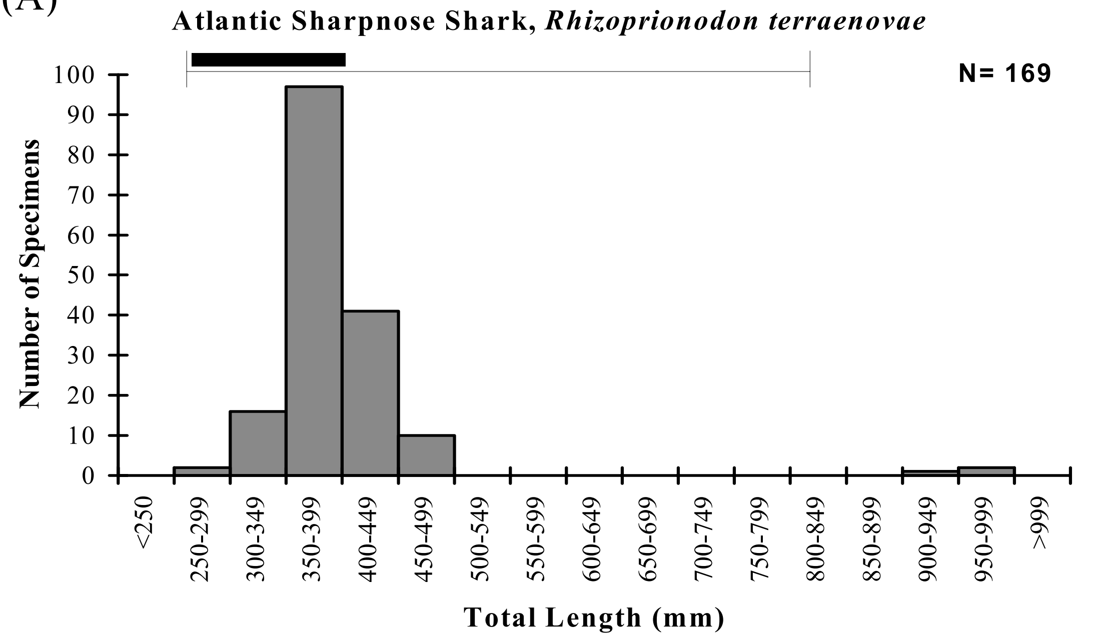
Few extensive studies have been done on the diet or feeding habits of this common coastal shark. Stomachs from many newborn pups caught in shrimp trawls during June and July near Dauphin Island, Alabama, contained fish and shrimp of the genus *Sicyonia* (Branstetter 1981). Clark and von Schmidt (1965) found stomachs of adult specimens from Florida to contain fishes such as mojarras (*Eucinostomus gula)*, monoacanthids, kingfish (*Menticirrhus* species), clupeids, menhaden (*Brevoortia* species), and shrimps. Compagno (1984) reported the diet of this species to include menhaden and other clupeids, snake eels, silversides, wrasses, small jacks, croakers, mojarras, toadfish, filefish, shrimp, crabs, and segmented worms.

Blacktip Shark, *Carcharhinus limbatus*

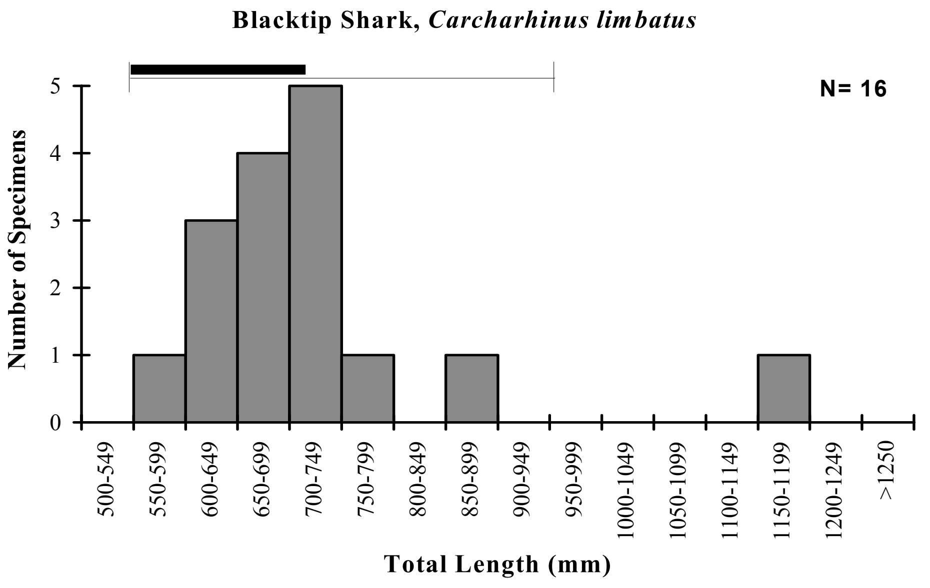
A total of 65 specimens of blacktip sharks were collected from the study area making this the second most abundant shark in this survey (Table 1). Blacktip sharks were collected in all sample areas except the upper Duplin River. Specimens were collected in waters with depths of 0 to 5 m, salinities of 22 to 26 ppt, and temperatures of 21 to 30°C. Catches increased from the middle of Duplin River to Doboy Sound suggesting a spatial pattern (Table 1). According to trends in CPUE, abundance appeared to increase in late June and peak in early July. As the summer progressed, the CPUE dropped from its highest (13.6) to 4.3 in early August. Similarly, blacktip sharks showed increased abundance in June and July within the north central Gulf of Mexico (Branstetter 1981).

The 16 specimens from the sample that were randomly measured, ranged from 559 to 1190 mm TL (1.0 to 9.5 kg), with a mean of 723 mm (±142 SD) and median 700 mm TL. No mature adults were caught during this survey. The gear used did not specifically select for larger sharks that may have evaded the trammel nets by using the un-sampled deep channels. From the length-frequency distribution in Figure 3B, the summer population appeared to consist primarily of neonates and small juveniles suggesting that the estuary system of Sapelo Island, Georgia serves as a nursery habitat for blacktip pups.

(A)



(B)



Figures 3A & B. **Total length-frequency distribution of A) *Rhizoprionodon terraenovae* and B) *Carcharhinus limbatus*. The total length range for juvenile and neonate life history stages of each species are indicated ├──┤ and ▬ , respectively (Clark & von Schmidt 1965, Branstetter 1981, 1987, Branstetter & Shipp 1980, Castro 1993a, 1993b, 1996, Compagno 1984, Parsons 1983, 1985).**

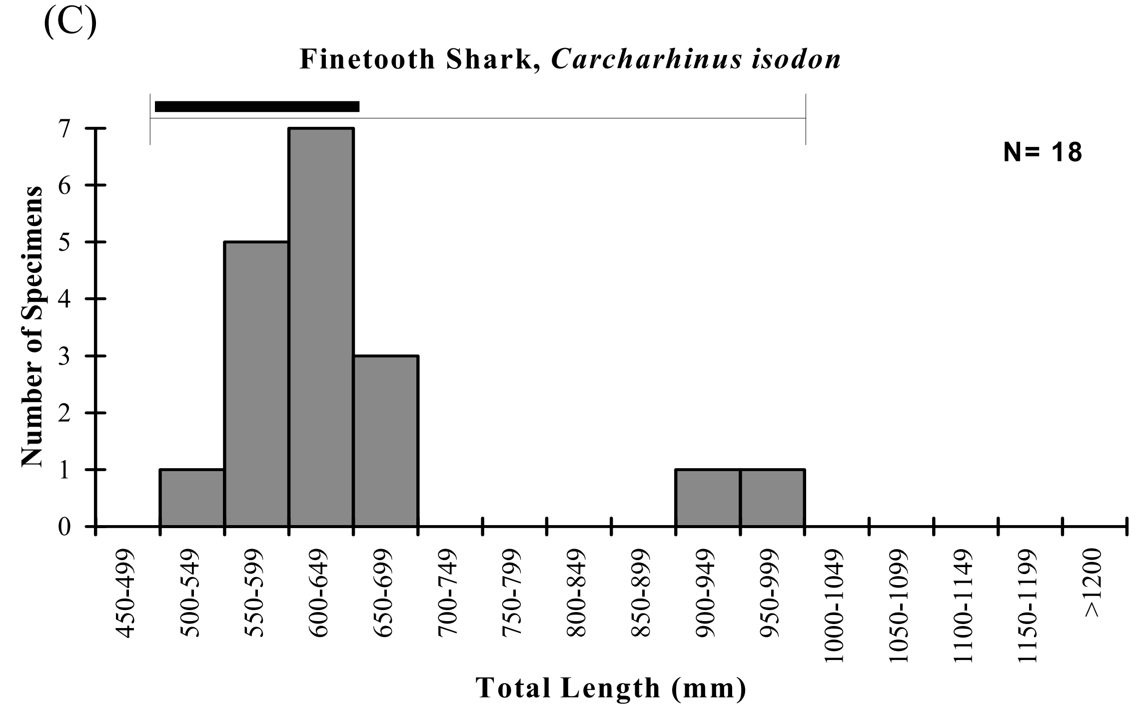
Table 2. Relative importance of prey items for the diet of four species of shark indicated by different indices.

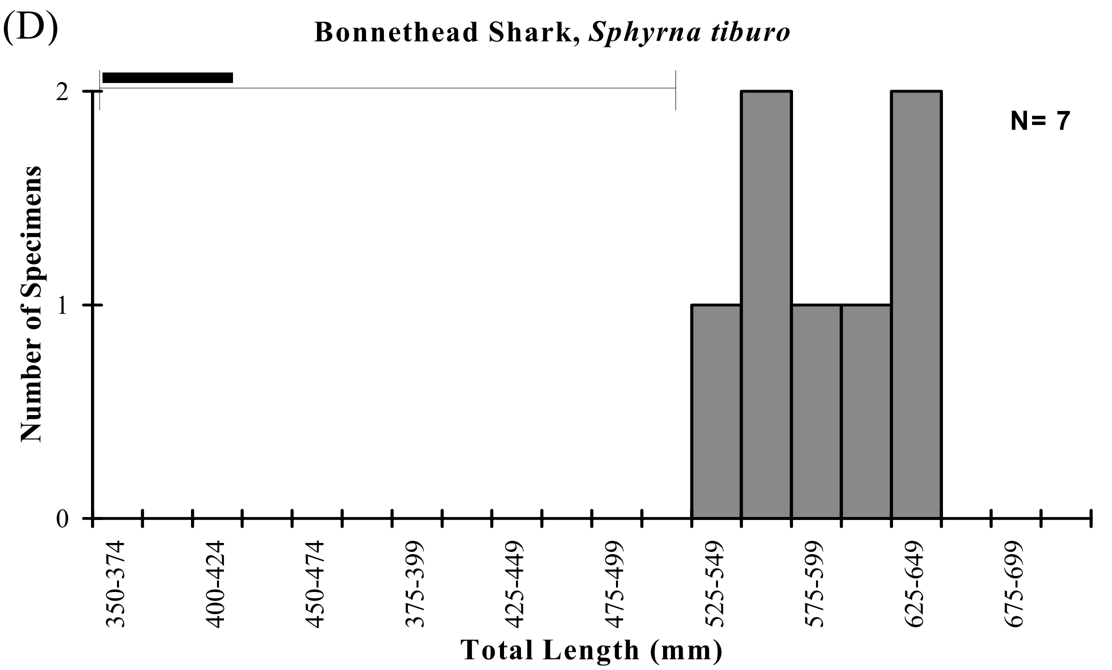
Food Type	%N	%W	%O	IRI	%IRI
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), n=86					
Teleostei	46.3	67.0	37.2	4214.8	62.20
Penaeidae	7.5	8.5	7.0	112.0	1.65
Teuthoidea	2.5	0.9	2.3	7.8	0.12
Stomatopoda	1.3	1.2	1.2	3.0	0.04
Brachyura	1.3	0.7	1.2	2.4	0.04
Caridea	1.3	1.3	1.2	3.1	0.05
Unidentified	40.0	25.4	37.2	2432.9	35.90
Bonnethead shark (*Sphyrna tiburo*), n=5					
Portunidae	50.0	75.9	80.0	10075.4	87.18
Other Brachyura	20.0	16.0	20.0	719.2	6.22
Penaeidae	10.0	3.6	20.0	272.2	2.36
Stomatopoda	10.0	2.4	20.0	248.1	2.15
Xanthidae	10.0	2.1	20.0	241.7	2.09
Blacktip shark (*Carcharhinus limbatus*), n=14					
Brevoortia Spp.	54.5	48.0	35.7	3660.8	65.92
Other Teleostei	27.3	42.7	21.4	1499.0	26.99
Unidentified	18.2	9.4	14.3	393.5	7.09
Finetooth shark (*C. isodon*), n=18					
Brevoortia Spp.	21.7	45.1	27.8	1857.0	25.55
Other Teleostei	56.5	41.1	50.0	4880.0	67.13
Teuthoidea	4.3	6.6	5.6	61.3	0.84
Penaeidae	4.3	0.2	5.5	24.7	0.34
Unidentified	13.0	7.1	22.2	446.2	6.14

The stomach contents of 14 specimens were found to contain menhaden, unidentified teleost remains, and penaeid shrimps (Table 2). By all indices used for analysis, menhaden was found to be the most important prey in its diet within the study area (Table 2). Castro (1996) found the diet of blacktip sharks in Bulls Bay, South Carolina to consist of mainly menhaden (*Brevoortia tyrannus)*, a ray (*Rhinoptera bonasus)*, Atlantic sharpnose and bonnethead sharks . In Castro's study, less than 2% of the stomachs contained spot (*Leiostomus xanthurus)*, Spanish mackerel (*Scomberomorus maculatus)*, Atlantic croaker (*Micropogonias undulatus)*, oyster toadfish (*Opsanus tau)*, gafftopsail catfish (*Bagre marinus)* or flounders (*Paralichthys* species). In addition to those prey species reported by Castro (1996), blacktip sharks have been known to eat jacks (*Caranx* species), snook (*Centropomus undecimalis)*, striped burrfish (*Chilomycterus schoepfi)*, hardhead catfish (*Arius felis)*, trunkfish (*Lactophrys tricornis),* pinfish (*Lagodon rhombroides)*, Atlantic threadfin (*Polydactylus octonemus)*, anchovies (*Anchoa* species), longspine porgy (*Stenotomus caprinus)*, Gulf butterfish (*Peprilus brutis)*, and invertebrates (Clark and von Schmidt 1965, Branstetter 1981).

Finetooth Shark, *Carcharhinus isodon*

In this study, the finetooth shark (38 specimens) was only found in the lower Duplin River and Doboy Sound (Table 1). Peak abundance occurred at the end of June and first half of July (Table 1). They were caught within the estuarine waters at all depths sampled (0 to 5 m) when bottom water temperatures were above 25 ºC and salinity ranged from 23 to 26 ppt. These specimens ranged from 537 to 980 mm TL (0.8 to 5.4 kg), with a mean of 619 mm (±114 SD) and median 646 mm TL. Judging from the size at birth, the majority of finetooth sharks sampled were neonates and early young-of-the-year juveniles (Figure 3C). The largest male, 914 mm TL, and female, 980 mm TL,





Figures 3C & D. **Total length-frequency distribution of C) *Carcharhinus isodon* and D) *Sphyrna tiburo*. The total length range for juvenile and neonate life history stages of each species are indicated ├──┤ and ▬ , respectively (Clark & von Schmidt 1965, Branstetter 1981, 1987, Branstetter & Shipp 1980, Castro 1993a, 1993b, 1996, Compagno 1984, Parsons 1983, 1985).**

were both immature suggesting the estuary serves as a nursery habitat for the finetooth shark.

The stomachs of 18 specimens were examined for prey items. By %IRI, prey items included unidentifiable bony fishes (67 %), menhaden (26 %), squid (0.84%), penaeid shrimp (0.34%) and 6.1% were unidentified remains. Castro (1993a) found that the major prey items in the diet of finetooth shark*s* consisted of menhaden (*B. tyrannus)*, spot, penaeid shrimp, Spanish mackerel, mullet (*Mugil* species.), and juvenile Atlantic sharpnose sharks.

Bonnethead Shark, *Sphyrna tiburo*

The total catch of 16 individuals occurred in all parts of the tidal Duplin River, but none were found in Doboy Sound (Table 1). No temporal patterns were found for the summer season (Table 1). This species was found in estuarine waters with depths of 0 to 5 m, bottom water temperatures of 23 to 29 ºC, and salinities of 22 to 26 ppt. Most bonnetheads were caught in a salinity of 22 ppt.

A random subsample of 7 specimens measured from 537 to 644 mm TL, with a mean of 590 mm TL (±41.5 SD) and median of 588 mm TL (Figure 3D). Total wet weight ranged from 0.5 to 1.1 kg. Based on their size, these bonnetheads were judged to be late juveniles and adults (Figure 2). The temporal and spatial occurrence of small juvenile and adult bonnetheads captured simultaneously, indicates that perhaps this species does not segregate by size.

Stomach analysis of five bonnetheads indicates that during the summer of 1997 the diet of these specimens consisted exclusively of crustaceans. This specialized predator fed on portunid crabs, particularly blue crabs (*Callinectes sapidus)* (87 %IRI), other true crabs such as calico crabs (*Hepatus epheliticus)* (6.2%IRI), penaeid shrimp (2.4 %IRI), mantis shrimp (2.2%IRI), and mud crabs (2.1%IRI) (Table 2). A diet dominated by blue crabs was reported for populations from Tampa Bay and Charlotte Harbor on Florida's west coast (Cortés et. al. 1996). In addition to the crustaceans observed in this study, mollusks including cephalopods and gastropods, seagrasses, teleosts and horseshoe crabs (*Limulus polyphemus)* have also been found in stomach contents of bonnethead sharks (Cortés et. al. 1996).

Coastal Alabama

Ten Atlantic sharpnose, three finetooth, two spinner (*Carcharhinus. brevipinna)*, and two blacktip sharks were continuously tracked for a mean duration of 2.5 ±1.8 SD h (0.5-5.9 h). Activity and movement suggested short-term survival was at least 94%. Juveniles of all species were studied in addition to adult Atlantic sharpnose sharks. Sharks displayed meandering behavior near a barrier island, a gas platform, and a sandbar.

Atlantic Sharpnose Shark, *Rhizoprionodon terraenovae*

Five adult and five juvenile Atlantic sharpnose sharks were caught and tracked between 22 June and 12 October 1999. Water depth ranged from 2.7 to 14 m. Individual size ranged from 67 to 100 cm TL (Table 3). Surface dissolved oxygen (DO) ranged from 4.3 to 7.2 mg/l, temperature ranged from 28.9 to 31.5 ºC, and salinity ranged from 28.6 to 31.5 ppt (Table 4). Bottom DO ranged from 0.3 to 4.5 mg/l, temperature ranged from 24.5 to 28.9 ºC, and salinity ranged from 31.4 to 36.3 ppt. Sharks were tracked from 45 to 354 minutes after release and all but one shark displayed meandering swimming behavior (Figures 4 to 8). One gill-hooked female of 100 cm TL stopped moving for ten minutes at the end of tracking session of 45 minutes suggesting post-release mortality (Table 3, Figure 8). All other sharks moved continually for the time periods tracked and suggested high (94%) short-term catch-and-release survival (Table 3). Mean rate of movement was 1.3 ±0.2 SE km/h.

Spinner Shark, *Carcharhinus brevipinna*

Two juvenile male spinner sharks were caught in water depths between 6.0 and 7.0 m. These sharks were caught on 16 July and 4 August 1999. Total lengths were 71 and 81 cm, respectively (Table 3). Dissolved oxygen ranged from 0.3 to 7.0 mg/l at the bottom and 5.7 to 7.4 mg/l at the surface. Water temperature ranged from 27.5 to 27.8 °C at the bottom and 29.4 to 31.5 °C at the surface. Salinity ranged from 34.3 to 36.3 ppt at the bottom and 23.5 to 26.6 ppt at the surface (Table 4). The smaller male was tracked continuously for 127 minutes a distance of 2.2 km at 1.2 ± 0.7 SD km/h within 1.5

Table 3. **Summary of estimated short term survival and movements for each tracked shark off coastal Alabama in 1999.**

No.	Species	TL (cm)	Sex	Site	Track Time (min)	Depth Change (m)	Distance (m) Net	Distance (m) Total	Net Direction (°)	Rate of Movement (km/h) ± SD	Survived
1	***Carcharhinus limbatus***	93	F	2	128	15.5	11,056	11,169	178	9.5 ± 6.6	Yes
2	***C. limbatus***	101	F	1	272	5.5	4,622	8,809	197	2.1 ± 0.8	Yes
3	***C. isodon***	94	F	1	110	0.3	731	1,396	251	4.5 ± 1.0	Yes
4	*C. isodon*	94	F	1	75	5.2	1,714	2,101	194	1.9 ± 0.8	Yes
5	*C. isodon*	108	F	1	77	2.7	1,715	1,755	188	1.4 ± 0	Yes
6	***Rhizoprionodon terraenovae***	80	M	3	267	-1.5	617	2,190	26	0.9 ± 0.8	Yes
7	***R. terraenovae***	90	M	3	87	-0.3	741	2,665	283	3.0 ± 3.8	Yes
8	*R. terraenovae*	71	F	2	304	1.2	915	4,009	146	1.5 ± 0.7	Yes
9	***R. terraenovae***	68	M	1	193	1.0	1,334	2,245	158	0.6 ± 0.3	Yes
10	*R. terraenovae*	86	M	1	309	0.6	1,731	4,634	277	1.0 ± 0.5	Yes
11	*R. terraenovae*	74	F	1	68	-0.9	534	1,446	314	1.6 ± 1.1	Yes
12	*R. terraenovae*	67	M	1	52	-3.1	573	933	2	1.0 ± 0.5	Yes
13	*R. terraenovae*	72	F	1	354	0	535	3,392	278	1.0 ± 0.9	Yes
14	*R. terraenovae*	97	M	1	51	0.9	914	1,396	224	1.6 ± 0.9	Yes
15	*R. terraenovae*	100	F	3	45	0	145	739	309	1.1 ± 0.4	No?
16	***C. brevipinna***	71	M	2	127	0.3	1,526	2,285	215	1.2 ± 0.7	Yes
17	*C. brevipinna*	81	M	1	32	0	236	257	160	0.8 ± 0.7	Yes

Table 4. **Mean dissolved oxygen (DO), temperature, and salinity at depth during retrieval for each shark.**

Shark No.	Species	Date	Relative Depth	Mean DO (mg/l)	Mean Temperature (^oC)	Mean Salinity (ppt)
1	Blacktip shark	14 Jul 99	Bottom	3.2	28.1	34.3
2	Blacktip shark	21 Aug 99	Surface	7.3	27.8	33.5
			Bottom	6.2	27.3	37.0
3	Finetooth shark	4 Aug 99	Surface	5.7	31.5	23.5
			Middle	4.8	30.0	33.0
			Bottom	0.3	27.5	36.3
4	Finetooth shark	9 Aug 99	Surface	5.3	30.8	30.4
			Bottom	2.4	30.1	33.3
5	Finetooth shark	16 Aug 99	Surface	7.3	28.8	32.4
			Middle	4.1	26.5	38.4
			Bottom	1.8	26.1	33.8
6	Atlantic sharpnose shark	22 Jun 99	Surface	6.3	28.6	30.9
			Middle	6.2	28.2	31.8
			Bottom	4.5	28.0	32.5
7	Atlantic sharpnose shark	3 Jul 99	Surface	7.2	29.1	27.8
			Middle	7.6	29.5	28.7
			Bottom	0.7	24.5	36.1
8	Atlantic sharpnose shark	28 Jul 99	Surface	4.3	28.9	30.7
9	Atlantic sharpnose shark	28 Jul 99	Surface	5.1	31.0	29.6
			Bottom	2.6	28.9	31.4
10	Atlantic sharpnose shark	1 Aug 99	Surface	6.0	29.8	26.8
			Bottom	0.5	27.6	36.2
11	Atlantic sharpnose shark	2 Aug 99	Surface	5.3	31.4	27.3
			Bottom	2.1	28.6	35.0
12	Atlantic sharpnose shark	2 Aug 99	Surface	5.3	31.4	27.3
			Bottom	2.1	28.6	35.0
13	Atlantic sharpnose shark	3 Aug 99	Surface	5.2	30.3	30.0
			Bottom	0.9	28.1	35.9
14	Atlantic sharpnose shark	4 Aug 99	Surface	5.7	31.5	23.5
			Middle	4.8	30.0	33.0
			Bottom	0.3	27.5	36.3
15	Atlantic sharpnose shark		N/A			N/A
16	Spinner shark		Surface			26.6
			Bottom			34.3
17	Spinner shark		Surface			23.5
			Middle			33.0
			Bottom			36.3

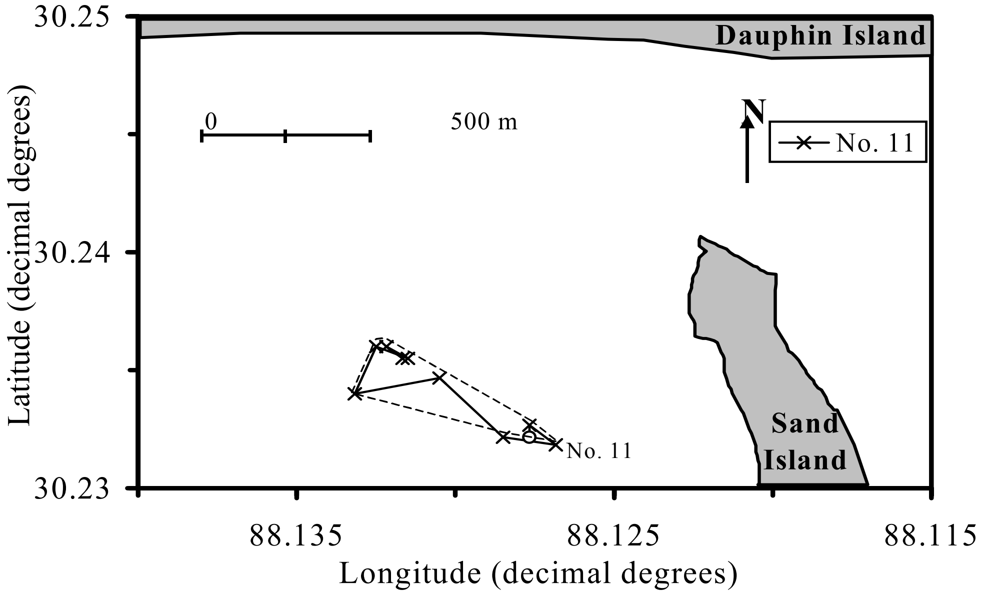


Figure 4. **Movements for *Rhizoprionodon terraenovae* (No. 11) at site 1. The start of the track is represented by an open circle and the swimming area is outlined in a dotted polygon.**

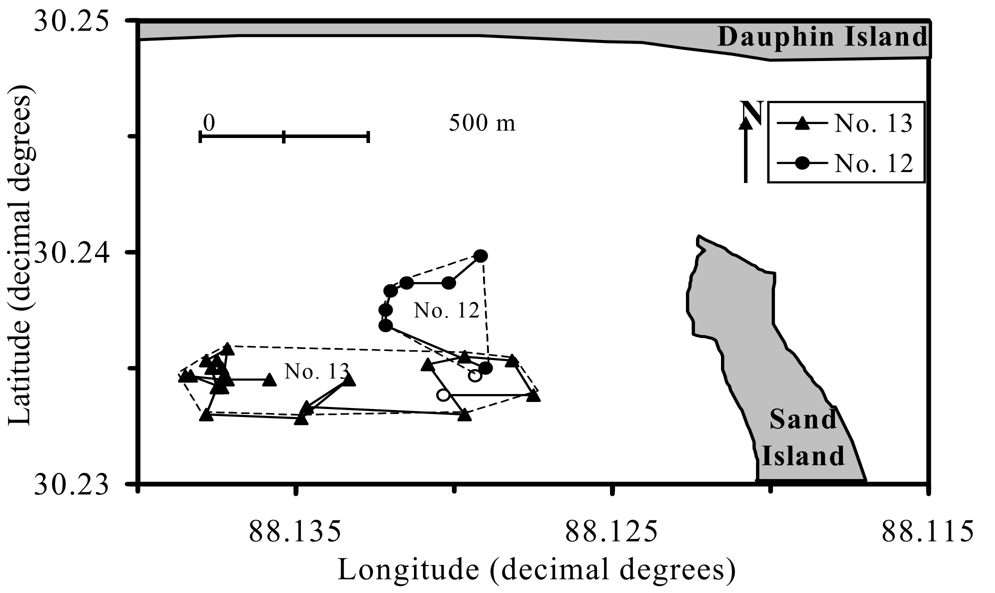


Figure 5. **Movements for *Rhizoprionodon terraenovae* (No. 12 and 13) at site 1. The start of each track is represented by an open circle and the swimming areas are outlined in dotted polygons.**

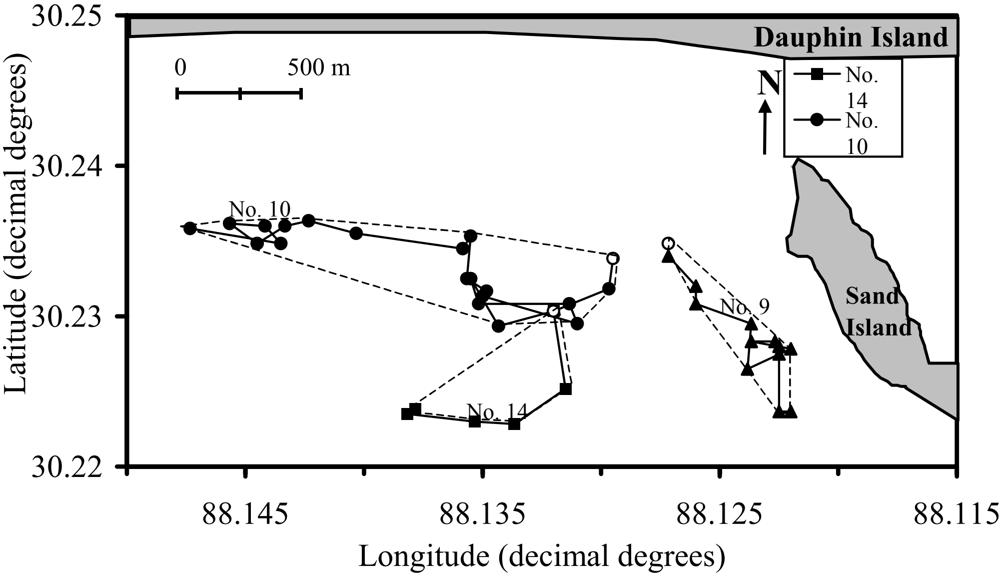


Figure 6. **Movements for *Rhizoprionodon terraenovae* (No. 9, 10, and 14) at site 1. The start of each track is represented by an open circle and the swimming areas are outlined in dotted polygons.**

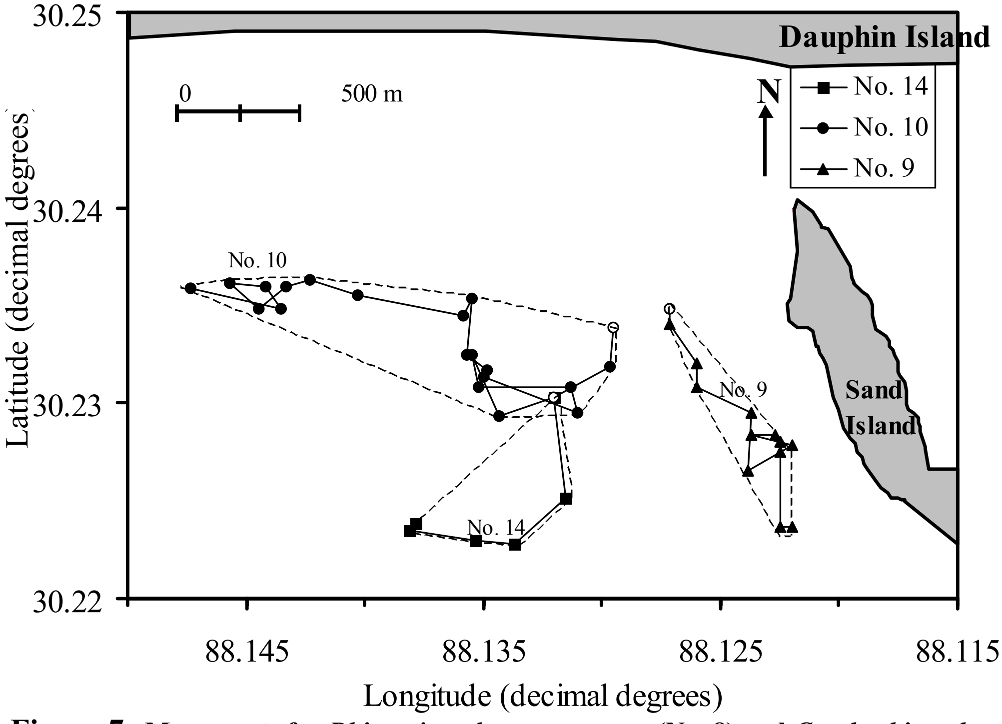
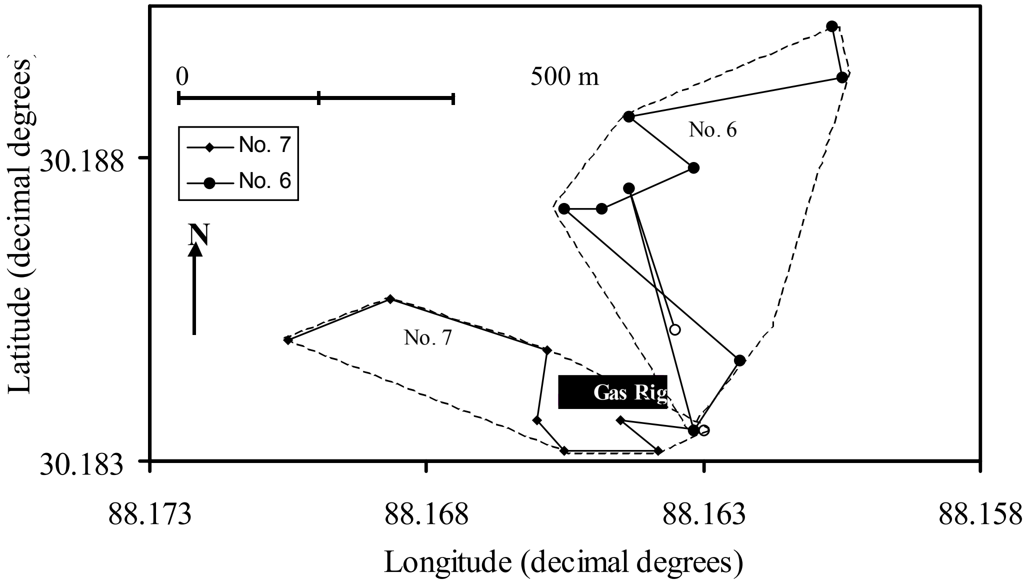


Figure 7. **Movements for *Rhizoprionodon terraenovae* (No. 8) and *Carcharhinus brevipinna* (No. 16) at site 2. The start of each track is represented by an open circle and the swimming areas are outlined in dotted polygons.**

Figure 8. **Movements for *Rhizoprionodon terraenovae* (No. 6 and 7) at site 3. The start of each track is represented by an open circle and the swimming areas are outlined in dotted polygons**



km of the release site (Table 3, Figures 7 and 9). The larger juvenile was only tracked for 32 minutes and insufficient data was collected. Mean rate of movement was 1.0 ±0.2 SE km/h.

Finetooth Shark, *Carcharhinus isodon*

Two females of 94 cm TL and one female of 108 cm TL were caught at the barrier island site, between 4 and 16 August 1999 (Table 3). Water depth at capture ranged from 4.9 to 7.6 m. Sharks were caught in bottom DO of 0.3 to 2.4 mg/l and surface DO of 5.3-7.3 mg/l. Salinity ranged from 33.3 to 36.3 ppt at the bottom and 23.5 to 32.4 ppt at the surface. Water temperature ranged from 26.1 to 27.5 °C at the bottom and 28.8 to 31.5°C at the surface (Table 4). Tracking duration ranged from 75 to 110 minutes with meandering swimming behavior suggesting that short-term post release survival occurred for these animals (Table 3, Figure 9). All three finetooth sharks moved to deeper water but within 1.7 km of the release site (Figure 9). Mean rate of movement was 2.6 ± 0.6 SE km/h.

Blacktip Shark, *Carcharhinus limbatus*

Two blacktip sharks were caught in water that ranged from 3.2 to 6.2 mg/l bottom DO, 27.3 to 28.1 °C bottom water temperature, and 34.3 to 37.0 ppt bottom salinity (Table 4). One immature female of 93 cm TL was caught south of Mobile Point in water 5.8 m deep on 14 July 1999. This shark traveled south more than 11 km to deeper water (21.3 m) at a mean rate of 9.5 ± 6.6 SD km/h after 128 minutes of continuous tracking (Table 3, Figure 10). Another immature female, 101 cm TL, was caught at the barrier island site in water 7.6 m on 21 August 1999. After a track of 272 minutes, this individual had swam about 8.8 km and was within 4.6 km of the release site at mean rate of 2.1 ± 0.8 SD km/h (Table 3, Figure 11).

Preliminary findings

Atlantic sharpnose, blacktip, finetooth, and bonnethead sharks were observed to inhabit the shallow waters of Sapelo Island National Estuarine Reserve, Georgia in 1997. Atlantic sharpnose, blacktip, finetooth, and spinner sharks were collected nearshore to Dauphin Island and the mouth of a large estuarine system, Mobile Bay, Alabama in 1999. Collection of large numbers of neonate Atlantic sharpnose, blacktip, and finetooth

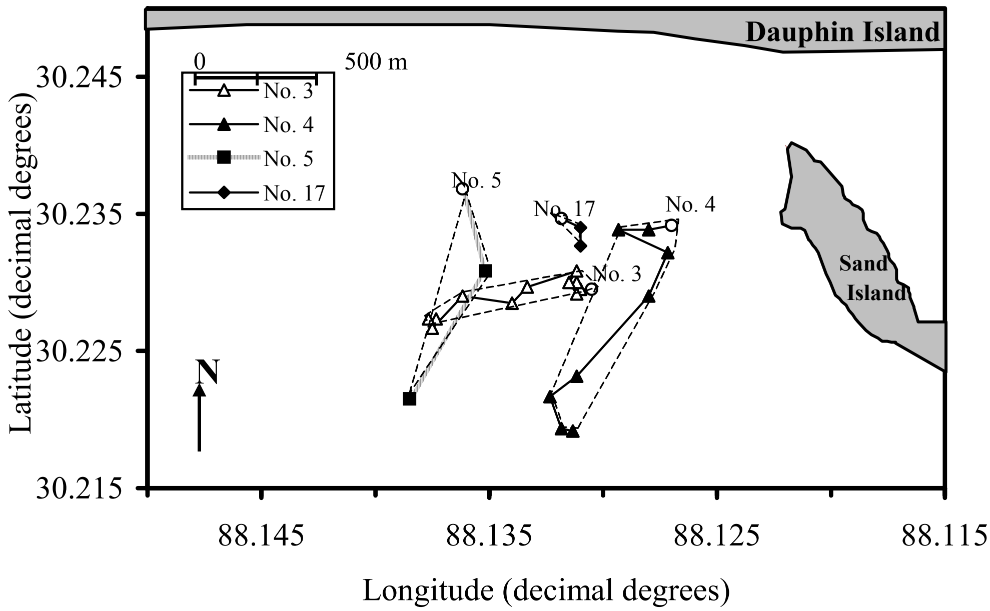


Figure 9. **Movements for *Carcharhinus isodon* (No. 3, 4, and 5) and *C. brevipinna* (No. 17) at site 1. The start of each track is represented by an open circle and the swimming areas are outlined in dotted polygons.**

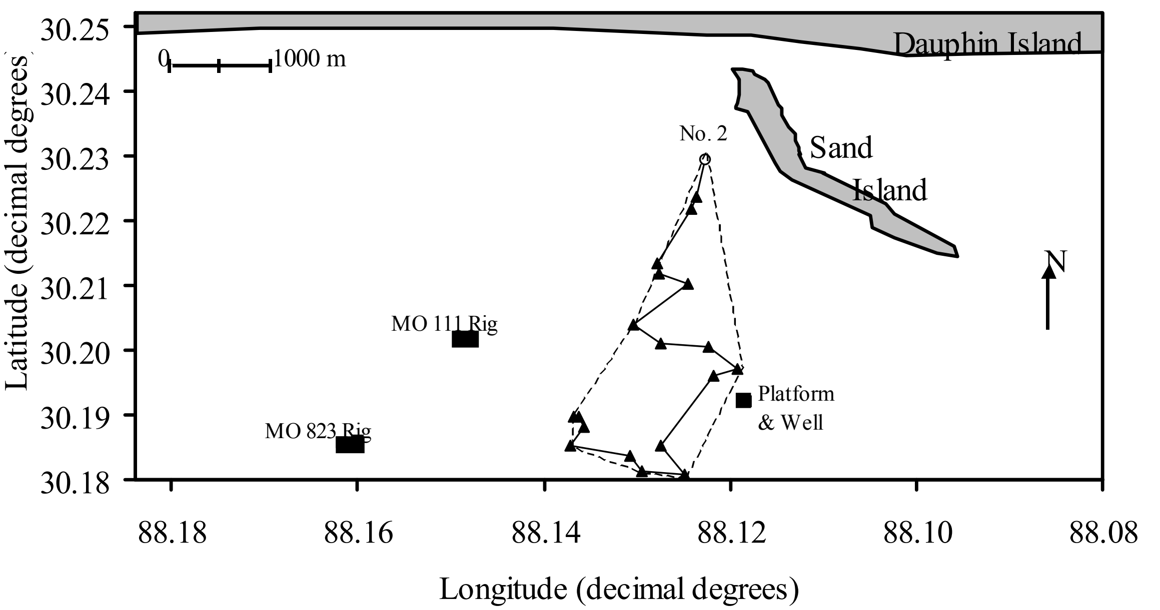


Figure 11. **Movements for *Carcharhinus limbatus* (No. 2) at site 1. The start of the track is represented by an open circle and the swimming area is outlined in a dotted polygon.**

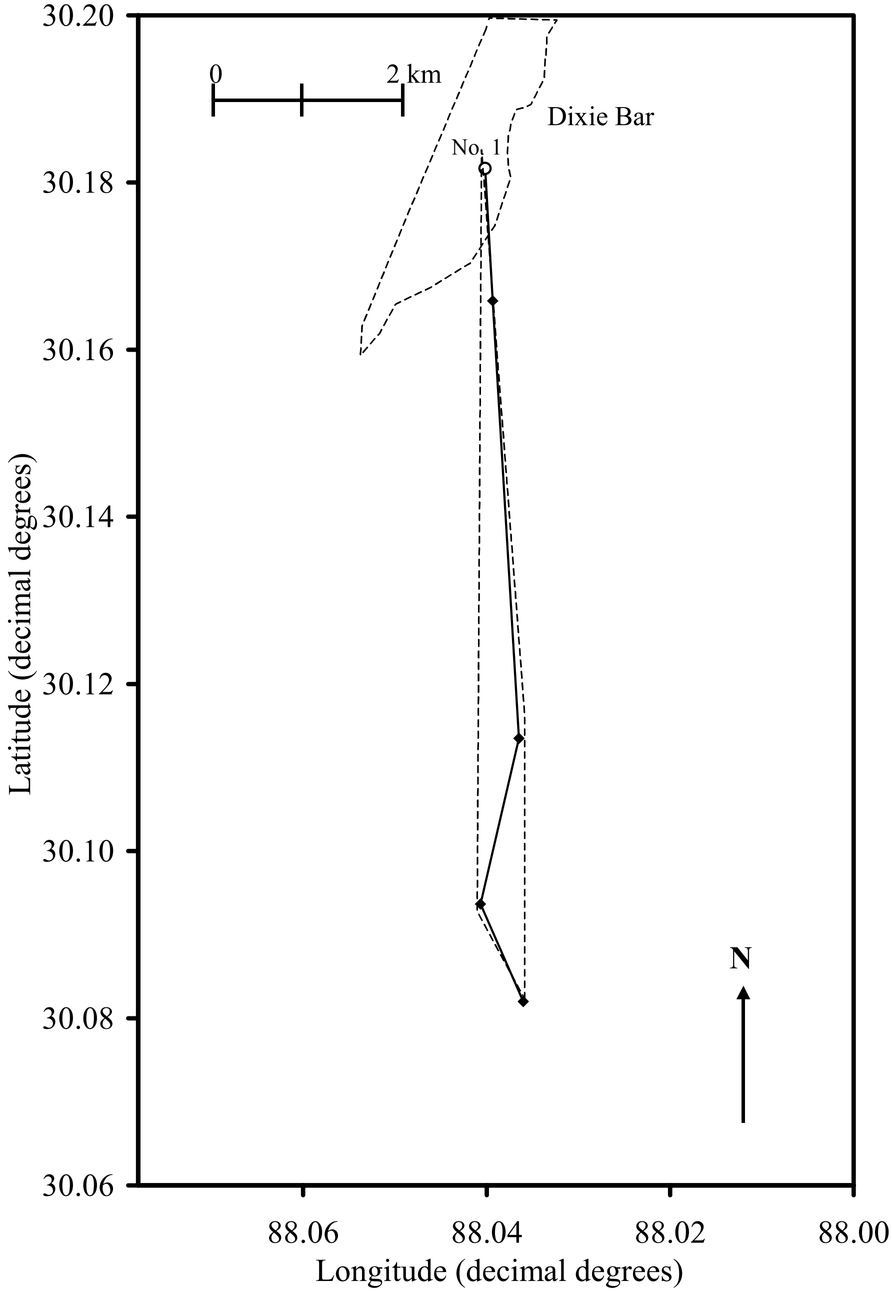


Figure 10. Movements for *Carcharhinus limbatus* (No. 1) at site 2. The start of the track is represented by an open circle and the swimming area is outlined in a dotted polygon.

sharks indicated that these species use the Sapelo Island National Estuarine Reserve in Georgia as primary nursery grounds during the early summer months. The analysis of stomach contents revealed teleosts form the majority of the diet for blacktip and finetooth pups, a variety of prey items including teleosts, penaeid shrimp, stomatopods, cephalopods, and brachyuran crabs for Atlantic sharpnose, and exclusively crustaceans, particularly blue crabs, for bonnethead sharks studied in the Sapelo Island area. The occurrence of neonates feeding on prey common to this estuary indicates the use of this estuarine system as a nursery ground by providing an abundance of food and some protection from larger sharks.

Tracks of young juvenile spinner, finetooth, blacktip and Atlantic sharpnose sharks in nearshore waters off the developed coast of Alabama where fishing pressure is high indicates the use of this area as a secondary nursery ground. Adult spinner, finetooth and blacktip sharks were not observed; yet the occurrence of both juvenile and adult Atlantic sharpnose sharks in these waters indicates this species might not segregate by size among most juveniles and adults during the summer. Most individuals tracked displayed some site attachment to a sandbar, gas platform, or small barrier island. Results also showed high short-term post-release survival (94%) for jaw, gill, and gut-hooked juveniles and small adult sharks. Recreational bycatch mortality on small carcharhinid sharks, particularly juveniles, in coastal nursery habitats of northeast Gulf of Mexico may be reduced if catch-and-release is practiced. Post-release survival is maximized and injury is avoided if the line is cut near the mouth, leaving the hook, while the shark remains in the water.

These findings show these two areas as nursery habitats for these species and should support development of additional national estuarine reserves. In addition, management and public awareness for recreational and commercial fishers using these habitats should be advocated.

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Center for Shark Research (CSR) U.S. Shark Nursery Research Overview 1991-2001

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Scope

Mote Marine Laboratory (MML) has conducted shark research since the laboratory was originally founded as the Cape Haze Marine Laboratory in 1955. Since then, MML has pioneered studies of shark anatomy, physiology, behavior and ecology. In 1991, the Center for Shark Research (CSR) was established at MML by the U.S. Congress as a national center for research on fisheries-related aspects of shark biology, to assist the National Marine Fisheries Service (NMFS) in the conservation and management of shark fisheries. This partnership with NMFS was later solidified with a Memorandum of Understanding (MOU) between MML and the NMFS Southeast Fisheries Science Center, establishing the CSR as a cooperative research center involving both MML and NMFS.

As part of its mission to provide the technical information NMFS requires to understand the status of shark fishery resources, the CSR initiated a long-term research program in November 1991 on the early life history of coastal sharks inhabiting the Gulf of Mexico. This program is designed to utilize field surveys, animal collections, and tagging and tracking studies to discover the distribution of shark nursery areas in the Gulf, the biology of juvenile sharks in those nurseries, and the migratory patterns of fisheries-relevant shark species.

The first of these studies was a project jointly funded in 1991-1993 by the Florida Department of Natural Resources (now part of the Florida Fish and Wildlife Conservation Commission, FFWCC) and NMFS through the Marine Fisheries Initiative (MARFIN) program (FDNR Grant Agreement 7237/7849 and NMFS/MARFIN Project NA17FF0378-01). This two-year study assessed the relative importance of two estuaries of southwest Florida's Gulf coast, Tampa Bay and Charlotte Harbor/Pine Island Sound, as shark nursery areas, and examined potential commercial fishing mortality of these young sharks in the nurseries. Biological aspects of the early life history of these shark species, including distribution, feeding, and migration, were also investigated. A total of 3,339 sharks of 13 species were documented during the nearly two years of sampling in the study areas (Hueter and Manire, 1994).

In 1995-1997, the CSR conducted a second NMFS/MARFIN-funded project on shark nurseries (NMFS/MARFIN Project NA57FF0034), this time to assess Florida's Gulf coastal areas as nurseries specifically for the blacktip shark (*Carcharhinus limbatus*), which had become the most important species in the U.S. east coast shark fishery. The project also documented nursery areas of other shark species, quantified relative abundance of juvenile blacktip and other sharks in these areas, determined bycatch mortality of these small sharks and associated fishes in gill net fishing gear, and conducted basic biological studies of shark distribution, feeding, growth and reproduction in the Florida Gulf. Monthly, random stratified sampling by gill net was conducted in three Florida coastal areas (Yankeetown, lower Tampa Bay, and Pine Island Sound/Charlotte Harbor). Over the course of this project, 3,227 sharks of 13 species were caught, including 1,416 juvenile blacktips (Hueter, 1999).

In addition to these projects, research funded primarily through the NMFS Highly Migratory Species (HMS) Division (NMFS Headquarters, Silver Spring, Md.) extended the CSR shark nursery studies in the eastern Gulf of Mexico from 1992-2001, allowing relatively continuous sampling of the juvenile sharks in these nurseries in the years between the two NMFS/MARFIN projects (1993-1995) as well as the years subsequent to MARFIN funding (1997-2001). This NMFS-sponsored research (NMFS Projects NA27FL0142, NA37FM0284, NA67FM0199, NA77FM0281, NA87FM0588, NA97FM0223 and NA07FM0459) included exploratory surveys, standardized gill net collections, abundance studies, and conventional tagging and acoustic tracking of juvenile sharks in nursery areas of the Florida Gulf coast. Relative abundance of juvenile blacktip sharks in the nursery areas of Yankeetown and Charlotte Harbor, Florida, continued to be monitored in 1999, 2000 and 2001. Gill net surveys during those years resulted in the capture of 1,949 sharks comprising seven species, of which 1,012 sharks were tagged and released.

A number of other studies have contributed to the body of 1991-2001 CSR data on shark nursery areas in the eastern Gulf. These include: collaborative field collections and shark tagging with FFWCC; research on sawfish ecology and behavior (supported by NMFS, National Geographic Society and Disney Wildlife Conservation Fund); an ongoing study of juvenile blacktip shark movements and habitat using acoustic tracking (initially funded by NMFS/HMS, now supported primarily by the National Science Foundation [NSF]); and studies of the endocrinology and reproduction of the bonnethead shark (*Sphyrna tiburo*). Among these last studies was a major U.S. Environmental Protection Agency (EPA)-funded project on the mechanisms and effects of endocrine disruption in the bonnethead. This research involved extensive field work and collections of small sharks in eastern Gulf coastal waters from 1998-2000, resulting in the capture of 1,439 sharks of eight species, with 772 being tagged and released.

From 1989-1998, MML organized and coordinated the Gulf Coast Shark Census Tournament, a 100% catch-and-release shark sportfishing tournament operating along the southwest Florida coast in late spring and early summer months. The tournament typically was funded by private donations and angler registrations, except in 1995, when a NMFS/Saltonstall-Kennedy (S-K) grant (No. NA37FD0086) helped fund the tournament as a demonstration project for catch-and-release shark fishing. After 10 years of coordinating the tournament, the CSR passed the operation to a local chapter of the Coastal Conservation Association (CCA), which ran the event one additional year (1999). Over these 11 years of operation (1989-1999), the tournament involved over 1,000 anglers catching, documenting, and releasing thousands of sharks, most of them small, inshore animals, many of which were juveniles in nursery areas. Because of the inherently lower quality of data collected by these anglers vs. trained biologists, the tournament data have not been incorporated into the CSR shark nursery database. However, CSR biologists accompanied tournament anglers in selected cases to tag their catch, and this effort resulted in the tagging of 649 sharks of seven species over the 11-year period. These data have been incorporated into the database.

In addition to these various projects in the eastern Gulf, the CSR also has collected data on shark nursery areas along the east coast of Florida (in collaboration with the University of Central Florida [UCF]), the Texas Gulf coast (in collaboration with the Texas Parks and Wildlife Department [TPWD]), and at a number of locations in Mexican coastal waters (in collaboration with Mexico's Instituto Nacional de la Pesca [INP]). These activities have been largely supported by NMFS/HMS funding to the CSR. The Texas research is an ongoing effort to study the exchange rate of western Gulf sharks between the U.S. and Mexico. The work in Mexico with INP is a long-term program, established in 1994, to understand the status of Mexican shark resources and distribution of shark nursery areas in Mexico. Data from the Florida Atlantic coast and Texas Gulf coast studies have been incorporated into the CSR shark nursery database reported here. The Mexican data have not been included as they were not collected in U.S. waters.

Sampling Materials and Methods

The CSR has conducted 2,290 monofilament gill net sets (out of 2,954 total sets of all gear types) since 1991, making gill nets the most widely used gear type in CSR shark nursery surveys. Field collections have utilized stretch mesh sizes of 3.0", 4.0", 4.5", 5.0", 5.5", and 6.0". A 4.5" stretch mesh has been the most often used (1,920 sets) due to its relatively high selectivity for small sharks and relatively low bycatch of other species. Typical methodology uses a net weighted to rest on the bottom, with a height of 10 ft and a length of 400 yds. Normally the net is anchored at both ends and is allowed to soak for one hour (from first mesh in to last mesh out) prior to retrieval, but other set times are sometimes used in exploratory surveys. After the net is deployed, location (by GPS), oceanographic (temperature, salinity, conductivity, dissolved oxygen), weather, bottom type, and other data are collected. The net is checked at least once during the soak time, and in some sampling is checked more often for the presence of sharks. In the case of standardized, quantitative sampling using a randomized, stratified design, 4.5" gill net sets of one hour are always used. Sharks collected in all gill net techniques (and in most other techniques described below) typically are identified, sexed, measured (precaudal length, PCL; fork length, FL; total length, TL; and stretch total length, STL) to the nearest cm, weighed to the nearest 0.1 kg, and either tagged and released or retained for study. In some cases, tissue samples (fin clips, blood, etc.) are taken from sharks prior to release. In addition to data on the shark catch, bycatch data (species identification, body measurements) are collected from all gill net surveys.

The CSR database also includes information on 404 longline sets conducted since 1991. About one-third of these sets (145) were from coastal shark abundance surveys (1995-97) aboard the NMFS research vessel *Oregon II*, where MML/CSR tags were used to tag sharks of less than 4 ft TL. These surveys, which were conducted in the Gulf of Mexico offshore from Texas to Florida, typically deployed one mile of mainline with 100 3/0 shark hooks soaked for one hour, using primarily Atlantic mackerel (*Scomber scombrus*) for bait. Longlines also have been used as the primary gear type for an ongoing project targeting smalltooth sawfish (*Pristis pectinata*). This project uses 400 yds of mainline, 14/0 and 16/0 circle hooks, a soak time of 1-2 hours, and various types of bait including mullet (*Mugil* spp.), pinfish (*Lagodon rhomboides*), and crevalle jack (*Caranx hippos*). Longline gear also has been used during CSR exploratory surveys of Tampa Bay and Charlotte Harbor (108 sets in1992-93). This work utilized 200-400 yds of mainline with 50-60 hooks (5/0, 6/0, 7/0, 8/0 J-hooks) and a soak time of one hour. A short longline of about 20 hooks also was used in 2000, in exploratory sets for sharks off the South Carolina coast in the vicinity of Bulls Bay.

Rod & reel was used in collection of sharks tagged in the Gulf Coast Shark Census Tournament from 1989-1999. Rod and reel also has been the main gear used in an ongoing NSF-funded project investigating the behavioral ecology of juvenile blacktip sharks in Terra Ceia Bay, Florida (a small bay inside the Tampa Bay system). This project was initiated in 1999 and to date has captured 129 sharks of three species using this gear type. Occasionally in other surveys, rod & reel also has been used concurrently with other gear types, such as gill nets or longlines, to augment the catch.

Beach seines (200 ft x 6 ft x ½" mesh) were used on three occasions to collect small sharks in the surf zone of the beaches near Sarasota, Florida. This gear was deployed from a shallow draft boat in a semi-circular formation with each end of the net on shore. The seine was then pulled in by hand from shore to capture the small sharks. This methodology has resulted in the capture of 24 sharks of two species.

In almost all cases, sharks caught and released alive in CSR research are tagged with a nylon-head, plastic barb tag (Hallprint, South Australia) inserted just below the first dorsal fin across the body midline, such that the tag head is firmly anchored in the cartilage and connective tissue below the fin. The total number of sharks tagged in U.S. waters using the CSR Hallprint tags is 10,155 to date. Other types of tags used in various CSR elasmobranch studies have included Rototags, NMFS M-tags, Mote M-tags, internal and external acoustic transmitters, electronic archival tags and satellite pop-off tags.

Description of Study Areas

The following sections provide brief descriptions of the main sampling areas where most of the data provided with this report were collected. The salinity and temperature ranges are based on measurements taken during field collections and do not necessarily reflect year-round characteristics or conditions in all areas within the nursery.

Florida Shark Nursery Areas (Fig. 1)

Yankeetown (Fig. 2)

The coastal area near Yankeetown, Florida, is a relatively open and pristine stretch of Florida Gulf of Mexico coastline that is marked by broad, shallow marine habitat including seagrass beds, sand/mud bottom, and nearshore oyster reefs. The

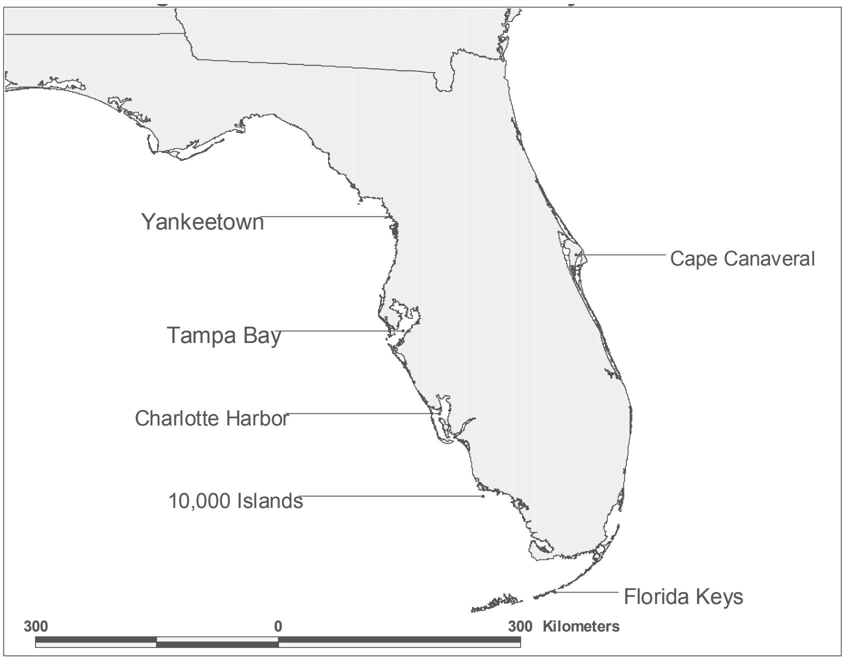

Figure 1. Florida coastal shark nursery areas.

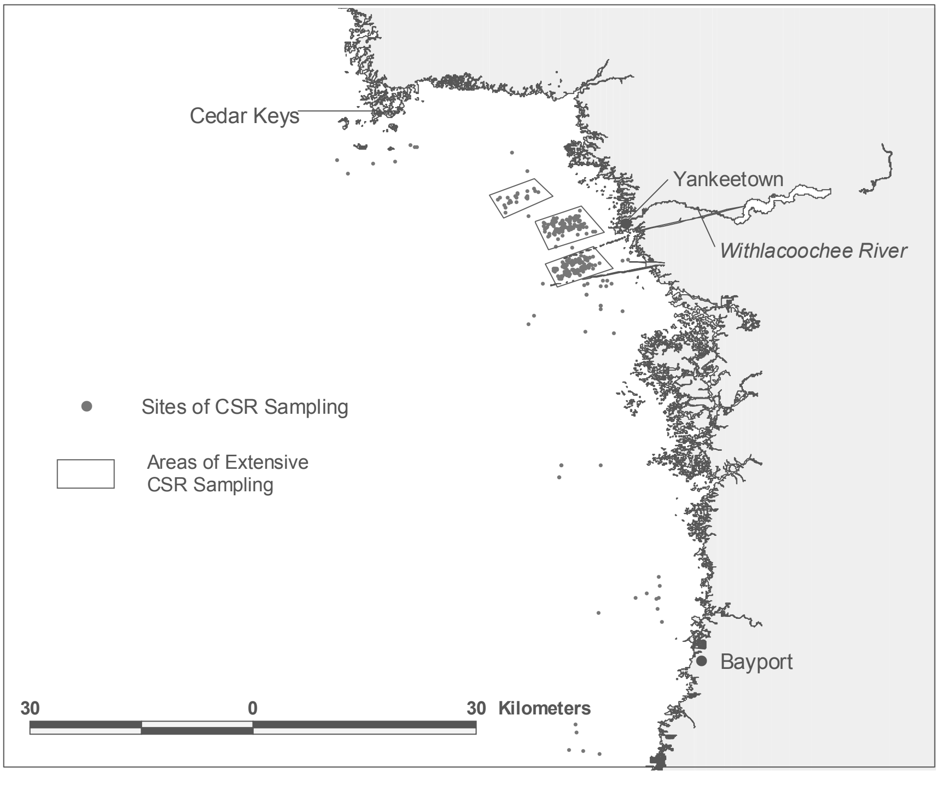

Figure 2. Yankeetown, Florida

Table 1. **Yankeetown Habitat Summaries for all Species (Neonates, YOY, Juveniles). TL = total length, Sal = salinity, Temp = temperature, DO = dissolved oxygen**

			TL (cm)		Sal (ppt)		Temp (^oC)		DO (mg/l)		Depth (ft)	
Species	**Stage**	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	Neonate	1	48	48	32.2	32.2	30.1	30.1	-	-	-	-
	YOY	3	46	50	32.2	33.0	30.1	30.2	-	-	8	11
	Juvenile	30	65	98	26.2	34.5	20.1	30.2	6.15	6.15	5	11
Carcharhinus brevipinna	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	2	61	72	21.0	26.0	29.0	30.1	-	-	6	13
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Carcharhinus isodon	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	1	63	63	15.8	15.8	23.2	23.2	-	-	9	9
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Carcharhinus leucas	Neonate	1	77	77	27.4	27.4	28.2	28.2	-	-	7	7
	YOY	3	79	88	22.0	22.0	23.3	23.3	-	-	6	6
	Juvenile	2	90	101	21.0	22.0	23.3	29.0	-	-	6	7
Carcharhinus limbatus	Neonate	440	51	74	20.5	32.0	25.2	32.0	5.37	8.59	4	15
	YOY	621	53	83	15.8	34.5	19.9	32.0	5.30	8.59	5	18
	Juvenile	109	70	125	20.4	34.5	23.0	32.0	5.37	8.59	5	15
Carcharhinus plumbeus	Neonate	3	48	63	20.4	25.9	25.0	29.0	-	-	8	12
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Mustelus norrisi	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	70	70	30.9	30.9	21.0	21.0	-	-	9	9
Rhizoprionodon terraenovae	Neonate	2	33	33	22.8	27.2	24.0	25.9	-	-	11	11
	YOY	1	50	50	27.6	27.6	23.2	23.2	-	-	9	9
	Juvenile	37	59	89	22.8	33.9	20.1	31.7	5.74	7.40	5	14
Sphyrna lewini	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	3	71	76	27.6	30.1	23.2	26.0	5.92	5.92	8	8
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Sphyrna mokarran	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	8	64	89	21.9	33.0	23.9	31.1	5.30	6.11	6	18
	Juvenile	20	94	186	15.8	32.0	23.0	31.0	5.37	6.15	6	17
Sphyrna tiburo	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	2	49	51	26.0	26.2	29.9	30.0	-	-	10	11
	Juvenile	328	49	88	20.2	34.3	21.0	32.4	5.30	8.59	5	16

average depth of this nursery area is about 6-8 ft with the outer, less productive areas being about 14-16 ft in depth. There is significant fresh water outflow into this region via the Waccasassa, Withlacoochee, Crystal, and Homosassa Rivers. CSR measurements have documented the salinity and temperature range in this area to be 15.8-34.9 ppt and 17.0-32.4^o C, respectively. The adjacent land areas are sparsely populated and not industrialized, with the ironic exception of a nuclear power plant south of the entrance to the Withlacoochee River. This plant produces a warm water effluent, which enters the Gulf on the inland side of the nursery area and is quickly dissipated, not affecting the nursery at large to any known significant extent. The Yankeetown nursery area extends north to Cedar Key (29.10N, 83.05W) including Waccasassa Bay and as far south as Bayport (28.36N, 82.78W). Characteristics of this nursery habitat are detailed in Table 1.

Tampa Bay (Fig. 3)

Tampa Bay is a large, semi-enclosed estuarine

Table 2. **Tampa Bay Habitat Summaries for all Species (Neonates, YOY, Juveniles). TL = total length, Sal = salinity, Temp = temperature, DO = dissolved oxygen**

			TL (cm)		Sal (ppt)		Temp (^{o}C)		DO (mg/l)		Depth (ft)	
Species	**Stage**	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	Neonate	16	42	50	34.0	37.0	28.7	29.0	6.50	7.07	5	6
	YOY	100	30	79	28.2	34.7	27.0	30.0	3.25	6.50	3	23
	Juvenile	429	50	123	28.0	37.0	17.3	32.0o	4.76	8.71	3	25
Carcharhinus brevipinna	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	15	48	71	27.4	34.0	28.7	31.7	5.12	7.07	3	13
	Juvenile	8	69	112	27.3	36.2	29.0	30.1	-	-	8	9
Carcharhinus leucas	Neonate	19	67	84	25.5	28.5	29.5	32.2	-	-	4	5
	YOY	54	68	94	22.3	34.0	16.1	31.0	4.96	8.21	3	15
	Juvenile	16	90	127	23.2	28.1	24.1	30.3	-	-	3	17
Carcharhinus limbatus	Neonate	152	51	69	27.1	38.1	22.7	32.2	4.50	7.60	3	15
	YOY	268	49	88	21.0	37.0	19.1	32.2	4.29	8.56	3	15
	Juvenile	223	72	143	23.5	37.0	18.5	33.0	4.96	9.60	4	20
Ginglymostoma cirratum	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	121	121	32.7	32.7	17.5	17.5	9.70	9.70	6	6
Mustelus norrisi	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	4	61	83	33.3	33.5	16.1	22.6	-	-	7	7
Negaprion brevirostris	Neonate	5	60	66	26.8	32.6	22.0	25.4	5.90	9.60	2	5
	YOY	4	65	86	31.6	38.5	19.6	33.0	6.50	7.12	4	4
	Juvenile	5	74	108	30.0	33.8	19.1	31.0	-	-	4	4
Rhizoprionodon terraenovae	Neonate	1	38	38	33.7	33.7	30.7	30.7	5.73	5.73	6	6
	YOY	120	35	67	26.3	36.2	18.4	29.9	4.75	8.56	3	13
	Juvenile	148	46	89	25.8	35.3	17.2	31.2	4.29	8.71	3	25
Sphyrna tiburo	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	49	30	67	22.3	34.0	16.1	31.0	4.96	8.21	3	15
	Juvenile	1106	44	89	20.0	35.5	16.1	32.3	3.25	10.46	2	14
Sphyrna lewini	Neonate	1	49	49	30.0	30.0	28.0	28.0	-	-	8	8
	YOY	1	53	53	28.1	28.1	29.0	29.0	-	-	13	13
	Juvenile	1	102	102	30.7	30.7	27.2	27.2	-	-	14	14
Sphyrna mokarran	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	3	70	79	32.2	34.2	30.0	30.1	6.25	6.25	6	13
	Juvenile	14	93	211	27.1	34.8	20.9	30.0	6.09	6.09	9	13

system with a surface area of 346 mi^2 and an average depth overall of 16.2 ft. Depth beyond the coastal shoals averages about 10 ft, increasing to 20-30 ft in the middle of the bay. The Tampa Bay system is characterized by the presence of seagrass, mangrove, and salt marsh habitats (Hueter and Manire, 1994). Freshwater inflow is limited in the north primarily to a few small rivers on the eastern side including the Hillsborough, Alafia and Little Manatee Rivers. On the extreme south end, the Manatee River contributes significant amounts of freshwater into the bay. The CSR has documented the salinity and temperature ranges in Tampa Bay nurseries to be 18.5-38.5 ppt and 14.0-33.0^{o} C, respectively. With the cities of Tampa and St. Petersburg surrounding it, Tampa Bay is exposed to significant industrial and human impacts. Efforts to clean up the bay have resulted in some improvements in water quality and seagrass distribution in recent years. The Tampa Bay nursery habitat description (Table 2) includes data from outside the bay proper to as far north as Anclote Key (28.24N, 82.80W) and as far south as Sarasota (27.10N, 82.50W).

Charlotte Harbor (Fig. 4)

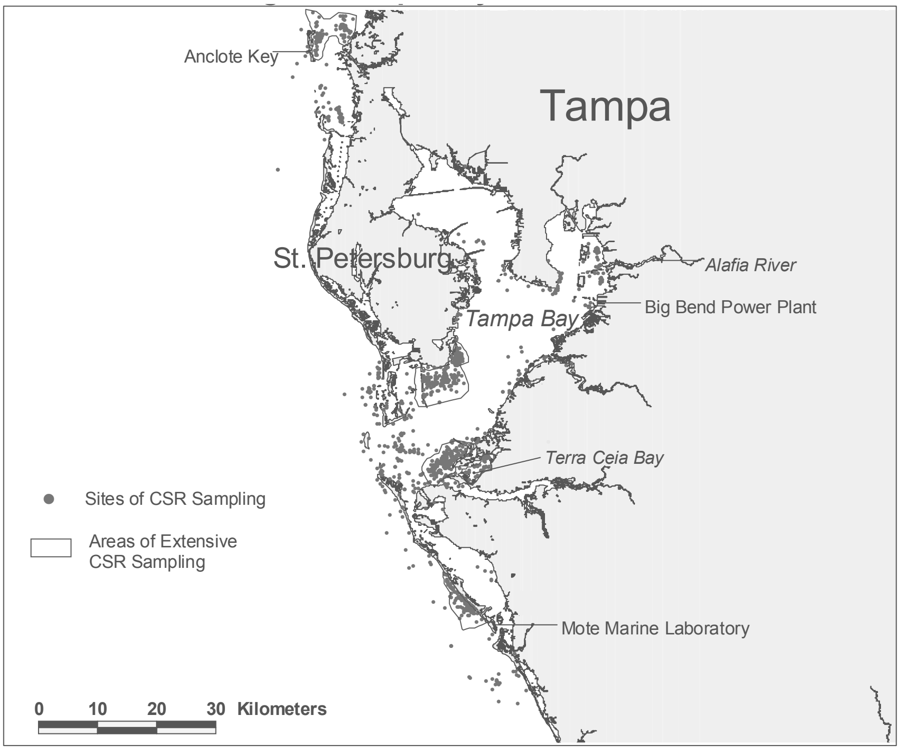

Figure 3. **Tampa Bay, Florida**

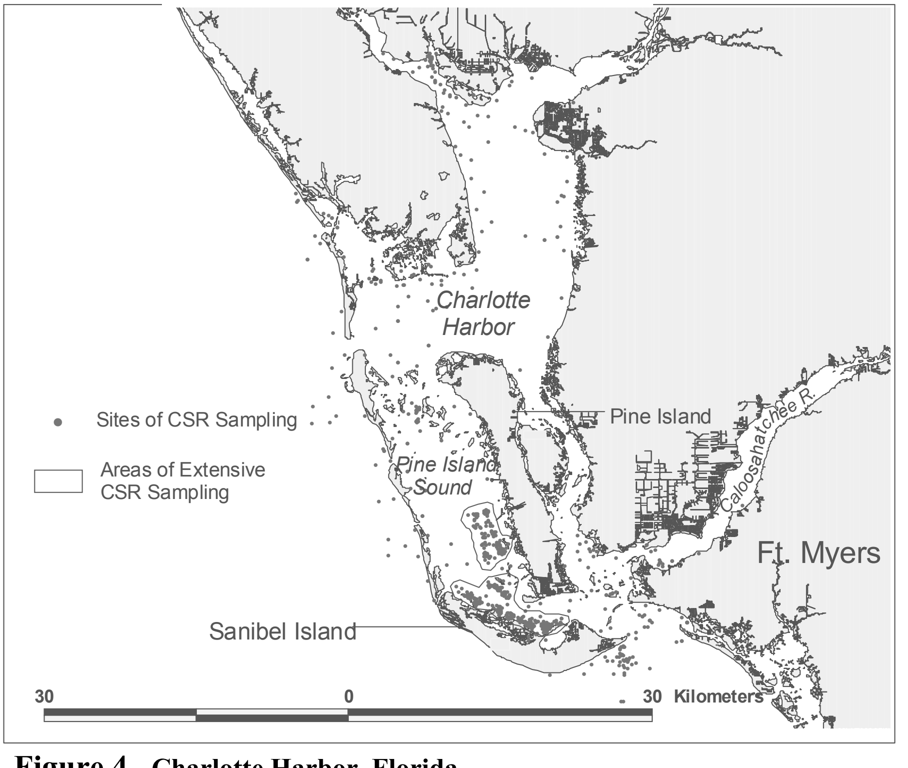

Figure 4. **Charlotte Harbor, Florida**

This complex, semi-enclosed estuarine system has a surface area of 311 mi^2. The average depth overall in the entire estuary is 8.3 ft, with the depth averaging about 10 ft beyond the shoal areas and increasing to about 15-20 ft in the middle of the bay (Hueter and Manire, 1994). Pine Island Sound (PI) and Matlacha Pass make up the southwestern and southeastern components of Charlotte Harbor, respectively. The overall system receives significant freshwater inflow from the Myakka and Peace Rivers to the north and the Caloosahatchee River to the south. This system is characterized by the presence of seagrass, mangrove, and salt marsh habitats (Hueter and Manire, 1994). The CSR has documented the salinity and temperature ranges in this area to be 3.0-36.4 ppt and 13.8-34.3^o C, respectively. The region adjacent to the harbor is moderately populated and industrialized, but many areas within the harbor are still relatively pristine and undeveloped. The nursery habitat characteristics for this area are broken down by species and reproductive stage in Table 3.

10,000 Islands (Fig. 5)

This nursery is located along approximately 25 miles of a coastal area containing numerous mangrove islands bordering inland, tannin-colored fresh and brackish bays to the northeast, and lush seagrass beds and sand communities in the coastal marine zone to the southwest. Features include Gullivan Bay on the western side and the Everglades National Park bordering the eastern side of the sampled region. The CSR has documented the salinity and temperature ranges in this area to be 21.5-34.2 ppt and 26.0-31.5^o C, respectively. This relatively pristine area is very sparsely populated and not industrialized. A summary of the shark nursery habitat characteristics of the 10,000 Islands area is presented in Table 4.

Florida Keys (Fig. 6)

The Florida Keys comprises a 126-mile island chain on the southern tip of the Florida peninsula. This is a tropical ecosystem that includes mangroves and seagrasses that grow on both the ocean (south/east) side and bay (north/west) side of the islands. Offshore coral reefs abound primarily on the ocean side. The bay side is relatively shallow and influenced significantly by water flow emerging from the Florida Everglades. This area has a relatively low population and minimal industrial development but water quality and the ecosystem's general health have degraded significantly in the last decade. The CSR's sampling efforts in this area have been mostly confined to the middle Keys (Long Key) and have not directly targeted nursery areas. Salinity and temperature ranges in this area have been documented to be 26.8-36.9 ppt and 22.0-32.8^o C, respectively. Some data from sawfish surveys conducted in the Everglades adjacent to the Keys on the north side have also been included in the shark nursery habitat summary for this area (Table 5).

Cape Canaveral (Fig. 7)

A small-scale tagging study of juvenile sharks was conducted in the Cape Canaveral area of the Florida east coast through collaboration with the University of Central Florida. (The Cape is not considered one of the five major Florida sampling areas as referred to in this narrative.) This study area extends north to Port Canaveral (28.44N, 80.29W) and south to the Cocoa Beach Fishing Pier (28.39N, 80.29W). The area can be generally characterized as open beach and sandy benthos with depth gradually increasing from shore to deep offshore waters. Bottom relief is minimal. The Southeast Shoal, located north of the Canaveral shipping channel, represents a much shallower zone than the surrounding areas. The area's water temperature ranged during the sampling period from 24.5^{o}C (March) to 30.5^{o}C (July) while salinity remained relatively stable (34-38 ppt).

Texas Shark Nursery Areas (Fig. 8)

Corpus Christi

CSR collaborations with recreational fishermen have been used in this area of the Texas coast to tag young sharks, particularly blacktips. Bob Hall Pier (BHP) has been the main site of fishing activity. BHP is located on the Gulf of Mexico (eastern) side of Padre Island and extends 1,200 ft into the gulf, where water depth below the pier averages 15 ft. The bottom is mostly sand with some shell. Limited shark tagging also has been conducted near offshore oil rigs in this area.

Table 3. Charlotte Harbor Habitat Summaries for all Species (Neonates, YOY, Juveniles). TL = total length, Sal = salinity, Temp = temperature, DO = dissolved

			TL (cm)		Sal (ppt)		Temp (°C)		DO (mg/l)		Depth (ft)	
Species	**Stage**	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	14	44	58	26.5	26.5	34.0	34.0	6.20	6.20	4	6
	Juvenile	8	49	93	25.0	35.2	25.0	32.0	6.20	6.20	-	-
Carcharhinus brevipinna	Neonate	3	66	71	-	-	-	-	-	-	17	17
	YOY	1	71	71	28.5	28.5	24.8	24.8	-	-	3	5
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Carcharhinus isodon	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	93	93	11.5	11.5	33.8	33.8	8.50	8.50	18	20
Carcharhinus leucas	Neonate	5	66	76	18.5	20.6	30.4	31.5	-	-	4	5
	YOY	6	55	95	3.0	33.3	23.9	34.0	5.21	8.40	6	6
	Juvenile	17	89	183	14.3	28.3	21.0	32.0	3.70	7.33	4	11
Carcharhinus limbatus	Neonate	346	52	70	25.5	35.6	25.0	32.0	5.16	9.00	3	9
	YOY	537	50	87	23.2	36.1	19.6	32.9	3.28	9.40	3	13
	Juvenile	119	75	119	23.2	35.1	21.0	33.6	5.16	9.40	4	9
Ginglymostoma cirratum	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	14	51	171	28.5	34.0	24.8	30.0	4.70	7.20	3	7
Mustelus norrisi	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	66	66	31.3	31.3	23.6	23.6	-	-	5	5
Negaprion brevirostris	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	3	120	133	28.5	33.0	21.4	32.1			6	7
Rhizoprionodon terraenovae	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	1	53	53	34.1	34.1	31.1	31.1	5.80	5.80	16	16
	Juvenile	28	42	84	24.9	35.5	26.2	33.3	6.12	8.60	4	11
Sphyrna lewini	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	12	45	58	28.9	32.8	29.8	30.2	5.09	5.09	8	9
	Juvenile	9	57	68	28.2	34.3	26.6	29.9			3	8
Sphyrna mokarran	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	5	74	84	34.5	34.9	30.0	30.0	-	-	9	13
	Juvenile	23	92	195	27.5	35.9	25.0	32.9	4.22	6.76	5	9
Sphyrna tiburo	Neonate	1	29	29	15.4	15.4	27.8	27.8	-	-	7	7
	YOY	32	35	65	25.0	35.6	15.9	31.5	3.70	9.20	4	9
	Juvenile	610	47	86	16.5	36.1	19.6	33.3	2.88	8.60	3	12

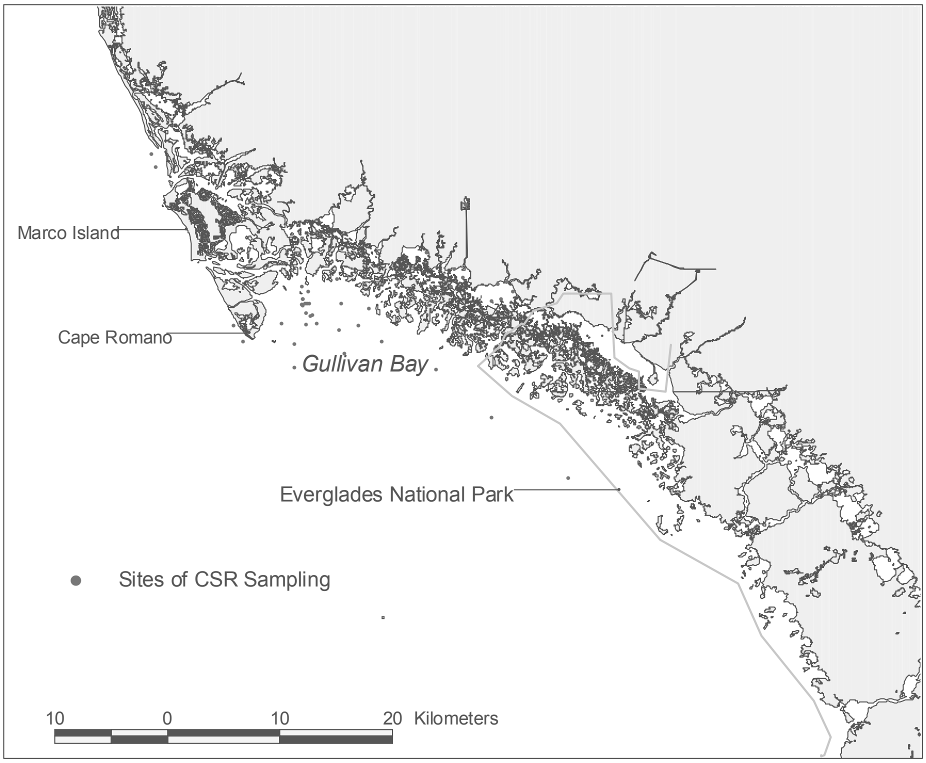

Figure 5. 10,000 Islands, Florida

			TL (cm)		Sal (ppt)		Temp (°C)		DO (mg/l)		Depth (ft)	
Species	**Stage**	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus leucas	Neonate	1	79	79	25.7	25.7	31.9	31.9	-	-	3	3
	YOY	4	75	97.5	14.2	29.7	30.1	32.2	4.70	4.60	3	4
	Juvenile	8	76	114	25.7	36.8	31.5	33.6	4.70	6.70	4	5
Carcharhinus limbatus	Neonate	9	53	64	33.0	41.1	26.1	33.6	5.40	6.70	4	7
	YOY	19	57	85	18.7	39.6	26.1	31.6	4.40	5.60	5	8
	Juvenile	3	77	84	33.0	33.1	26.1	26.2	-	-	6	7
Negaprion brevirostris	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	2	73	76.5	25.8	29.7	30.8	31.6	5.90	5.90	3	6
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Rhizoprionodon terraenovae	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	1	50	50	25.3	25.3	30.0	30.0	-	-	5	5
	Juvenile	1	60	60	33.0	33.0	26.2	26.2	-	-	7	7
Sphyrna mokarran	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	110	110	28.1	28.1	31.0	31.0	-	-	-	-
Sphyrna tiburo	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	11	44	54	28.1	34.2	26.0	31.0	-	-	3	11
	Juvenile	16	52	77	18.7	33.2	26.1	30.8	4.40	5.90	3	6

Table 4. 10,000 Islands Habitat Summaries for all Species (Neonates, YOY, Juveniles). TL = total length, Sal = salinity, Temp = temperature, DO = dissolved oxygen

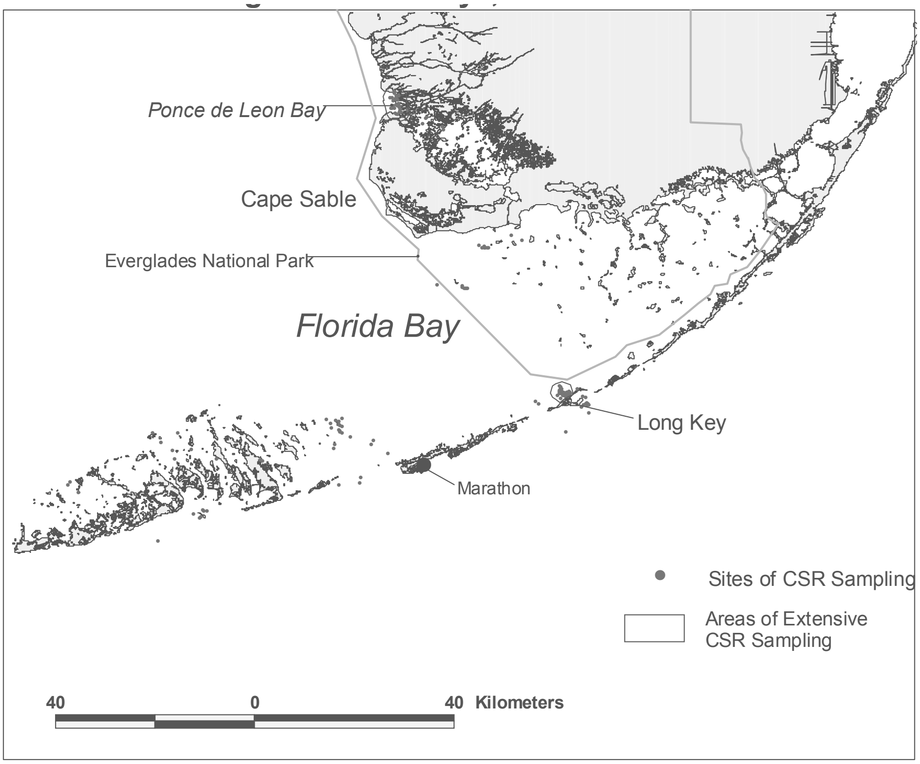

Figure 6. Florida Keys, Florida

Species	Stage	N	TL (cm) Min	TL (cm) Max	Sal (ppt) Min	Sal (ppt) Max	Temp (^oC) Min	Temp (^oC) Max	DO (mg/l) Min	DO (mg/l) Max	Depth (ft) Min	Depth (ft) Max
Carcharhinus acronotus	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	14	44	58	26.5	26.5	34.0	34.0	6.20	6.20	4	6
	Juvenile	8	49	93	25.0	35.2	25.0	32.0	6.20	6.20	-	-
Carcharhinus brevipinna	Neonate	3	66	71	-	-	-	-	-	-	17	17
	YOY	1	71	71	28.5	28.5	24.8	24.8	-	-	3	5
	Juvenile	0	-	-	-	-	-	-	-	-	-	-
Carcharhinus isodon	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	93	93	11.5	11.5	33.8	33.8	8.50	8.50	18	20
Carcharhinus leucas	Neonate	5	66	76	18.5	20.6	30.4	31.5	-	-	4	5
	YOY	6	55	95	3.0	33.3	23.9	34.0	5.21	8.40	6	6
	Juvenile	17	89	183	14.3	28.3	21.0	32.0	3.70	7.33	4	11
Carcharhinus limbatus	Neonate	346	52	70	25.5	35.6	25.0	32.0	5.16	9.00	3	9
	YOY	537	50	87	23.2	36.1	19.6	32.9	3.28	9.40	3	13
	Juvenile	119	75	119	23.2	35.1	21.0	33.6	5.16	9.40	4	9
Ginglymostoma cirratum	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	14	51	171	28.5	34.0	24.8	30.0	4.70	7.20	3	7
Mustelus norrisi	Neonate	0	-	-	-	-	-	-	-	-	-	-
	YOY	0	-	-	-	-	-	-	-	-	-	-
	Juvenile	1	66	66	31.3	31.3	23.6	23.6	-	-	5	5

Table 5. Florida Keys Habitat Summaries for all Species (Neonates, YOY, Juveniles). TL = total length, Sal = salinity, Temp = temperature, DO = dissolved oxygen

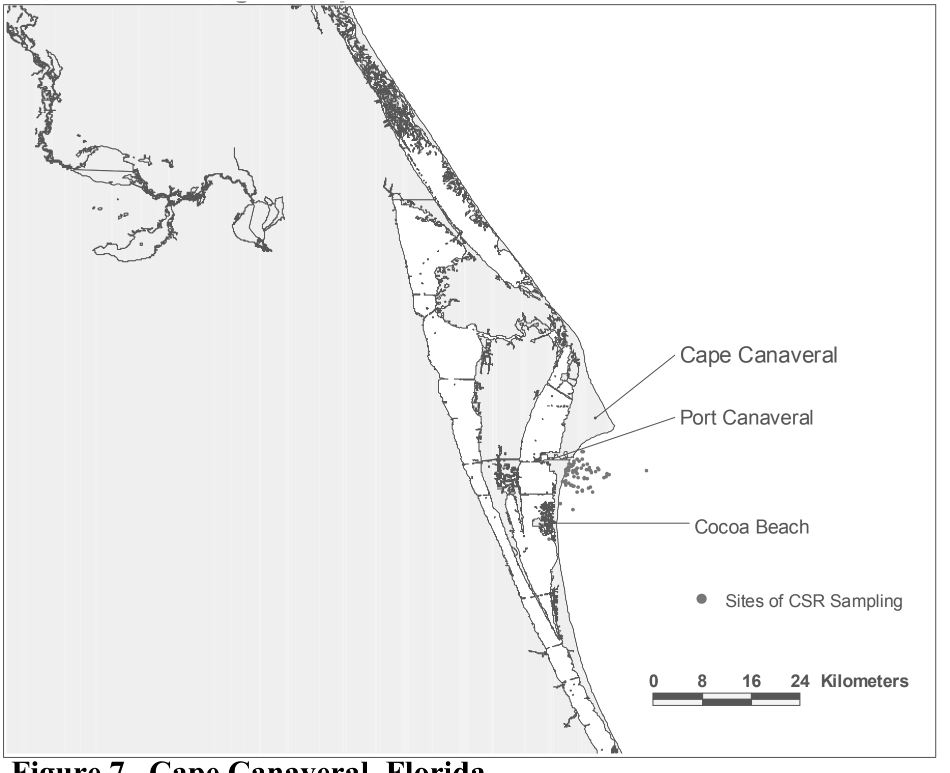

Figure 7. Cape Canaveral, Florida

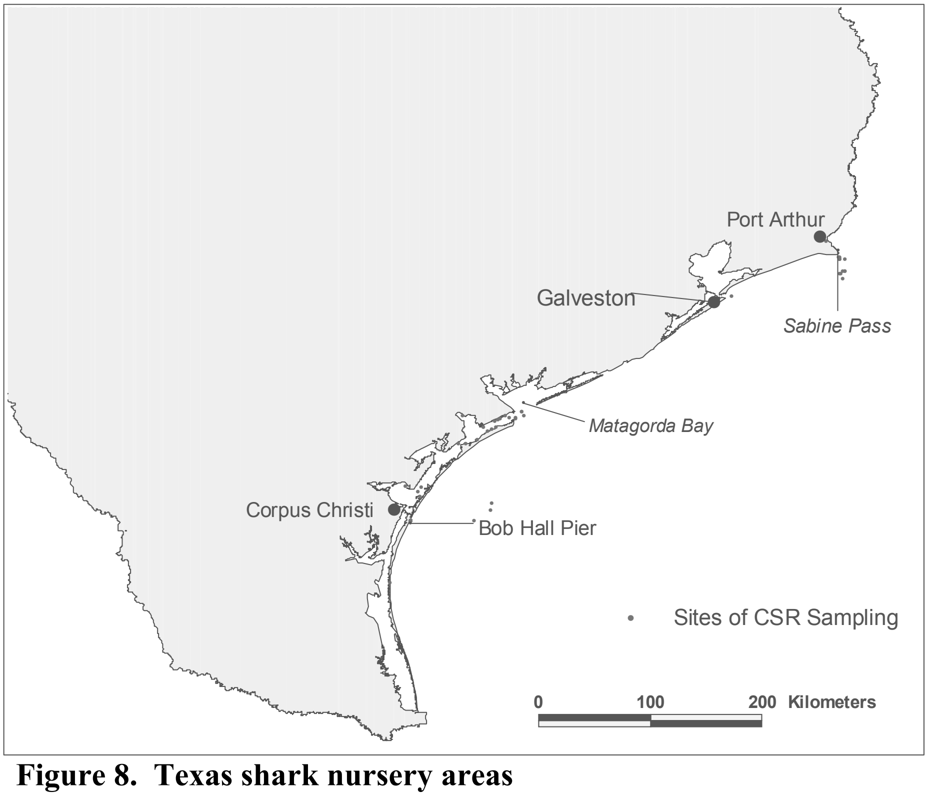

Figure 8. Texas shark nursery areas

Sabine Pass and Nearshore Oil Rigs

CSR tagging work in collaboration with recreational fishermen has focused on the Sabine Pass area, which lies on the Texas/Louisiana border and is the natural opening between Sabine Lake and the Gulf of Mexico. The salinity is highly variable in this area due to fluctuating flow rates from the Sabine River. Gulf waters surrounding nearshore oil rigs (2-3 miles from shore) have had salinities measured as low as 17 ppt. These rigs provide habitat that supports significant numbers of young sharks of several species.

Matagorda Bay Area

A collaboration with field staff from the Texas Parks and Wildlife Department (TPWD) has permitted the tagging of juvenile sharks during TPWD spring/fall gamefish surveys in the Matagorda Bay area. These surveys were undertaken primarily in the estuarine areas of Matagorda, Espiritu Santo, and San Antonio Bays on the Texas Gulf coast. These bays are protected by the Matagorda Peninsula and are fed primarily by the Colorado and Guadalupe Rivers.

Summary of Major Results

Bycatch and catch-release mortality of small sharks and associated fishes in the estuarine nursery grounds of Tampa Bay and Charlotte Harbor

This study conducted in 1991-93 identified Tampa Bay and Charlotte Harbor as nursery areas for a number of commercially and recreationally important shark species, including blacktip, spinner, bull, Atlantic sharpnose, blacknose, great and scalloped hammerhead, lemon, and bonnethead sharks. Analyses of fishing mortality determined that the immediate, observable mortality (30.6%) combined with an estimated delayed mortality (34.8%) yielded an estimated total mortality from a single fishing event of 54.8% of all juvenile and small adult sharks caught by gill net in this study. Although based on a low sample size, relatively low shark bycatch was found for the inshore commercial fisheries indicating that at least some of these fisheries are capable of operating in coastal waters without significantly impacting juvenile sharks. Tag recaptures indicated exchanges by individual sharks between the two estuarine systems for at least two species (bull and bonnethead). A pattern of spring/summer residence in the estuaries, with overwintering at another location and return to the estuaries the following spring/summer, was indicated for at least one species (blacknose) (Hueter and Manire, 1994).

Early life history and relative abundance of blacktip and other coastal sharks in Eastern Gulf of Mexico nursery areas, including bycatch mortality of sharks and associated fishes

In 1995-97, no consistently increasing trends were detected in relative abundance of juvenile blacktip sharks in any of the study areas (Yankeetown, Tampa Bay, and Charlotte Harbor), providing no direct evidence of a significant increase in juvenile recruitment through stock rebuilding of blacktip shark populations in the eastern Gulf of Mexico. Fall and winter recaptures indicate that young blacktips inhabiting these three eastern Gulf nursery areas in the spring and summer leave the nurseries in the fall and generally migrate south, with some recaptures in winter occurring as far south as the Florida Keys. Returns of one and two year-old juvenile blacktips back to their natal nurseries in the spring/summer of subsequent years also are indicated. Additionally, one-hour gill net sets resulted in an immediate, observable mortality of 43% for the juvenile blacktips. Post-release mortality as a result of gill net capture was estimated at 14% producing a total gill net mortality of 57% of young blacktips during the study (Hueter, 1999).

Preliminary Results from Additional Studies

Movement and Behavior Patterns of Blacktip Sharks in a Florida Nursery

An array of acoustic receivers deployed within Terra Ceia Bay, a known blacktip shark primary nursery area, has been used to monitor the long-term movements and behavior patterns of young blacktips. Over the course of three years, 92 neonate *Carcharhinus limbatus* were fitted with acoustic transmitters and monitored for periods of 1-167 days. Data from these animals suggest three types of movement/behavior patterns: 1) animals that leave the nursery area after a relatively short duration and do not return; 2) animals that move into and out of the nursery area; and 3) animals that remain within the nursery area until the end of the summer when they leave to migrate south. The initial activity space of juvenile *C. limbatus* inside Terra Ceia Bay is small and confined to one portion of the nursery area. However, habitat use increases over time as the sharks expand their home ranges and the proportions of the bay used. Temperature appears to provide a strong cue for animals to leave the nursery area as the colder fall months approach.

Movement and Migration Using Conventional and Acoustic Tagging Methods

To date, the CSR has tagged 10,354 sharks of 16 species and has received data on 359 recaptures (3.5%). Of these recaptures, the maximum distance traveled was 330 nm (finetooth shark, *Carcharhinus isodon*) and the longest time at large was 2,461 days (Atlantic sharpnose shark, *Rhizoprionodon terraenovae*). A trend of philopatric behavior, possibly resulting in natal homing, has emerged from these data. Tagged sharks of several species, in particular blacknose, bonnethead, and blacktip, have been recaptured in essentially the same location after significant periods at large and on annual cycles, i.e. approximately 1.0, 2.0, 3.0, etc. years later. In some cases, sharks have been recaptured on the same grassflat where they were originally tagged after being at large for five or more years. Current research utilizing both genetic analysis and acoustic tagging technology is testing the philopatry hypothesis with respect to the blacktip shark. In the Terra Ceia study to date, three 1 year-old juvenile blacktips and two 2 year-olds have returned to their natal nursery on annual cycles, as detected using acoustic telemetry.

Species Profiles

The following section provides general profiles of the 16 shark species for which juveniles have been documented by the CSR. The sample size (N) refers to the total number of specimens sampled from all CSR studies (in U.S. waters) combined. Detailed habitat characteristics for each species are separated into developmental stages (neonate, young-of-the-year [YOY], and juveniles) and reported in Tables 6, 7, and 8. The N values provided in these tables refer to the numbers of sampled specimens where environmental data were available and thus do not necessarily correspond with the N values provided in the following profiles.

Table 6. **CSR Nursery Overview -** ***Habitat Characteristics of Neonates (all areas sampled)***

		Temperature (°C)		Salinity (ppt)		Dissolved O_2 (mg/l)		Depth (ft)	
Species	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	17	28.1	30.1	32.2	37.0	6.50	7.07	5	6
Carcharhinus brevipinna	3	-	-	-	-	-	-	17	17
Carcharhinus falciformis	-	-	-	-	-	-	-	-	-
Carcharhinus isodon	-	-	-	-	-	-	-	-	-
Carcharhinus leucas	27	28.2	32.2	18.5	28.5	2.83	6.64	3	15
Carcharhinus limbatus	1001	22.7	33.6	20.5	41.1	3.69	9.00	3	41
Carcharhinus plumbeus	3	25.0	29.0	20.4	25.4	-	-	8	12
Galeocerdo cuvier	-	-	-	-	-	-	-	-	-
Ginglymostoma cirratum	-	-	-	-	-	-	-	-	-
Mustelus canis	-	-	-	-	-	-	-	-	-
Mustelus norrisi	-	-	-	-	-	-	-	-	-
Negaprion brevirostris	5	22.0	25.4	26.8	32.6	5.90	9.60	1	6
Rhizoprionodon terraenovae	3	24.0	30.7	22.8	33.7	5.73	5.73	6	11
Sphyrna lewini	1	28.0	28.0	30.0	36.0	-	-	3	20
Sphyrna mokarran	-	-	-	-	-	-	-	-	-
Sphyrna tiburo	1	27.8	27.8	15.4	15.4	-	-	3	7

Table 7. CSR Nursery Overview - *Habitat Characteristics of Young-of-the-Year (all areas sampled)*

		Temperature (^oC)		Salinity (ppt)		Dissolved O_2 (mg/l)		Depth (ft)	
Species	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	105	27.0	34.0	26.5	34.7	3.25	6.20	3	30
Carcharhinus brevipinna	86	24.7	31.7	21.0	37.0	4.60	7.07	2	126
Carcharhinus falciformis	-	-	-	-	-	-	-	-	-
Carcharhinus isodon	1	23.2	23.2	15.8	15.8	-	-	9	9
Carcharhinus leucas	70	21.5	34.0	3.0	33.3	3.70	8.40	2	10
Carcharhinus limbatus	1610	19.1	32.9	15.8	39.6	3.28	10.26	3	41
Carcharhinus plumbeus	-	-	-	-	-	-	-	-	-
Galeocerdo cuvier	8	30.8	30.8	31.8	31.8	4.90	4.90	66	162
Ginglymostoma cirratum	2	31.7	31.7	33.9	33.9	7.01	7.01	7	7
Mustelus canis	-	-	-	-	-	-	-	-	-
Mustelus norrisi	-	-	-	-	-	-	-	-	-
Negaprion brevirostris	7	19.6	31.6	25.8	34.7	6.50	7.12	2	4
Rhizoprionodon terraenovae	125	18.4	31.1	25.3	37.0	4.75	8.56	2	15
Sphyrna lewini	21	23.2	30.2	27.6	32.8	5.09	5.92	8	15
Sphyrna mokarran	16	23.9	31.1	21.9	34.9	5.00	5.30	5	20
Sphyrna tiburo	69	16.1	31.7	22.3	35.6	4.96	8.21	2	18

Table 8. CSR Nursery Overview - *Habitat Characteristics of Juveniles (all areas sampled)*

		Temperature (^oC)		Salinity (ppt)		Dissolved O_2 (mg/l)		Depth (ft)	
Species	**N**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Carcharhinus acronotus	497	17.3	32.5	25.6	37.0	4.76	8.71	3	198
Carcharhinus brevipinna	43	21.9	30.1	17.1	36.2	3.00	9.84	7	174
Carcharhinus falciformis	4	25.7	25.7	33.7	33.7	-	-	84	145
Carcharhinus isodon	31	33.8	33.8	11.5	11.5	8.50	8.50	7	18
Carcharhinus leucas	69	21.0	33.6	14.3	36.8	2.56	7.43	3	21
Carcharhinus limbatus	556	18.5	33.6	17.1	37.7	3.50	9.60	4	90
Carcharhinus plumbeus	10	25.7	25.7	27.0	27.0	-	-	96	96
Galeocerdo cuvier	3	23.4	30.2	32.0	36.5	6.90	6.90	6	192
Ginglymostoma cirratum	45	17.5	32.9	28.0	37.6	3.92	9.70	2	7
Mustelus canis	1	23.4	23.4	35.8	35.8	-	-	216	216
Mustelus norrisi	6	16.1	23.6	30.9	33.5	-	-	5	9
Negaprion brevirostris	20	19.1	33.0	19.5	38.5	5.61	7.30	2	7
Rhizoprionodon terraenovae	286	17.2	33.3	22.8	36.7	2.90	8.71	2	144
Sphyrna lewini	20	24.9	28.0	28.2	36.3	5.30	5.50	6	174
Sphyrna mokarran	60	20.9	32.9	15.8	35.9	4.22	6.76	5	108
Sphyrna tiburo	2340	15.9	33.0	16.5	36.9	2.88	10.46	2	16

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

The Atlantic sharpnose shark is a ubiquitous species in coastal Gulf waters. Juvenile sharpnose are frequently encountered in Florida in the Yankeetown, Tampa Bay, Charlotte Harbor, 10,000 Islands, Florida Keys, and Cape Canaveral areas. Collaborative field efforts have identified nursery areas in several of the northern Gulf States. Despite the widespread occurrence of this species, primary pupping grounds for the Atlantic sharpnose shark are not clearly delineated in the CSR database, probably due to the size selectivity of the CSR's primary gear (4.5" mesh gill net), which may miss the very small neonates of this species. Neonate sharpnose (N=4, TL 32-38 cm) are found in the Florida areas of Yankeetown and Tampa Bay from May to July and along the Texas coast in July. YOY sharpnose (N=141, TL 35-67 cm) are common throughout all the main Florida study areas with the exception of the Keys. First-year sharpnose have also been found during the month of May in the Cape Canaveral area of Florida's east coast. YOY sharpnose remain in their inshore and estuarine nursery areas throughout the summer and into the fall before migrating out by November. As one year-olds, these animals return the following spring to the nursery areas as early as March. Older juvenile sharpnose (N=289, TL 52-84 cm) return to the secondary nurseries along Florida's Gulf coast beginning in the early spring and are common in the nearshore waters of Cape Canaveral and Texas by mid-May. The juveniles utilize these nearshore nursery areas throughout the summer but offshore coastal nurseries have also been found off Texas, Louisiana, and Mississippi through longline surveys in the months of July and August. Similar to other species, juvenile sharpnose sharks begin to migrate out of these nearshore nursery areas as water temperatures decline, and few are seen after November or when the water temperature falls below 20^{o}C. Older juveniles are, however, found in the Florida Keys during the winter and also can be found in the warm water effluents of Tampa Bay power plants during the coldest months.

Blacknose shark, *Carcharhinus acronotus*

The blacknose shark is a relatively common component of CSR field sampling and has been found in the areas of Yankeetown, Tampa Bay, Charlotte Harbor, and the Florida Keys. Neonate blacknose sharks (N=17, TL 42-50 cm) are found along Gulf beaches in the Tampa Bay area throughout the month of June. YOY blacknose (N=143, TL 43-62 cm) remain present through the warm months along Gulf beaches but also in the estuarine areas of Tampa Bay and Charlotte Harbor and then migrate out of the area by late October. They are found in temperatures of 27-34^{o}C and in salinities as low as 26.5 ppt. Older juveniles of this species (N=497, TL 60-118 cm) are present along the Gulf beaches of Tampa Bay and Charlotte Harbor beginning in early March and remain present throughout the summer months. These older year classes have been a significant component of the shark catches in the annual CSR-sponsored Shark Census Tournament in which fishing activity has been focused heavily in the Tampa Bay region, but juveniles are also common in the areas of Yankeetown, Charlotte Harbor, and the Florida Keys. Juvenile blacknose are rarely seen after October in the inshore Gulf waters but are present in the Keys during the winter months. Tag-recapture data for this species suggest strong philopatric behavior and an annual homing cycle, i.e. seasonal returns to specific home areas on an annual basis.

Blacktip shark, *Carcharhinus limbatus*

Understanding the nursery dynamics of the blacktip shark has been a major priority of the CSR research agenda. Of the five Florida areas of study, Yankeetown has proven to be the most productive blacktip primary nursery followed by Charlotte Harbor, Tampa Bay, 10,000 Islands and the Florida Keys. Neonate blacktips (N=1,003, TL 51-71 cm) have been documented in all five of these Florida areas, and significant pupping takes place along the Texas coast as well. Blacktip pupping begins as early as mid-April and can continue as late as the first week of September, with the peak occurring in June. The primary nurseries can vary greatly in both water temperature and salinity (23-33^{o}C and 18.5-28.5 ppt, respectively). YOY blacktips (N=1,616, TL 49-90 cm) remain in the nurseries throughout the warm months and begin their fall migration in October and November when water temperatures fall to around 20^{o}C. Tag/recapture data suggest that first-year blacktips leaving the north-central Florida nurseries (Yankeetown area) in the fall migrate south as far as the Marquesas Islands west of the Florida Keys. YOY blacktips begin their northward spring migration back into the primary nurseries as early as late February but more typically in March and April. These areas additionally function as secondary nurseries, as the habitats of one year-old and older juvenile blacktips tend to overlap to a large extent with the primary nursery habitats. Older juvenile year classes (N=571, TL 68-143 cm) return to these nursery areas beginning in March and remain there throughout the summer before undergoing their fall migration in October and November. These juveniles often move well into estuaries and are found in salinities as low as 17 ppt. CSR collaborative studies indicate that immature blacktips also are commonly found associated with nearshore oil rigs during the warm months along the upper Texas coast as well as coastal areas of Mississippi and Louisiana. Similar to the bull shark, YOY and juvenile blacktip sharks have been found in the warm water effluents of Tampa Bay and Yankeetown power plants during the winter months.

Bonnethead shark, *Sphyrna tiburo*

Young bonnethead sharks are extremely abundant in the bays and estuaries and along the beaches of Florida's Gulf Coast. However, the precise locations of bonnethead primary nurseries are still not known, most likely due to the size selectivity of the primary gear type, which, as for the sharpnose, probably excludes the small bonnethead neonates. Late-term pregnant females (N=22) are found in July and August in the areas of Yankeetown, Tampa Bay and Charlotte Harbor. The only neonate bonnethead (TL = 29 cm) in the CSR database was found in Charlotte Harbor in early September. There appears to be significant latitudinal variation in the timing of bonnethead parturition. For example, pupping in the Florida Keys takes place in July whereas Tampa Bay bonnetheads pup in August. YOY bonnetheads (N=120, TL 30-55 cm) remain in these shallow nursery areas through September and begin their fall southward migration in October when water temperatures approach 20^{o}C. These first-year migrating animals are often found along the beaches in the late fall and winter, particularly during warming trends when water temperatures increase close to shore. YOY bonnetheads begin returning to their warm-season nurseries by March and are found in the bays and estuaries of Florida's Gulf waters throughout the summer. Juvenile bonnetheads (N=2,325, TL 51-89 cm) are common throughout all five of the CSR's major study sites as well as in Texas coastal waters. They often appear along the beaches in the late winter and early spring (February and March) and gradually move into the bays and estuaries by April where they are found in salinities as low as 16.5 ppt. Tag-recapture data suggest they return to their natal areas and remain in these secondary nurseries during summer and fall. The juveniles begin to leave the bays and estuaries in October when water temperatures drop to near 20^{o}C. They are rarely found in the bays after November. As with blacktip, bull, and sharpnose sharks, bonnetheads are commonly found during the winter months in the warm water effluents of Tampa Bay power plants. During their fall migration, juvenile bonnetheads are often found along the beaches very close to shore in November and December. In the Florida Keys, where temperatures are more stable, juveniles can be found at all times of the year.

Bull shark, *Carcharhinus leucas*

Young bull sharks are somewhat common during the warm months along Florida's Gulf coast and have been documented by the CSR in the areas of Yankeetown, Tampa Bay, Charlotte Harbor, 10,000 Islands and the Keys, as well as in Texas. The primary nursery areas for this species are typically in lower salinity estuaries and river mouths (as low as 3 ppt). Neonate bulls (N=27, TL 66-84 cm) have been found in the areas of Yankeetown, Tampa Bay, Charlotte Harbor, 10,000 Islands and in Texas between the months of May and August. YOY bulls (N=84, TL 68-100 cm) are found in these same areas throughout the warms months and remain in these nurseries until as late as November or until water temperatures fall to about 21^{o}C. The YOY bulls then return to these nursery areas the following spring as early as March. These same Florida areas (Yankeetown, Tampa Bay, Charlotte Harbor, 10,000 Islands and the Keys) also function as secondary nurseries for the bull shark. Juvenile bulls (N=80, TL 90-169 cm) return to these nursery areas in the spring as early as April and remain in the bays throughout the summer before undertaking their fall migration in October and November.

Texas bulls show a similar temporal pattern. Although juvenile bulls utilize the estuarine nursery areas (14-37 ppt), they do not appear to venture as far into freshwater as the neonate and YOY bulls. Additionally, YOY and juvenile bull sharks have been found in the warm water effluents of Tampa Bay and Yankeetown power plants during the winter months. It is believed these sharks become entrapped within these warm water plumes when the temperature of the surrounding water falls below the sharks' tolerance level, but definitive data are lacking. CSR studies of this phenomenon have recently been initiated.

Finetooth shark, *Carcharhinus isodon*

The finetooth shark is uncommon in the central to south Florida Gulf and Atlantic coastal waters but is relatively common in the northern Gulf, including along the Florida panhandle and Texas coasts. The primary nursery areas for this species have not been clearly identified (no CSR documented neonates) but pupping activity presumably occurs in the northern Gulf. One YOY was observed in October in the Yankeetown area of Florida (TL = 63 cm). Older juveniles (N=39, TL 66-127 cm) are commonly observed along the beaches of the lower Texas coast during spring and fall migrations.

Florida smoothhound shark, *Mustelus norrisi*

Young Florida smoothhounds are found close to shore along beaches and in bays of the Florida Gulf during the winter and early spring. The primary nursery areas for this species are not known as neonates have yet to be documented. Juveniles (N=8, TL 61-83 cm) are seen in the Tampa Bay and Charlotte Harbor areas from December to April with water temperatures of 16-23.5^{o}C.

Great hammerhead shark, *Sphyrna mokarran*

The great hammerhead shark utilizes shallow coastal waters along Florida's Gulf coast as nursery areas throughout the warm months. The location of their primary pupping grounds in this area is uncertain, as no neonates have been documented by the CSR, suggesting that their pupping grounds may be located off the beaches or further offshore along Florida's Gulf coast. The presence of YOY great hammerheads (N=20, TL 64-94) in June and July indicates that pupping occurs in late spring and early summer. YOY great hammerheads can been found in the Yankeetown, Tampa Bay and Charlotte Harbor areas throughout the summer but are seldom seen after October. These first-year animals return to the nursery grounds the following March and April. Juvenile great hammerheads (N=56, TL 98-211 cm) are commonly found close to shore in the bays and estuaries of the Yankeetown, Tampa Bay, Charlotte Harbor and 10,000 Islands areas. Longline surveys of Texas coastal waters have also revealed offshore secondary nurseries for this species.

Lemon shark, *Negaprion brevirostris*

Young lemon sharks are relatively common along Florida's southwest coast. Primary pupping grounds have been found in CSR surveys as far north as the shallow grass flats of Tampa Bay, where neonate lemons (N=5, TL 60-66 cm) have been found in the month of May in multiple years (1992 and 1993) in water temperatures of 22-25^{o}C. These Tampa Bay pupping areas most likely are on the northern fringes of lemon shark nurseries and probably contribute marginally to overall population recruitment. YOY lemons (N=14, TL 64-86 cm) are found in the summer and fall in Tampa Bay, the 10,000 Islands, and the Florida Keys. A few YOY lemons have been captured in December along the beaches of the south end of the Tampa Bay area, presumably during their fall migration southward. Older lemon shark juveniles (N=20, TL 85-225 cm) are seen in the spring as early as March and remain in their secondary nurseries along Florida's Gulf coast throughout the summer but have been rarely documented after November. Juvenile lemons are seen throughout the year in the Florida Keys area.

Nurse shark, *Ginglymostoma cirratum*

The primary nursery areas for the nurse shark have not been well documented, perhaps due in part to their small size at birth and tendency to avoid entanglement in gill nets. No neonates have been captured in any CSR-directed field collections. YOY specimens (N=6, TL 49-62 cm) are found at varying times throughout the year in Charlotte

Harbor and the Florida Keys. Older juveniles (N=48, TL 63-153 cm) are commonly observed from April to November in the areas of Tampa Bay, Charlotte Harbor, 10,000 Islands and the Florida Keys.

Sandbar shark, *Carcharhinus plumbeus*

Young sandbar sharks have not been found to any significant extent along the central and south Gulf coast of Florida but apparently are more common in the northern Gulf. A few neonates of this species (N=3, TL 48-63 cm) have been documented in the spring and early summer in the Yankeetown area. Secondary nursery areas for juvenile sandbars (N=10, TL 100-117 cm) have been found during the spring and summer along the upper Texas coast, Louisiana, and Bulls Bay, South Carolina.

Scalloped hammerhead shark, *Sphyrna lewini*

Young scalloped hammerhead sharks are not common in the nearshore waters of the Florida Gulf but are more prevalent in the shallow coastal waters of the northern Gulf as well as along the beaches of Florida's east coast. Neonates of this species (N=16, TL 44-51 cm) are frequently observed along the beaches of the lower Texas coast in late spring and early summer and also are occasionally seen in the Tampa Bay area at that time. YOY scalloped hammerheads (N=30, TL 45-76 cm) are present in the bays and nearshore nurseries during the summer months in the Florida areas of Yankeetown, Tampa Bay, Charlotte Harbor, and Cape Canaveral as well as along the beaches of the lower Texas coast. These first-year sharks typically move out of these areas by late October. Older juvenile scalloped hammerheads (N=11, TL 88-119) are fairly common along the beaches of Cape Canaveral from March to June and are occasionally seen in the Tampa Bay area. Secondary nursery areas for this species extend into deeper coastal waters, particularly off Texas where they have been captured during longline surveys and on rod & reel around offshore oil rigs.

Silky shark, *Carcharhinus falciformis*

The primary nursery areas for the silky shark are presumably in deeper offshore waters; no neonates or YOY have been collected during CSR directed field sampling or collaborative efforts. Juvenile silkies (N=4, TL 91-109 cm) are present in Gulf offshore waters off Florida in August and in the offshore waters off the lower Texas coast during April and May.

Smooth dogfish shark, *Mustelus canis*

There is minimal information on southern nursery areas for the smooth dogfish. One juvenile (TL=73 cm) was documented by the CSR as part of a NMFS survey off Louisiana where depth to the bottom was 216 ft.

Spinner shark, *Carcharhinus brevipinna*

The spinner shark is only an occasional catch component of CSR field sampling along Florida's Gulf coast but has been more frequently seen through collaborative studies based in Texas and on Florida's east coast near Cape Canaveral. The primary pupping grounds for this species in Florida are not clearly defined. Neonate spinners (N=3, TL 66-71 cm) have been documented in the middle of June off the beaches of Charlotte Harbor. YOY of this species (N=98, TL 59-90 cm) are occasionally seen during the summer months in the Tampa Bay and Yankeetown areas but are more common around the Cape Canaveral area, where they are seen from late May to the end of October. Additionally, YOY spinners are fairly common along the beaches and in the bays of Texas during the summer months and have been observed as late as mid-October. Juvenile spinners (N=48, TL 69-145 cm) are commonly found associated with nearshore oil rigs on the upper Texas coast, as well as in the coastal waters of Mississippi and Louisiana, during the warm months. In Florida, juvenile spinners are occasionally seen along the beaches of Tampa Bay, Charlotte Harbor, and the Cape Canaveral areas and they also enter estuarine areas with salinities as low as 17 ppt.

Tiger shark, *Galeocerdo cuvier*

Young tiger sharks are not commonly found in Gulf nearshore waters of the Florida peninsula. The majority of tiger shark specimens documented by CSR researchers have been those captured on the *Oregon II* during NMFS longline surveys in which

Mote Marine Laboratory dart tags were used. The CSR database contains no records of neonate tiger sharks to date. YOY specimens (N=10, TL 87-102 cm) have been collected during NMFS longline surveys (depths 66-162 ft) in July and August along the Louisiana, Mississippi, Alabama, and Florida coasts. Older juveniles (N=3, TL 127-242 cm) have been occasionally documented in the coastal waters of the Tampa Bay, 10,000 Islands and Mississippi areas.

Conclusions

Over the past decade Mote Marine Laboratory's Center for Shark Research has collected data on over 15,000 sharks of 16 species and four families that utilize coastal areas of the U.S. Gulf of Mexico and southeast Atlantic coasts as pupping and nursery areas. Each of these 16 species has its own temporal and spatial patterns of habitat use in the coastal zone. However, the following general trends have been observed in these Gulf and Atlantic shark nursery areas:

- The majority of pupping activity typically occurs in late spring and early summer. Neonate and YOY sharks inhabit the primary nurseries throughout the summer and into the fall.
- As water temperatures begin to drop in the fall, YOY sharks leave the primary nurseries and undergo typically southerly, and in some cases offshore, migrations to winter nursery areas.
- One year-old juveniles return to the summer nurseries the following year, and in some cases for several years after that, beginning in early spring. These juveniles leave the summer nursery in the fall to return to their winter nursery areas.
- Annual cycles of philopatric behavior, in which juveniles migrate back to specific nursery areas, are seen in large and small coastal shark species.

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The Florida Keys Nurse Shark Breeding and Nursery Grounds

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Scope

The NMFS / Albion College Nurse Shark Mating and Nursery Grounds Project has resulted from a cooperative effort between the NOAA/NMFS Apex Predators Program, Narragansett, RI and Albion College, Albion, Michigan. This project was supported by funds from NOAA's Highly Migratory Species Management Division, Silver Spring, MD. This project was also supported in part by funds from the Hewlett-Mellon Faculty Development funds and also from the A. Merton Chickering Endowed Professorship of Albion College. Logistical support was provided by the National Park Service. Directed field work on nurse shark (*Ginglymostoma cirratum)* reproduction has shown a close relationship between specific habitat and reproductive life history stages, particularly courtship, breeding and their primary and secondary nursery grounds. Many reproductive life stages are accessible in the Dry Tortugas. In June and July, adult nurse sharks use shallow coastal and insular waters to aid and control mating efforts. In September and October gravid females utilize the same shallow breeding waters during a time that precedes parturition. Neonates are born in late October, early November and young-of-the-year are found here year round. This species fully exploits and is probably dependant on such shallow habitats as these for these vital parts of their life history.

We have methodically studied this population of nurse sharks since 1992. Our study encompasses life stages from neonates to adults. Our sample sizes are fairly modest, but our non-invasive techniques allow us to capture many of the same sharks repeatedly. Both static and acoustic tags have been used to identify sexually active individuals and define their movements. We have tagged 187 nurse sharks to date and identified another 18 using unique body and fin markings.

Materials and Methods

Sharks have been observed since 1992, and tagged and sampled since 1993. Our earliest observations in 1992 and 1993 were hindered by our inability to identify individual sharks. Approximately 10% of the population of mating nurse sharks have useful and distinctive natural markings. Some natural marks heal rapidly, grow over or change in time, and fin notches look alike. Thus we chose tagging as the best method to identify individuals.

Tagging of adults began in June of 1993 as an aid to help us to better understand the dynamics of mating events. We use heavily constructed hand nets to capture the sharks. Six different types of tags have been used in this study. Tags were placed on dorsal fins and attached to the shark's body at the dorsal fin base. In the early years identification of sexually active individuals was accomplished by tagging mature males and females with passive, diver identifiable body tags using a modified speargun. NMFS 'M' type dart tags were chosen because they have good return rates on nurse sharks (Carrier 1985, Kohler, et al. 1998). They were easily modified for diver recognition by adding strings of coded beads made of 6 x 6 mm styrene plastic. After the second year, the 'M' tags, particularly on the males, became so overgrown with biofouling that they could not be 'read' by diving observers. After several trials, we switched to beads and alternate short sections of copper tubing painted with different colors of copper based boat bottom paint that, in conjunction with the copper beads, resisted biofouling. The size of the beads and their unique color combinations facilitated identification of individuals by divers and by surface observers, even when using binoculars from relatively long distances. Some adult nurse sharks in our study have probably lost their dart tags to coral bottoms, predators and other marine life. Lost tags are an inevitable long-term problem in tag studies.

In 1995 we started tagging juvenile nurse sharks with Hallprint tags and in 1997 shifted to Dalton - Henley nylon livestock ear 'Rototags' for juveniles and 'Jumbotags' for adults. Livestock are placed in the first dorsal fin on females and in the second dorsal fin on males. Although these tags still foul, they seem to foul less than dart tags and Hallprint tags, even when the latter has antifouling coatings. To provide a durable marker, all captured nurse sharks were also tagged internally with passive integrated transponder (P. I. T.) tags approximately 10mm under the dermis, beneath the right base of the first dorsal fin. See: Results 1991 – 2002 Tagging (below).

Because we work in a National Park and with a rarely encountered mating population of sharks, we have had to pioneer the use of novel capture methods (hand and cast nets) instead of the traditional gill nets and longlines. In the 2000, 2001, and 2002 field seasons, we employed a large hoop net to aid in the capture of adult animals. We believe that this is a new and unique technique for capturing large adult sharks in shallow water. We have been able to capture 28 large (250 – 275 cm TL) reproductively active sharks from our study population using these nets. Total length and sex were recorded from all captured sharks. Blood and tissue samples were taken from all sharks that were then tagged or retagged and released. Juvenile sharks are weighed to the nearest gram.

Remote observations of tagged and untagged breeding adult sharks were made from a temporary 7m high tower constructed of scaffolding and from small boats and kayaks. ‘In situ’ observations were made by free diving and photography.

Photographs of resighted and recaptured external tags will provide a permanent record of 'visual resightings.' Both still and video photography were utilized for recording mating behavior. Videography was useful in validating identification of animals but primarily in enumerating and quantifying the complex behaviors associated with mating. We equipped the video housings with external hydrophones to permit the addition of field observer voice records directly to videotape for later transcription and with underwater still cameras to combine videography with still photography.

Tracking Sharks with Moving Hydrophone Telemetry

Ultrasonic telemetry is a powerful tool to determine the fine scale daily activities of a few sharks and is used to track male and female adult sharks when they leave the lagoon and to determine their home ranges and activity cycles. Selected individuals were tagged with Vemco (Shad Bay, Nova Scotia) ultrasonic transmitters for telemetry. Receivers and hydrophones were deployed from small boats and kayaks to track tagged sharks. Transmitters were usually accompanied by a NMFS ‘M’ tag designed to remain after the transmitter breaks away.

Continuous Telemetry

Long term movement studies utilizing continuous telemetry technology has been shown to be useful in fisheries management (Wetherbee, et al. 2001). Our current work utilizes Vemco VR2 bottom monitors and R-Coded tags. To date seventeen sharks have been marked with ultrasonic transmitters that should have a life expectancy exceeding 12 months. As they communicate with eight Vemco VR-2 bottom monitors placed strategically around the study area, seasonal patterns of movements and habitat use are revealed.

Short Term Attached Video and Data Instrumentation

Another monitoring technique was the deployment of an instrument package known as Crittercam. This unit details short term (hourly) activities of the study population, shows mating depth and frequency for the animals involved, and, in the next deployment season, may reveal identities of participants in sexual encounters. Crittercam is finding broad applications in habitat and behavior studies of large sharks (Heithaus et al. 2001). We made five deployments of Crittercam in 2001 and four in 2002.

Genetics

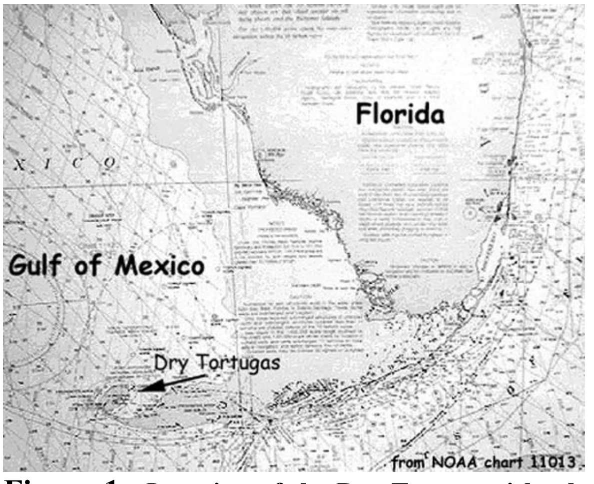

Figure 1. **Location of the Dry Tortugas island group (from NOAA chart 11013).**

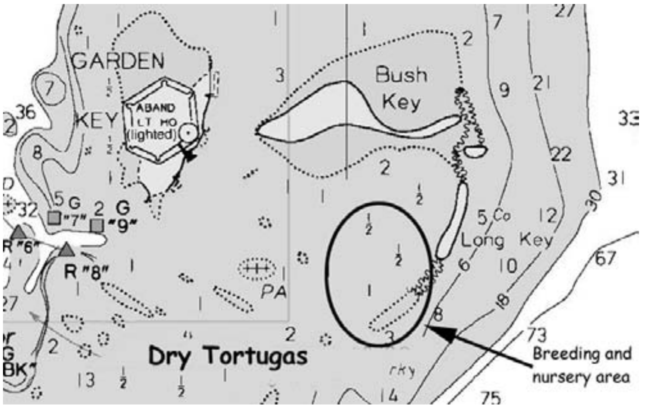

Figure 2. **Dry Tortugas nurse shark site. Garden Key and Fort Jefferson are to the left Approximate location of courtship / nursery area is indicated ellipse (from NOAA Chart 11438).**

In collaboration with Dr. Ed Heist of the University of Southern Illinois at Carbondale we have initiated a genetic study of these sharks. An important technological advance has been the development of highly polymorphic single locus markers (e.g. microsatellite loci) that provide far greater power in assessing genetic relatedness than was previously available. In this project we will use multiple highly-polymorphic microsatellite loci to discern details of the mating system in the Tortugas nurse shark population.

Description of Study Area

The study area is a shallow lagoon within the Dry Tortugas National Park in the Dry Tortugas archipelago west of Key West, Florida (Figure 1). Most observations were made in an area approximately 0.8 square hectares bracketed by Bush Key and Long Key (Figure 2). The depth of the water in the area varied from 0-1.8m. The lagoon is enclosed to the east by a spit of land that is submerged at high tide; its western side is a harbor of refuge 4-6 m deep bordering Garden Key. Most of the lagoon is a rich grass flat area with sand patches and shoals dominated by turtle grass, *Thalassia testudinum,* and manatee grass, *Syringodium filiforme.* The fishes are roving lutjanids (snappers), sparids (porgies) and carangids, (jacks). The shallowest parts are intertidal during spring and neap tides and have a mixed flora of brown and red algae grading up to coral rubble / mollusk shell bars and beaches. The common fauna of these area are pomacentrids (damsel fishes) and gerreids (mojarras). The deeper areas of the lagoon have coral patch reefs dominated by heads of *Montastrea cavernosa* up to 35 square meters with typical undercuts and caves. The fishes are typical reef residents, fishes of the families Haemulidae, Chaetodontidae, Labridae and Scaridae. A rich invertebrate fauna includes spiny lobsters and other crustaceans as well as the algal / coelenterate coral community complex.

These coral patch reef provide excellent habitat for juvenile nurse sharks [60 to 150 cm total length (TL)] and the grass flats and intertidal areas provide a rich forage area.

Tag and Recapture Data on Nurse Sharks

Diver identifiable tags are used to determine the identity, frequency and time period in which individuals participate in mating. Since 1993, we have tagged 187 nurse sharks (68 adults and 119 juveniles) in the Dry Tortugas study population. Of the identified adults, 55 were subsequently sighted (visually recaptured), at least once, and some more frequently, in one case as many as 65 times over the course of 11 years. Observations from tagging and natural markings indicate that most adult males visit the study site faithfully every year, with three dominant males and one 'alpha' male consistently observed since 1992. Results from our tag studies continue to support our hypothesis that adult females visit the study area to mate in alternate years. Females that have actively mated in one year have never returned the following year, but some sharks return after an absence of two or more years.

Four of the adults captured in 2000, three in 2001, and two in 2002 were originally tagged by us with spear-placed tags in 1994, 1995, and 1996.

Results of Courtship Behavior Studies

Between 1992 and 1998, we have witnessed over 380 nurse shark mating events at the Dry Tortugas, 30 (8%) ending with copulation (see 'Avoidance', below). Polygyny and polyandry have been found to be common, often with daily multiple matings. Typically, in the second and third weeks of June, females arrive in the shallow, 0.8 hectare, study lagoon.

Some females are chased into the shallow waters, swimming rapidly before the pursuing males (Figure 3). In some instances females were observed working their way slowly down the island's outer coast toward the lagoon. They were repeatedly driven to shoal against the rocky, algae covered, wave-beaten shore by two to four following males, before their arrival in the lagoon. With male pursuit a female movement of 300 m may take five to six hours. Females will often be in the company of one to four males that will circle in the shallow waters with them. We have noticed that male sharks will also closely follow each other during the mating season while in pursuit of females and while patrolling. We have conducted discreet 'in situ' inspections of all sharks when they first arrive to look for past tags and body condition. All newly arriving females exhibited fresh bite marks on their pectoral fins that varied in severity from mild scratches to bleeding, open wounds. Except for occasional healed scars and fin notches, males are generally unmarked.

Observations from tagging and natural markings indicate that most adult males visit the study site every year, sometimes in pairs or larger groups, with three males dominant in our observations since 1992. Typically the males enter the lagoon and rapidly swim a search pattern, apparently seeking females. After five to 60 min they depart the lagoon. Males may repeat these sorties alone or in company with three or more males several times a day. About 8% of the courtship events result in copulation (Figure 4.) For a detailed description of courtship and mating behaviors see: Pratt and Carrier (2001).

Recaptures from sightings of our modified dart tags show that adult females visit the study area to mate in alternate years, roughly half of the females being present in any one year. This biennial mating pattern is common in elasmobranch females and probably allows the post-partum females the time to rebuild reproductive reserves before mating again.

Results of the Telemetry Studies

Males tagged with ultrasonic transmitters in 1996 and 1997 showed a great deal of active swimming in their local patrolling behaviors supporting Springer's (1967) remarks of increased activity of males during the mating season. Males repeatedly patrolled the coast of the bracketing island in 2-12 m of water, resting at intervals near reef structure.

Six tagged adult females were released back into the study area after nearly 12 months of confinement at SeaWorld. All females rapidly departed the area at release. A transmitter placed on one of these females on 3 Jun 1998, at 10:27h showed movement south for eight hours after tagging and release. The shark traveled along the 10m depth contour, then southeast into open, deeper waters until lost at 18:39 h.

These observations indicate a different behavior than seen in the females seeking to stay in the lagoon. We believe that females released from a year of confinement in SeaWorld are physiologically unprepared to be in a mating area (wrong alternate year for these individuals) and quickly leave the mating grounds, possibly to return to their home range. Post confinement shock syndrome may also play a role. More information is necessary to elucidate these ideas.

Nursery Grounds

Evidence that the breeding area may also serve as a nursery area was forthcoming early in our study of mating behavior. In 1992 we found a juvenile nurse shark (57 cm TL) with the spotted markings characteristic of a very young shark in the turtle grass flats south of Bush Key and within our study area (Figure 5). To date, we have spent approximately 100 person hours looking for neonates and have yet to identify a unique niche specific to neonates. In our study area, very small nurse sharks are commonly found resting in turtle grass and swimming along shallow coral rubble beaches (~ 20-30 cm deep) often on rising tides. They also occur in cryptic spaces beneath coral heads, under narrow rock ledges and in Octcorillia (soft coral) communities.

Figure 3. **Female nurse shark, (upper) about to be grasped by a male as a prelude to mating.**

Figure 4. **Nurse sharks copulating in the study area. Each shark is approximately 2.5 m in total length.**

Figure 5. **Juvenile nurse shark 47 cm TL caught in study area with one of the seasonal closure buoys.**

Figure 6. Adult females segregated in the study area in October

Castro (2000) concludes that embryos are born at 28 to 30.5 cm in November and early December. Carrier and Luer (1990) reported growth in the first year of 13 cm +/- 9 cm. Therefore, we can estimate the size range of one year old nurse sharks to be between 32 to 52 cm. We have captured 7 sharks in this size range or 8.33% of the non-adult sharks captured.

If we define a neonate as a shark no more than six months old, with an estimated size range of 30 to 41 cm, then only one of the seven was a neonate. Some juveniles retain their dermal pigment spots for at least a year. Spots are not a reliable indicator of the neonate condition.

On warm sunny afternoons in October gravid females rest on the bottom in the shallow study area (Figure 6). Empty egg cases are found among them on the bottom at this time. Directed investigations following these assemblages and during the time of parturition (October – November) should be undertaken to quantitatively assess the location, distribution, and niche requirements of neonates.

Species profile

Nurse shark, *Ginglymostoma cirratum*

The nurse shark, *Ginglymostoma cirratum*, is a "keystone species" to understanding shark reproduction. Although widely distributed throughout the Florida Keys and Caribbean Sea, and commonly encountered by fishermen and divers, nurse sharks have not been comprehensively studied. Nurse sharks are a tropical to subtropical species associated with coral communities and live bottom, low relief rock outcrops encrusted with sponge and gorgonians.

The nurse shark is not far ranging; most individuals spend their entire life cycle within an area of a few hundred square kilometers (Kohler et. al. 1998, Carrier and Luer. 1990). They live for the most part in shallow, clear, nearshore waters, facilitating observation. Thus the Dry Tortugas population has many of the advantages of a captive group of sharks: individuals may be repeatedly observed and recaptured, yet still exist in a wild, uncompromised state. Since nurse sharks are fairly docile, individuals up to 2.7m in length (the size of the largest adults) may be captured by hand, measured and tagged, and tissue samples taken with a minimum of stress. Furthermore, adults apparently carry out some or most of their courtship and mating in shallow water where it is visible to observers.

Environmental information for the Dry Tortugas study area is similar to most small insular areas. Salinity is that of full ocean ranging close to 36 ppt. Seawater temperature averages range from 22 to 30 degrees C. Annual air temperature means are from 21 to 29 degrees C.. Oxygen levels are close to saturated. Oxygen levels are supersaturated in the well vegetated shallows. Tidal range is about 2 m on spring and neap tides.

Acknowledgments

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Sharks of the Ten Thousand Islands Estuary in Florida

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Scope

This report gives shark capture results taken from two different studies conducted by researchers from the University of Basel, Switzerland as part of their doctoral theses. The Rookery Bay National Estuarine Research Reserve, Florida Department of Environmental Protection, Naples and Mote Marine Lab's Center for Shark Research, Sarasota assisted in the development and realization of the two studies within the estuary of the Ten Thousand Islands (TTI), Florida. After preliminary investigations in 1997 and 1998 the following projects were created: A) A study of the activity patterns of two carcharhinid shark species, the bull shark, *Carcharhinus leucas,* and the blacktip shark, *Carcharhinus limbatus* using ultrasonic telemetry; B) A study focusing on two aspects within the TTI estuary: environmental circumstances and shark abundance and distribution. Both of these aspects were looked at with spatial and a temporal point of view. Connecting one aspect with the other made it possible to examine the environmental factors likely to be affecting the distribution and abundance of coastal shark species within the estuary of the TTI.

A total of 1146 sharks representing nine species were caught between 1997 and 2000 during the preliminary investigations and the two studies in the Ten Thousand Islands estuary.

Sampling Materials and Methods

After the exploratory sampling in 1997 and 1998, sampling was conducted at regular intervals from May through October in 1999 and 2000. Each microhabitat (see below) was sampled once a week using the principles of simple random sampling. Sampling effort per microhabitat was kept constant during all seasons. Since most of the area to be sampled was not navigable during low tide, gillnetting was undertaken 2½ hours before high tide until 2½ hours after high tide. The preliminary investigations showed that the sharks are most active during the night and early morning hours, leading to the decision to concentrate sampling between midnight and noon.

A 91.5 m (300 ft) long by 2.4 m (8 ft) gillnet comprising 6.5 cm (2.5 inch) stretch mesh made of #12 (16 lb test) nylon monofilament and a 91.5 m (300 ft) long by 1.8 m (6 ft) gillnet comprising 3.8 cm (1.5 inch) stretch mesh made of #6 (8 lb test) nylon monofilament were used. Gillnets were set for 30 minutes. Anchors at the beginning and the end of the net prevented drifting and inflatable net buoys marked the net. Observing the net continuously helped to recognize bigger animals swimming into the net. In this case the entangled animals were removed immediately. After 30 minutes the net was hauled back. All sharks were measured (STL, TL, FL, PCL, CLL), weighed, sexed and tagged with a Hallprint dart tag if possible. The sharks were released and their condition was recorded. Rays were identified, sexed, weighed and measured (disk width, disk length). In addition all fishes were removed from the net and were identified, measured (TL) and weighed.

A 10 hook floating longline was also used. The mainline consisted of 100 m (328 ft) of 5/16" hollow braided nylon polyrope and 10 gangions comprised of #1 Mustad shark hooks and 2 m of multifilament stainless cable with standard snap on connectors. Frozen mullet (*Mugil cephalus*) and crevalle jack (*Caranx hippos*) were used as bait. Longlines were set with a gangion every 10 m and a weight was attached at 50 m. An anchor and an inflatable buoy were attached on each end of the line. A small float was attached to each gangion. Two movable nylon knots before and after each float made it possible to use the float at varying water depths. Using this method, the hook with the bait was suspended in the water column at all times.

The line was checked every hour and the bait was replaced every two hours. Fishes on the longline were identified, measured (TL) and weighed. Sharks were measured (STL, TL, FL, PCL, CLL), weighed, tagged and released from the hook.

A total of 1612 gillnets and 176 longlines was set during the following periods of time:

From:	To:	# of gillnets	# of Longlines
03 April 1997	28 May 1997	115	0
11 Feb.1998	01 April 1998	140	20
14 May 1998	15 Aug. 1998	150	49
04 May 1999	26 Oct. 1999	560	51
01 May 2000	26 Oct. 2000	647	56
TOTAL	1997-2000	1612	176

For the tracking studies coded ultrasonic tags (Type CT-82-2), a directional hydrophone (Type: DH-2) and a wide band receiver (Type: USR-W5) from SONOTRONICS, Inc. (Tucson, AZ) were used. Shark locations were recorded at 15-minute intervals using a Global Positioning System (GARMIN GPS II plus). The ultrasonic tags were attached to the first dorsal fin of the shark.

Description of Study Area

The Ten Thousand Islands National Wildlife Refuge is located south-east of the small village of Goodland in Collier County, on the southwest coast of Florida, and is part of the extensive TTI estuary (Figure 1). The TTI estuary borders the Everglades National Park in the Southeast.

The most prominent habitat type of the TTI estuary is the mangrove forest that dominates most tidal fringes and the numerous islands. There are also areas of beach dunes, seagrass beds, tropical hardwood hammocks, and salt marshes. The mangrove forests of southwest Florida are composed of four species: red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*) black mangrove (*Avicennia germinans*) and a mangrove associate, the green buttonwood (*Conocarpus errectus*). The TTI estuary belongs to the biggest mangrove forest in North America and is a natural environment to many species of plants and animals, both marine and non marine (Odum *et al.*1982). An inventory of the floral and faunistic species is reported in Nalley *et al.* (1997), excluding the sharks.

The TTI estuary is shallow with a water level usually less than 2 m deep. Some channels flowing through the estuary can be as deep as 6 m. Salinity in this region is usually stable (> 30 ‰), except after the rainy season in summer when salinity can get as low as 10 ‰. Water temperature is about 30 °C in the summer and around 20 °C in the winter (Nalley *et al.* 1997).

The following water quality ranges were measured at the sampling stations during the periods of 1999 and 2000 (no water quality measurements were made in 1997 and 1998): water temperature: 19.7 °C – 32.1 °C (mean: 27.8 °C, SD: 1.9 °C), salinity: 12.8 ‰ – 41.7 ‰ (mean: 32.7 ‰, SD: 5 ‰), dissolved oxygen: 2.5 mg/l – 7.6 mg/l (mean: 4.8, SD: 0.9 mg/l), and depth: 0.5 m - 6.8 m (mean: 1.6 m, SD: 0.6 m).

Sampling took place along two transects characterized by a river entering the estuary. Both transects could clearly be distinguished into three different microhabitats representing the sampling sites: Backwater area, Transition area and Gulf Edge area (Figure 2). These microhabitats comprise gradients defined by salinity, temperature, oxygen and turbidity, especially during the wet season. Furthermore there are differences in depth, substratum, tidal exposure and degree of protection. These heterogeneous conditions and environmental diversity offered a great opportunity to study the responses of different shark species to different but nearby microhabitats.

Relative Abundance and Distribution

A total of 1146 sharks were caught, of which 1062 were caught with gill nets and 84 with longlines. Six hundred ninety-seven (61%) sharks were tagged, with 29 (4%) of these being recaptured. Of the sharks caught, 383 were mature, 437 were immature, 204 were young-of-the-year and 96 were neonates. For an overview of catches and recaptures

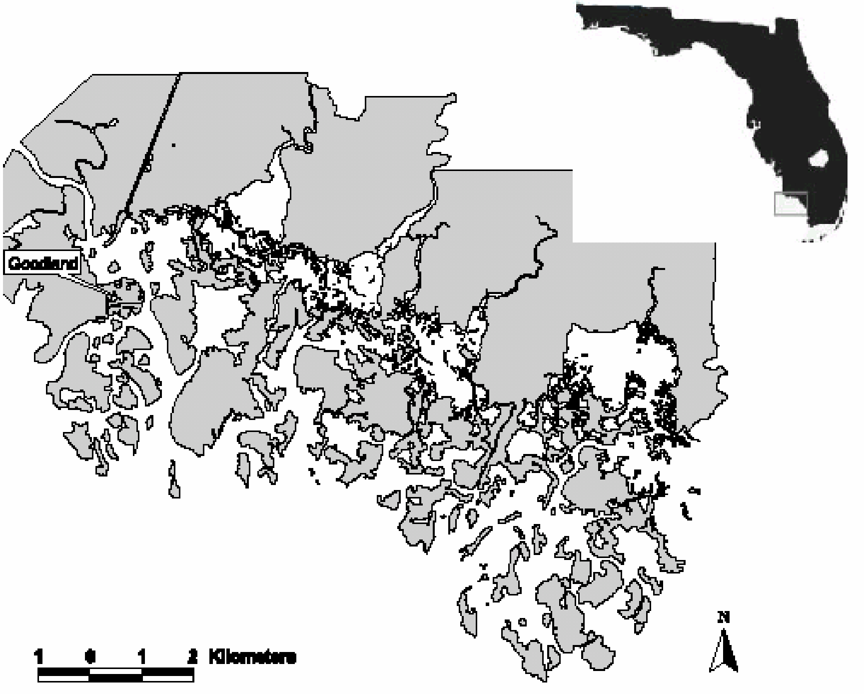


Figure 1. **The Ten Thousand Islands Estuary, Florida.**

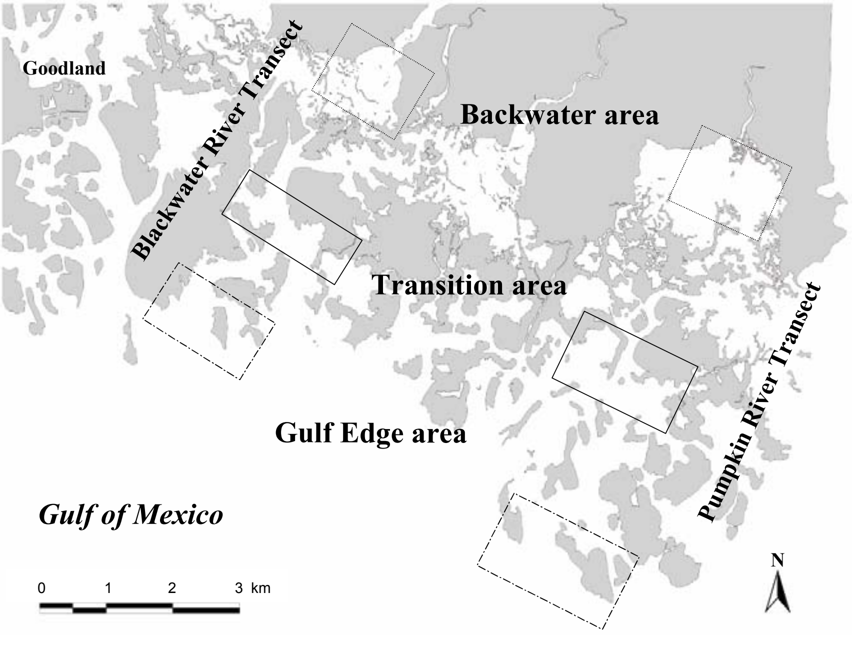


Figure 2. **Rectangles define sampling area within the three microhabitats of the Ten Thousand Islands Estuary from May through October 1999 and 2000.**

Table 1. Overview of all sharks caught in the Ten Thousand Islands Estuary from 1997 through 2000.

Species	#	m	f	not sexed	gillnet	LL	tagged	adult	immature	yoy	neonate	recaptures
Sphyrna tiburo	667	379	280	8	667	0	428	382	263	3	2	19
Carcharhinus limbatus	300	131	161	8	289	11	171	0	18	189	89	7
Carcharhinus leucas	75	26	41	8	57	18	68	0	63	7	3	1
Negaprion brevirostris	55	18	33	4	21	34	6	0	49	4	1	2
Ginglymostoma cirratum	26	12	10	4	7	19	7	0	24	0	0	0
Sphyrna mokarran	13	2	11	0	12	1	11	0	13	0	0	0
Rhizoprionodon terraenovae	7	4	2	1	7	0	6	1	5	0	1	0
Sphyrna lewini	2	2	0	0	2	0	0	0	1	1	0	0
Galeocerdo cuvier	1	1	0	0	0	1	0	0	1	0	0	0
TOTAL	**1146**	**575**	**538**	**33**	**1062**	**84**	**697**	**383**	**437**	**204**	**96**	**29**

see Table 1 & 2. Due to a lack of experience there was no differentiation made between neonate and young-of-the-year animals in the years 1997 and 1998. In addition to the sharks a total of 66 species of rays, teleosts, reptiles, crustaceans and other invertebrates were caught as bycatch (Table 3).

Catch per unit effort (CPUE) was measured as sharks per hour of gillnetting. No CPUE analyses were made with longline sets.

The temporal pattern for shark catches in 1999 & 2000 showed (Figure 3):

- The bonnethead shark started of with low catches in May followed by a steady increase in early summer, a peak of abundance in July, 1999 and in August, 2000 and a continuous decrease towards the end of season.
- The blacktip shark was the most abundant shark in late spring reaching its peak in July 1999 and June 2000, followed by a marked drop in the second half of the season.
- The bull shark showed a contrary pattern to the blacktip shark with low catches the first half of the season and an increased CPUE during the second half.
- The lemon shark showed no obvious pattern with low catches all season.

The spatial pattern for shark catches in 1999 & 2000 showed (Figure 4):

- The bonnethead shark showed no significant difference in CPUE among the three microhabitats.
- The CPUE for the blacktip shark was significantly lower within the Backwater area than within the other two microhabitats and this species was most abundant within the Gulf Edge area (especially in 1999).
- The bull shark was nearly absent within the Gulf Edge area, showed relatively low catches within the Transition area and had a significantly higher CPUE within the Backwater area.
- The lemon shark showed no differences among microhabitats in terms of CPUE.

To consolidate the spatial patterns described above we calculated the index of selectivity (L), which showed the following trends in habitat preferences (Figure 5):

- The bonnet head shark appeared to be a spatial opportunist, with a slight preference for the Transition area in 2000.
- The blacktip shark showed a clear avoidance of the Backwater regions and a marked selectivity for microhabitats being closer to the Gulf.
- The bull shark was concentrating on the Backwaters and was avoiding the Transition and the Gulf Edge area.
- The lemon shark showed a similar selectivity as the bull shark but less marked.

Listing the sites of captures for each species along a transect from the river mouth to the Gulf using a box plot we found a clear spatial separation between the bull shark and the blacktip shark (Figure 6). The bonnet head shark showed the broadest use of the area whereas the blacktip had restricted habitat utilization.

One of the main questions during this study was: Are certain environmental factors responsible

Table 2. **Recaptures within the Ten Thousand Islands Estuary 1997-2000.**

species	sex	growth PCL (cm)	days	distance* (km)
S. tiburo	f	2	461	4.7
S. tiburo	f	3	392	8.2
S. tiburo	f	0	15	0.0
S. tiburo	m	4	1231	0.0
S. tiburo	f	4	127	0.0
S. tiburo	m	0	0	0.0
S. tiburo	m	0	9	0.0
S. tiburo	m	0	30	0.0
S. tiburo	f	0	5	11.1
S. tiburo	m	1	338	0.0
S. tiburo	m	0	358	0.0
S. tiburo	m	0	404	0.0
S. tiburo	m	0	323	3.0
S. tiburo	f	1	42	0.0
S. tiburo	f	1	60	10.5
S. tiburo	f	0	6	0.0
S. tiburo	f	0	0	0.0
S. tiburo	m	0	1	0.0
C. limbatus	f	0	25	1.0
C. limbatus	f	0	25	4.7
C. limbatus	f	0	17	0.0
C. limbatus	m	0	3	0.0
C. limbatus	f	3	48	0.0
C. limbatus	m	0	0	0.0
C. limbatus	m	0	14	0.0
C. leucas	f	0	0	0.0
N. brevirostris	f	0	1	0.0
N. brevirostris	m	0	3	0.0

* 0.0 kilometers means the shark was caugth within the same bay (within 500 m from first capture)

Table 3. Gillnet bycatch Ten Thousand Islands Estuary 1997 - 2000.

Elasmobranchii

Aetobatus narinari	Spotted Eagle Ray
Dasyatis americana	Southern Stingray
Dasyatis sabina	Atlantic Stingray
Gymnura micrura	Smooth Butterfly Ray
Narcine brasiliensis	Lesser Electric Ray
Pristis pectinata	Smalltooth Sawfish
Raja sp.	Skate
Rhinobatos lentiginosus	Atlantic Guitarfish
Rhinoptera bonasus	Cownose Ray

Teleosts

Archosargus probatocephalus	Sheepshead
Arius felis	Hardhead Catfish
Bagre marinus	Gafftopsail Catfish
Bairdiella chrysoura	Silver Perch
Brevoortia smithi	Yellowfin Menhaden
Brevoortia sp.	Menhaden
Caranx hippos	Creavalle Jack
Centropomus undecimalis	Common Snook
Chaetodipterus faber	Atlantic Spadefish
Chilomycterus schoepfi	Striped Burrfish
Cynoscion nebulosus	Spotted Seatrout
Diapterus plumieri	Striped Mojarra
Echeneis naucrates	Sharksucker
Elops saurus	Ladyfish
Ephinephelus ijatara	Jewfish
Eucinostomus argenteus	Spotfin Mojarra
Hippocampus sp.	Seahorse
Lagodon rhomboides	Pinfish
Leiostomus xanthurus	Spot
Lobotes surinamensis	Tripletail
Lutianus griseus	Mangrove Snapper
Megalops atlanticus	Tarpon
Menthicirrus americanus	Southern Kingfish
Micropogonias undulatus	Atlantic Croacker
Mugil cephalus	Striped Mullet
Mugil gyrans	Fantail Mullet
Ogcocephalus radiatus	Polka-Dot Batfish

Teleosts continued

Oligoplites saurus	Leatherjacket
Opisthonema oglinum	Atlantic Thread Herring
Paralichthys albigutta	Gulf Flounder
Paralichthys lethostigma	Southern Flounder
Pogonias chromis	Black Drum
Pomatomus saltatrix	Bluefish
Rachycentron canadum	Cobia
Scaphthalmus aquosus	Windowpane
Sciaenops occelatus	Red Drum
Scomberomorous maculatus	Spanish Mackerel
Scomberomorous regalis	Cero
Selene vomer	Lookdown
Trachinotus carolinus	Florida Pompano
Trachinotus falcatus	Permit

Reptiles

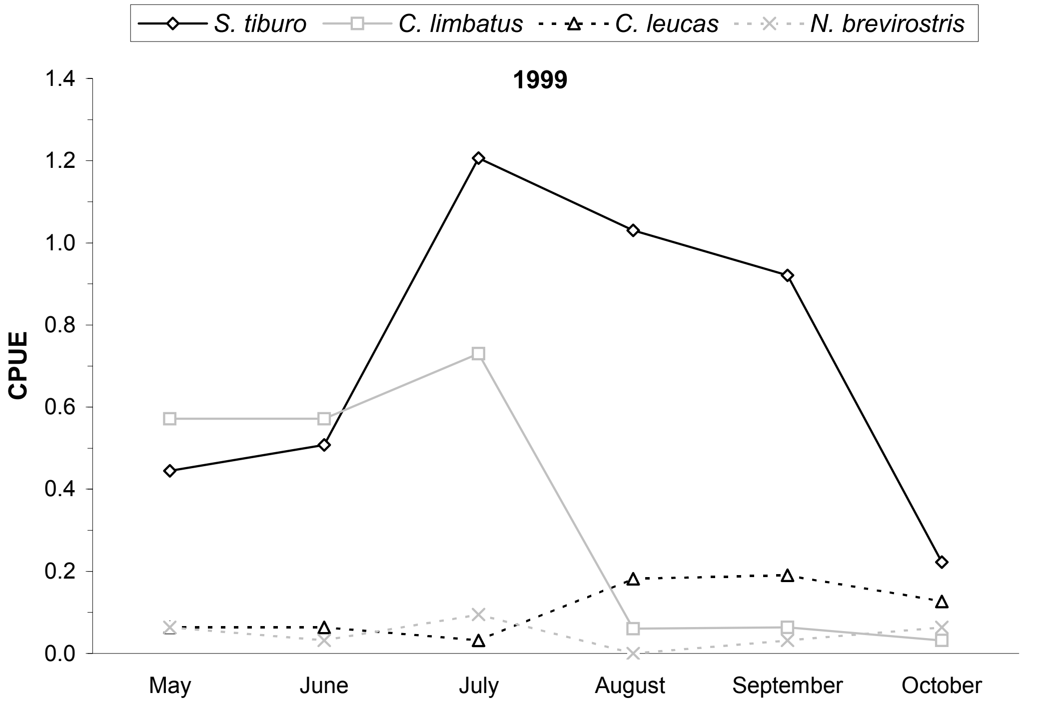
Caretta caretta	Loggerhead Turtle
Chelonia mydas	Green Sea Turtle
Lepidochelys kempi	Kemp's Ridley Sea Turtle

Crustacea

Calinectes sapidus	Blue Crab
Libina dubia	Spider Crab
Menippe mercenaria	Stone Crab
Petrochirus diogenes	Giant Hermit Crab
Stenocionops furcata	Giant Decorator Crab

Other Invertebrates

Aurelia aurita	Moon Jelly
Bursatella leachii pleii	Ragged Sea Hare
Busycon contrarium	Lightning Whelk
Cassiopeia xamachana	Mangrove Upside-Down Jellyfish
Echinaster spinulosus	Brown Soiny Sea Star
Limulus polyphemus	Horseshoe Crab
Luidia senegalensis	Nine-Armed Sea Star



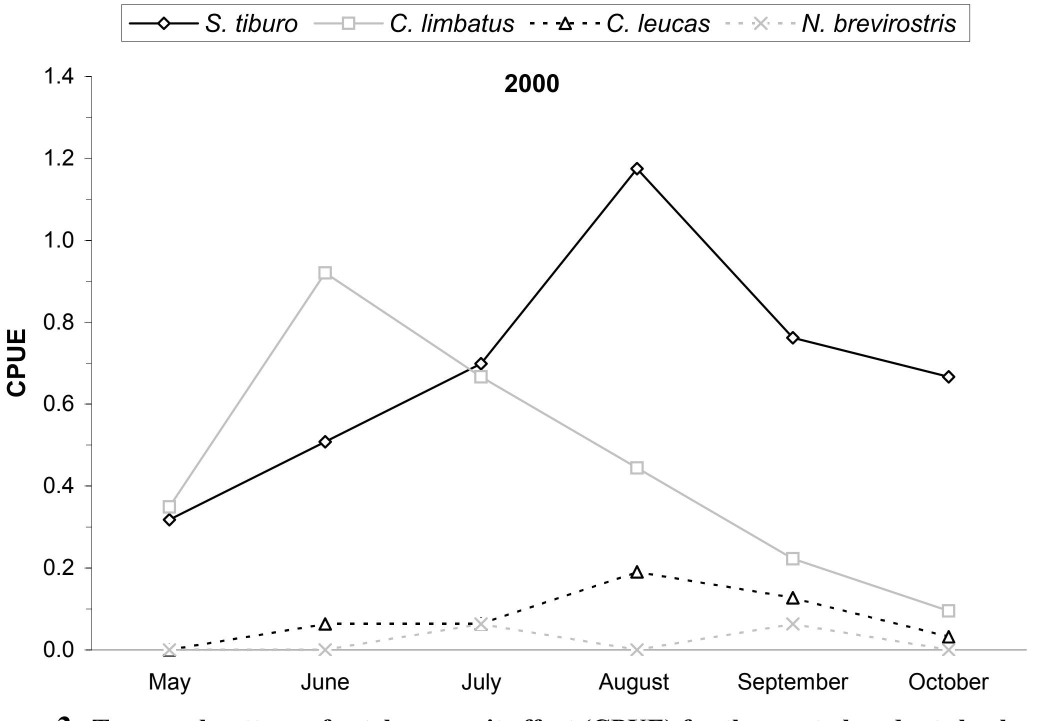


Figure 3. **Temporal pattern of catch-per-unit effort (CPUE) for the most abundant sharks species within the Ten Thousand Islands Estuary, Florida from May through October 1999 and 2000.**

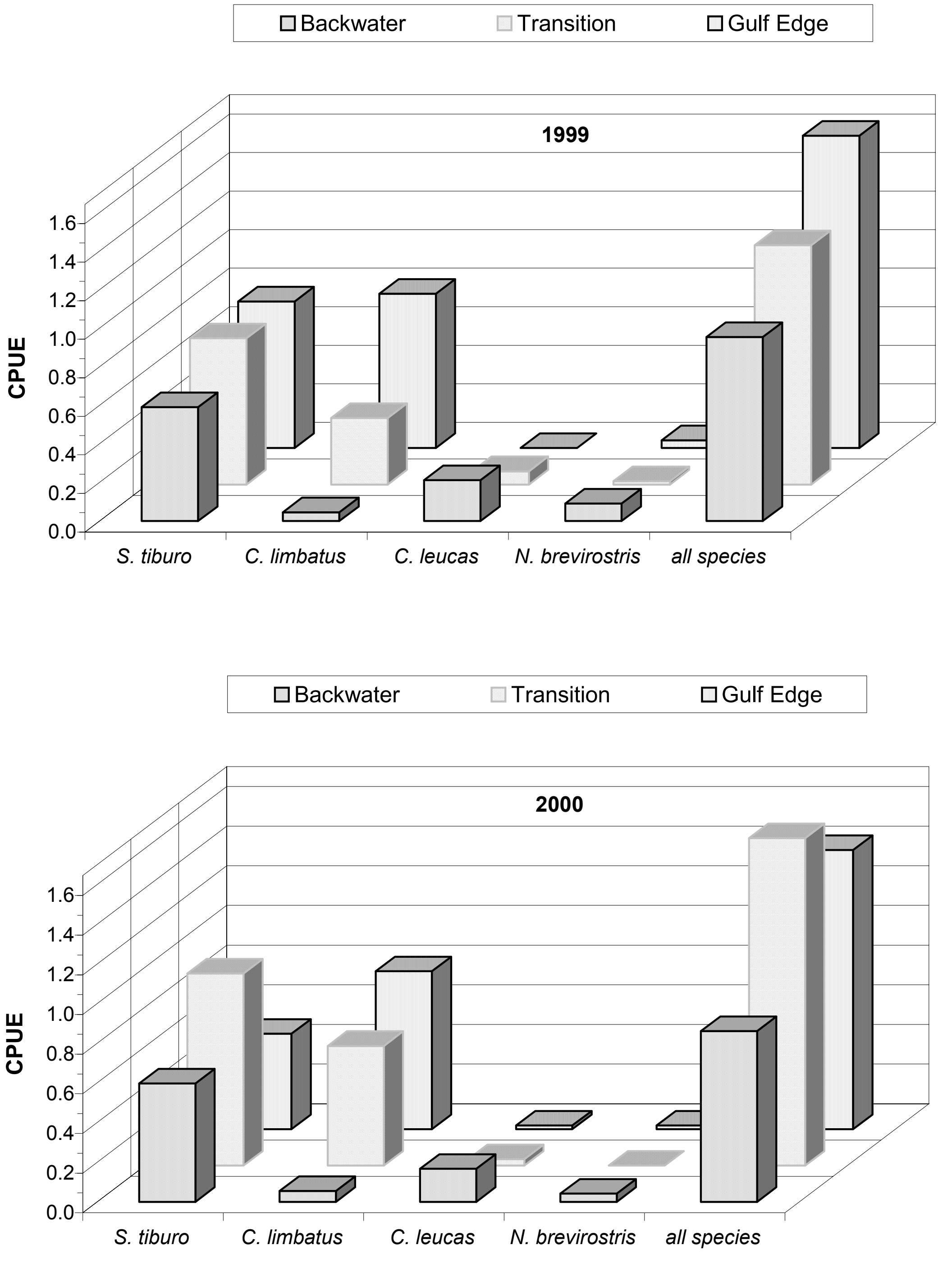
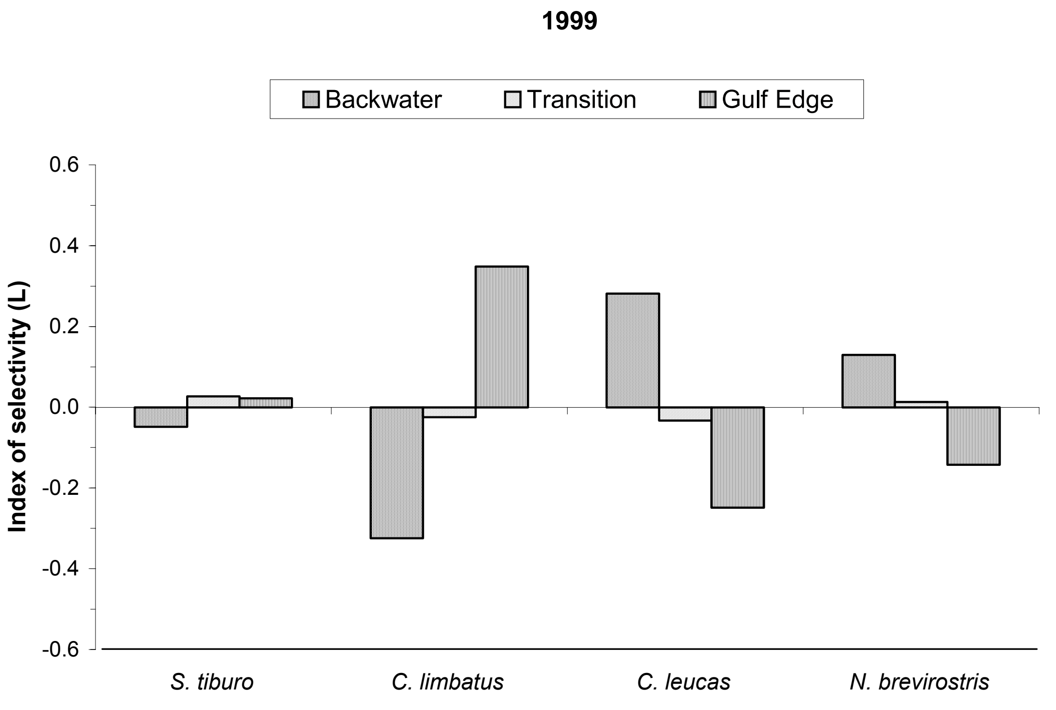


Figure 4. **Mean catch-per-unit effort (CPUE) for the four most abundant sharks species in three microhabitats within the Ten Thousand Islands Estuary, Florida from May through October in 1999 and 2000.**



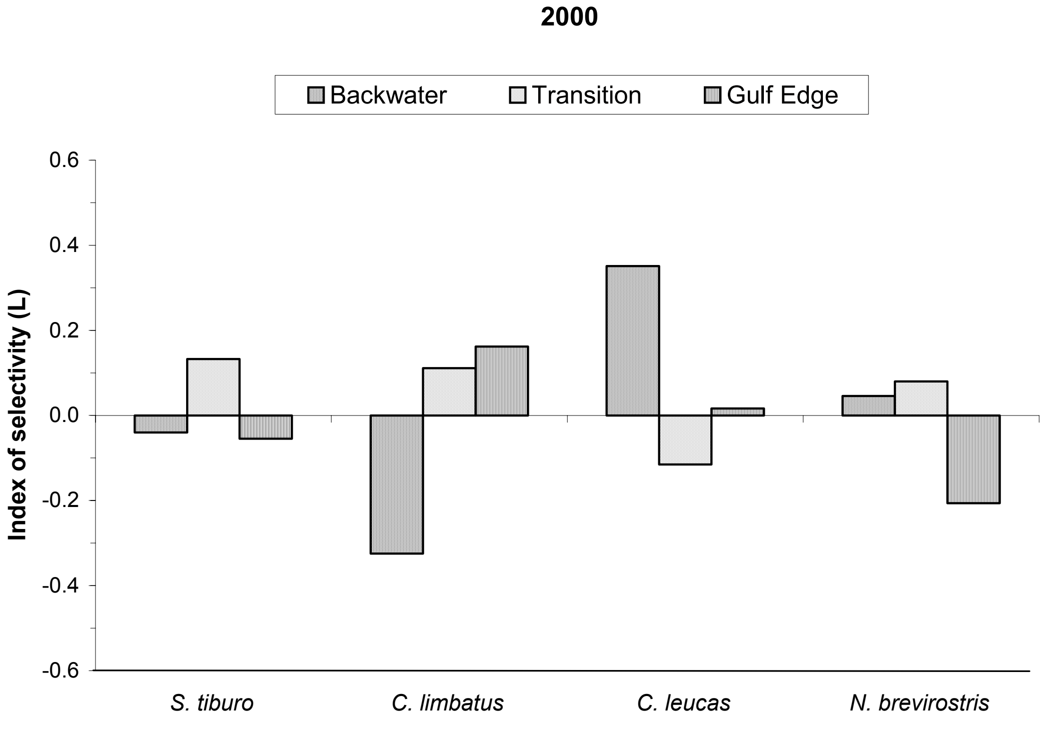


Figure 5. **Microhabitat selectivity (L) of the most abundant shark species within the Ten Thousand Islands Estuary, Florida in 1999 and 2000. All months combined (May through October).**

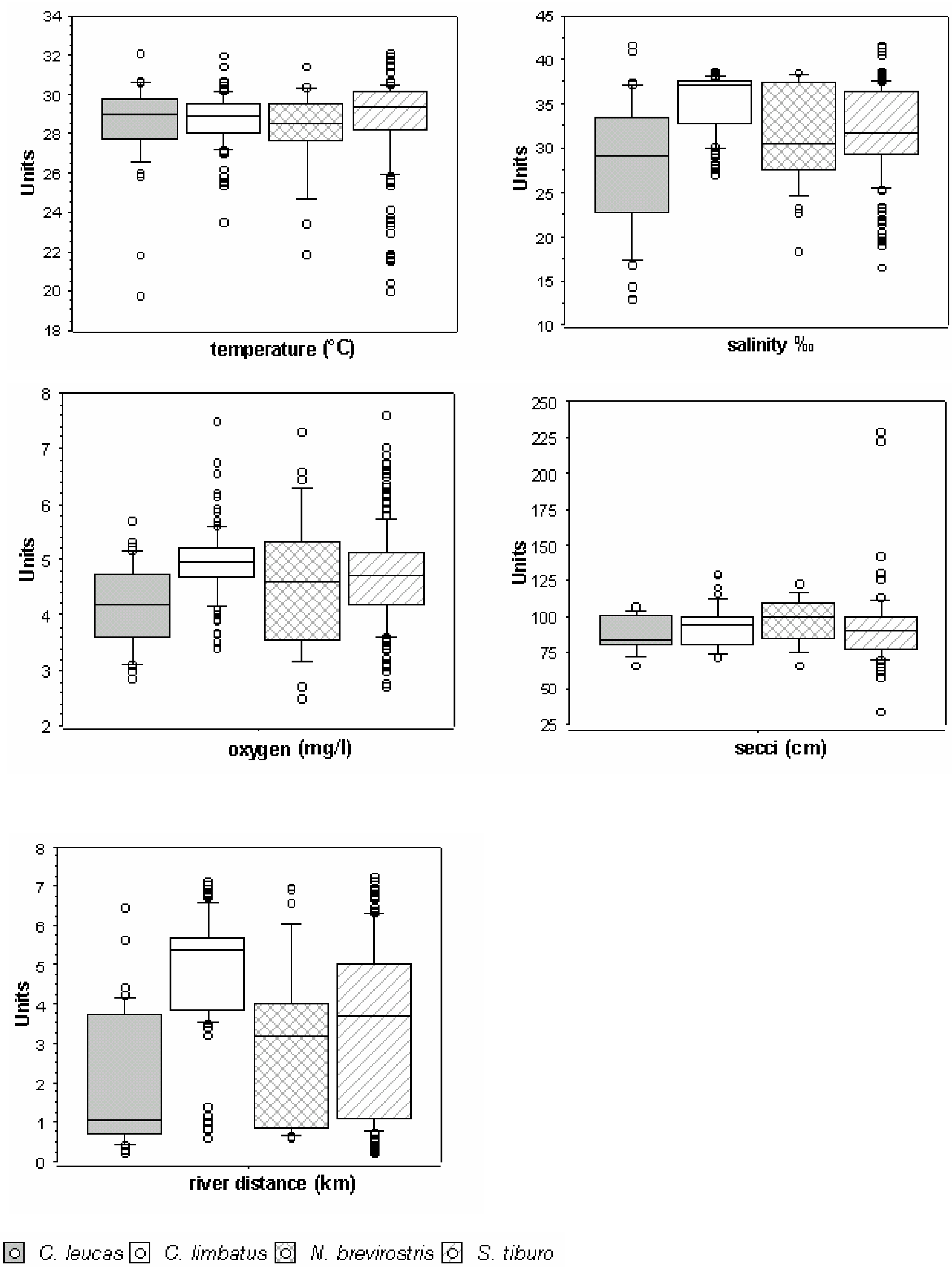


Figure 6. **Usage of the physical environment by four shark species within the Ten Thousand Islands estuary, Florida from May through October 1999 and 2000. Length of box plot = interquartile range (IQR); horizontal line = median; vertical line = +/- 1.5 IQR.**

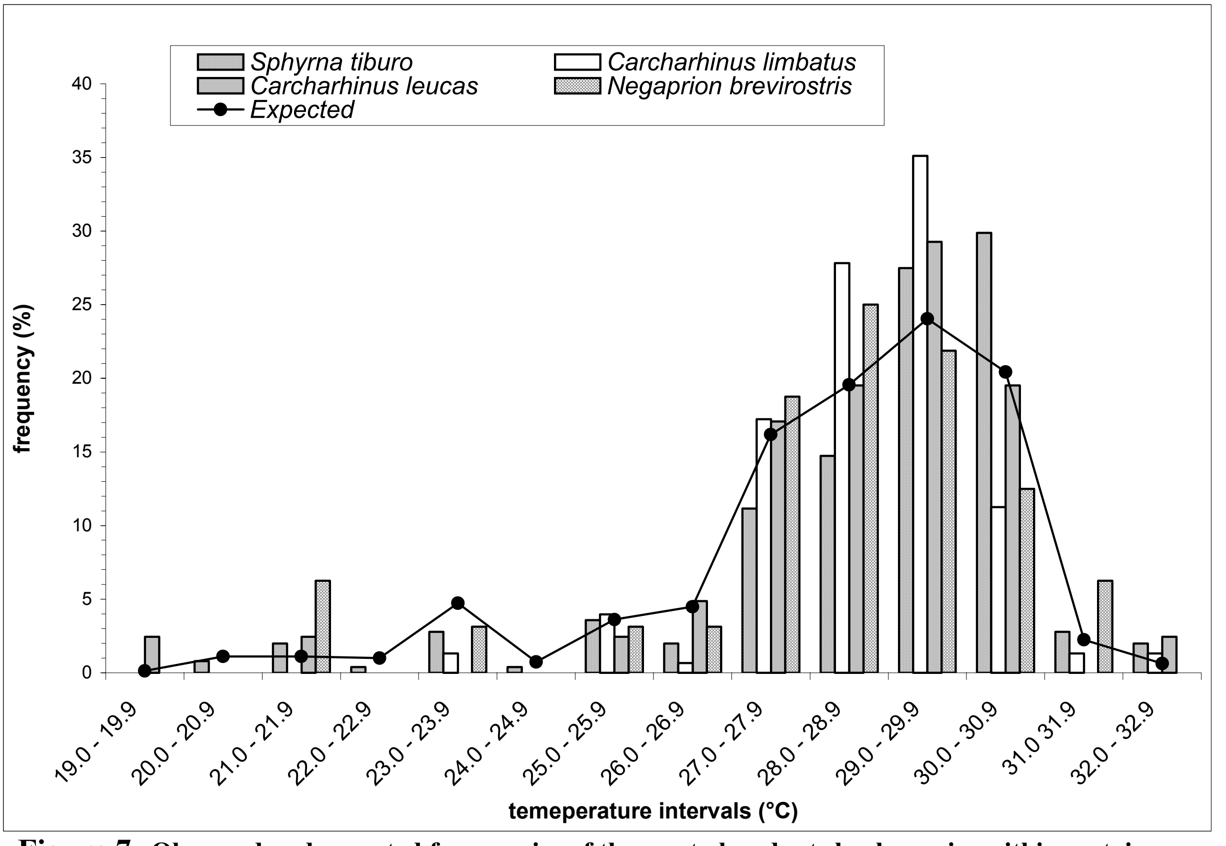


Figure 7. Observed and expected frequencies of the most abundant shark species within certain temperature classes measured in the Ten Thousand Islands Estuary, Florida from May through October 1999 and 2000.

for the spatial and temporal patterns found for these shark species? Relative to temperature we found more or less all sharks distributed as expected (Figure 7). Relative to salinity the blacktip shark was far over represented within higher salinity ranges and absent within lower ranges (Figure 8). The bull shark on the other hand had low frequencies within higher salinity ranges but was more frequent as expected within lower ranges. The bonnet head shark was more abundant than expected in mid salinity ranges. Salinity can be interpreted as one of the factors causing the spatial separation in sharks (especially between blacktip and bull sharks) within the estuary. Relative to dissolved oxygen (DO) the patterns were not as clear but again the blacktip shark was by far more frequent than expected within a narrow range of mid oxygen values and less abundant within all other ranges (Figure 9). The bull shark was over represented within low and mid DO ranges and the lemon was more frequently found in either low or high DO ranges. Dissolved oxygen levels may also contribute to the spatial separation between the blacktip shark and the bull shark.

Summarizing the frequency distribution with dependence on environmental factors using a box plot we found (Figure 6): all sharks were concentrated around an equal temperature median and showed relatively low temperature ranges. Temperature is possibly the main factor forming the temporal patterns described above, but does not appear to influence the spatial distribution. Most of the sharks left the area with decreasing temperature with the blacktip shark being the first, followed by the lemon shark and finally the bull shark. The bonnet head shark did not completely leave the area but was retreating from the Backwater and the Transition area into the adjacent Gullivan Bay (Gulf Edge area) at lower temperatures.

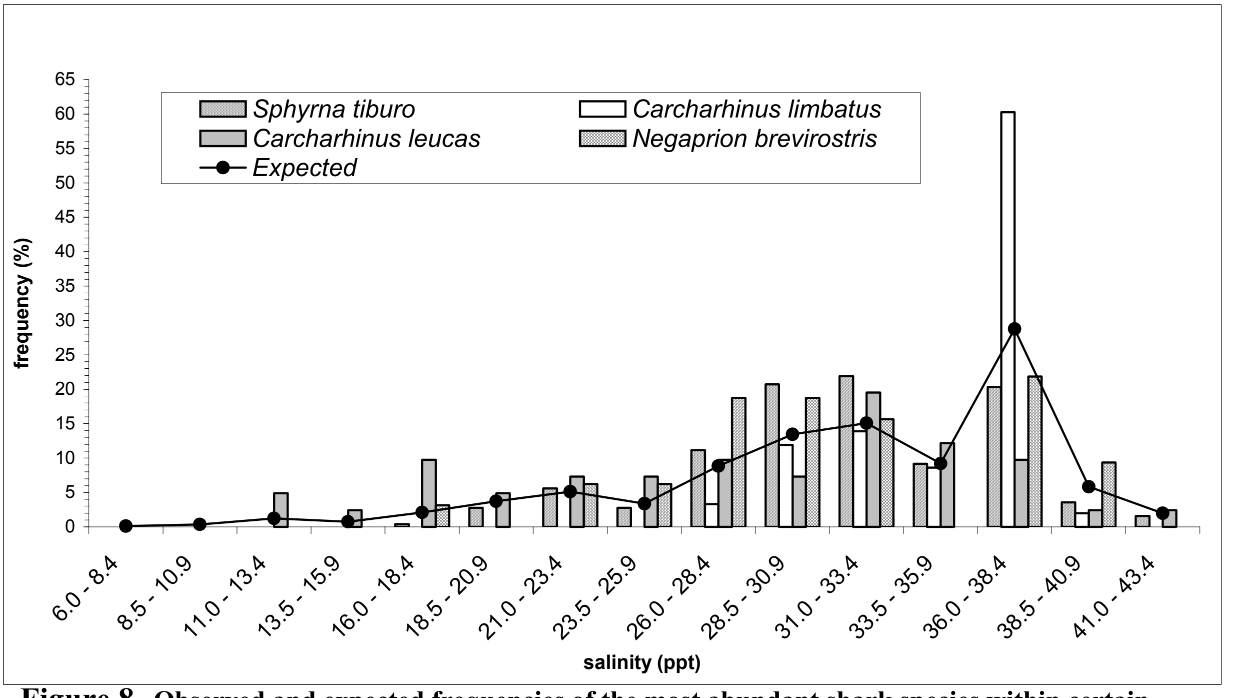


Figure 8. **Observed and expected frequencies of the most abundant shark species within certain salinity classes measured in the Ten Thousand Islands Estuary, Florida from May through October 1999 and 2000.**

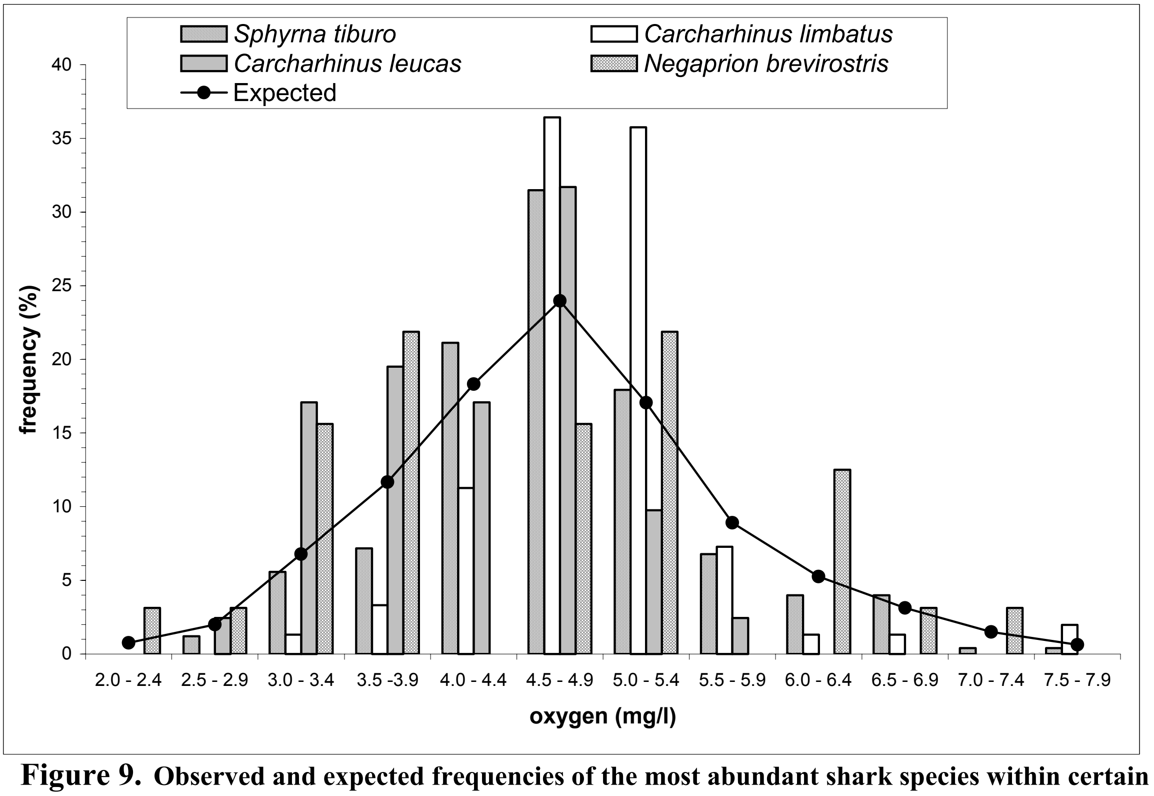


Figure 9. **Observed and expected frequencies of the most abundant shark species within certain dissolved oxygen classes measured in the Ten Thousand Islands Estuary, Florida from May through October 1999 and 2000.**

Tracking Results

During this study a total of 28 sharks were tracked, of which 11 were bull sharks and 17 were blacktip sharks. The sharks were followed for 3 to 24 hours. All of the blacktip sharks tracked were neonates and young-of-the-year; the bull sharks were neonates, young-of-the-year and immature.

Comparing the movement patterns of the two shark species, it was obvious that the bull sharks preferred to stay in the backwaters or even penetrated the rivers, whereas the blacktip sharks swam towards the open water or swam out into the Gulf a couple of kilometers, but always returned back to the capture area. These patterns are represented by figures 10 and 11. With the exception of a larger female bull shark (tl = 157 cm) none of the sharks ever left the area while being tracked.

One of the factors that influenced the movement patterns was the tidal current. for every shark the mean angle of directional movement in degrees was calculated between successive locations using the trigonometric functions described in Batschelet (1981). All the directional data for each shark species was pooled respective to tidal phase (incoming or outgoing). The *v* test was then used to determine whether the observed angles of the sharks' directions have a tendency to cluster around the vector of tidal direction, and thus whether the distribution differs significantly from randomness (Batschelet 1981). It was found that the blacktip sharks do swim with the tides whereas bull sharks do not.

Another factor of interest was whether the two shark species occupied core areas. A grid was laid over each track to test if the location fixes differed significantly from a normal distribution within the grid. Both sharks species showed core areas, with location fixes that differed significantly from a normal distribution ($p<0.05$).

Species Profiles

Bonnethead shark, *Sphyrna tiburo*

A total of 667 bonnethead sharks were captured, of which 379 were male, 280 were female, and 8 were unable to be sexed. All bonnethead sharks were caught with gill nets. For capture sites of bonnethead sharks see Figure12. Of the bonnethead sharks caught 382 were mature, 263 were immature, three were young-of-the-year, and two were neonates. Captured bonnethead sharks ranged in size from 27 cm to 86 cm FL (34 cm to 103 cm TL). Four hundred twenty eight of the sharks captured (64%) were tagged and released, with 19 of these being recaptured. The longest time between tag and recapture was 1231 days, where the place of recapture was within 0.5 km of the tagging site. The longest distance traveled between the site of capture and recapture was 11.1 km over a time span of five days.

Bonnethead sharks were caught in every month of sampling. The two neonates were caught in May 1999 and in June 2000. The four young-of-the-year animals were caught in July 1999, October 1999, and October 2000.

Bonnethead sharks were captured in water temperatures ranging from 20.0 °C to 32.1 °C (mean: 28.8 °C; SD: 2.1 °C); salinity from 16.4 ‰ to 41.7 ‰ (mean: 31.7 ‰; SD: 4.8 ‰); and dissolved oxygen from 2.7 mg/l to 7.6 mg/l (mean: 4.7 mg/l; SD: 0.9 mg/l). The depth range for bonnethead sharks was 0.8 m to 4.0 m (mean: 1.6 m; SD: 0.5 m).

Blacktip shark, *Carcharhinus limbatus*

A total of 300 blacktip sharks were captured, of which 131 were male, 161 were female, and eight were unable to be sexed. Two hundred eighty-nine of these sharks were caught with gillnets and 11 with longlines. For capture sites of blacktip sharks see Figure 13. There were no mature specimens, while 18 were immature, 189 were young-of-the-year, and 89 were neonates. One hundred seventy-one (57%) of the sharks caught were tagged, of which seven were recaptured. The longest time period between tag and recapture was 48 days, and this shark was recaptured within 0.5 km of the original tagging site. The longest distance traveled by blacktip sharks was 4.7 km, and this shark was recaptured 25 days after the first capture.

Blacktip sharks ranged in size from 37 cm FL (46 cm TL) to 142 cm FL (TL was not measured). No blacktip sharks were caught in February 1998, and there was only one captured in March 1998 and another in October 1999. Specimens were captured in every other month of

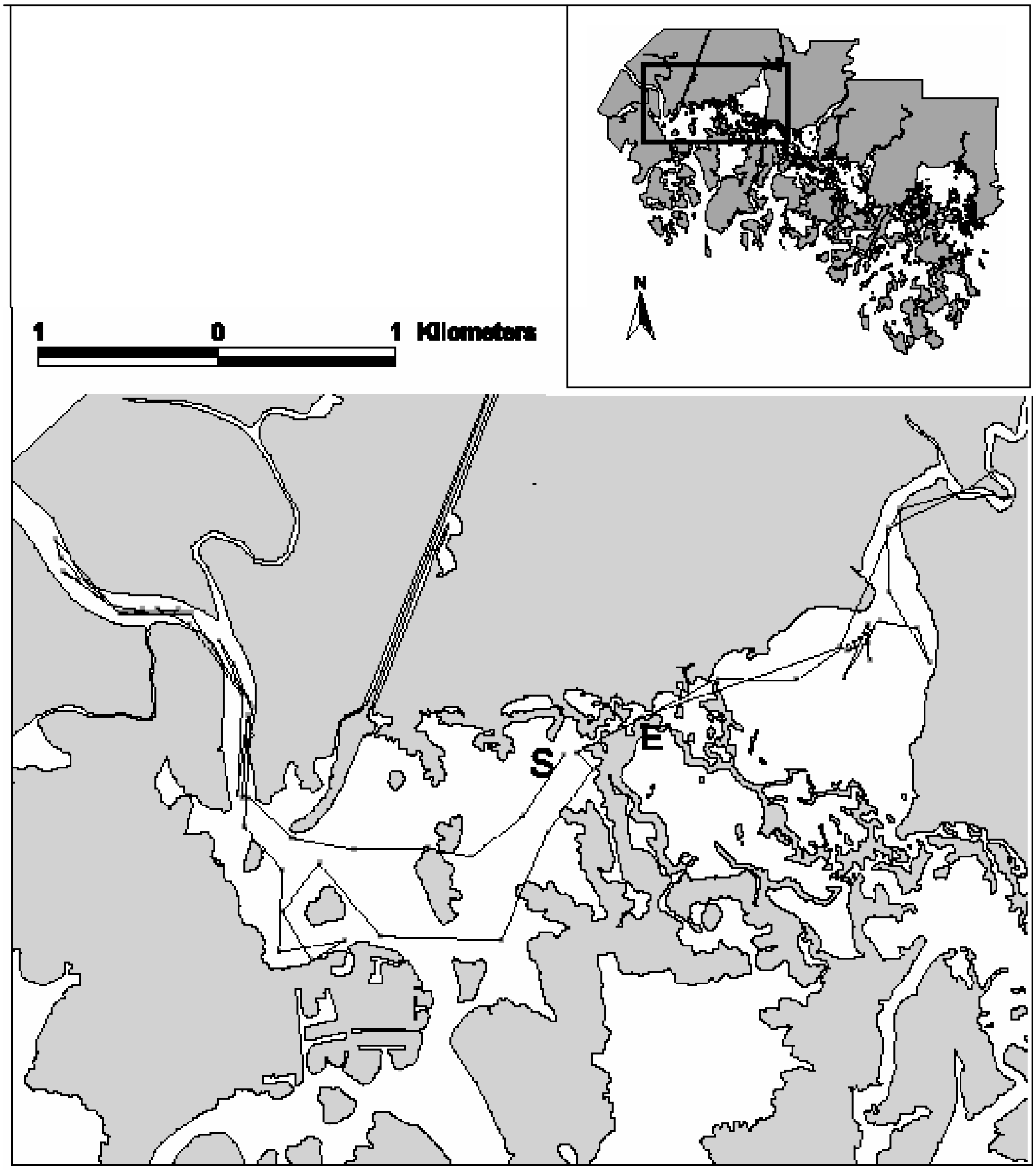


Figure 10. **Bull shark track in the Ten Thousand Islands, Florida.**

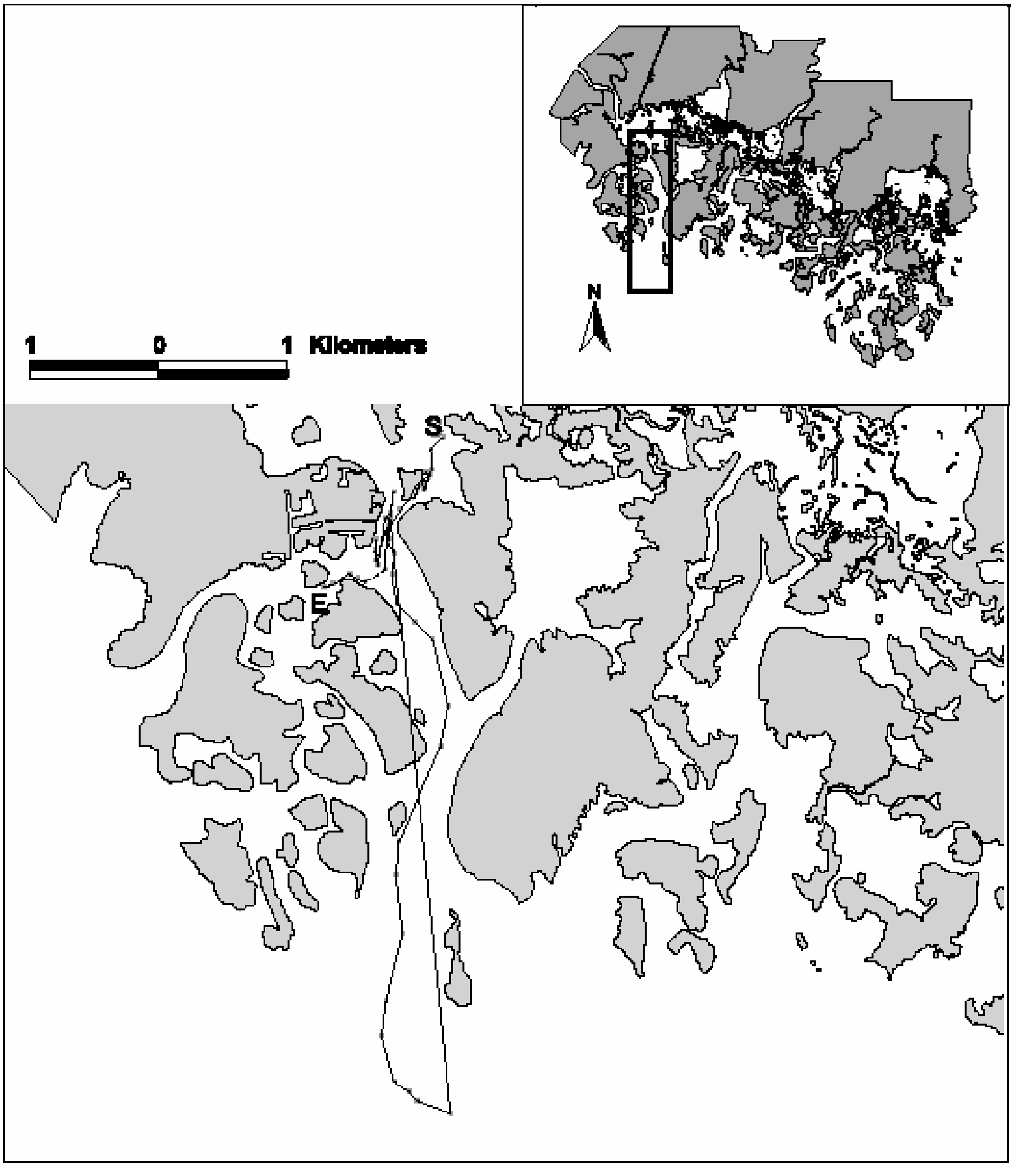


Figure 11. **Blacktip shark track in the Ten Thousand Islands, Florida.**

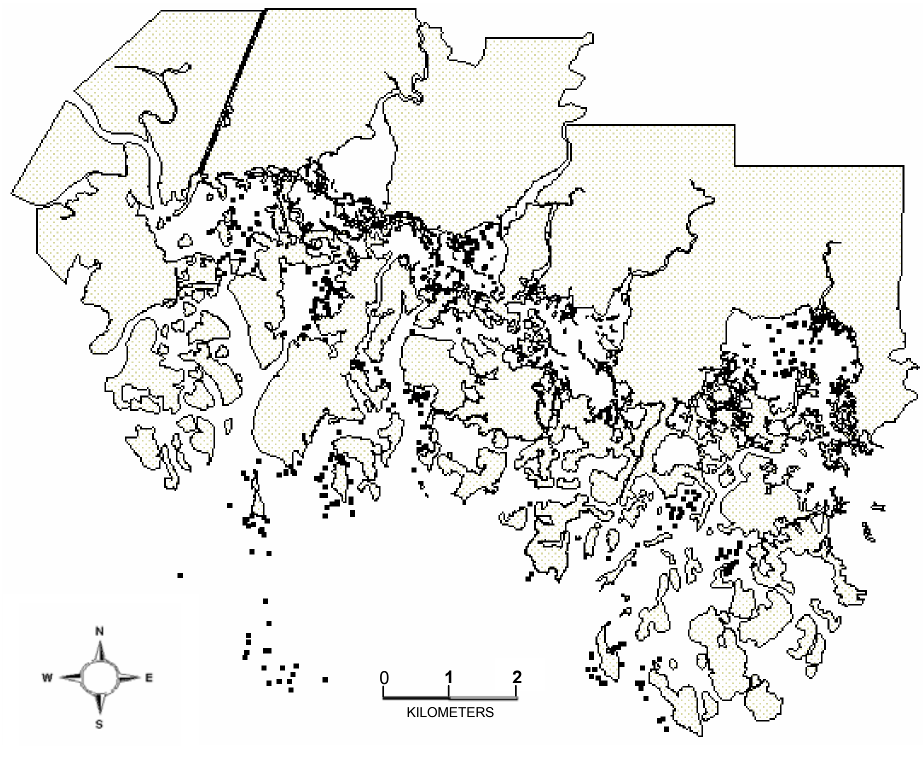


Figure 12. **Capture sites of *S. tiburo.* Ten Thousand Islands 1997 – 2000.**

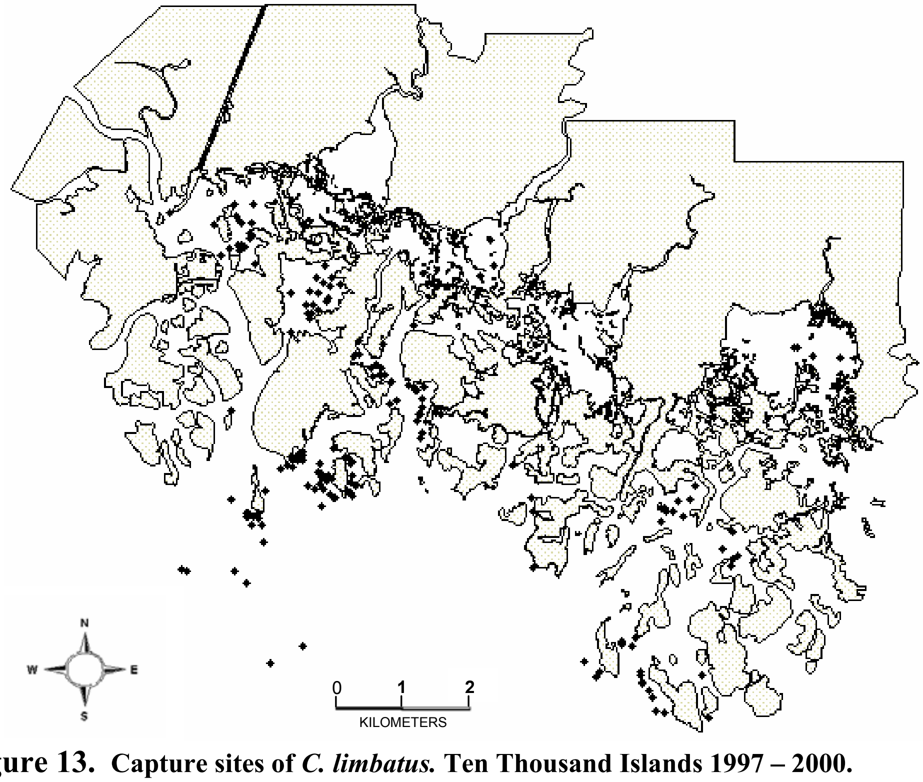


Figure 13. **Capture sites of *C. limbatus.* Ten Thousand Islands 1997 – 2000.**

sampling but mainly from May through August. Neonates were caught from 19 May to 21 July in 1999, and from 3 May to 6 August in 2000. Young-of-the-year animals were caught from 23 June to 20 October in 1999, and 2 June to 20 October in 2000. The neonates ranged from 37 cm FL to 57 cm FL (46 cm to 69 cm TL), and the young-of-the-year ranged from 43 cm FL to 66 cm FL (53 cm to 83 cm TL).

Blacktip sharks were captured in water temperatures ranging from 23.5 °C to 32.0 °C (mean: 28.8 °C; SD: 1.4°C), salinity from 27.0 ‰ to 38.6 ‰ (mean: 35.3 ‰; SD: 3.2 ‰) and dissolved oxygen from 3.4 mg/l to 7.5 mg/l (mean: 5.0 mg/l; SD: 0.7 mg/l). The depth range for blacktip sharks was 0.8 m to 4.2 m (mean: 1.7 m; SD: 0.5 m).

Bull shark, *Carcharhinus leucas*

A total of 75 bull sharks were captured, of which 26 were male, 41 were female, and eight were unable to be sexed. Fifty-seven of these sharks were caught with gillnets and 18 with longlines. For capture sites of bull sharks see Figure 14. There were no mature specimens. Sixty-three were immature, seven were young-of-the-year, and three were neonates. A total of 68 bull sharks were tagged with only one being recaptured. This shark was recaptured at the same location on the day of tagging.

Bull sharks ranged in size from 58 cm FL (70 cm TL) to 139 cm FL (TL was not measured). Bull sharks were caught in every month of sampling except for March 1998 and May 2000. One neonate was caught on 17 June 1999, one on 29 June 2000 and one on 10 July 2000. One young-of-the-year was caught on 5 August 1998, three between 24 September and 18 October 1999, and another three between 31 July and 18 August 2000. The neonates ranged in size from 58 cm to 60 cm FL (70 cm to 75 cm TL) and the young-of-the-year ranged from 63 cm to 74 cm FL (73 cm to 88 cm TL).

Bull sharks were captured in water temperatures ranging from 19.7 °C to 32.1 °C (mean: 28.6 °C; SD: 2.1 °C), salinity from 12.8 ‰ to 41.7 ‰ (mean: 28.6 ‰; SD: 6.6 ‰) and dissolved oxygen from 2.8 mg/l to 5.2 mg/l (mean: 4.2 mg/l; SD: 0.8 mg/l). The depth range for bull sharks was 0.8 m to 2.5 m (mean: 1.5 m; SD: 0.5 m).

Lemon shark, *Negaprion brevirostris*

A total of 55 lemon sharks were caught, of which 18 were male, 33 were female, and four were unable to be sexed. Twenty-one of these sharks were caught with gillnets and 34 with longlines. For capture sites of lemon sharks see Figure 15. There were no mature specimens. Forty-nine were immature, four were young-of-the-year and one was a neonate. A total of six lemon sharks were tagged, of which two were recaptured. The time between capture and recapture was one and three days respectively. Both animals were recaptured in the area of the initial capture site.

Lemon sharks ranged in size from 60 cm to 182 cm FL (71 cm to 215 cm TL). Sharks of this species were caught in every month of sampling except for May 1997, and in February, April and May of 1998. The one neonate was caught on 22 June 1999. The two young-of-the-year animals were caught on 31 July and 20 October 1999, while another two were caught on 19 and 21 September 2000. The neonate shark had a FL of 60 cm (71 cm TL) and the four young-of-the-year sharks ranged in size from 65 cm to 71 cm FL (75 cm to 84 cm TL).

Lemon sharks were captured in water temperatures ranging from 21.9 °C to 31.4 °C (mean: 28.2 °C; SD: 2.2°C), salinity from 18.4 ‰ to 38.6 ‰ (mean: 31.9 ‰; SD: 5.2 ‰) and dissolved oxygen from 2.5 mg/l to 6.6 mg/l (mean: 4.3 mg/l; SD: 1.0 mg/l). The depth range for lemon sharks was 0.6 m to 3.3 m (mean: 1.6 m; SD: 0.6 m).

Nurse shark, *Ginglymostoma cirratum*

A total of 26 nurse sharks were caught, of which 12 were male, 10 were female, and four were unable to be sexed. All nurse sharks captured were immature, and there were no neonate or young-of-the-year. The smallest individual, with a PCL of 45 cm, was probably a YOY. Due to a lack of experience this was not noted at the time of capture. Of the 26 nurse sharks caught, seven were caught with gillnets, and the remaining 19 by longline. For capture sites of nurse sharks see Figure 16. A total of seven nurse sharks were tagged and there have been no recaptures to date.

Nurse sharks ranged in size from 45 cm to 127 cm PCL (62 cm to 180 cm TL). Animals of

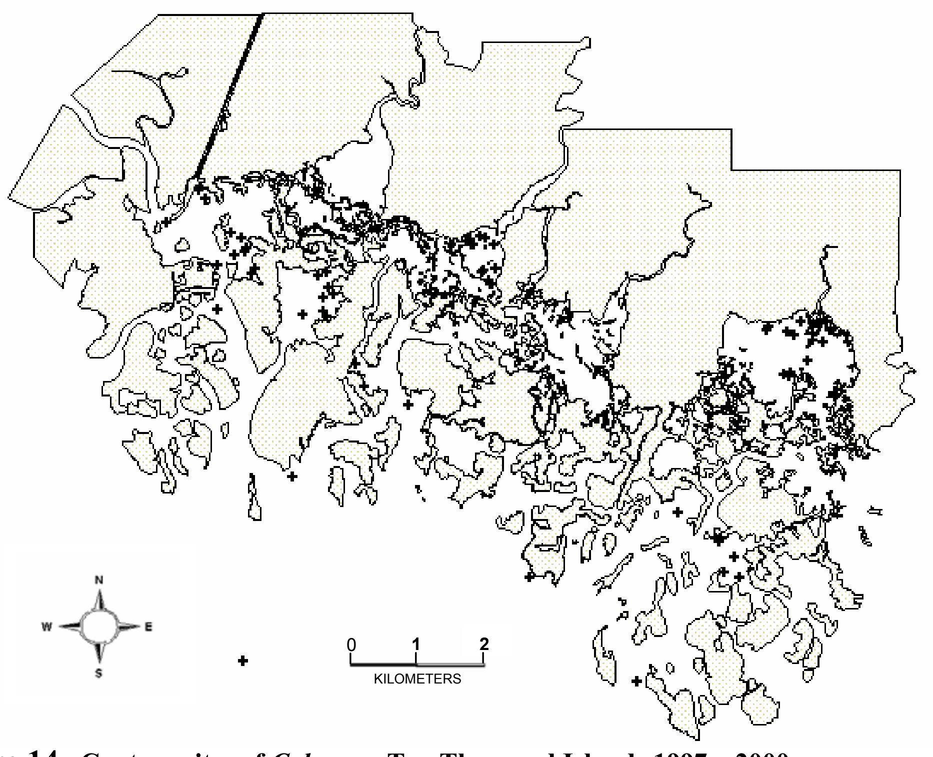


Figure 14. **Capture sites of *C. leucas.* Ten Thousand Islands 1997 – 2000.**

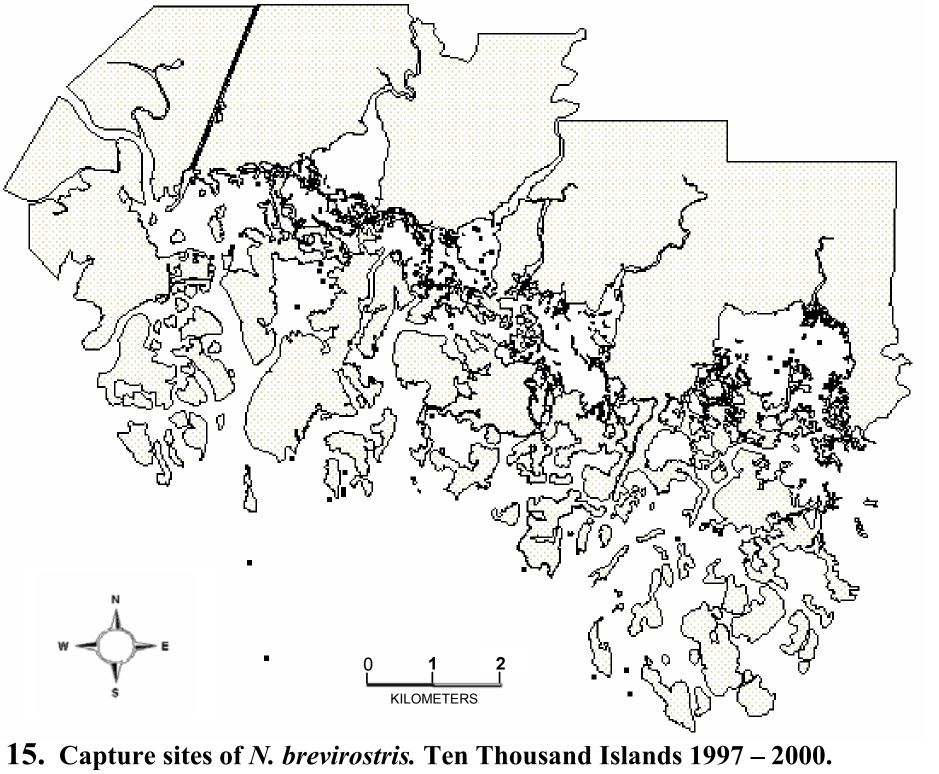


Figure 15. **Capture sites of *N. brevirostris.* Ten Thousand Islands 1997 – 2000.**

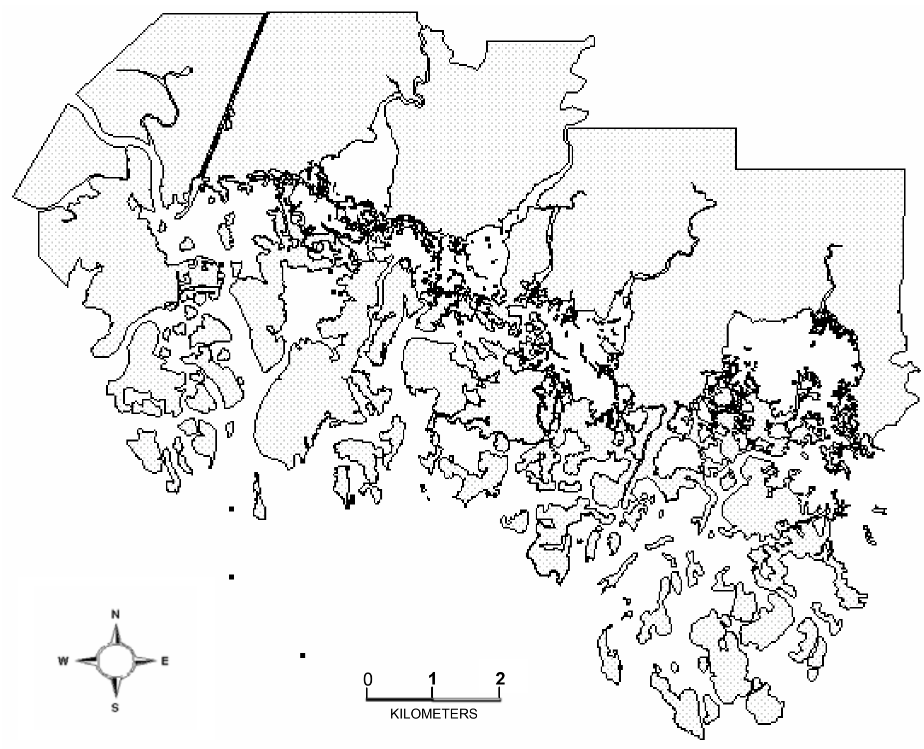


Figure 16. **Capture sites of *G. cirratum.* Ten Thousand Islands 1997 – 2000.**

this species were not caught in the following sampling months: May 1997; March and May 1998; June, August and September 1999; and May, September and October 2000.

Nurse sharks were captured in water temperatures ranging from 28.0 °C to 30.5 °C (mean: 28.9 °C; SD: 1.0°C), salinity from 31.5 ‰ to 38.5 ‰ (mean: 34.4 ‰; SD: 3.4 ‰) and dissolved oxygen from 3.1 mg/l to 6.6 mg/l (mean: 4.8 mg/l; SD: 0.7 mg/l). The depth range for nurse sharks was 0.8 m to 2.9 m (mean: 1.6 m; SD: 0.7 m).

Great hammerhead shark, *Sphyrna mokarran*

A total of 13 great hammerhead sharks were caught, of which two were male and 11 were female. There were no mature specimens caught, all 13 animals were immature, there were no young-of-the-year nor neonate sharks caught either. The number of great hammerhead sharks caught with gillnets was 12 while the remaining one was captured with the longline. For capture sites of great hammerhead sharks see Figure 17. Eleven (85%) of the 13 sharks captured were tagged and none of these have been recaptured to date.

Great hammerhead sharks ranged in size from 107 cm FL (146 cm TL) to 166 cm FL (TL was not measured). Animals were caught in May 1997; May and August 1999; and May, June, July and August 2000.

Great hammerhead sharks were captured in water temperatures ranging from 23.4 °C to 30.5 °C (mean: 27.7 °C; SD: 3.3°C), salinity from 32.4 ‰ to 41.4 ‰ (mean: 36.6 ‰; SD: 3.9 ‰) and dissolved oxygen from 3.6 mg/l to 7.1 mg/l (mean: 4.6 mg/l; SD: 0.9 mg/l). The depth range for great hammerhead sharks was 1.0 m to 3.1 m (mean: 1.6 m; SD: 0.5 m).

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

A total of seven Atlantic sharpnose sharks were caught, of which four were male, two were female, and one was unable to be sexed. There was one mature specimen caught, while five were immature, and one was a neonate. All animals were caught with gillnets, with six being tagged and none being

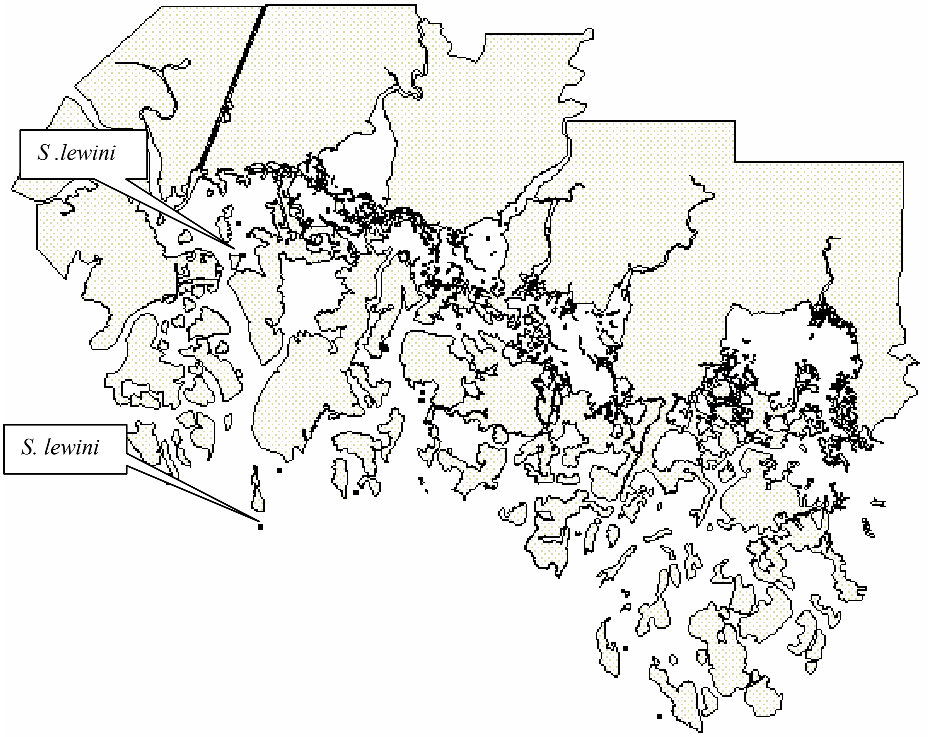


Figure 17. **Capture sites of *S. mokarran* and *S. lewini.* Ten Thousand Islands 1997 – 2000.**

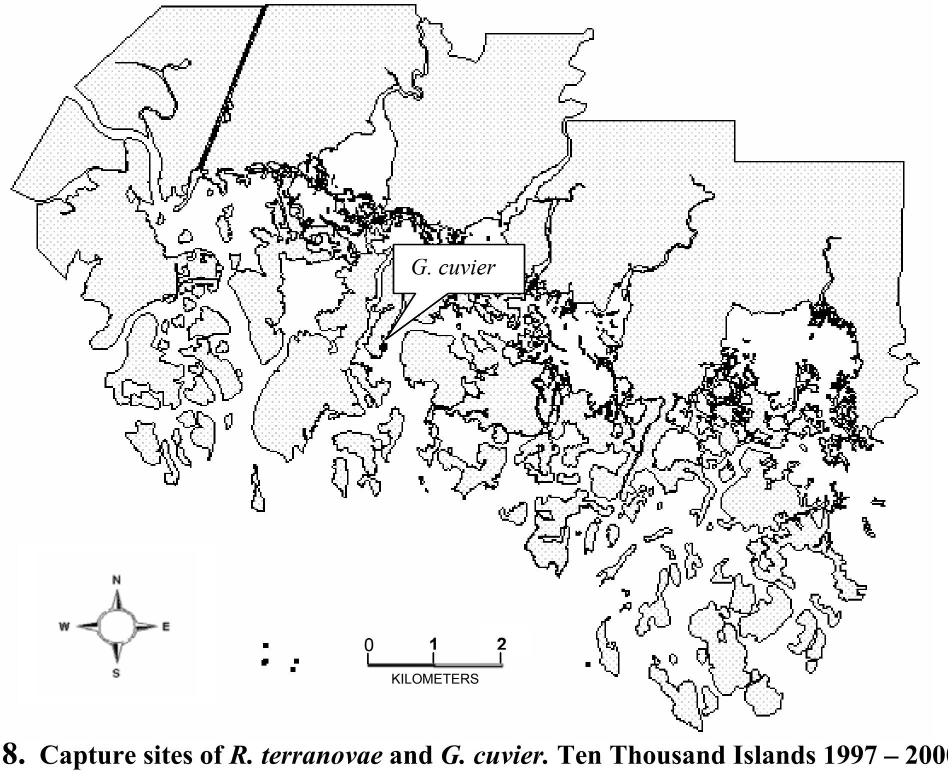


Figure 18. **Capture sites of *R. terranovae* and *G. cuvier.* Ten Thousand Islands 1997 – 2000.**

recaptured to date. For capture sites of Atlantic sharpnose sharks see Figure 18.

Atlantic sharpnose sharks ranged in size from 26 cm to 73 cm FL (31 cm to 85 cm TL). Animals were caught in February and March 1998, June 1999, and in May and June 2000. The neonate specimen was caught on 3 June 1999.

The environmental data is only available for two sets in which Atlantic sharpnose sharks were captured. These sharks were captured in water temperatures of 27.0 °C (1999) and 28.0 °C (2000). Salinity values were 37.4 ‰ in 1999 and 37.9 ‰ in 2000. Dissolved oxygen was 5.0 mg/l in 1999 and 6.6 mg/l in 2000. Atlantic sharpnose sharks were caught at a depth of 1.5 m in 1999 and 1.3 m in 2000.

Scalloped Hammerhead, *Sphyrna lewini*

A total of two male scalloped hammerhead sharks were caught. One of them was immature and one was a young-of-the-year. Both were caught with gill nets. For capture sites of scalloped hammerhead sharks see Figure 17.

No scalloped hammerhead sharks were tagged. Scalloped hammerhead sharks ranged in size from 41 cm FL (52 cm TL) to 52 cm FL (68 cm TL). The two animals were caught in July 1998 and July 2000.

Water quality was only reported for the shark caught in 2000. Salinity was 37.3 ‰, dissolved oxygen was 6.23 mg/l and water temperature was 30.6 °C.

Tiger shark, *Galeocerdo cuvier*

Only one specimen of tiger sharks was caught. It was an immature male captured by longline on 18 May 1999. The FL was 173 cm and TL was 218 cm. For the capture site of the tiger sharks see Figure 18.

Water temperature at capture was 27.7 °C, salinity was 38.2 ‰ and dissolved oxygen was 4.9 mg/l. Tiger sharks were caught at a depth of 4.5 m.

Preliminary Findings

The results of the two studies provided evidence that the Ten Thousand Islands estuary is an important nursery ground for several different species of sharks. This area seems to be a pupping and nursery ground for the bonnethead shark, whereas the blacktip and the bull shark probably use the estuary as a secondary nursery ground. No mature or even pregnant females of these species were ever caught. The presence of neonate or young-of-the-year lemon sharks, sharpnose sharks and scalloped hammerhead sharks within the TTI indicate that this shallow habitat might be used as a nursery ground for these species although the numbers caught were very low.

The changing environmental conditions within the TTI estuary are one of the driving forces in building temporal and spatial patterns of distribution and abundance for the shark species found within this estuary. The bonnethead shark is an environmental opportunist and therefore did not show any obvious temporal or spatial pattern. The blacktip shark on the other hand was restricted to narrow ranges and high values of salinity, temperature and dissolved oxygen. This species was therefore avoiding the Backwaters and was mainly caught during the first half of the season (May – July). The bull shark showed a contrary distribution and abundance to the blacktip shark by being absent within the Gulf Edge area but preferring the Backwaters with its broad ranges and often low values in salinity, temperature and dissolved oxygen.

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Shark Nurseries in the Northeastern Gulf of Mexico

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Scope

Sharks were sampled by the National Marine Fisheries Service, Panama City Laboratory from March 1993-October 2000 as part of various studies on shark population dynamics and life history. All studies were directed towards sharks but focused on establishing a fishery independent index of abundance in the northeastern Gulf of Mexico; collecting information on age, growth, and reproduction; longline and gillnet selectivity; and feeding ecology. All studies were funded by NMFS/Highly Migratory Species Office, Washington, D.C.; Southeast Fisheries Science Center's Sustainable Fisheries Division; and the NMFS Panama City Facility.

Sampling Materials and Methods

Sampling for sharks took place April to October of each year, occasionally from November to March. Because funding was not continuous and sampling was directed at various objectives, the variability in sampling design and methodology precluded quantification of an index of abundance (i.e., CPUE) throughout the entire survey period. In general, gillnets were multi-paneled and ranged in length from 30.4 to 273.6 m. Stretched mesh sizes ranged from 5.1 cm to 20.3 cm. Panel depths when fishing were 1.5 to 3.1 m. Webbing for all panels, except for 20.3-cm, was of clear monofilament, double knotted and double selvaged. The 20.3-cm stretched mesh webbing was made of #28 multifilament nylon, single knotted, and double selvage. The nets when set were anchored at both ends and fished on the bottom.

The longline was constructed of a mainline made of 152-m lengths of 425.8 kg-test monofilament line. A 15.2-m length of 0.79-cm diameter braided polypropylene line connected each 152-m length. Depending on the number of hooks fished, the longline ranged in length from 152 to 608 m. Polyethylene floats or weights (1.3 kg) made of 1.5-m lengths of 136-kg test monofilament line with a snap were attached to the mainline every 30.4 m. Gangions were placed at 15.2-m intervals along the mainline. Gangions (136-kg test) were 0.9-1.8 m long and hooks were size Mustad #12/0 or #3/0. Bait was either menhaden (*Brevoortia* spp.) or Atlantic mackerel (*Scomber scombrus*). The mainline, when set, was tethered to an anchor on each end with a 30.4-m, 0.79-cm polypropylene rope between the anchor and the end of the mainline. A buoy (3.6-m aluminum pole with 1.8-kg weight and 50.8-cm poly float), with a strobe light and flag extended 2.4 m above the float, was attached at each end of the mainline.

Survey Design

For each survey period, the sampling gear was set randomly within each area or at a fixed station. Both random and fixed sets were designated on LORAN C coordinates. The nets and/or longlines were set over a 24 hr period at various times. In some surveys, the gillnets were checked and cleared of catch, or pulled and reset every 1.0-2.0 hr. In other surveys, gillnets were set at dusk, left to soak overnight, and hauled back the next day. For longlines, soak time ranged from 1.0-1.5 hr. Following each soak period, the longline was checked and all gangions that had caught sharks, been broken or damaged, or had damaged or lost baits, were removed from the mainline and a fresh-baited gangion attached. Sharks captured using either method were measured to the nearest cm for body lengths (precaudal, fork, total, and stretch total length) and data for sex and life history stage

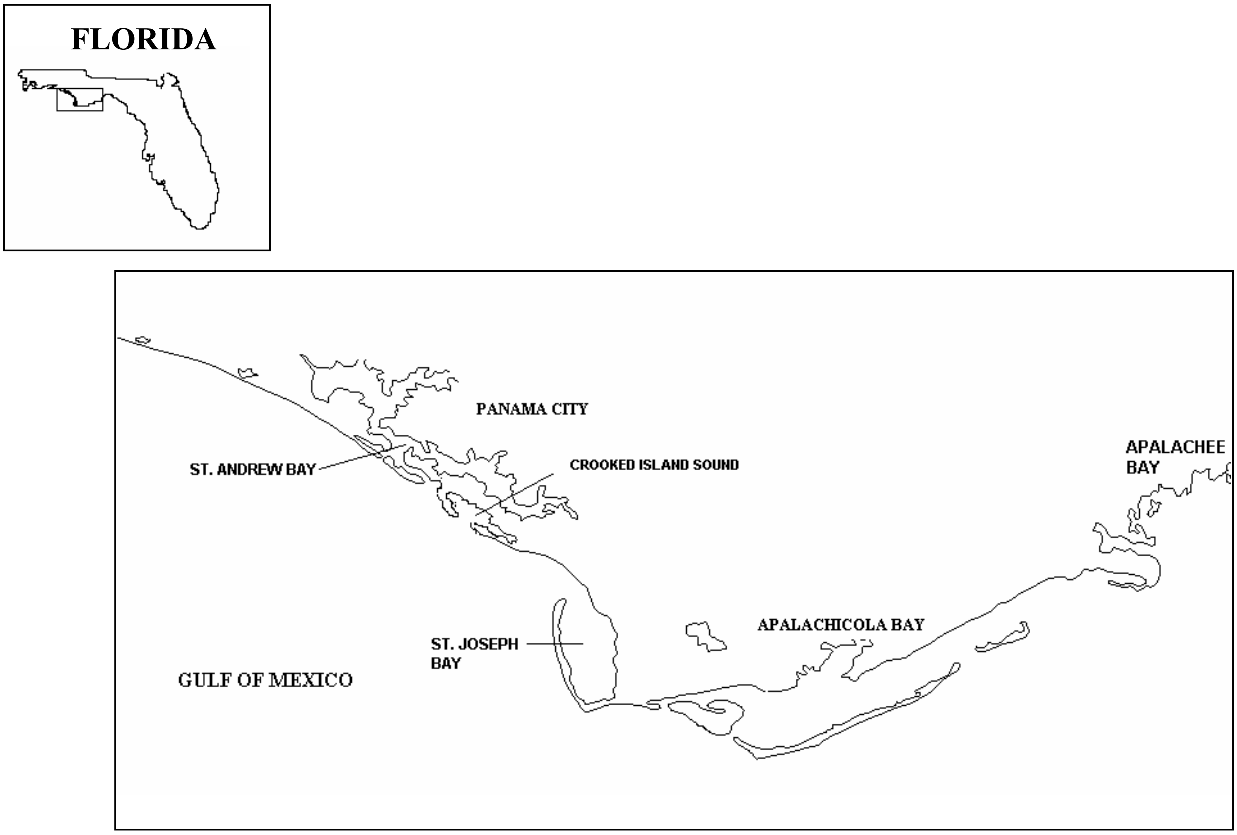

Figure 1. Map of study site illustrating major bay systems.

(neonate, young-of-the-year, juvenile, adult) were recorded. Sharks that were in poor condition were sacrificed for life history studies and those in good condition were released or tagged with a nylon-head dart tag and released.

Environmental data were collected prior to sampling. Mid-water temperature (°C), and dissolved oxygen (mg l^{-1}) was measured with a YSI Model 55 oxygen meter and light transmission (cm) was determined using a secci disk. Salinity (ppt) was measured with a refractometer. When possible, qualitative bottom type was recorded based on visual observation, sampling with a ponar grab, or visual inspection of the sediment type on the anchor.

Description of Study Areas

Sampling sites were located in five major areas along the northeastern portion of the Gulf of Mexico, Apalachee Bay to St. Andrews Bay, FL (Figure 1). Physical and chemical characteristics of each area are found in Table 1. The eastern part of this area has irregular coastline, few beaches and enclosed bay systems. Some bay systems contain large amounts of submergent, *Thalassia* spp., *Syringodium* spp and *Halodule* spp., and emergent vegetation, *Spartina* spp. and *Juncus* spp. The western part has numerous barrier islands and sand beaches and is composed of semi-enclosed bays. Tidal amplitude in the bays is highest in Apalachee Bay and generally decreases toward the west.

Apalachee Bay is an open ocean bay without barrier islands separating the area from the open Gulf of Mexico. The bay is broad, shallow (average 3 m), and extends about 15 km offshore. Salinity ranges from 22-36 ppt and tidal amplitude averages 1.1 m. Wave energy is low and the area has large areas of submerged vegetation.

Sampling in the Apalachicola Bay system occurred in the delta area between 0.5-3 km south of St. Vincent Island in the Gulf of Mexico where

Table 1. **Environmental Characteristics of the Five Bay Systems. Numbers is parentheses represent minimum and maximum values observed.**

System	Surface Area (acres)	Maximum Tidal Range (m)	Mean Water Depth (m)	Temperature (°C)	Salinity (ppt)	Light Transmission (cm)	Dissolved Oxygen (mg l^{-1})
Apalachee Bay	61,322	1.10	5.3 (4.5-8.0)	25.2 (19.0-31.0)	25.0 (23.0-26.0)	96.2 (68.0-108.0)	N/A
Apalachicola Delta	82,197	0.73	4.7 (2.1-10.0)	27.5 (19.5-31.4)	29.0 (19.0-39.0)	81.9 (15.0-200.0)	5.5 (3.6-7.3)
Crooked Island Sound	4,707	0.78	4.0 (1.7-8.7)	26.5 (16.0-31.2)	31.4 (21.0-38.0)	174.9 (10.0-450.0)	6.1 (4.6-8.3)
St. Andrew Bay	21,499	0.53	3.5 (1.0-5.2)	24.9 (16.5-31.0)	31.2 (22.0-38.0)	101.7 (0.0-250.0)	7.2 (5.4-8.1)
St. Joseph Bay	43,872	0.47	2.3 (0.7-6.2)	28.3 (20.0-33.6)	35.3 (30.0-38.0)	172.4 (8.3-300.0)	6.6 (2.0-8.3)

water depths average 5-10 m. The bay system surrounding this area is largely a line of barrier islands fronting the intersection of the Apalachicola delta. As a result of river discharge, there is little submergent vegetation due to high turbidity. Salinity fluctuates from 19-39 ppt and tidal range is 0.73 m.

St. Joseph Bay transcends from a broad, shallow, heavily, vegetated habitat to a relatively deep oceanic habitat. It is connected to the Gulf of Mexico by a deep navigation channel. The southern portion of the bay contains large expanses of *Thalassia* spp., *Halodule* spp., and *Syringodium* spp. The entire bay surface area covers approximately 43,000 acres and maximum tidal range is 0.47 m.

Crooked Island Sound (St. Andrew Sound) is a small semi-enclosed marine lagoon. It is about 14.5 km long and 0.2-2.0 km wide and has water depths from 3.5-4.5 m deep (mean high tide). This system also contains expanses of submergent vegetation but generally only along the edges of the bay where the water depth averages 1-2 m. Salinity ranges from 25-36 ppt and tidal amplitude averages 0.42 m. The sound exchanges water with the Gulf of Mexico through a pass 0.5-2.0 km wide.

St. Andrew Bay consists of several embayments, averages 1.9-5.7 m deep, and covers an area of about 21,500 acres. Because of its proximity to Panama City, FL this bay is subjected to much anthropogenic activity from commercial and recreational activity such as shipping traffic by commercial tankers, municipal and industrial discharge and tourism. Salinity ranges from 13-32 ppt and tidal amplitude averages 0.48 m. The system exchanges water with the Gulf of Mexico via a human-made pass at the western end.

Results

A total of 15 species of sharks were collected with gillnets and longlines. For all areas combined, the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, a member of the small coastal management group, was the most abundant shark captured and the blacktip shark, *Carcharhinus limbatus*, was the most abundant species captured in the large coastal management group, using longlines and gillnets. The bonnethead shark, *Sphyrna tiburo*, was the second most abundant species captured in the small coastal group and overall was the third most encountered species. The remaining species commonly captured in decreasing abundance were the finetooth shark, *C. isodon*; spinner shark, *C. brevipinna*; blacknose shark, *C. acronotus;* scalloped hammerhead shark, *S. lewini* and sandbar shark, *C. plumbeus.* Other species caught but not consistently captured were Florida smoothhound, *Mustelus norrisi;* bull shark, *C. leucas*; lemon shark, *Negaprion brevirostris*; nurse shark, *Ginglymostoma cirratum*; tiger shark, *Galeocerdo cuvieri*; dusky shark, *C. obscurus* and great hammerhead shark, *S. mokarran*.

Overall species distribution varied by area (Figure 2). The Atlantic sharpnose shark and bonnethead were the most abundant species captured in Crooked Island Sound. In Apalachee Bay, the Atlantic sharpnose and blacktip shark were the most frequently encountered. The bonnethead and Atlantic sharpnose shark were most commonly

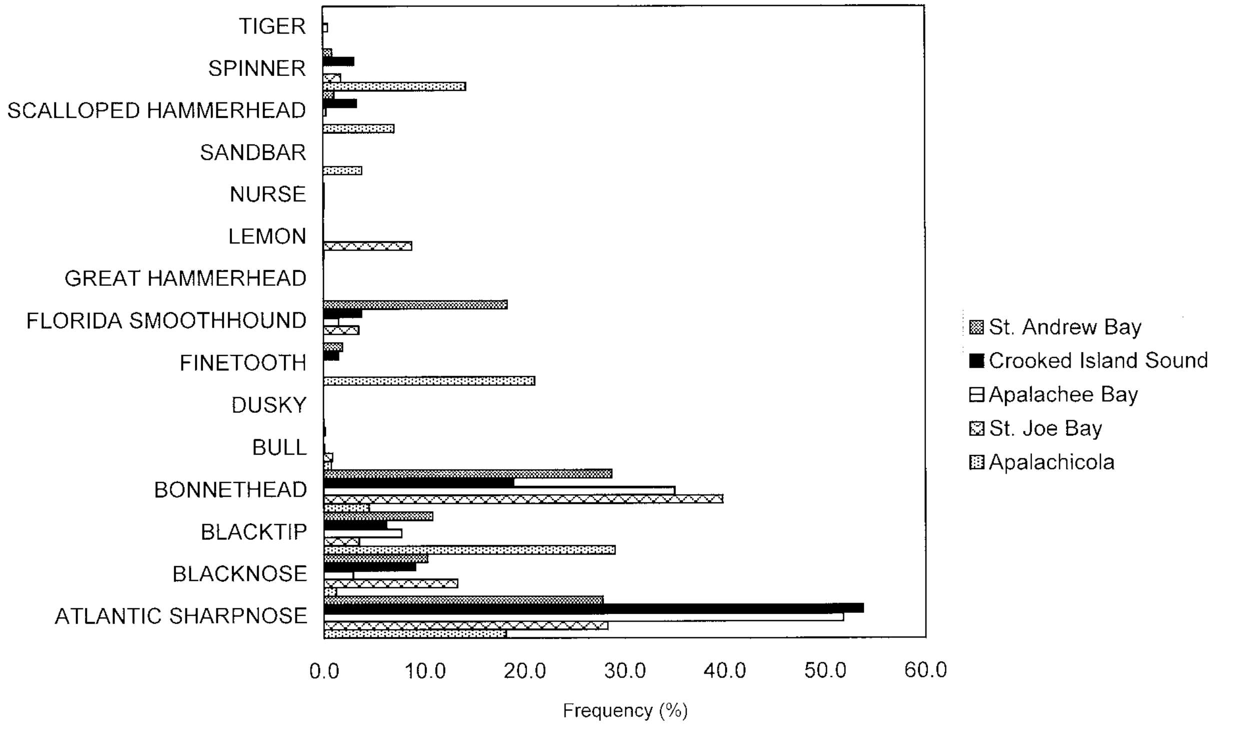

Figure 2. Frequency distribution of sharks within the major sampling areas.

caught in St. Joseph Bay and St. Andrew Bay. The blacktip and finetooth shark were the most abundant species found in Apalachicola.

Apalachee Bay

Sampling occurred in Apalachee Bay in 1993 and 1995. Sharks were captured in temperatures ranging from 19.0-31.0° C and salinities from 23.0-26.0 ppt. Nine species were encountered in this bay system with Atlantic sharpnose and bonnethead shark being the most commonly occurring (Table 2). With the exception of the bonnethead shark, juveniles were the dominant life stage captured (Figure 3). Other species captured were blacknose, blacktip, bull, Florida smoothhound, nurse, and scalloped hammerhead. Apalachee Bay is the only area surveyed where tiger sharks were encountered.

Apalachicola Delta

A total of 4,148 sharks were captured in the Apalachicola delta in 8 years of sampling. Because this system receives large amounts of freshwater from the Apalachicola River, sharks were captured over a broad range of salinities (19-39 ppt) and light transmission (15-200 cm). Of the 13 species found in this system, species with larger juveniles and young-of-the-year (>50 cm TL) were found most often (Table 3). These species were blacktip, spinner, sandbar, and finetooth sharks. Mostly adults were found in this area among species with smaller neonates and juveniles (e.g. Atlantic sharpnose, blacknose) (Figure 4). Within Apalachicola, neonate (open or partially healed umbilical scar) blacktip and finetooth sharks were first captured in May and June indicating parturition occurs for these species around this time. Following these species, neonate spinner and sandbar sharks were first encountered in July. Older juvenile blacktip and finetooth sharks immigrated into this area beginning in April or May depending on water temperature (>20° C) and juveniles of most other species were present by June. Almost all species present in this system usually emigrated out beginning in October. Of all bay systems surveyed, bull sharks were most often captured in Apalachicola and this is the only area where dusky sharks were encountered.

Table 2. **Descriptive statistics of sharks captured using gillnets and longlines in Apalachee Bay. All measurements are in cm total length.**

Species	Mean size captured	Standard deviation	Range	N
Atlantic sharpnose	69.2	13.6	29.3-102.0	472
Blacknose	82.4	21.0	43.1-114.4	26
Blacktip	104.9	24.5	72.3-174.0	70
Bonnethead	74.0	14.6	39.8-110.4	319
Bull	65.0	-	-	1
Florida smoothhound	65.0	6.0	45.8-71.0	14
Nurse	213.5	-	-	1
Scalloped hammerhead	99.8	33.4	73.1-137.2	3
Tiger	115.5	28.4	87.0-154.0	5

Table 3. **Descriptive statistics of sharks captured using gillnets and longlines in Apalachicola delta. All measurements are in cm total length**

Species	Mean size captured	Standard deviation	Range	N
Atlantic sharpnose	74.4	23.0	30.0-111.5	752
Blacknose	110.9	15.2	53.2-134.0	52
Blacktip	96.7	22.4	51.2-181.0	1204
Bonnethead	88.5	14.0	49.0-122.0	186
Bull	185.0	61.4	67.0-267.0	31
Dusky	102.7	9.02	94.0-112.0	3
Finetooth	101.5	20.6	48.0-150.0	872
Great hammerhead	240	-	-	1
Lemon	170	-	170.0-170.0	3
Nurse	110.0	15.5	95.0-126.0	3
Sandbar	97.7	23.0	55.0-164.0	160
Scalloped hammerhead	58.6	16.6	37.2-238.0	291
Spinner	88.3	15.8	53.0-135.3	589

Table 4. **Descriptive statistics of sharks captured using gillnets and longlines in St. Joseph Bay. All measurements are in cm total length.**

Species	Mean size captured	Standard deviation	Range	N
Atlantic sharpnose	78.2	13.9	38.0-99.0	32
Blacknose	59.3	20.6	43.0-118.0	15
Blacktip	91.0	23.0	66.0-116.0	4
Bonnethead	60.9	11.9	45.0-80.0	45
Bull	141	-	-	1
Florida smoothhound	67.8	4.6	62.0-72.0	4
Lemon	95.3	8.1	79.0-105.0	10
Spinner	101.5	21.9	86.0-117.0	2

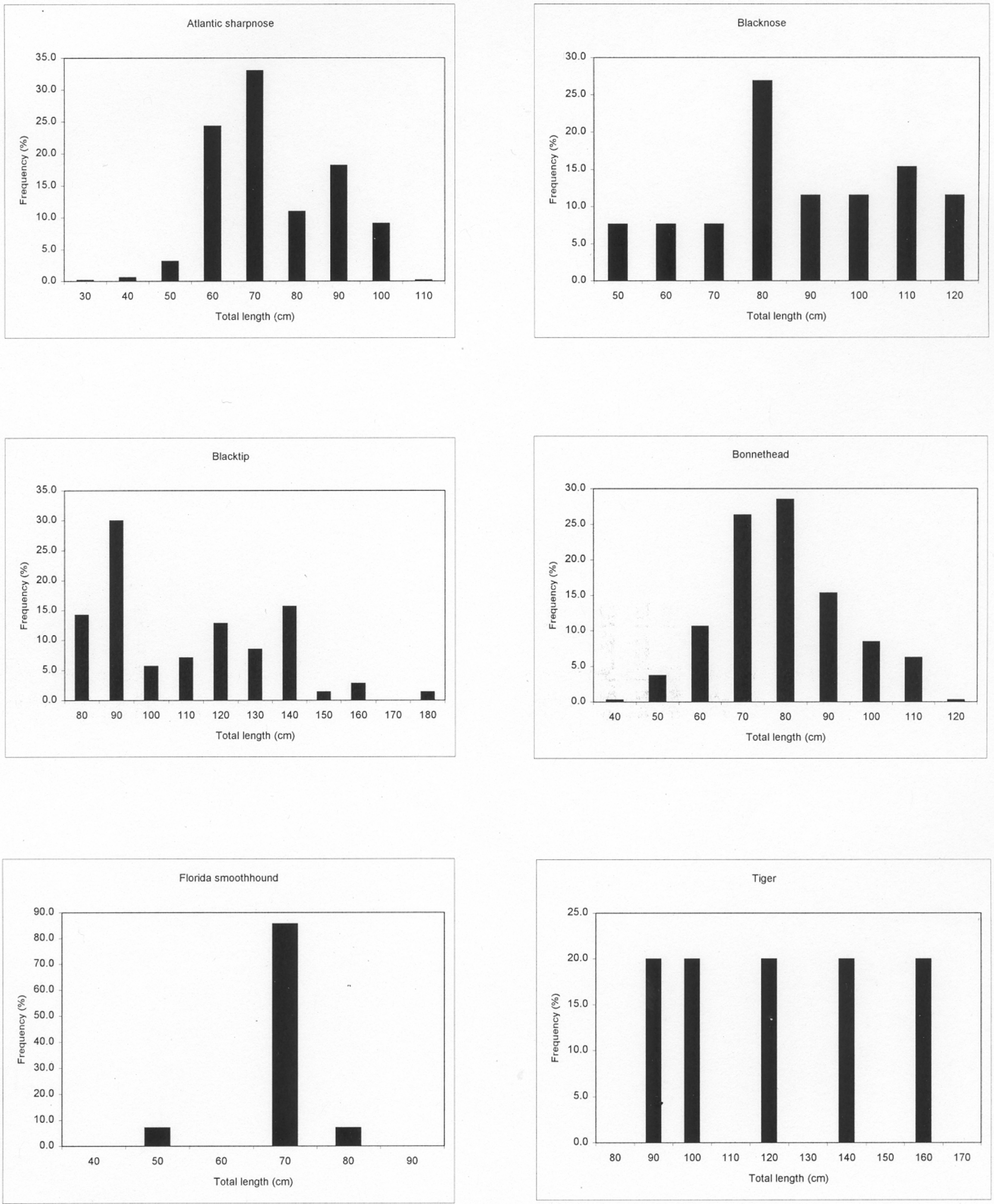

Figure 3. **Length frequency distributions of the most abundant species captured in Apalachee Bay**

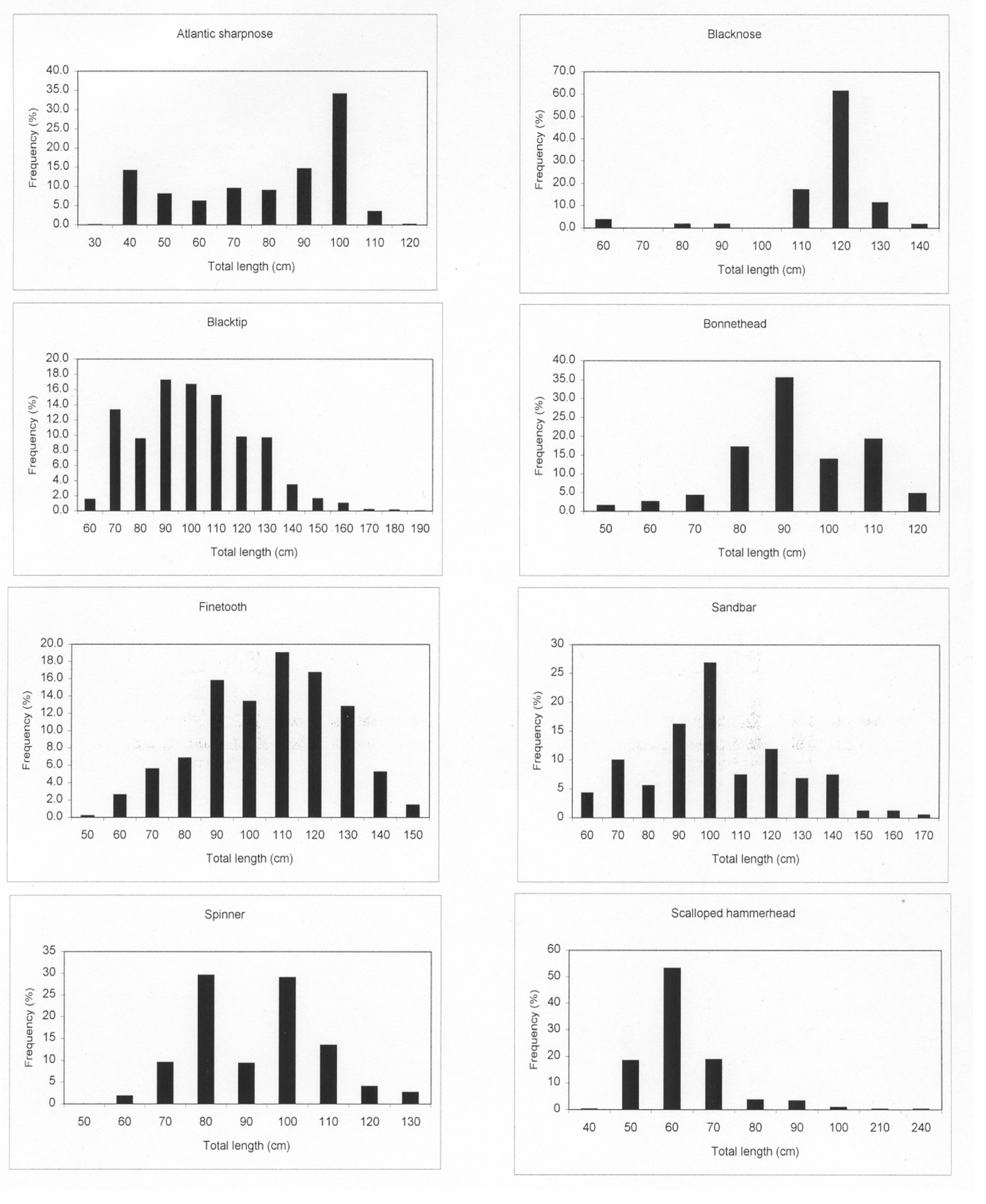

Figure 4. **Length frequency distributions of the most abundant species captured in Apalachicola Bay**

Table 5. Descriptive statistics of sharks captured using gillnets and longlines in Crooked Island Sound. All measurements are in cm total length.

Species	Mean size captured	Standard deviation	Range	N
Atlantic sharpnose	65.7	15.8	30.4-110.9	3015
Blacknose	61.4	18.9	39.5-132.1	511
Blacktip	90.0	19.9	48.5-148.0	348
Bonnethead	60.2	15.8	37.4-121.0	1058
Bull	151.0	1.4	150.0-152.0	2
Finetooth	110.1	19.9	55.3-141.0	85
Florida smoothhound	69.2	9.2	43.9-107.4	212
Great hammerhead	204.8	6.0	200.5-209.0	2
Nurse	154.7	8.0	150.0-167.6	7
Sandbar	83.5	16.3	72.0-95.0	2
Scalloped hammerhead	59.7	29.5	38.0-252.0	187
Spinner	81.4	14.8	55.1-124.1	176

St. Joseph Bay

St. Joseph Bay was surveyed from 1998-2000. A total of 113 sharks were captured in this bay system, the majority in shallow (2-3 m deep) areas over seagrass beds. Because this bay has little freshwater inflow, sharks were captured at higher salinities (30-38 ppt) than in other areas. Species such as blacknose and bonnethead, with smaller juveniles and young-of-the-year (<50 cm TL), were caught most often (Table 4). Adult Atlantic sharpnose and juvenile blacktip sharks were also found in St. Joseph Bay (Figure 5). St. Joseph Bay was the only bay system where young lemon sharks (~Age1-2; Brown and Gruber, 1988) were encountered. Lemon sharks were captured in a habitat type (shallow grass beds) that is similar to areas where lemon sharks are found in the Florida Bay ecosystem (E. Cortés, NMFS, SEFSC, Panama City, FL, pers. commun., 2000).

Crooked Island Sound

Sampling began in Crooked Island Sound in 1993 and has run continuous through 2000. A total of 5,605 sharks from 12 species have been captured in this area (Table 5). Generally, species with smaller neonates and juveniles (<50 cm TL) are most often captured in this system. Atlantic sharpnose, bonnethead, and blacknose sharks made up 82% of the sharks found.

Recruitment of young-of-the-year and/or pupping in this area followed a consistent pattern over most years sampled. Young-of-the-year bonnethead sharks recruited to the area beginning in April sometimes when water temperatures were recorded as low as 16° C. Neonate Atlantic sharpnose sharks were first observed in May when water temperatures approached 20-25° C followed by blacknose neonates and females with near-term pups in June. Gravid scalloped hammerhead sharks and neonates where captured in July. Additional recruitment of juvenile species such as blacktip, spinner, and finetooth shark occurred throughout June and July. Similar to Apalachicola, most species emigrated out of the bay system beginning in October. Florida smoothhound sharks were generally captured in cooler water temperatures (20° C) in March, April, and October.

St. Andrew Bay

A total of 464 sharks from 9 species were captured in St. Andrew Bay in 1993, 1998, and 1999. Species composition was fairly similar to that observed in Crooked Island Sound (Table 6). Most species observed were juvenile Atlantic sharpnose, bonnethead, and blacknose sharks (Figure 7). However, fewer neonates and gravid females were captured in this area than in Crooked Island Sound. Other species commonly observed within this bay system were juvenile blacktip and Florida smoothhound sharks. Other species caught but not consistently captured were finetooth, scalloped hammerhead, and spinner sharks.

Figure 5. **Length frequency distributions of the most abundant species captured in St. Joseph Bay**

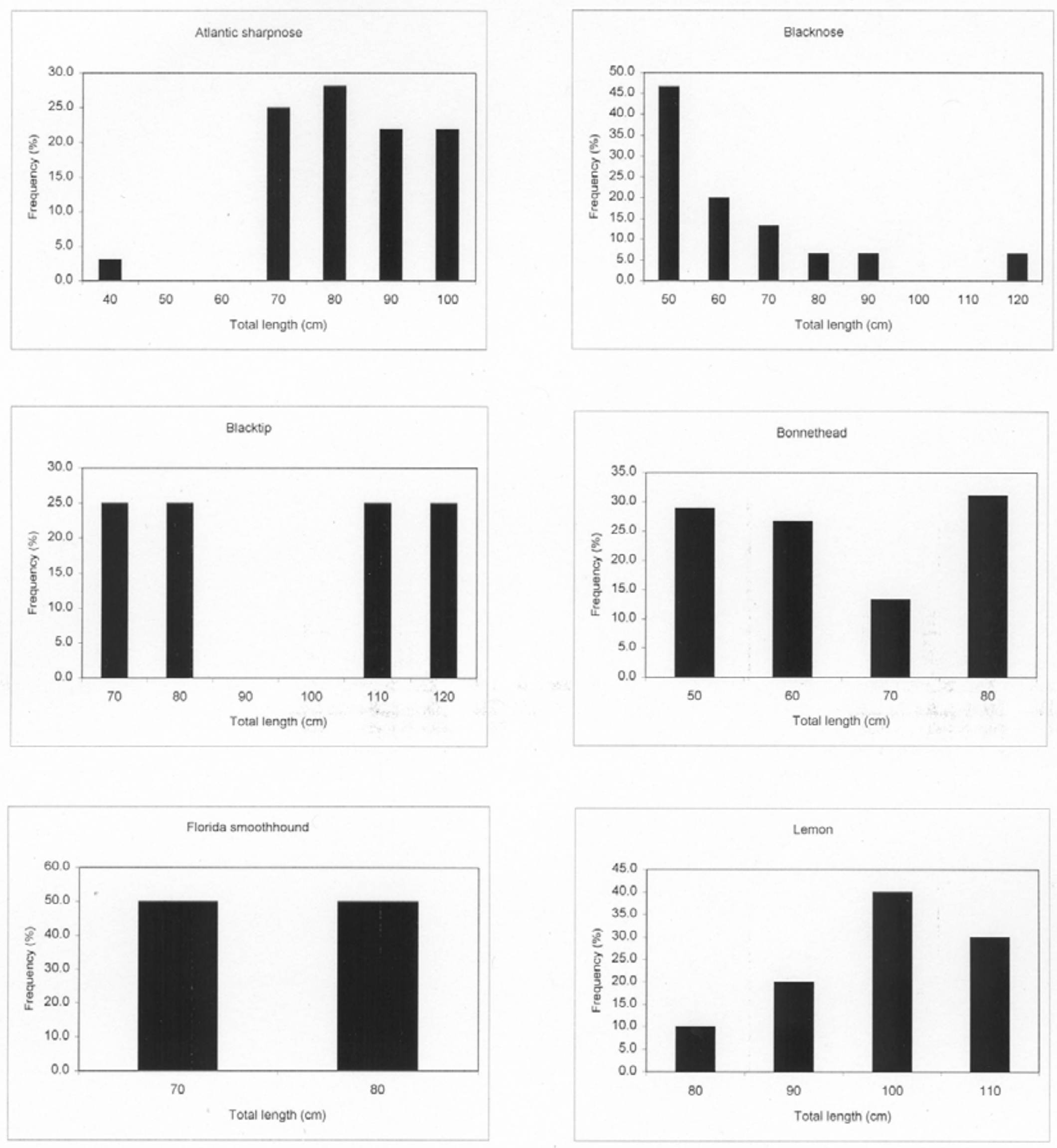

Table 6. **Descriptive statistics of sharks captured using gillnets and longlines in St. Andrew Bay. All measurements are in cm total length.**

Species	Mean size captured	Standard deviation	Range	N
Atlantic sharpnose	68.9	12.1	36.4-101.0	129
Blacknose	69.9	22.0	46.2-122.5	48
Blacktip	108.2	22.7	69.8-180.3	50
Bonnethead	62.5	12.5	42.0-92.8	133
Bull	200	-	-	1
Finetooth	109.4	14.8	102.0-148.2	9
Florida smoothhound	69.0	8.1	46.5-97.0	85
Scalloped hammerhead	88.6	90.7	48.0-250.8	5
Spinner	92.1	2.6	89.6-95.5	4

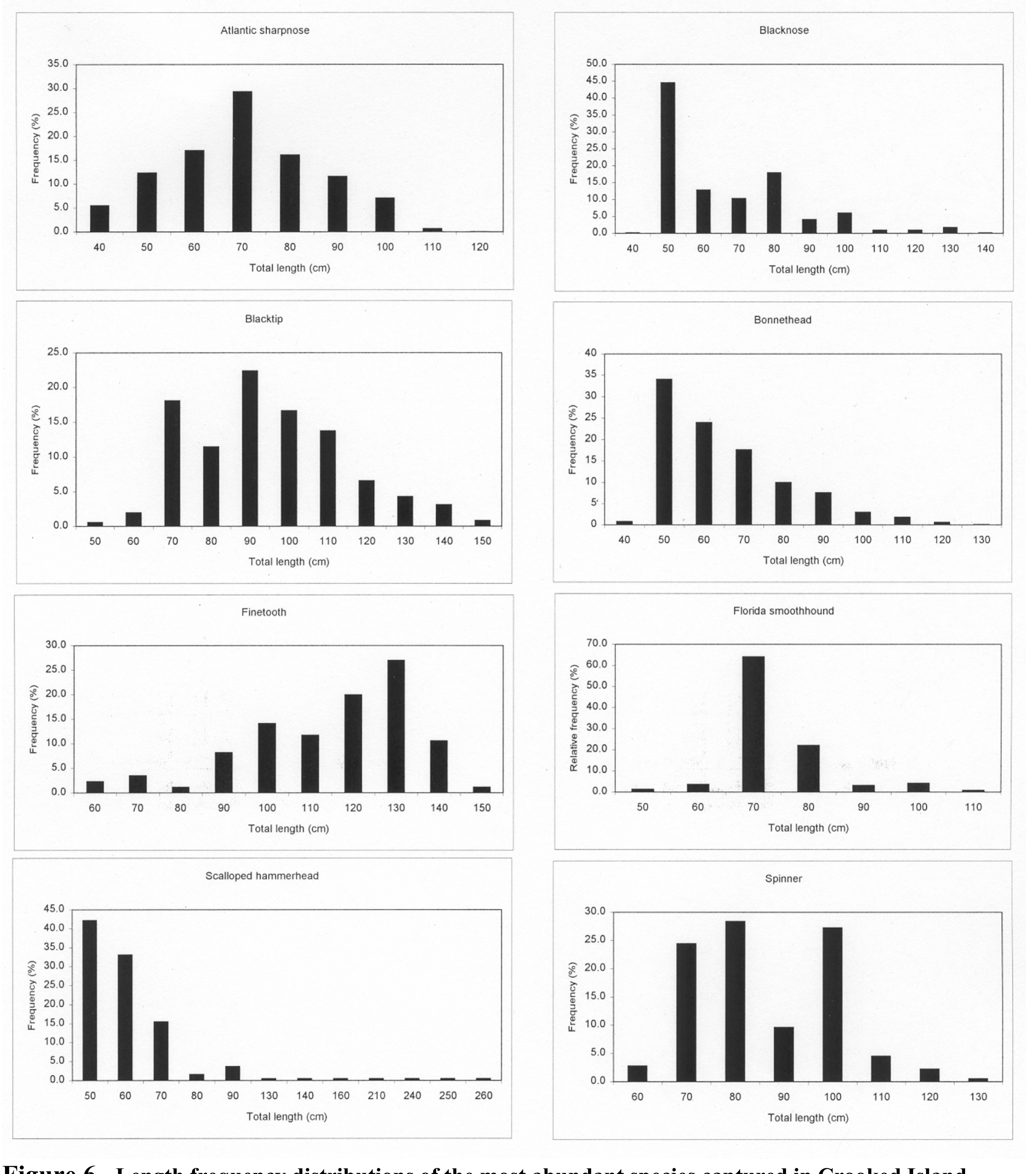

Figure 6. Length frequency distributions of the most abundant species captured in Crooked Island Sound

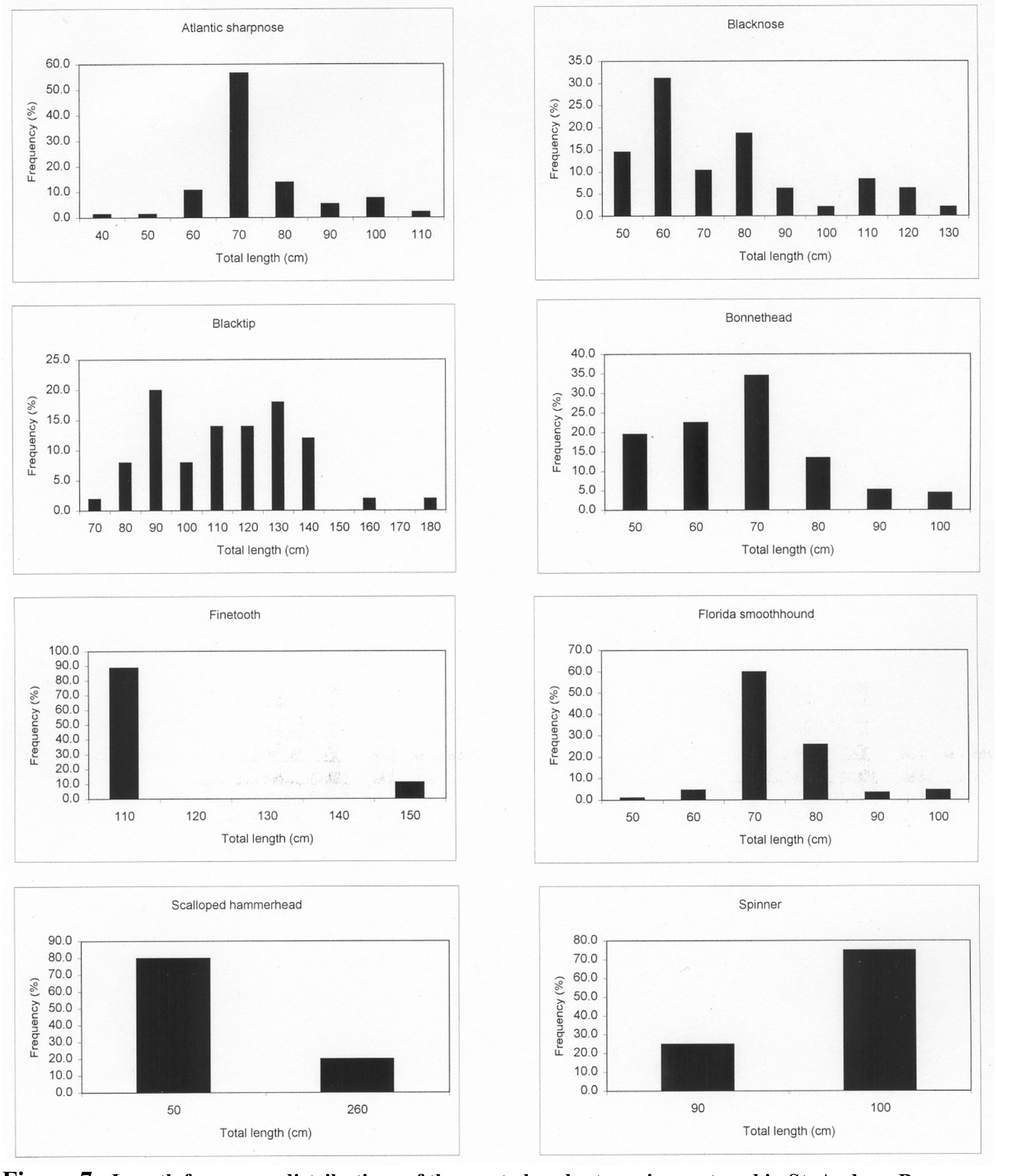

Figure 7. Length frequency distributions of the most abundant species captured in St. Andrew Bay

Tag/recaptures

A total of 1,117 sharks have been tagged and released since 1993 and 50 have been reported recaptured. This represents a recapture rate of 4.5%. The longest time at liberty was 2,461 days for an Atlantic sharpnose shark. This shark was recaptured in the same area, Crooked Island Sound, that it was originally tagged in. The largest distance traveled was for a blacktip shark that was recaptured offshore southwest of Tampa, FL. This shark traveled 205 nautical miles from Apalachicola Bay in 102 days.

Comparison of Abundance among Areas

Despite some apparent differences in abundance among the various sampling areas, caution should be taken when making inferences about the importance of one area over another (using abundance as a indicator) without considering the problem of sampling bias. Because funding was not continuous and sampling was directed at various objectives, prior to 1996 the sampling gear (gillnets and longlines) and sampling strategy varied. Since selectivity functions have not been calculated for all species with the respective gear types, it cannot ascertained whether some species are naturally low in abundance in some areas sampled or whether this is an artifact due to sampling bias.

Correlation of Abundance with Environmental Factors

When effort was standardized (see Carlson and Brusher 1999), correlations were examined among the most abundant species captured (log transformed CPUE) and environmental variables measured. Multiple linear regression was used to examine the relationship between shark abundance and temperature (°C), salinity (ppt), dissolved oxygen (mg l^{-1}), and light transmission (cm; measured as the depth of the photic zone). A significant relationship was found between abundance of spinner and scalloped hammerhead sharks and water temperature (spinner:r^2=0.19, p=0.02; scalloped hammerhead; r^2=0.16, p=0.03), but not with salinity, dissolved oxygen, or light transmission ($r^2$0.05). All remaining species had poor correlation coefficients and non-significant relationships (Table 7).

Species Profiles

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

A total of 4,400 Atlantic sharpnose sharks were captured from all areas sampled. Sharks ranged in size from 29.3-111.5 cm TL. Generally, sharks were captured in water temperatures from 26.6-28.0º C, salinities averaging 31.6 ppt, and depths of 4.1 m (Table 8). Atlantic sharpnose sharks were found over a variety of bottom types.

Blacknose shark, *Carcharhinus acronotus*

Blacknose sharks were captured in water temperatures from 20.8-33.6º C, salinities averaging 32.1 ppt, and depths of 3.7 m (Table 9). Blacknose sharks (n=652) caught ranged in size from 39.5-134 cm TL. Blacknose sharks were found over a variety of bottom types and tolerated dissolved oxygen levels to 2.0 mg l^{-1}.

Blacktip shark, *Carcharhinus limbatus*

Blacktip sharks captured (n=1676) ranged in size from 48.5-181 cm TL, but the majority of these were neonates and juveniles. Blacktip sharks appear to be a relatively tolerant species to a variety of habitat conditions, being found in water temperatures between 16.0-31.8º C, salinities of 19-38 ppt and depths of 2-7 m (Table 10). Similar to results of Grace and Henwood (1997), some blacktip sharks were captured in areas with low dissolved oxygen concentrations.

Bonnethead shark, *Sphyrna tiburo*

A total of 1,741 sharks were captured over the length of study. Bonnethead sharks ranged in size from 37.4-122 cm TL. Similar to blacktip shark, the bonnethead was found in a variety of habitat conditions (Table 11). Bonnethead sharks were collected in water temperatures between 16-32.5º C, salinities of 19-38 ppt, dissolved oxygen levels to 1.9 mg l^{-1} , and depths of 2-7 m. Preliminary

Table 7. **Correlation coefficients and significance levels of between log transformed CPUE and temperature, salinity, light transmission and dissolved oxygen.**

SPECIES	FACTOR	r^2	P
Atlantic sharpnose	Temperature	0.01	0.87
	Salinity	0.05	0.24
	Light transmission	0.01	0.49
	Dissolved oxygen	0.02	0.42
Blacknose	Temperature	0.07	0.16
	Salinity	0.04	0.33
	Light transmission	0.09	0.14
	Dissolved oxygen	0.11	0.66
Blacktip	Temperature	0.07	0.18
	Salinity	0.02	0.42
	Light transmission	0.01	0.85
	Dissolved oxygen	0.14	0.58
Bonnethead	Temperature	0.01	0.60
	Salinity	0.09	0.12
	Light transmission	0.03	0.40
	Dissolved oxygen	0.24	0.36
Finetooth	Temperature	0.02	0.51
	Salinity	0.10	0.10
	Light transmission	0.06	0.20
	Dissolved oxygen	0.06	0.69
Sandbar	Temperature	0.07	0.18
	Salinity	0.02	0.83
	Light transmission	0.01	0.85
	Dissolved oxygen	0.11	0.38
Scalloped hammerhead	Temperature	0.16	0.03
	Salinity	0.07	0.67
	Light transmission	0.08	0.65
	Dissolved oxygen	0.08	0.73
Spinner	Temperature	0.19	0.02
	Salinity	0.02	0.81
	Light transmission	0.07	0.68
	Dissolved oxygen	0.11	0.51

Table 8. **Summary of the habitat associations for Atlantic sharpnose sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	28.0 (19.5-31.2)	31.8 (24.0-37.0)	4.0 (0.7-6.2)	128.7 (15.0-280.0)	5.8 (3.6-7.7)	Silt/clay Sand
Juveniles	27.0 (16.0-32.4)	32.5 (19.0-38.0)	4.1 (2.0-6.4)	208.5 (15.0-400.0)	6.2 (4.5-8.3)	Silt/clay Seagrass, Sand
Adults	26.6 (19.8-32.4)	30.5 (19.0-38.0)	4.1 (1.7-6.4)	156.5 (15.0-400.0)	6.2 (4.5-8.3)	Silt/clay Sand

Table 9. **Summary of the habitat associations for blacknose sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	27.6 (24.7-33.2)	33.1 (29.0-35.0)	3.6 (1.0-6.3)	201.0 (100.0-290.0)	5.9 (4.6-7.4)	Silt/clay Seagrass, Sand
Juveniles	28.0 (20.8-33.6)	32.1 (27.0-38.0)	3.5 (0.7-5.0)	196.9 (8.3-400.0)	6.8 (2.0-8.3)	Silt/clay Seagrass, Sand
Adults	26.0 (22.5-30.6)	31.2 (26.0-37.0)	4.2 (1.3-5.0)	119.1 (50.0-290.0)	5.7 (5.5-6.6)	Silt/clay Sand

Table 10. **Summary of the habitat associations for blacktip sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	28.4 (22.5-31.4)	29.8 (19.0-38.0)	4.1 (2.1-6.0)	97.0 (50.0-200.0)	5.1 (3.6-7.0)	Silt/clay Sand
Juveniles	27.8 (16.0-31.8)	30.1 (19.0-37.0)	4.1 (2.0-7.0)	128.9 (15.0-400.0)	5.7 (3.6-8.3)	Silt/clay Sand
Adults	28.3 (22.8-31.2)	31.9 (24.0-38.0)	3.9 (3.0-6.2)	119.5 (15.0-250.0)	5.5 (4.8-6.5)	Silt/clay Sand

Table 11. **Summary of the habitat associations for bonnethead sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	27.2 (16.0-32.5)	32.9 (19.0-38.0)	3.7 (0.7-6.4)	183.9 (25.0-365.0)	6.6 (1.9-8.3)	Seagrass Silt/clay, Sand
Juveniles	27.2 (16.0-32.5)	32.9 (19.0-38.0)	3.7 (0.7-6.4)	183.9 (25.0-365.0)	6.6 (1.9-8.3)	Seagrass Silt/clay, Sand
Adults	26.5 (16.0-31.4)	29.0 (19.0-38.0)	3.5 (1.0-6.4)	137.0 (25.0-365.0)	5.7 (4.5-8.1)	Sand Silt/clay

evidence suggests young-of-the-year bonnethead sharks prefer shallow sea grass beds while adults prefer deeper areas with a sand/clay bottom.

Bull shark, *Carcharhinus leucas*

Of all species collected, bull sharks seemed to prefer the most particular habitat type (Table 12). Bull sharks (n=36) ranging in size from 65-267 cm TL were only collected in areas with silt/clay sediment, high volumes of freshwater inflow, and high turbidities (water clarity from 66-103 cm). This species was found in water temperatures between 20.7-31.8º C, salinities of 25-36 ppt and depths of 2.5-5.3 m.

Finetooth shark, *Carcharhinus isodon*

A total of 966 finetooth sharks were captured from all areas sampled. Sharks ranged in size from 48-150 cm TL. Generally, sharks were captured in water temperatures averaging 27.3º C, salinities 27.9 ppt, and depths of 4.2 m (Table 13). Finetooth sharks were generally found in habitats with a predominately silt/clay sediment type.

Florida smoothhound shark, *Mustelus norrisi*

Florida smoothhound sharks (n=315) ranging in size from 43.9-107.4 were collected in cooler water temperatures averaging 20.5º C (Table 14). This species was found in depths from 1.7-5.0 m and in salinities from 27-36 ppt.

Nurse shark, *Ginglymostoma cirratum*

A total of 11 nurse sharks were captured ranging in size from 95-213.5 cm TL. Nurse sharks were found in temperatures from 22.6-28.1º C, salinities averaging 33.8 ppt and depths of 4.1 m (Table 15).

Lemon shark, *Negaprion brevirostris*

Lemon sharks were only captured in shallow protected areas with vast expanses of sea grass. Juveniles tended to prefer shallow depths (~1.1 m) where water temperatures averaged 30.9º C and salinities were 33.6 ppt (Table 16). Of the 14 lemon sharks captured (range 79-202 cm TL), most were younger juveniles (mean size=118 cm TL).

Sandbar shark, *Carcharhinus plumbeus*

Sandbar sharks were captured in water temperatures from 26.6-27.3º C, salinities averaging 34.0 ppt, and depths of 3.6 m (Table 17). Sandbar sharks (n=162) collected ranged in size from 55-164 cm TL. Sandbar sharks were found only over of bottom types of a silt/clay composition and in waters with low water clarity (40-107 cm).

Scalloped hammerhead shark, *Sphyrna lewini*

A total of 486 scalloped hammerhead shark were captured throughout the study period. Sharks ranged in size from 38.2-252 cm TL but the majority of these were juveniles. Generally, sharks were captured in water temperatures from 27.5-29.5º C, salinities averaging 32.2 ppt, and depths from 2.3-6.0 m (Table 18).

Spinner shark, *Carcharhinus brevipinna*

Spinner sharks captured (n=771) ranged in size from 53-135.3 cm TL. Spinner sharks were collected in water temperatures between 20.9-31.2º C, salinities of 19-38 ppt and depths of 2-6 m (Table 19). Spinner sharks were found over a variety of bottom types.

Preliminary Findings

Juveniles were the dominant life history stage captured in all areas sampled. It appears that species with larger juveniles and young-of-the-year (>50 cm TL) were found in Apalachicola. These species being blacktip, spinner and sandbar sharks. Species with smaller juveniles and young-of-the-year (<50 cm TL) (e.g. Atlantic sharpnose, bonnethead, and blacknose) were captured in more protected areas such as Crooked Island Sound and in the shallower areas of St. Joseph Bay and Apalachee Bay. The difference in spatial distribution among juveniles of different species may reflect an attempt to avoid predation (Springer, 1967; Branstetter, 1990) as all areas appear to have

Table 12. **Summary of the habitat associations for bull sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	N/A	N/A	N/A	N/A	N/A	N/A
Juveniles	29.5 (20.7-31.8)	29.6 (25.0-36.0)	4.0 (2.5-5.0)	103.4 (30.0-200.0)	5.1 (4.5-6.6)	Silt/clay
Adults	24.6 (21.5-30.8)	25.7 (25.0-27.0)	5.2 (4.9-5.3)	66.7 (60.0-80.0)	N/A	Silt/clay

Table 13. **Summary of the habitat associations for finetooth sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	27.9 (26.4-31.4)	26.1 (25.0-36.0)	4.2 (3.3-5.0)	73.5 (50.0-90.0)	5.0 (4.5-5.6)	Silt/clay
Juveniles	27.4 (19.5-31.4)	27.9 (19.0-38.0)	4.3 (2.3-5.3)	97.8 (15.0-365.0)	5.4 (3.6-6.8)	Silt/clay Sand
Adults	26.8 (19.5-30.3)	29.7 (19.0-38.0)	4.0 (2.6-6.0)	147.0 (15.0-365.0)	6.2 (4.8-7.0)	Silt/clay Sand

Table 14. **Summary of the habitat associations for Florida smoothhound sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	N/A	N/A	N/A	N/A	N/A	N/A
Juveniles	20.5 (16.0-22.0)	30.2 (27.0-35.0)	3.5 (3.0-5.0)	252.9 (110.0-365.0)	7.5 (6.0-8.2)	Silt/clay Seagrass, Sand
Adults	20.3 (16.0-29.2)	31.1 (27.0-36.0)	3.8 (1.7-5.0)	230.7 (100.0-370.0)	7.5 (6.0-8.2)	Silt/clay Seagrass, Sand

Table 15. **Summary of the habitat associations for nurse sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	N/A	N/A	N/A	N/A	N/A	N/A
Juveniles	25.8 (22.6-28.1)	33.8 (27.0-37.0)	4.1 (3.5-6.0)	158.8 (15.0-400.0)	6.3 (5.0-8.3)	Silt/clay Sand
Adults	N/A	N/A	N/A	N/A	N/A	N/A

Table 16. **Summary of the habitat associations for lemon sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	N/A	N/A	N/A	N/A	N/A	N/A
Juveniles	30.9 (27.2-34.0)	33.6 (26.0-39.0)	1.9 (0.7-6.3)	110.1 (8.3-300.0)	5.6 (2.0-8.1)	Seagrass
Adults	N/A	N/A	N/A	N/A	N/A	N/A

Table 17. **Summary of the habitat associations for sandbar sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	26.6 (26.6-30.8)	39.0 (19.0-39.0)	3.0 (3.0-5.2)	40.0 (40.0-265.0)	5.5 (5.0-7.3)	Silt/clay
Juveniles	27.3 (19.8-30.8)	29.4 (19.0-36.0)	4.2 (2.1-5.2)	106.9 (15.0-265.0)	5.5 (5.0-7.3)	Silt/clay
Adults	N/A	N/A	N/A	N/A	N/A	N/A

Table 18. **Summary of the habitat associations for scalloped hammerhead sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	29.3 (25.5-31.2)	33.4 (25.0-39.0)	3.8 (2.3-7.0)	116.9 (30.0-290.0)	5.9 (4.6-6.2)	Silt/clay Sand
Juveniles	29.5 (20.4-31.4)	32.1 (25.0-39.0)	4.2 (2.3-6.0)	140.6 (15.0-365.0)	5.9 (4.5-6.0)	Silt/clay Sand
Adults	27.5 (27.0-28.6)	31.3 (31.0-32.0)	3.8 (3.5-3.9)	203.3 (200.0-210.0)	N/A	Silt/clay Sand

Table 19. **Summary of the habitat associations for spinner sharks by life history stage. Mean values are presented and numbers is parentheses represent minimum and maximum values measured. Young-of-the-year includes neonates.**

Life stage	Temperature (°C)	Salinity (ppt)	Depth (m)	Water clarity (cm)	Dissolved O_2 (mg l^{-1})	Bottom type
Young-of-the-year	26.5 (22.5-30.5)	29.2 (25.0-35.0)	4.4 (2.7-5.0)	107.3 (50.0-280.0)	5.6 (5.4-6.0)	Silt/clay Seagrass
Juveniles	28.3 (20.9-31.2)	30.5 (19.0-38.0)	4.1 (2.0-6.0)	126.4 (15.0-400.0)	5.6 (4.9-8.3)	Silt/clay Sand
Adults	N/A	N/A	N/A	N/A	N/A	N/A

a high forage base. Crooked Island Sound is a small, semi-enclosed sound where few larger adult sharks were found. Thus, species with small neonates and juveniles may be selecting this area as a nursery based on low predation levels. Moreover, larger bull sharks were found in greatest abundance in Apalachicola and tiger sharks were captured only in the deeper areas of Apalachee Bay.

The poor relationship among environmental parameters and abundance suggest that additional environmental parameters not measured could be associated with habitat selection. Relationships may exist on multi-dimensions that would involve more robust statistical analysis that presented herein. Thus, more specific studies are needed to fully evaluate the interrelationships of abiotic and biotic factors and how they affect the abundance and distribution of sharks in nursery areas.

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Identification of Shark Nursery Grounds along the Mississippi and Alabama Gulf Coasts

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Scope

The National Marine Fisheries Service, MARFIN program provided funds for researchers at the University of Mississippi to conduct a gillnet survey of shark nursery grounds in the northern Gulf of Mexico extending from St. Louis Bay, Mississippi to Perdido Bay, Alabama. The survey began in October 1997 and ended in September 2000. Collections were made from April to October of each year with at least four sites sampled each month. During the survey a total of 111 collections were made at approximately 60 different sites. Approximately 2700 sharks were collected during the study. Approximately 500 sharks were collected in each of the first and second years of the study. However, over 1700 sharks were taken in the third year of the study. A total of 1908 juvenile sharks representing nine species were captured. Shark populations along the Mississippi and Alabama gulf coasts are dominated by three species, the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, the blacktip shark, *Carcharhinus limbatus*, and the finetooth shark, *C. isodon.* However, if only neonates and juveniles are considered the blacktip is the most common. Other species captured included the bull, *C. leucas*, the scalloped hammerhead, *Sphyrna lewini*, the bonnethead, *S. tiburo*, the spinner, *C. brevipinna,* the blacknose, *C. acronotus*, and the sandbar, *C. plumbeus* sharks. The objectives of this project were to identify shark pupping/nursery grounds along the Mississippi and Alabama gulf coasts in the northern Gulf of Mexico and to determine their extent.

Sampling Materials and Methods

From October 1997 to September 2000, sharks were collected at sites along the northern Gulf of Mexico extending from St. Louis Bay, Mississippi to Perdido Bay, Alabama (Figure 1). Collections were made from April to October of each year with at least four sites sampled each month; two sites in Mississippi waters and two sites in Alabama waters. Sites were randomly selected such that a large geographical area could be covered. However, site selection was limited by weather, sea state, and shrimping activity. For these reasons, most sites chosen were within the Mississippi Sound in the lee of the extensive barrier island system. Additionally, because the gillnet was approximately 2 meters deep, it was not effective to use the net in very shallow waters.

We used a 182.9 m (600 ft) gillnet consisting of six 30.5 m (100 ft) panels of the following sizes: 4.5, 5.1, 5.7, 6.4, 7.0 and 10.2 cm (1.75, 2.0, 2.25, 2.5, 2.75 and 4.0 in) square mesh. In the final year of the study we added an additional 30.5 m (100 ft) panel of netting consisting of 3.8 cm (1.5 in) square mesh. This change was effected to insure the capture of neonate sharpnose sharks (*Rhizoprionodon terraenovae)*. The net was fished from 1500 until 2200 hours each day. Depending upon the rate of capture and the environmental conditions prevalent the net was checked every 0.25 to 1.0 hour. Each time the net was checked, we recorded the time of day sharks were captured.

As each shark was cleared from the net, the mesh size from which that shark was taken was recorded. As expeditiously as possible the shark was measured (total length, TL) and its sex, species, and maturity state were recorded. Sharks that were judged in good condition were tagged using Floy dart tags and released. The condition at release was scored according to the following scale: (1.) very strong swimming, (2.) strong swimming, (3.)

Figure 1. The shark nursery ground study area. The symbols indicate all sites examined during the study. The filled symbols represent sites where neonate or juvenile sharks were captured. The open symbols represents sites where no sharks were captured. Note that some symbols represent multiple sampling sites.

sluggish swimming, and (4.) little or no obvious swimming. A suite of environmental parameters, water temperature, salinity, dissolved oxygen, current speed, Secchi depth and water depth were measured at each site. We also noted weather conditions, sea state and used GPS to record latitude and longitude.

For comparative purposes we calculated catch per unit effort (CPUE) in sharks per net hour. We used the StatView statistics program for data analysis.

Description of Study Areas

The coasts of Mississippi and Alabama represent approximately 200 linear kilometers. The Mississippi Sound, where most of the nursery areas were identified, extends approximately from Grand Isle, Louisiana to Mobile Bay, Alabama and is over 1300 square kilometers. Two prominent features of the coast in this area are the Mobile Bay and the extensive barrier island system (Figure 1). The tides along the entire north central Gulf of Mexico are diurnal and typically average less than 0.5 m. Mean environmental parameters for all sites where neonate and juvenile sharks were collected were calculated by species (Table 1). For all sites and species combined, the averages were: depth, 4.0 m; surface temperature, 29.1 ˚C; bottom temperature, 28.3 ˚C; surface salinity, 18.2 ppt; bottom salinity, 20.3 ppt; surface dissolved oxygen, 7.1 ppm; bottom dissolved oxygen, 6.4 ppm; surface current speed, 18.2 cm/s; Secchi depth 112 cm.

Relative Abundance and Distribution

Total catch

During the survey a total of 111 collections (gillnet sets of at least 15 minutes duration) were made at approximately 60 sites (Figure 1). We made 72 collections in Mississippi waters and 39 in Alabama waters. Approximately 25 different sites were sampled in Alabama waters and 35 in Mississippi waters. Approximately 2700 sharks were collected during the study (Table 2). About 500 sharks were

Table 1. **The environmental parameters of the sites where neonate (N) and juvenile (J) sharks were collected. Means are recorded except in cases where single individuals were collected. Sharp.=sharpnose, Blackt.=blacktip, Bonnet.=bonnethead, Sand.=sandbar, Blackn.=blacknose, Scallop.=scalloped hammerhead, Fine.=finetooth, Bull.=bullshark, Spin.=spinner. D.O.= dissolved oxygen, Sur.=surface, Bot.=bottom.**

Species	Depth (m)	Temperature (C^o) Sur.	Temperature (C^o) Bot.	Salinity (ppt) Sur.	Salinity (ppt) Bot.	D. O. (ppm) Sur.	D. O. (ppm) Bot.	Surface Current (cm/s)	Secchi Depth (cm)
Sharp-N	6.9	30.1	29.2	18.5	20.6	6.5	5.5	13.5	130
Sharp-J	8.2	28.0	27.1	19.7	20.4	7.3	6.5	14.1	126
Blackt-N	3.4	30.6	29.3	17.8	20.3	6.6	6.6	20.3	117
Blackt-J	3.1	28.8	28.0	17.7	19.4	6.9	6.3	14.7	123
Bonnet-N**	3.0	29.5	28.0	15.5	24.0	8.8	7.8	6	---
Bonnet-J	3.4	30.1	28.9	19.3	20.4	6.4	5.7	20.2	128
Sand-J	2.1	24.4	23.3	13.4	14.8	8.3	8.0	11.3	109
Blackn-N**	4.6	32.0	29.0	17.2	26.2	7.2	7.0	21.0	---
Blackn-J	4.6	24.8	27.7	24.5	20.3	8.2	5.4	23.7	---
Scallop-N	3.4	29.2	29.1	18.9	19.9	7.1	5.6	14.2	111
Scallop-J	2.9	30.0	29.3	17.6	18.8	6.1	6.0	28.7	84
Fine-N	3.4	29.5	29.1	18.0	19.2	5.8	5.8	18.8	80
Fine-J	3.6	28.2	27.2	17.9	19.6	6.8	6.3	10.7	94
Bull-N	---	30.0	29.0	14.0	14.5	9.0	9.1	5.0	---
Bull-J	2.8	30.6	29.7	14.9	17.1	7.3	6.3	14.8	83
Spin-N**	---	30.0	28.5	24.0	27.0	6.0	4.8	50	150
Spin-J	4.6	28.7	27.9	20.9	22.4	6.7	5.8	22.8	120

**** indicates only a single individual captured**

Table 2. **Northern Gulf of Mexico shark catch summary.**

Species	Total catch	Total tagged	Size range	Neonates	Juveniles	Adults
Carcharhinus limbatus	774	315	49-152	412	348	14
C. isodon	450	223	48-148	123	281	46
Rhizoprionodon terraenovae	1346	690	33-126	89	558	699
C. leucas	46	38	88-160	2	44	0
C. brevipinna	19	7	72-141	1	18	0
Sphyrna lewini	13	5	48-148	9	4	0
C. acronotus	5	4	49-132	1	4	0
C. plumbeus	4	3	98-106	0	4	0
S. tiburo	29	14	35-106	1	9	19
TOTALS	2688	1301		638	1270	778

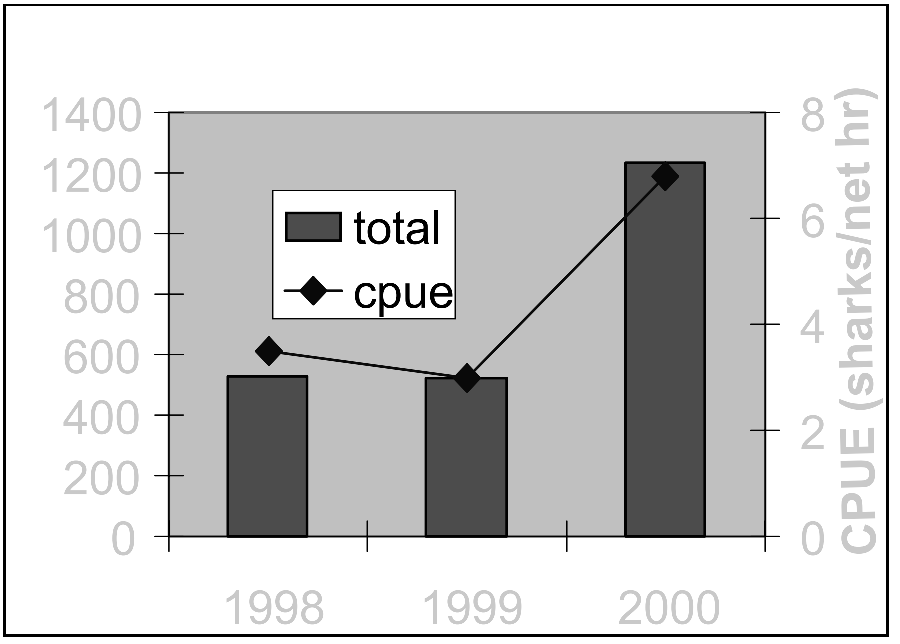

Figure 2. Total catch and catch per unit effort (CPUE, sharks per net hour) for all sharks taken during the study. All sites, species, and years combined.

collected in each of the first and second years of the study. However, over 1700 sharks were taken in the third year of the study. We collected 1048 sharks from Alabama waters and 1677 from Mississippi waters.

There was a significant change in the availability of sharks between 1999 and 2000 (Figure 2). After adjusting for the addition of extra netting in the year 2000, we compared catch per unit effort (CPUE) between years (Figure 2). CPUE increased significantly during the study from around 3.5 sharks per net hour in both 1998 and 1999, to about seven sharks per net hour in 2000. It was very apparent early in 2000 that the year was going to be atypical because we began catching sharks in large numbers early in the year. The increase in catch is difficult to explain but two possibilities should be considered. First, the severe drought that occurred that year resulted in highly saline waters near shore. It is possible that reduced freshwater input into coastal areas may have allowed sharks to move closer to shore. This reduced estuarine environment may have had a "concentrating effect" on these animals, forcing them into a narrower band of habitat and thus making them more available for capture. A second possibility is that the coasts of Alabama and Mississippi may be enjoying a "windfall" of sharks from Florida waters because of the stricter regulations on netting that exist there. This alternative explanation would be favored if shark captures continue to be high in typical rainfall years. This would likewise suggest an increase in shark numbers rather than simply an increase in their availability due to a concentrating effect.

We examined the total number of sharks collected by species for each year of the study (Figures 3 and 4). The Atlantic sharpnose shark *Rhizoprionodon terraenovae* is by far the most common shark taken when all size classes are considered. We collected approximately 300 sharpnose in each of 1998 and 1999. In 2000, over 750 sharpnose sharks were collected. Interestingly, in collecting over 1200 sharpnose sharks including many adult males, only five adult females were collected. Two of these females were gravid. Adult female sharpnose apparently rarely enter the Mississippi Sound. Second in abundance was the blacktip shark, *Carcharhinus limbatus* with about 160 and 75 sharks collected in 1998 and 1999, respectively. Almost 550 blacktip sharks were collected in 2000. The third most abundant species was the finetooth shark *Carcharhinus isodon* with approximately 50, 100 and 300 captured in 1998, 1999 and 2000, respectively. Shark populations along the Alabama and Mississippi gulf coasts are

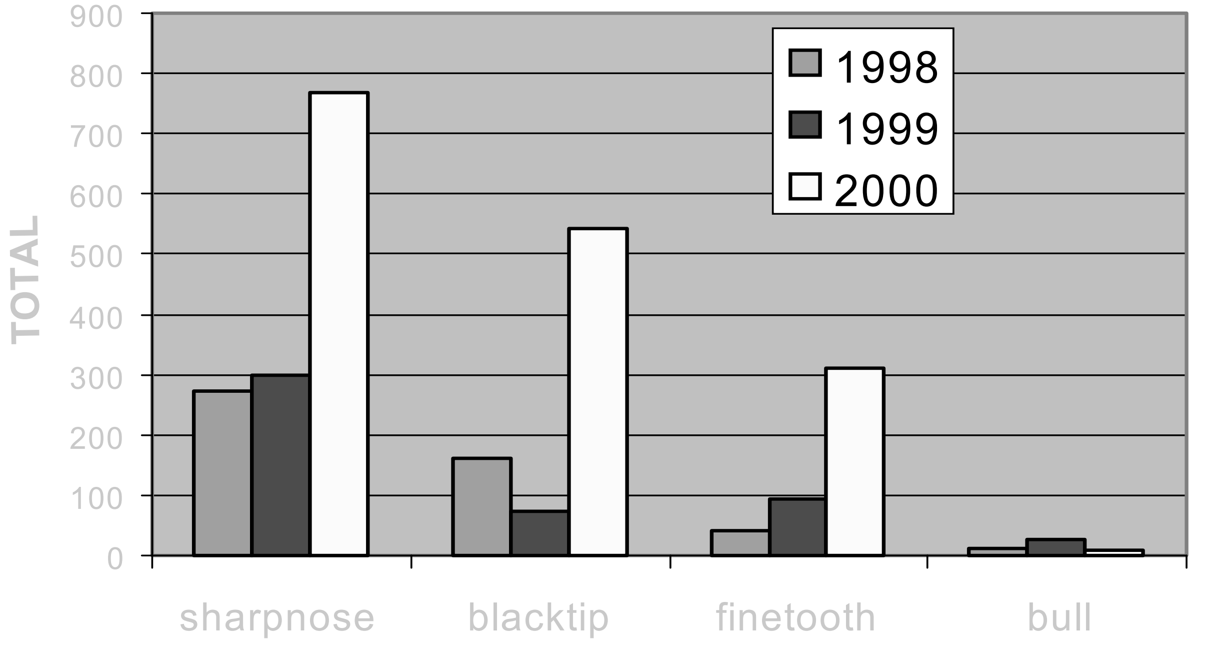

Figure 3. **Total catch of sharks by species and year**

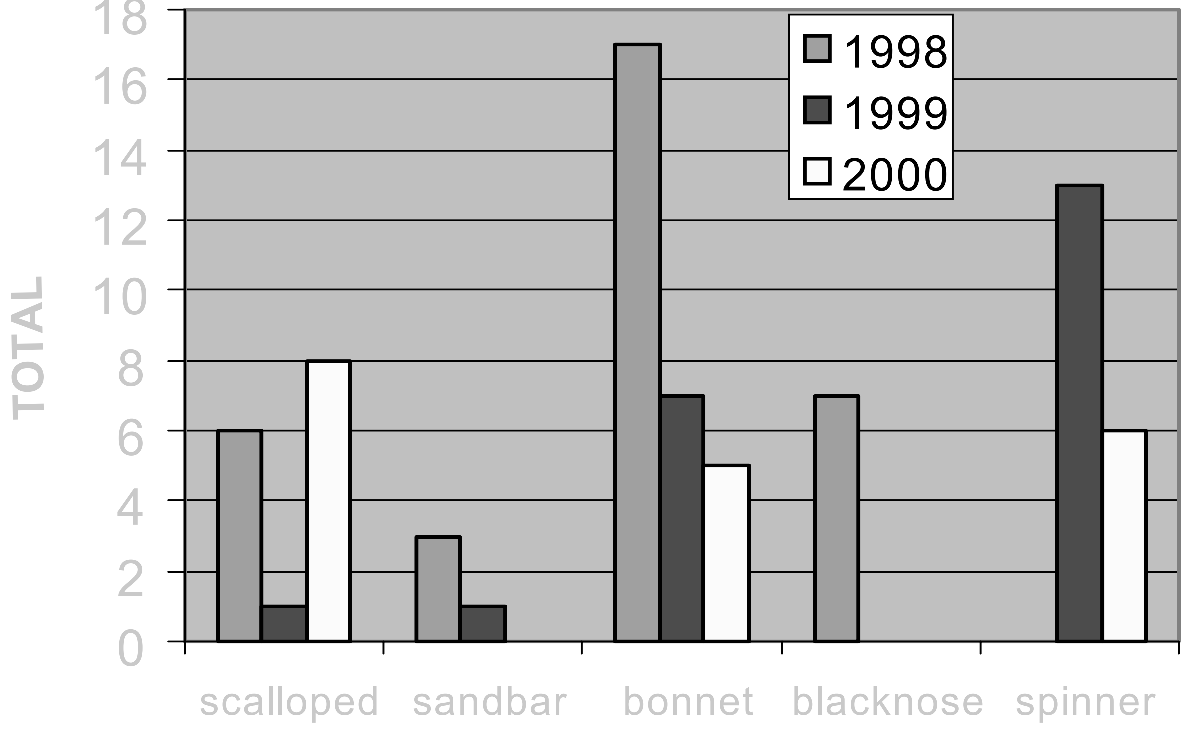

Figure 4. **Total catch of sharks by species and year**

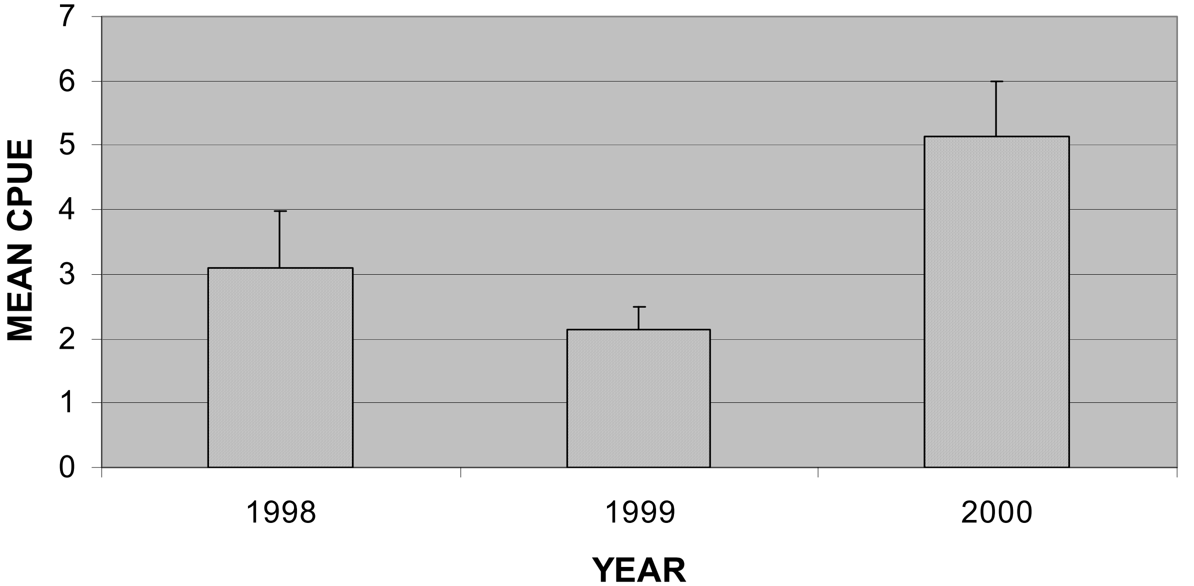

Figure 5. **Catch per unit effort (CPUE) of neonate and juvenile sharks for each year of the study**

dominated by the above three species representing almost 95% of the total catch of sharks.

Several other species were taken in much lower numbers. The bull shark *Carcharhinus leucas* was observed on occasion, along with the scalloped hammerhead shark *Sphyrna lewini,* the bonnethead shark *S. tiburo,* the spinner shark *C. brevipinna*, the blacknose shark *C. acronotus,* and the sandbar shark *C. plumbeus.* The capture of sandbar sharks was significant and somewhat unexpected whereas the low numbers of blacknose sharks, bull sharks and bonnethead sharks was not anticipated.

Distribution of Neonate and Juvenile Sharks

Neonate and juvenile sharks were collected from many areas in the Mississippi Sound and around Cat, Ship, Horn, Petit Bois, Round and Dauphin Islands (Figure 1). We compared the catch per unit effort (CPUE) of only juvenile and neonate sharks between the Mississippi and Alabama coasts. All species of neonates and juveniles were pooled for this analysis. We compared only the months of May to August for each year because sharks were fully recruited into inshore areas during those months. There was no significant (Student's t-test, P = 0.709) difference in CPUE between the coasts of Mississippi (mean = 3.37, S.E. = 0.66) and Alabama (mean = 3.71, S.E. = 0.76). We therefore pooled all of the stations sampled from May to August from both coasts and used ANOVA to compare CPUE between years (Figure 5). There was a significant (P = 0.032, F value = 4.11, D.F. = 2, 20, n = 24) difference in CPUE between years. Post-hoc analysis revealed that CPUE in the year 2000 was significantly different (P = 0.0104) than that in 1999 but no other differences were revealed.

The CPUE analysis suggests that, as nursery grounds, the Mississippi and Alabama gulf coasts are not significantly different. This is not surprising considering that the areas are continuous and there is no *a-priori* reason to expect one area to be superior to the other. The significant difference in CPUE of neonate and juveniles between years reflects the overall increase in shark catch already discussed above.

The probability of capturing neonate and juvenile sharks was very high in many areas along the two coasts. However, it was apparent that some areas consistently produced greater numbers of neonates and/or juveniles of certain species. The distribution of each species collected, roughly in order of abundance is discussed in the species profiles section.

Tag and Recapture Data

Tagging was conducted during each year of the study. In 1998, we tagged 300 of the 539 sharks captured for a 56% tagging rate. In 1999, we tagged 269 of 524 sharks captured for a 51% tagging rate. In 2000, 732 sharks were tagged out of 1662 captured for a 44% rate of tagging. The percentage tagged decreased in 2000 primarily because of the dramatic increase in catch rate. The increase in catch rate caused an increase in the average time that an individual shark remained in the net, because of the increase in the amount of time it took to clear the net. This resulted in higher mortality rates and lower tagging rates.

We tagged 1301 sharks and had only seven recaptures. Our collecting efforts never resulted in a single recaptured shark, all were returned to us by recreational fishermen. This is a very disappointing recapture rate of 0.5%. We had two sharks reported in each of 1998 and 1999 and three in 2000. Most sharks were at large for a few months to a few days. One individual was recaptured after one year. All sharks were recaptured from the same general area where they were tagged. The low recapture rate is likely attributable to several factors:

(1.) Gillnetting is a stressful method for capturing sharks and no doubt some sharks did not survive capture, tagging and release. However, when sharks were released their overall condition was scored. We found that 730 were given a #1 release condition, 285 were scored as #2, 216 were scored #3 and 181 were scored #4. In light of the very large number of sharks that were judged to be in good or excellent shape, it seems unlikely that high tagging mortality is the primary reason for low recaptures.

(2.) It is possible that the low return rates are due to the absence of a significant shark fishery in this area, particularly for the small individuals that we targeted. Aside from a few recreational fishermen, these small sharks are not targeted by fishermen. If this is the case then it is likely that we will see significant returns at a later date as sharks are recruited into the "offshore" fishery that does exist for larger individuals. This could be particularly true for species such as blacktip, spinner, and finetooth sharks because these species are a significant portion of the commercial catch in the gulf.

(3.) Finally, non-reporting of recaptures is a problem in any tag and release study. Although a reward was offered and the tags were clearly visible, the number of recaptures that were not reported cannot be estimated and may be significant. It is interesting that all of the recaptures were made by recreational fishermen. It seemed unlikely to us, given the intensity of commercial shrimping in the Mississippi Sound, that no sharks were captured by commercial fishermen, particularly shrimpers. Either shark by-catch is very low during shrimp trawling or there was significant non-reporting of recaptures. The magnitude of the shark by-catch in the shrimping industry is unknown and research in this area is indicated.

Species Profiles

Blacktip shark, *Carcharhinus limbatus*

We collected greater numbers of neonate and juvenile blacktip sharks than any other species (Tables 1 and 2). The environmental parameters of sites where juvenile and neonate blacktip sharks were collected ranged from 3.1 to 3.4 m depth, 28.0 to 30.6^{o}C, 17.7 to 20.3 ppt salinity, 6.3 to 6.9 ppm dissolved oxygen, 14.7 to 20.3 cm/s surface current and 117 to 123 cm Secchi depth. A total of 760 neonate and juvenile blacktip sharks were collected at 48 different sites ranging from the mouth of St. Louis Bay, Mississippi to the tip of Fort Morgan, Alabama. We captured 153 neonates and juveniles at three sites clustered around the eastern tip of Dauphin Island, Alabama. Likewise, we collected 89 neonates and juveniles at two sites in Mississippi Sound just north of Dauphin Island. Finally, we collected a total of 94 sharks from three sites just south of Round Island and 105 sharks from two sites north of Horn Island, Mississippi. In addition to these we made 22 collections wherein 10 or more blacktip neonates or juveniles were collected. From the above it is apparent that the north central Gulf of Mexico is an important nursery area for blacktip sharks.

Finetooth shark, *Carcharhinus isodon*

We collected a total of 404 neonate and juvenile finetooth sharks at 41 different sites (Tables 1 and 2). The environmental parameters of sites where juvenile and neonate finetooth sharks were collected ranged from 3.4 to 3.6 m depth, 27.2 to 29.5 ^{o}C, 17.9 to 19.6 ppt salinity, 5.8 to 6.8 ppm dissolved oxygen, 10.7 to 18.8 cm/s surface current and 80 to 94 cm Secchi depth. Finetooth sharks were collected from Cat Island, Mississippi to the tip of Fort Morgan, Alabama. We collected a total of 158 neonates and juveniles at several sites around the eastern tip of Dauphin Island and just north of Dauphin Island in Mississippi Sound. At seven sites in the vicinity of Round Island, Mississippi we caught 131 neonate and juvenile sharks. At various sites north of Horn Island, Mississippi we caught 43 finetooth sharks. We caught 45 finetooth sharks in one collection made just southwest of Biloxi, Mississippi and another 45 at a site about half way between Cat Island and Gulfport, Mississippi. These waters are an important nursery area for finetooth sharks.

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

The environmental parameters of sites where juvenile and neonate sharpnose sharks were collected ranged from 6.9 to 8.2 m depth, 27.1 to 30.1^{o}C, 18.5 to 20.6 ppt salinity, 5.5 to 7.3 ppm dissolved oxygen, 13.5 to 14.1 cm/s surface current, and 126 to 130 cm Secchi depth (Table 1). Considering the large numbers (558 total) of neonate and juvenile sharpnose collected (Table 2), it is not surprising that they were found across the entire study area appearing in 51 collections. This was the most widely distributed species, but our catch of sharpnose was greatest in certain areas. We collected 101 neonate and juvenile sharpnose sharks at a site just north of Dauphin Island. North of the western end of Horn Island, Mississippi we collected 69 sharks and a site just south of Round Island, Mississippi produced 26 sharks. We caught five or more neonate and juvenile sharpnose sharks at 24 different sites during the study. This area is an important nursery ground for sharpnose sharks.

Bull shark, *Carcharhinus leucas*

We collected only 46 bull sharks at 13 different sites during the study. All bull sharks collected were neonates or juveniles. The environmental parameters of sites where juvenile and neonate bull sharks were collected were 2.8 m depth, 29.0 to 30.6^{o}C, 14.0 to 17.1 ppt salinity, 6.3 to 9.1 ppm dissolved oxygen, 5.0 to 14.8 cm/s surface current and 83 cm Secchi depth. Bull sharks were found from Bon Secour Bay, Alabama to the mouth of St. Louis Bay, Mississippi. We caught 11 just north of Little Point Clear on Fort Morgan Peninsula, Alabama and another six just south of the east end of Dauphin Island, Alabama. We caught 11 just north of the west end of Cat Island, Mississippi. Bull sharks were never caught in large numbers, the largest collection at one time being 11 sharks. Bull sharks are euryhaline and it is possible that we would have captured greater numbers if we had sampled lower salinity waters perhaps closer to the mainland. However, the consistent appearance of bull sharks in collections suggests that this species uses these waters as a nursery ground.

Spinner shark, *Carcharhinus brevipinna*

Although the spinner shark was an uncommon capture (a total of 19 neonates and juveniles) it was distributed over practically the entire study area ranging from Perdido Bay, Alabama to St. Louis Bay, Mississippi. This shark was captured at eight different sites. We caught six spinner sharks at the mouth of Perdido Bay and six just north of Cat Island, Mississippi. The rarity of this species was not unexpected since it is not known to occur in this area in large numbers. The environmental parameters of sites from which juvenile and neonate spinner sharks were collected were 4.6 m depth, 27.9 to 30.0^{o}C, 20.9 to 27.0 ppt salinity, 4.8 to 6.7 ppm dissolved oxygen, 22.8 to 50 cm/s surface current and 120 to 150 cm Secchi depth. Despite the fact that it was a rare capture, the spinner shark nevertheless uses these waters as a nursery area.

Scalloped hammerhead shark, *Sphyrna lewini*

The scalloped hammerhead shark was collected at nine different sites but only 13 total neonates and juveniles were taken. The sharks averaged 56.8 cm TL and all captured had prominent or discernible umbilical scars. The shark was never captured in large numbers, the largest being three individuals taken at one site. The most interesting aspect of the scalloped hammerhead distribution is the apparent concentration of captures around Dauphin Island, Alabama. Of the 13 individuals captured, 10 were collected from seven locations around Dauphin Island. This is particularly noteworthy considering that there were more sites and more total effort was expended in Mississippi waters. The environmental parameters of sites from which juvenile and neonate scalloped hammerhead sharks were collected ranged from 2.9 to 3.4 m depth, 29.1 to 30.0°C, 17.6 to 19.9 ppt salinity, 5.6 to 7.1 ppm dissolved oxygen, 14.2 to 28.7 cm/s surface current and 84 to 111 cm Secchi depth. Although we never found large numbers of this species, this suggests that the waters around Dauphin Island, Alabama and perhaps other areas may be an important nursery ground for this species.

Blacknose shark, *Carcharhinus acronotus*

The blacknose shark is apparently an infrequent visitor to the waters of the north central Gulf of Mexico. Only seven blacknose sharks, were taken during the study, all neonates or juveniles. This was surprising because we expected to see this species with more regularity. Branstetter (1981) reported on the capture by longline of 34 blacknose sharks from deeper waters of the north central Gulf of Mexico. This may indicate that the blacknose shark is a deeper water resident. The environmental parameters of sites from which juvenile and neonate blacknose sharks were collected were 4.6 m depth, 27.7 to 32.0°C, 17.2 to 26.2 ppt salinity, 5.4 to 8.2 ppm dissolved oxygen, and 21.0 to 23.7 cm/s surface. These results suggest that the north central gulf waters are not an important nursery ground for this species but additional study is indicated.

Sandbar shark, *Carcharhinus plumbeus*

The environmental parameters of sites from which juvenile and neonate sandbar sharks were collected were 2.1 m depth, 23.3 to 24.4°C, 13.4 to 14.8 ppt salinity, 8.0 to 8.3 ppm dissolved oxygen, 11.3 cm/s surface current and 109 cm Secchi depth. The capture of four neonate/juvenile sandbar sharks was unexpected. Three of the specimens were captured just north of Cat Island, Mississippi and one was taken just north of Horn Island, Mississippi. Although the waters of the Florida panhandle are important as a nursery area for sandbar sharks (Carlson 1999) our results suggest that the central gulf waters are not. However, it is possible that the infrequent occurrence of neonate and juvenile sharks in this area is related to the recent apparent decline (1997 to 2000 Coastal shark Assessment, NMFS, Mississippi Laboratories, Pascagoula, Mississippi) in sandbar shark numbers in the Gulf of Mexico.

Bonnethead sharks, *Sphyrna tiburo*

The environmental parameters of sites from which juvenile and neonate bonnethead sharks were collected ranged from 3.0 to 3.4 m depth, 28.0 to 30.1°C, 15.5 to 24.0 ppt salinity, 5.7 to 8.8 ppm dissolved oxygen, 6.0 to 20.2 cm/s surface current and 128 cm Secchi depth. Bonnethead sharks were not commonly taken in our collections. We collected nine juveniles and only a single neonate during the study. It is interesting that all specimens taken came from two sites, one north of Horn Island, Mississippi and the other near the mouth of St. Louis Bay, Mississippi. Again, considering the large numbers of bonnethead sharks that appear in collections in shallow waters of the Florida panhandle and the fact that in areas where this species occurs it is typically very common (Parsons 1993), it was surprising to find so few in the waters of the north central Gulf of Mexico. At least in the areas we sampled, this area does not appear to be an important nursery for this species.

Conclusions

Previous research in the northern Gulf of Mexico has suggested that this area serves as a nursery ground for bull sharks, *Carcharhinus leucas* (Caillouet et al. 1969), Atlantic sharpnose sharks (Parsons 1983) and sandbar sharks, *Carcharhinus plumbeus* (Carlson 1999). Recently, information gathered by the NMFS-Panama City laboratory suggests that certain areas of the northern Gulf of Mexico serve as important nursery areas for many more shark species than was previously thought. Research in Saint Andrews Sound along the northern Florida gulf coast by Trent et al. (in review) resulted in the collection of 2,052 neonate, juvenile, and small adult sharks representing 10 species. Several of the species collected, (sandbar, blacktip, spinner, blacknose) are important components of the Gulf of Mexico shark fishery.

Based on the results of the present survey we can conclude that an important shark nursery is found in the inshore waters of the north central Gulf of Mexico.

The observation in this study that shark availability can change dramatically from year to year was important. The great degree of variation in shark availability, even over the short time period covered by this project, make anthropogenic changes in shark abundance difficult to identify. Uninterrupted, long term monitoring is needed to describe "natural" changes in abundance. With this information in hand, changes in abundance due to over-harvest can be more clearly identified.

Nursery grounds for several shark species were identified in this study. However, the observation that in at least one species the adult females almost never enter inshore waters raises interesting questions concerning nursery/pupping grounds. If gravid females rarely (never?) enter inshore waters then this suggests that the "pupping" grounds and nursery grounds are disjunct. It appears that for at least one species (Atlantic sharpnose), pups are born in deeper waters and migrate into shallower inshore nursery grounds where they spend the first few months (years?) of life. This may be true of other species as well. Additional study is needed to determine if disjunct pupping/nursery grounds exist and to determine which species demonstrate this life history strategy. This would require sampling in deeper offshore waters during the pupping season.

Most of our sampling took place within the Mississippi Sound, north of the extensive Gulf of Mexico barrier island system. As noted above we know little about what is happening in deeper waters south of the barrier islands and study in this area is indicated. In addition, nursery ground surveys in waters closer to the mainland are needed. Although low salinity may preclude the occurrence of many shark species in those areas, the bull shark, a euryhaline species, may be utilizing these areas as nursery grounds. During periods of reduced rainfall other more stenohaline species may also be utilizing these areas.

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Shark Nursery Areas of Louisiana's Nearshore Coastal Waters: A Preliminary Review

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Scope

In an effort to gain more insight into the role that Louisiana's nearshore coastal waters function as nursery habitat for sharks in the north central Gulf of Mexico, a three-year study was initiated in late 1998. This study was funded by the Coypu Foundation and conducted by researchers at the Coastal Fisheries Institute, Louisiana State University (LSU). A total of 1002 sharks representing eight species were caught in Louisiana's coastal waters from 1999 to 2001. Two hundred and fifty-eight of the sharks sampled were tagged and released.

Sampling Materials and Methods

Sampling locations were haphazardly randomly chosen, using both the historical data from the Tulane Museum of Natural History and the Louisiana Department of Wildlife and Fisheries (LDWF), and the physio-chemical and biological characteristics that would make a suitable nursery habitat, such as low freshwater input, and the presence of barrier islands or bait fish. Selection of sampling locations was limited by shallow water depth, boat traffic, and underwater obstructions.

The primary goal of the experimental gillnet sampling in 1999 was to locate areas where sharks congregated within Terrebonne/Timbalier Bay system in central Louisiana (Figure 1). Sampling was conducted primarily during daylight hours, with sets being conducted within the bay and Gulf of Mexico (Figure 2). Sampling trips were conducted once in May, approximately every two weeks June through August, and then once a month September through November. Duration of fishing ranged from 1 hour 40 minutes to over six hours, with most sets falling within the 2 - 4 hour range. A minimum set time of three hours was attempted but was not always possible due to time or weather constraints.

For the 2000 sampling season, we expanded our spatial coverage of the Timbalier and Terrebonne Bay complex (Figure 3). One sampling trip was conducted in March, April, and September, two trips were conducted in May, and three trips per month were conducted June through August. From July through August a small-scale temporal component was added to the sampling protocol. The sampling day was divided into 5 time periods: Dawn, Day AM (before noon), Day PM (after noon), Dusk, and Night for both Bay and Gulf locations. The target set duration was three hours and soak times ranged from 1 hour 15 minutes to six hours, with most sets lasting between 2.5 and 4.5 hours.

The sampling protocol for the 2001 season closely followed that used the previous year. Two modifications were instituted at the start of the season. The first was the establishment of two

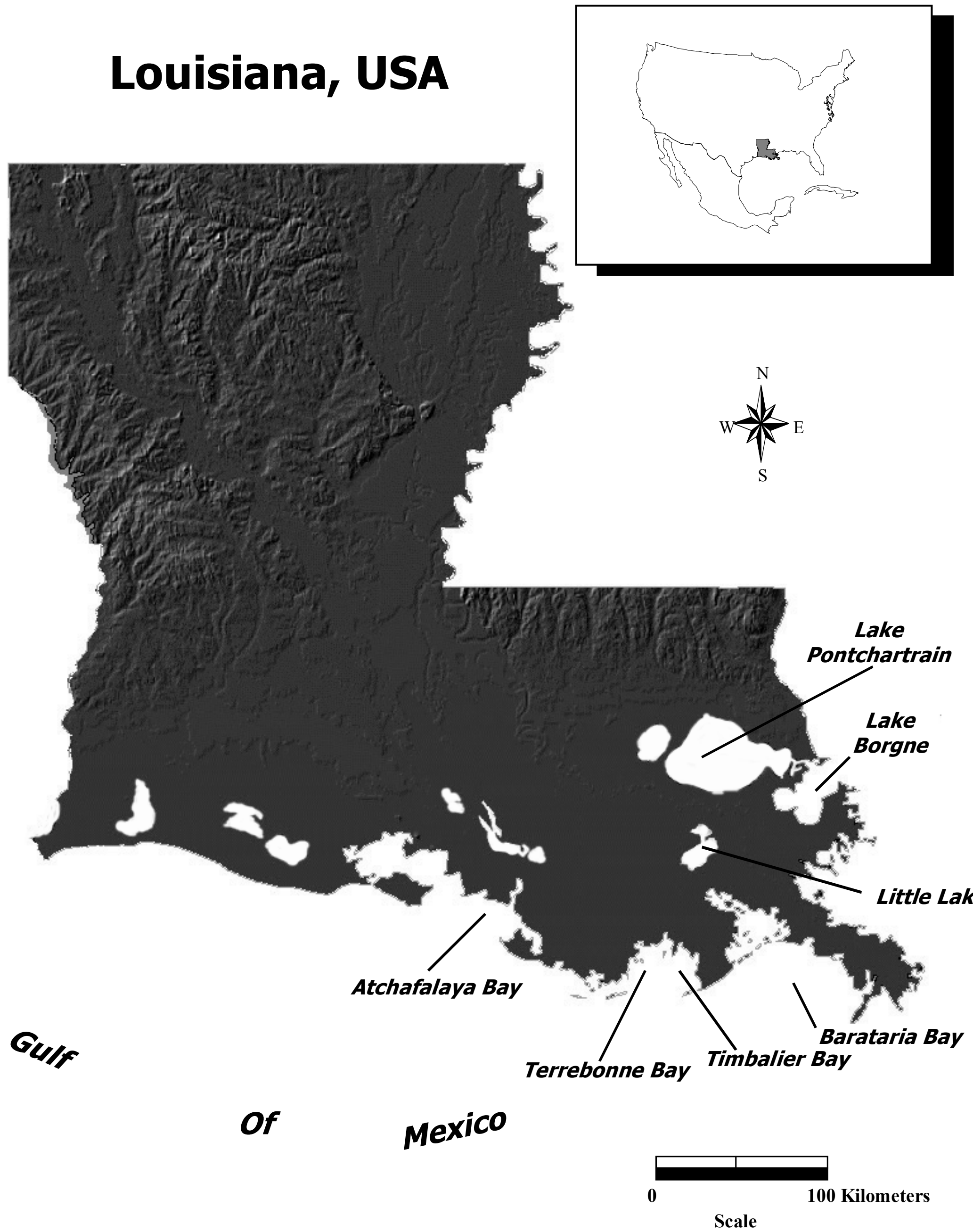

Figure 1. The state of Louisiana, with many of the major water systems indicated.

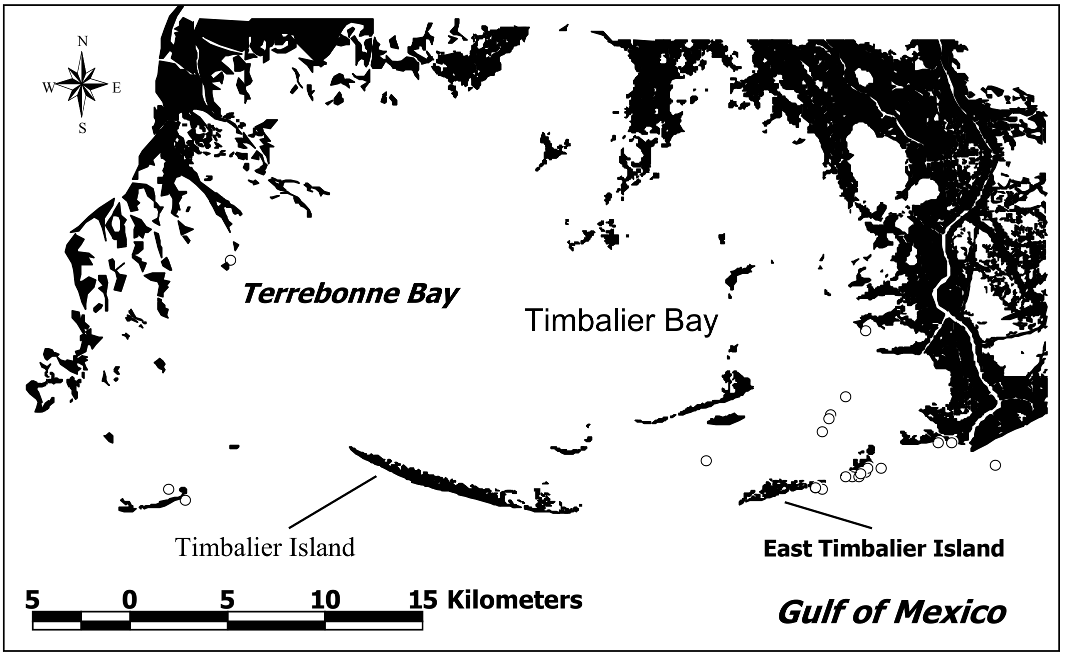

Figure 2. **1999 experimental gillnet sampling stations.**

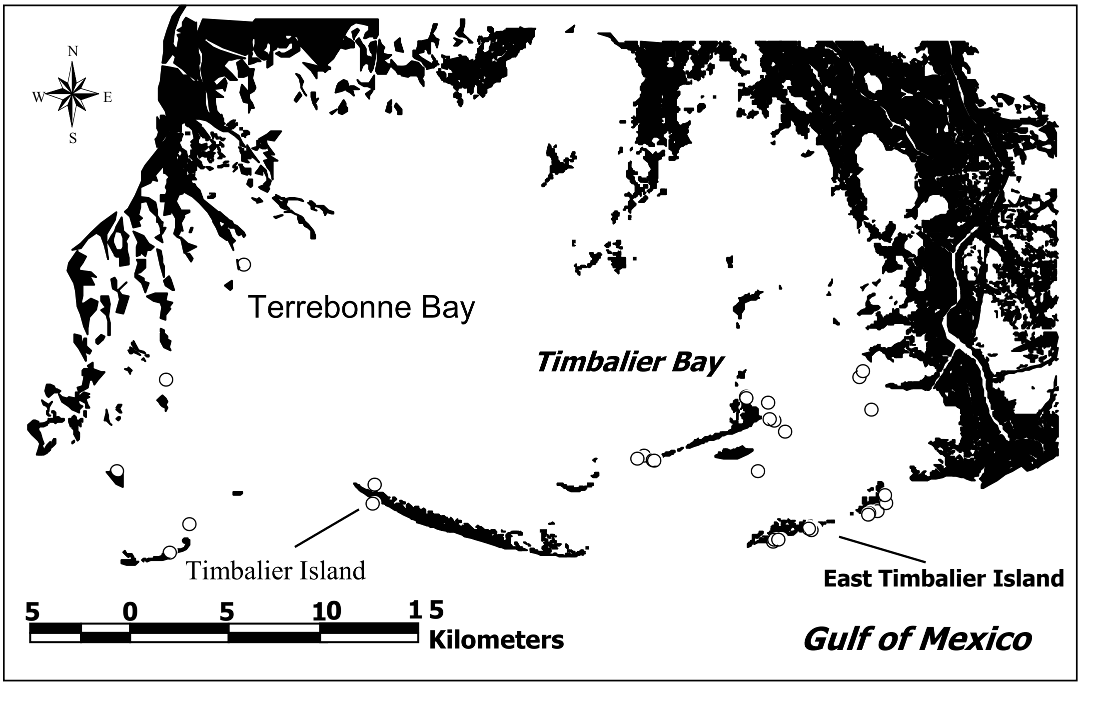

Figure 3. **2000 experimental gillnet sampling stations.**

permanent stations that were to be sampled every trip (Figure 4). These stations were established in order to allow examination of both inter- and intra-annual species trends. The second change was within the small-scale temporal component to the sampling, with the Night period being divided up into Night PM (before midnight) and Night AM (after midnight). The target set duration was again three hours and soak times ranged from 1 hour 15 minutes to six hours 57 minutes, with most sets lasting between 3 and 3.5 hours. Sampling trips were conducted approximately every two weeks from May through August, with one additional trip in September.

A 186 m long gillnet with six panels was utilized for sampling. Individual panels were 30.4 m long and 1.8 m deep, with a hanging coefficient of 0.5. The floatline was made of ½" (1.27 cm) polyfoam with a buoyancy of 1.42 kg of lead per 30.4 m. The bottom line consisted of a braided synthetic cover over a lead core, 11.025 kg of lead per 30.4 m. Stretched mesh (SM) sizes ranged from 8.9 cm (3.5 in) to 14.0 cm (5.5 in) in steps of 1.27 cm (0.5 in), with an additional size of 20.3 cm (8.0 in) in 1999. During the 2000 sampling season, SM sizes ranged from 10.18 cm (4 in) to 15.27 cm (6 in) in steps of 1.27 cm (0.5 in), with an additional size of 20.3 cm (8.0 in). Webbing for all panels, except for the 20.3 cm SM, were of clear monofilament, double knotted and double selvaged. The webbing of the 20.3 cm SM panel was made of #18 multifilament nylon (353 kg break strength), single knotted and double selvaged. Panels were tied together sequentially to make one continuous net. Empty five-gallon containers were painted fluorescent orange and attached to the floatline between each of the panels and at both ends. The net was anchored at both ends using 22.05 kg anchors attached to the net using 4.6 m bridles.

The net was deployed over the bow of the boat, secured, and environmental parameters recorded. Latitude and longitude of each set was determined with a handheld GPS unit. Water temperature, salinity, dissolved oxygen, and conductivity were recorded using a hand held YSI 85. Depth was recorded from the depth finder on the boat and turbidity was determined for all daylight sets using a Secchi disk. Bottom type was determined by examining the sediments on the net anchors. Additionally, weather information such as Beaufort state, wind direction, and cloud cover was recorded starting in 2000 (Table 1). The net was checked approximately every hour while in the water. The net was walked either along the side of the boat or over the bow, depending on weather conditions. For all sharks and bycatch encountered, the mesh size was recorded and the animal removed from the net. The sex, precaudal length, fork length, total length (1999 only), stretched total length, and maturity level (based on umbilical scar condition and clasper information for males) was recorded for all elasmobranchs. Sharks were classified as neonates (open umbilical scar), young-of-the-year (healed scar), juvenile (no scar), adult, or unknown. All live sharks were tagged with a LSU Floy plastic barbed tag in 1999 or a tag provided by the Shark Population Assessment Group at the NMFS facility in Panama City, Florida in 2000 and released. In 2001, a portion of the live blacktip and Atlantic sharpnose shark catches were sacrificed for an ongoing feeding study. The remaining live sharks were tagged using the NMFS tags used in 2000 sampling season. If in poor condition or dead, the shark was retained for further biological sampling in a laboratory setting. Laboratory processing included measuring and weighing all animals and a more thorough reproductive examination. Vertebrae were collected for all sharks and rays examined in the laboratory during all sampling seasons, and during the 2000 and 2001 sampling seasons, stomachs were also collected.

In addition to our independent sampling program, we also collected specimens in cooperation with Louisiana Department of Wildlife and Fisheries (LDWF) personnel, other scientists and recreational fishers. These additional specimens were helpful in broadening our understanding of sharks in Louisiana waters.

Description of Study Area

Present and past lobes of the Mississippi Delta dominate the current coastline of Louisiana and an understanding of this relationship is important to understanding the fish dynamics that occur here. The Mississippi River has built six major delta complexes over the last 7000 years (Frazier 1967). The barrier island systems observed today developed due to delta abandonment when the river

Figure 4. **2001 experimental gillnet sampling stations.**

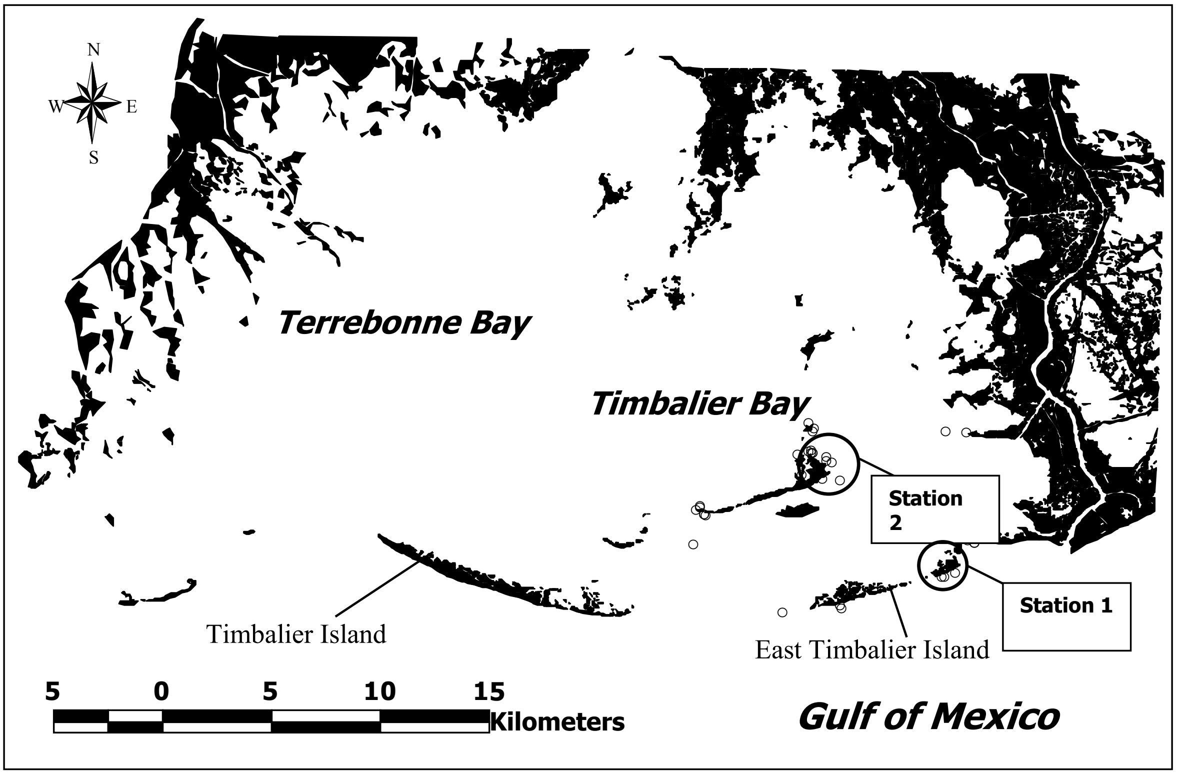

Table 1. **Environmental parameters collected during experimental gillnet sampling. Values listed represent the minimum and maximum observed for that parameter.**

Parameter	1999	2000	2001
Temperature (^oC)	22.2 - 31.4	22.5 - 32.4	26.4 - 32.1
Dissolved Oxygen (%)	58.4 - 108.0	64.9 - 127.8	45.6 - 137.6
Dissolved Oxygen (mg/L)	3.80 - 8.12	4.09 - 8.24	2.89 - 9.61
Conductivity (mS)	---	38.99 - 56.20	29.32 - 47.10
Salinity (ppt)	11.0 - 33.8	24.7 - 37.3	18.0 - 31.5
Depth (m)	1.2 - 5.2	1.5 - 4.9	0.9 - 4.4
Turbidity (m)	0.1 - 2.0	0.3 - >2	0.3 - 1.4
Beaufort State	---	0 - 3	0 - 3
Cloud Cover	---	0.01 - 0.90	0.0 - 0.9

switched courses (Kolb and Van Lopik 1966). The Isles Dernieres and Bayou Lafourche barrier island systems are both transgressive island arcs and the creation and evolution of these barrier island systems follows the three-stage model as described in Penland et al (1985). Currently, Louisiana's barrier islands are experiencing landward migration, land loss, and island narrowing (McBride and Byrnes 1997). This is a consequence of a complex interaction of global sea level rise, wave and storm processes, compactional subsidence, inadequate sediment supply and significant human disturbance (van Heeden and DeRouen 1997). Many of the barrier islands along the Louisiana coast are currently undergoing beach renourishment and island restoration and stabilization projects (Louisiana Coastal Wetlands Conservation and Restoration Task Force (undated), Williams 1998). The potential impacts these activities may have on the shark nursery habitat of this region are unknown.

Our sampling was confined primarily to the Terrebonne/Timbalier Bay system in central Louisiana (Figure 1). This system is typical of most central Louisiana nearshore coastal zones, consisting mainly of shallow, turbid waters protected from the Gulf of Mexico on its southernmost edge by the barrier islands of Timbalier Island, East Timbalier Island, and the Isles Dernieres barrier island chain. The bottom type of the region is predominantly mud or a mud-shell composite. It is a microtidal habitat (< 50 cm), with local predominant winds often having more dominant effects than the tidal cycle due to the shallowness (< 2 m) of most of the region (Marmer 1954). Water temperatures ranged from 22.2 – 32.4 ^{o}C during our sampling, with the salinity ranging from 11.0 – 37.3 ppt.

Results and Discussion

A total of 219 sharks, representing six species, were observed in 1999 (Tables 2 and 3). Twenty-six gillnet sets were conducted between May and November for a total fishing time of 93.25 hours. The catch per unit effort (defined as sharks/net hour) for all species combined was 2.35 sharks/net hour. Blacktip sharks were the most numerically abundant, followed by spinner, bull, finetooth, Atlantic sharpnose, and lemon sharks. Catch per unit effort by species is shown in Table 4.

The tagging component to the 1999 season was not successful as we had extreme difficulty with the tags breaking during tagging. A total of 47 sharks were tagged with LSU Floy barb tags. No recaptured sharks have been reported.

During the 2000 survey season, a total of 576 sharks representing six species were observed (Tables 2 and 3). Thirty gillnet sets were conducted between March and September for a total fishing time of 107.75 hours. The catch per unit effort for all species combined was 5.35 sharks/net hour. Blacktip sharks were again the most numerically abundant, followed by Atlantic sharpnose, bull, finetooth, bonnethead, and scalloped hammerhead sharks. Catch per unit effort by species is shown in Table 4.

A total of 214 sharks were tagged during the 2000 sampling season using National Marine Fisheries Service streamer tags. Unfortunately, 17 of those animals were recaptured dead during the same sampling set that they were initially tagged.

Two hundred and seven sharks were caught in the experimental gillnets during the 2001 sampling season. Thirty-two gillnet sets were conducted between May and September for a total fishing time of 119.65 hours. The catch per unit effort for all species combined was 1.73 sharks/net hour. Blacktip sharks were the most numerically abundant, followed by bull, Atlantic sharpnose, finetooth, bonnethead, and scalloped hammerhead sharks. Catch per unit effort by species is shown in Table 4.

Only 14 additional sharks were tagged during the 2001 sampling season using NMFS streamer tags: nine bull sharks, three blacktip sharks, one bonnethead shark and one Atlantic sharpnose shark. Currently, there are 158 tagged sharks at large. No recaptured sharks have been reported at this time.

Species Profiles

Blacktip shark, *Carcharhinus limbatus*

Blacktip sharks were the most abundant shark species captured in our gillnet samples, with 65 sharks encountered in eight of 26 sets in 1999. Fifteen sharks were determined to be neonates, with

Table 2. **Comparison of shark species caught in the experimental gillnet surveys in all survey years (1999 - 2001).**

		MALES			FEMALES		
Species	**Sampling Year**	**Number observed**	**Size Range (FL, cm)**	**Maturity Stages Observed**	**Number observed**	**Size Range (FL, cm)**	**Maturity Stages Observed**
Carcharhinus limbatus Blacktip shark	1999	26	51 - 96	neonate, YOY, juvenile	38	50 - 103.5	neonate, YOY, juvenile
	2000	155	45.6 - 109.5	neonate, YOY, juvenile	188	45.8 - 108.7	neonate, YOY, juvenile
	2001	62	45.7 - 104.7	neonate, YOY, juvenile, adult	76	43.9 - 110.8	neonate, YOY, juvenile, adult
	* 1 additional specimen of unknown sex collected in 1999, 11 collected in 2000, and 7 collected in 2001						
Carcharhinus leucas Bull shark	1999	20	60 - 104	neonate, YOY, juvenile	11	79.5 - 101.5	YOY, juvenile
	2000	14	89.5 - 116.3	YOY, juvenile	13	88.8 - 110.0	YOY, juvenile
	2001	8	96.1 - 117.6	juvenile	12	91.9 - 120.0	juvenile
	* 8 additional specimens of unknown sex collected in 1999, 16 collected in 2000, and 13 collected in 2001						
Carcharhinus isodon Finetooth shark	1999	15	73 - 103.5	juvenile, adult	23	72 - 117.9	juvenile, adult
	2000	16	49.2 - 108.8	YOY, juvenile, adult	13	40.8 - 89.0	neonate, juvenile
	2001	2	54.5 - 99.1	juvenile, adult	2	44.2 - 48.6	YOY
	* 1 additional specimen of unknown sex collected in 2000						
Rhizoprionodon terraenovae Atlantic sharpnose shark	1999	14	39 - 82.6	YOY, juvenile, adult	8	35.5 - 42	YOY
	2000	87	33.1 - 83.8	neonate, YOY, juvenile, adult	22	29.8 - 54.1	YOY, juvenile
	2001	19	29.8 - 82.6	neonate, YOY, juvenile, adult	1	39.1	juvenile
	* 1 additional specimen of unknown sex collected in 1999, and 6 collected in 2000						

Table 3. **Summary of shark species caught in the experimental gillnet surveys in only one or two of the survey years.**

Species	Sampling Year	MALES Number observed	MALES Size Range (FL, cm)	MALES Maturity Stages Observed	FEMALES Number observed	FEMALES Size Range (FL, cm)	FEMALES Maturity Stages Observed
Carcharhinus brevipinna Spinner shark	1999	26	55 - 67.5	YOY, juvenile	21	50 - 103.5	neonate, YOY, juvenile
	2000	-	-	-	-	-	-
	2001	-	-	-	-	-	-
	* 1 additional specimen of unknown sex collected in 1999, 11 collected in 2000, and 7 collected in 2001						
Negaprion brevirostris Lemon shark	1999	-	-	-	1	1830**	adult
	2000	-	-	-	-	-	-
	2001	-	-	-	-	-	-
	* 8 additional specimens of unknown sex collected in 1999, 16 collected in 2000, and 13 collected in 2001						
Sphyrna tiburo Bonnethead shark	1999	-	-	-	-	-	-
	2000	10	47.9 - 56.7	juvenile	7	45.5 - 60.2	juvenile
	2001	3	55.5 - 71.5	juvenile	-	-	-
	* 1 additional specimen of unknown sex collected in 2000						
Sphyrna lewini Scalloped hammerhead shark	1999	-	-	-	-	-	-
	2000	3	36.8 - 44.3	neonate, juvenile	22	41.8	juvenile
	2001	1	38.8	YOY	-	-	-
	* 1 additional specimen of unknown sex collected in 1999, and 6 collected in 2000						

** estimated total length of specimen

Table 4. Species specific catch per unit effort (defined as sharks per net hour) for sharks collected in the experimental gillnet sampling.

	1999		2000		2001	
Species	Number observed	CPUE (sharks/ net hour)	Number observed	CPUE (sharks/ net hour)	Number observed	CPUE (sharks/ net hour)
Carcharhinus limbatus Blacktip shark	65	0.70	354	3.29	145	1.21
Carcharhinus brevipinna Spinner shark	44	0.47	-	-	-	-
Carcharhinus leucas Bull shark	39	0.42	43	0.40	33	0.28
Carcharhinus isodon Finetooth shark	38	0.41	34	0.32	4	0.03
Rhizoprionodon terraenovae Atlantic sharpnose shark	23	0.25	117	1.09	20	0.17
Negaprion brevirostris Lemon shark	1	0.01	-	-	-	-
Sphyrna lewini Scalloped hammerhead shark	-	-	4	0.04	1	0.01
Sphyrna tiburo Bonnethead shark	-	-	17	0.16	3	0.03

the remaining 50 animals split between young-of-the-year and juvenile individuals. Sizes of the sharks observed were 51.0 - 103.5 cm FL. Blacktips were collected June through September, and additionally in November, from depths ranging between 1.2 and 5.2 m. Water temperatures at collection ranged from 23.6 - 31.4 ^{o}C, with salinities between 18 - 33.8 ppt.

In 2000 blacktip sharks were again the most abundant shark species captured in our gillnet samples, with 354 sharks encountered in 20 of 30 sets. Forty-five sharks were determined to be neonates, 62 were juveniles, and the remaining sharks (247) were classified as young-of-the-year individuals. The size of the sharks observed ranged from 45.6 - 109.5 cm FL. Blacktip sharks were collected April through August, from depths ranging between 1.5 and 4.9 m. Water temperatures at collection ranged from 22.6 - 32.4 ^{o}C, with salinities between 25.2 - 34.7 ppt.

One hundred forty-five blacktip sharks were captured in our 2001 gillnet samples. The species occurred from May through September in 20 of 32 sets. One adult male was collected, along with 28 neonates. The remaining sharks were split between young-of-the-year and juvenile individuals. Sizes of the sharks ranged from 43.9 - 109.9 cm FL. Blacktips were collected May through September from depths ranging between 1.2 and 4.4 m. Water temperatures at collection ranged from 26.4 - 32.1 ^{o}C, with salinities between 18 - 30.1 ppt.

LDWF personnel provided four neonate blacktip sharks to us in 1999. The sharks had been captured in June 1997 and were all males, ranging in size from 55 - 61 cm FL. Nine additional blacktip sharks were given to project personnel during the 2000 season. Two neonate blacktip sharks (48.5 and 50.5 cm FL) were collected in April by another LSU researcher while trawling in Terrebonne Bay. One neonate (46.2 cm FL) was collected in May and a young-of-the-year individual (62.1 cm FL) in August by LDWF scientists. LDWF personnel collected five additional blacktip sharks (67.4 - 74 cm FL); unfortunately no capture information is available at this time.

Spinner shark, *Carcharhinus brevipinna*

In 1999 forty-four spinner sharks were captured in four of the 26 gillnet sets. Spinner sharks were captured in August and September, when the water temperature ranged between 28.2 and 30.3 ^{o}C. The sharks were collected in 4.6 to 5.2 m of water, with salinities ranging from 24 to 29 ppt. All spinner sharks were determined to be young-of-the-year and juveniles, ranging in size from 55 .0 – 67.5 cm FL.

One additional spinner shark was collected by hook and line in 1999. The male young of the year individual was captured in September off one of the barrier islands. It measured 56.2 cm FL.

While no spinner sharks were collected in the directed gillnet sampling in 2000, six specimens were received from LDWF personnel. One neonate spinner shark (54.2 cm FL) was collected in July, while three sharks ranging in size from 57.4 - 59.7 cm FL were collected in August. Two additional neonate sharks (51.1 and 53.3 cm FL) were also collected. All sharks were collected from the Grand Isle/Grand Terre Beach. No additional spinner sharks were encountered in the 2001 sampling season.

Bull shark, *Carcharhinus leucas*

Bull sharks were collected in June, July, and September of 1999, in 1.5 -5.2 m of water. The sharks ranged in size from 79.5 - 104.0 cm FL. Four sharks were classified as neonate, three as young-of-the-year, and the remaining 32 as juveniles. Bull sharks were observed in 8 of the 26 gillnet sets, with salinities ranging from 11 - 29 ppt, and water temperatures between 28.1 - 29.9 ^{o}C.

Louisiana Department of Wildlife and Fisheries scientists collected forty-one bull sharks for our study in 1999. Sharks were collected in June, July, and August, most caught using a gillnet left set overnight in Little Lake, one of the inland lakes. The collected sharks ranged in size from 60.0 - 96.0 cm FL. All were determined to be juveniles except one female (60 cm FL) collected in July, who was classified as a neonate.

Forty-three bull sharks were collected in March, June, July, and August of 2000, in 1.5 –4.6 m of water. The sharks ranged in size from 88.8 – 116.3 cm FL, and were classified as young-of-the-year individuals and juveniles. Bull sharks were observed in seven of the 30 gillnet sets, with salinities ranging from 25 – 32.4 ppt, and water temperatures between 22.5 - 32 ^{o}C.

LDWF scientists collected fifty-three bull sharks for our study in 2000. Fifty of these sharks were collected in March in upper Barataria Bay using gillnets as part of a water diversion study. Sharks ranged in size from 70.0 - 99.2 cm FL, with seven neonates represented in the catch. Three additional juvenile bull sharks were collected in June, July, and November 2000.

A total of 33 bull sharks were encountered during the 2001 sampling season. The sharks were observed in May - September, in 1.5 - 4.4 m of water. Bull sharks were caught in nine of the 32 gillnet sets, with salinities ranging from 20.3 - 28 ppt, and water temperatures between 27.1 - 31 ^{o}C. The sharks ranged in size from 89.5 – 120.0 cm FL, and were classified as young-of-the-year individuals and juveniles.

Scientists at the Louisiana Department of Wildlife and Fisheries collected 38 bull sharks for our study in 2001. All of these sharks were collected in May in upper Barataria Bay using gillnets as part of a water diversion study. Sharks ranged in size from 62.4 - 117.0 cm FL, with three neonates represented in the catch.

Finetooth shark, *Carcharhinus isodon*

Thirty-eight finetooth sharks were observed in the 1999 gillnet sampling, ranging in size from 72.0 - 117.9 cm FL. Sharks were collected in waters 0.6 - 1.2 m deep in June, August, and September. Finetooth sharks were collected in four of the 26 sets. Salinities at collection ranged from 19 - 29 ppt and water temperatures were 28.2 - 31.4 ^{o}C. Both juveniles and adults were observed in the catch.

Thirty finetooth sharks were observed in the 2000 gillnet sampling, ranging in size from 40.8 - 108.8 cm FL. Sharks were collected in waters 1.5 – 4.9 m deep in May, June, July, and August. Finetooth sharks were collected in seven of the 30 sets. Salinities at collection ranged from 25 – 34.3 ppt and water temperatures were 25.3 - 32 ^{o}C. Four adults and one neonate were observed in the catch, with the remaining sharks being either young-of-the-year individuals or juveniles.

LDWF personnel at the Grand Terre lab collected two additional finetooth sharks in 2000. Both specimens were adults, the male being 107.1 cm FL, and the female 117.1 cm FL. Collection date information is unavailable.

Four finetooth sharks were caught in the 2001 gillnet sampling. These sharks ranged in size from 42.9 - 97.7 cm FL, and were collected in June and July. Sharks were collected in three of the 32 gillnet sets, in waters 1.7 - 4.3 m deep. Salinities at collection ranged from 22.9 – 30.1 ppt and water temperatures were 29.0 - 32.1 ^{o}C. Three of the sharks were determined to be juveniles, with the remaining shark an adult.

Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

In 1999 Atlantic sharpnose sharks were encountered in six of the 26 gillnet samples. Sharks were observed May - August when water temperatures were between 23.7 - 30.3 ^{o}C. Nine adults, four juveniles, and 11 young-of-the-year individuals were collected from water depths of 1.8 - 4.6 m. Salinity ranged from 23 - 27.5 ppt on date of capture. Sizes ranged from 35.5 to 82.6 cm FL.

Eight additional Atlantic sharpnose shark samples with a size range of 58.5 - 75.7 cm FL were collected using hook and line in 1999. Four sharks were obtained by LSU personnel in July at the Grand Isle Fishing Rodeo, and three additional sharks were caught off Elmers Island Beach in August. The two remaining sharks were collected in November 1998 on a SEAMAP cruise.

One hundred seventeen Atlantic sharpnose sharks were encountered in 19 of the 30 gillnet samples 2000. Sharks were observed April - August when water temperatures were between 22.6 - 32.4 ^{o}C. Shark sizes ranged from 29.8 – 83.8 cm FL, with all age classes represented in the catch (neonates, young-of-the-year, juveniles, and adults). Individuals were collected from water depths of 1.5 - 4.9 m. Salinity ranged from 28.9 – 37.3 ppt on date of capture.

Louisiana Department of Wildlife and Fisheries personnel collected twenty-one additional Atlantic sharpnose sharks using hook and line in 2000. Two of the individuals were collected in June from Grand Isle Beach. Ten sharks were collected in July from SEAMAP Station D812. The July specimens were all adult females, with six containing very early term embryos. These sharks ranged in size from 73.4 - 81.9 cm FL. One 57.0 cm FL male was collected from SEAMAP Station D824 in October. We also obtained seven adult females from an additional SEAMAP cruise in November 2000. These sharks ranged in size from 67.6 - 83.3 cm FL and were pregnant. The final Atlantic sharpnose shark collected by LDWF in 2000 was a 32.6 cm FL female.

A total of 20 Atlantic sharpnose sharks were collected during the 2001 sampling season. The sharks occurred in seven of the 32 gillnet sets and ranged in size from 29.8 to 82.6 cm FL. All age classes (neonates, young-of-the-year, juveniles, and adults) were represented in the catch. Sharks were observed May - August when water temperatures were between 26.4 - 32.1 ^{o}C. Salinities at collection ranged from 23.7 - 30.1 ppt and individuals were collected from water depths of 1.2 - 4.3 m.

Lemon shark, *Negaprion brevirostris*

One mature lemon shark (~183 cm TL) was collected in August 1999. The shark was captured at a water temperature of 30.5 ^{o}C and a depth of 4 m. The female shark was released without a tag in good condition. Information from archived museum specimens indicate that young lemon sharks are known to congregate around the barrier islands off the Louisiana coast.

LDWF scientists gave two lemon shark specimens to the project. One shark was collected from Raccoon Point in June 1997 and was a female with a fork length of 77.4 cm. The second shark was also a female and was collected November 1999 with a fork length of 62.4 cm. Capture location data is unavailable for the second shark. No lemon sharks were collected in the directed gillnet sampling in 2000.

Although no lemon sharks were encountered during the 2001 directed gillnet survey, three were acquired from other sources during the year. One female shark was collected in July by LDWF personnel, and measured 88.8 cm FL. Project personnel collected a second shark during a sampling trip to gather blood samples of bull sharks. The shark was a 112.5 cm FL female collected via gillnet. The final lemon shark was also a female, 56.6 cm FL, and was captured on rod and reel by project personnel. Both gillnet and rod and reel sharks were collected in September. Salinities at collection ranged from 26.0 – 28.6 ppt and water temperatures were 29.0 - 32.0 ^{o}C.

Scalloped hammerhead shark, *Sphyrna lewini*

In 2000 a total of four scalloped hammerhead sharks were collected in three of 30 gillnet sets, ranging in size from 36.8 – 44.3 cm FL. One shark was determined to be a neonate and the remaining three young-of-the-year individuals. These sharks were collected in June and July from depths between 1.5 – 2.4 m. Water temperatures at capture were 28.4 – 32.4 ^{o}C and salinities ranged from 29.5 – 34.3 ppt.

One scalloped hammerhead shark was collected in July 2001. The shark was a juvenile male and measured 39.5 cm FL. It was collected in waters 1.2 m deep. The water temperature at capture was 30.1 ^{o}C and salinity was 20.1 ppt.

Bonnethead shark, *Sphynra tiburo*

Seventeen juvenile bonnethead sharks were captured in six of the 30 gillnet sets in 2000. They ranged in size from 45.5 – 60.2 cm FL. Sharks were captured May through August from water depths of 1.8 – 2.4 m. Salinities at collection ranged from 29.1 – 34.3 ppt and water temperatures were 28.4 - 31.4 ^{o}C.

A total of three bonnethead sharks were observed in the 2001 sampling season. The sharks ranged in size from 55.5 to 71.5 cm FL and were all juvenile males. One of the sharks was collected in May, with the remaining two sharks being captured in August. Bonnethead sharks occurred in two of the 32 gillnet sets, in 1.8 m of water. Water temperatures at collection were 28.7 - 29.7 ^{o}C and salinities ranged from 25.3 – 29.6 ppt.

Preliminary Findings

Louisiana's nearshore coastal waters appear to be important pupping and nursery areas for several species of small and large coastal sharks. A total of 1002 sharks were captured in our 320.42 hours of gillnet sampling, for an overall CPUE of 3.13 sharks/net hour. We encountered eight species of sharks, with four of those species occurring in our gillnet samples in all three years: blacktip, bull, finetooth, and Atlantic sharpnose sharks (Table 2). Two species of sharks, bonnethead and scalloped hammerhead sharks, occurred in both the 2000 and 2001 sampling seasons (Table 3). The two remaining shark species, spinner and lemon sharks, only occurred in our gillnet sets during the 1999 sampling season (Table 3). The vast majority (~ 80%) of the sharks observed were neonate and young-of-the-year individuals, with the remaining 20% of the catch dominated by young juveniles.

Utilization of the nearshore area varied temporally for several species (Figure 5). Blacktip sharks regularly frequent these areas in June and July, while spinner sharks were only encountered in August and September. Finetooth sharks were encountered most frequently in the mid to late summer months, with pregnant females being collected in September. One neonate finetooth shark was collected in May, so they may use these areas for pupping in early spring as well. Bull sharks were encountered in fairly consistent numbers throughout the summer months, as were Atlantic sharpnose sharks.

The assemblage of sharks encountered also varied temporally (Figure 6). Blacktip sharks were the most frequently encountered and consistent member of the nearshore assemblage, being collected May through September. Atlantic sharpnose sharks were the second main component, occurring May through August in all sampling years. Bull sharks made up the last main component to the assemblage encountered. Although rarely present in large numbers, they were a common species captured in almost all months sampled. As stated above spinner and finetooth sharks appear in the catch in August and September. The remaining members of the assemblage varied by month, with one or two additional species collected per month. Bonnethead, scalloped hammerhead, and lemon sharks showed no discernable trend, most likely due to the small sample sizes encountered for each species.

Published records of shark nursery areas in Louisiana are limited, focusing mainly on bull sharks. Caillouet et al. (1969) and Hoese (1976) discuss the presence of immature bull sharks (*Carcharhinus leucas*) from the Vermillion/Atchafalaya Bay region, and Thompson and Verret (1980) discuss the collection of immature bull sharks from Lake Pontchartrain, but little other historical information is available. Our sampling encountered a much more diverse assemblage of sharks. These findings, along with those of de Silva *et al.* (2001), indicate that Louisiana's coastal waters and barrier island systems are important nursery habitat for a variety of shark species.

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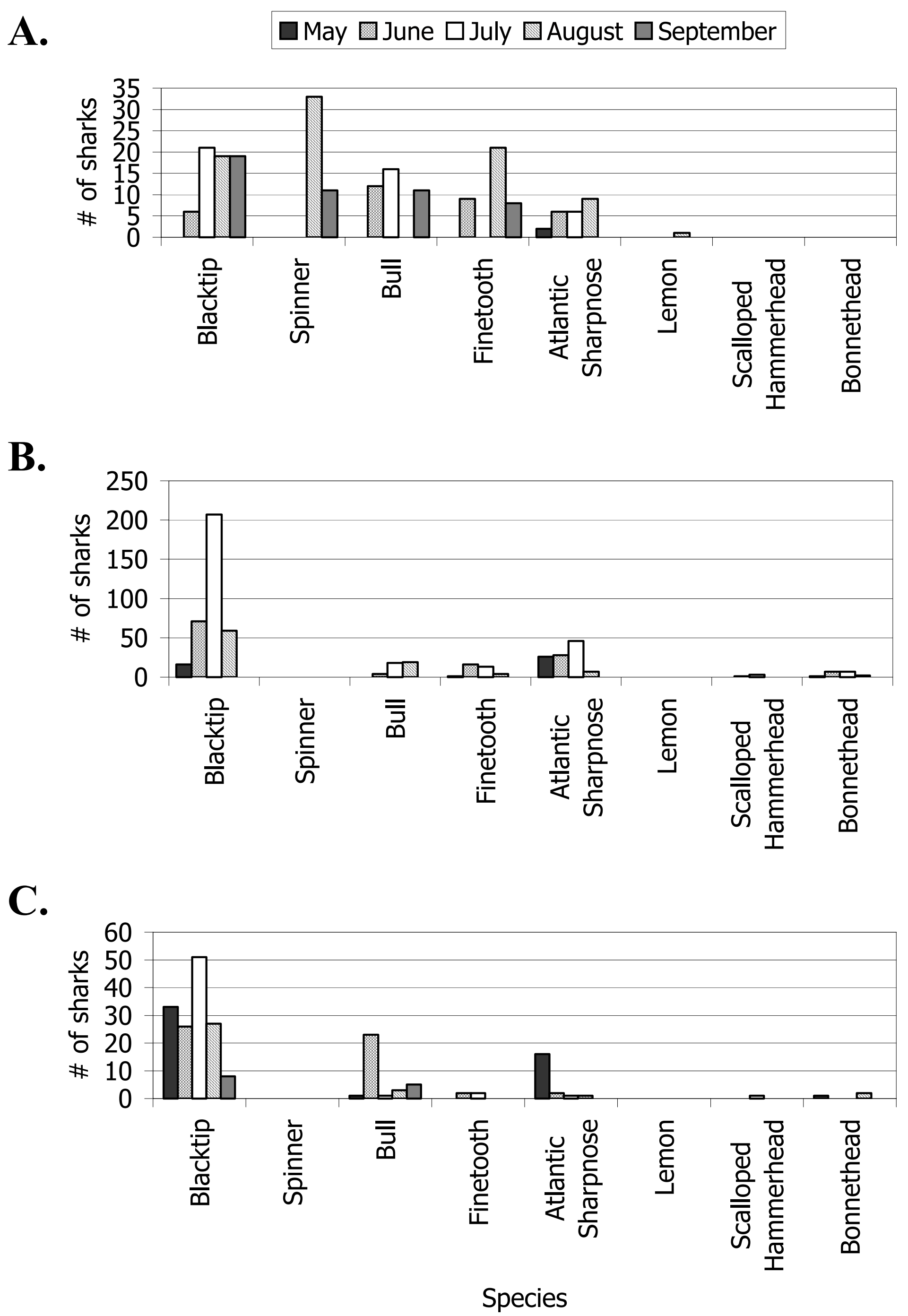

Figure 5. Monthly species-specific shark abundance encountered in the experimental gillnet sampling. A. 1999 sampling season B. 2000 sampling season C. 2001 sampling season. Please note differing scales on y-axes.

A.

B.

C.

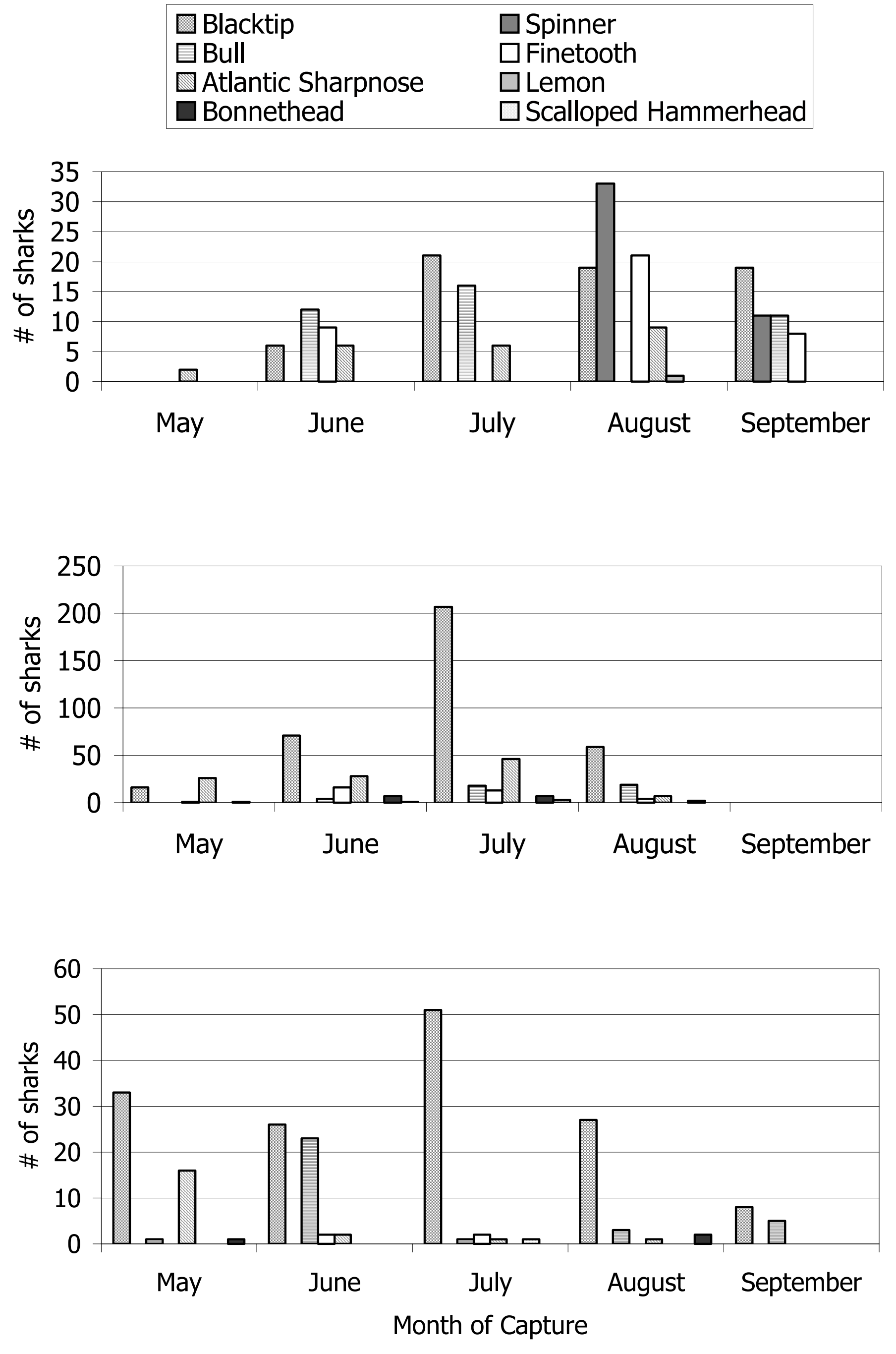

Figure 6. **Species assemblages encountered by month in the experimental gillnet sampling. A. 1999 sampling season B. 2000 sampling season C. 2001 sampling season. Please note differing scales on y-axes.**

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Appendix I

Species	Conversion Equation	R^2	n
C. isodon	FL = 1.0972*(PCL) + 8.6441	0.9991	73
C. limbatus	FL = 1.1072*(PCL) + 1	0.9921	304
C. leucas	FL = 1.0918*(PCL) + 16.769	0.9934	161
R. terraenovae	FL = 1.0725*(PCL) + 9.38	0.999	87
S. tiburo	FL = 1.099*(PCL) - 4.8325	0.9958	13

FL = fork length (mm)
PCL = precaudal length (mm)

Shark Nursery Areas in the Bay Systems of Texas

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Scope

This summary was developed from data collected by the Texas Department of Parks and Wildlife during annual gill net surveys conducted in eight major bay systems of Texas from 1975 - 1995. Included in the data were records of shark captures (7314 sharks representing 16 species, Table 1) that are useful for identifying shark nursery or pupping areas and for examining relative abundance trends for young sharks in Texas bay systems. Gill net sampling was partially funded by the U.S. Fish and Wildlife Service under the Federal Aid in Sport Fish Restoration Act (Project F-34-M).

Sampling Materials and Methods

Non-directed gill net sampling was conducted at randomly selected stations using gill nets consisting of 4 panels of differing mesh sizes (76 mm, 102 mm, 127 mm, and 152 mm stretched mesh) combined to form one net 184 m long and 1.2 m deep (Green 1982). Nets were set perpendicular to shore within one hour of sunset, allowed to soak overnight, and retrieved within one hour of sunrise. From 1975 through 1982, gillnet sampling occurred in all months, although not all months were sampled in all years. Beginning in 1983, sampling was restricted to spring (April through June) and fall (September through November). Data includes identification of shark species to lowest possible taxon, total length (TL mm), date, location (latitude and longitude), water temperature (ºC), salinity (ppt), and effort (lapsed time in hours), however not all information was recorded for all stations. Scientific and common names follow Robins et al. (1991).

Description of Study Area

The eight major Texas bay systems sampled during these surveys are Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Corpus Christi Bay and the Upper and Lower Laguna Madre (Figure 1). The major bays are bar-built estuaries with offshore bars enclosing relatively shallow bay systems, most of which consist of at least primary and secondary bays (Figure 2) (Britton and Morton 1989). The Texas bay systems comprise 2198 square miles of surface area (NOAA 1990). Salinities and temperatures in all bays can vary drastically with season. Climate, in general, ranges from warm-humid in the northeastern zone (San Antonio Bay northward) to the more arid southwestern zone (south of San Antonio Bay) (Diener 1975, Armstrong 1987, Britton and Morton 1989, Monaco et al. 1989, NOAA 1990). Bay systems in the northeastern zone tend to experience lower salinities due to higher average precipitation, while those in the southwestern zone can experience periods of hypersalinity. All bays are affected to some extent by pollution that can include domestic and industrial wastes and agricultural runoff (Diener 1975, NOAA 1990).

Young-of-the-year Relative Abundance and Distribution

To address relative abundance, catch per unit effort (CPUE) was calculated as sharks per net hour. Because of the change in the temporal distribution of effort beginning in 1983 (i.e. no sampling in July and August when most young-of-the-year (YOY) age classes are abundant), the data were separated into two time series (1975-1982 and 1983-1995,

Table 1. **Total shark captures by species and age class 1975-1995.**

Species	YOY	Juveniles (age 1+)	Adults	Total
Carcharhinus leucas	2118	1387	14	3519
Carcharhinus limbatus	1189	45	35	1384
Sphyrna tiburo	343	378	579	1300
Rhizoprionodon terraenovae	119	124	114	357
*Carcharhinus isodon**	33	173	23	229
Negaprion brevirostris	96	101	1	198
*Sphyrna lewini**	66	63	0	129
Carcharhinus plumbeus	0	13	1	14
Carcharhinus brevipinna	64	8	0	72
*Carcharhinus porosus**	2	16	0	18
*Carcharhinus obscurus**	7	2	0	9
Carcharhinus falciformis	2	0	0	2
Mustelus canis	1	0	1	2
*Sphyrna mokarran**	0	6	0	6
Carcharhinus acronotus	0	1	0	1
*Sphyrna tudes**	0	3	0	3

* Due to a lack of published data only neonates were included in the YOY class for this species

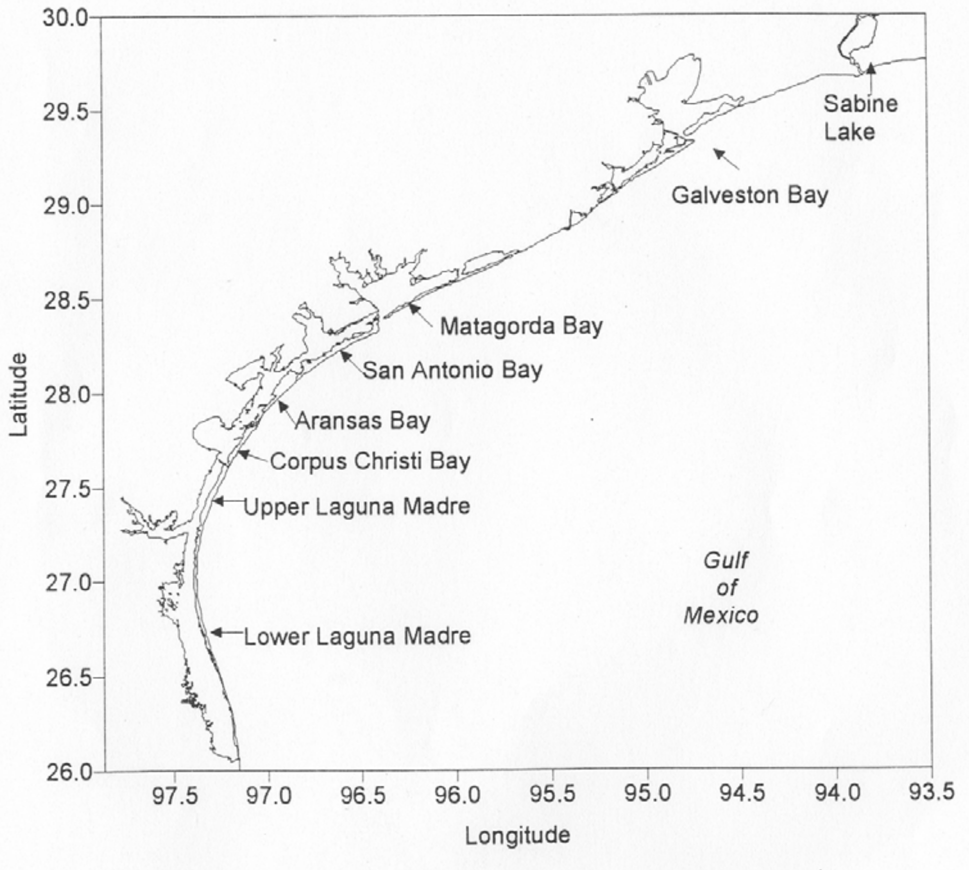

Figure 1. **Major bay systems of Texas.**

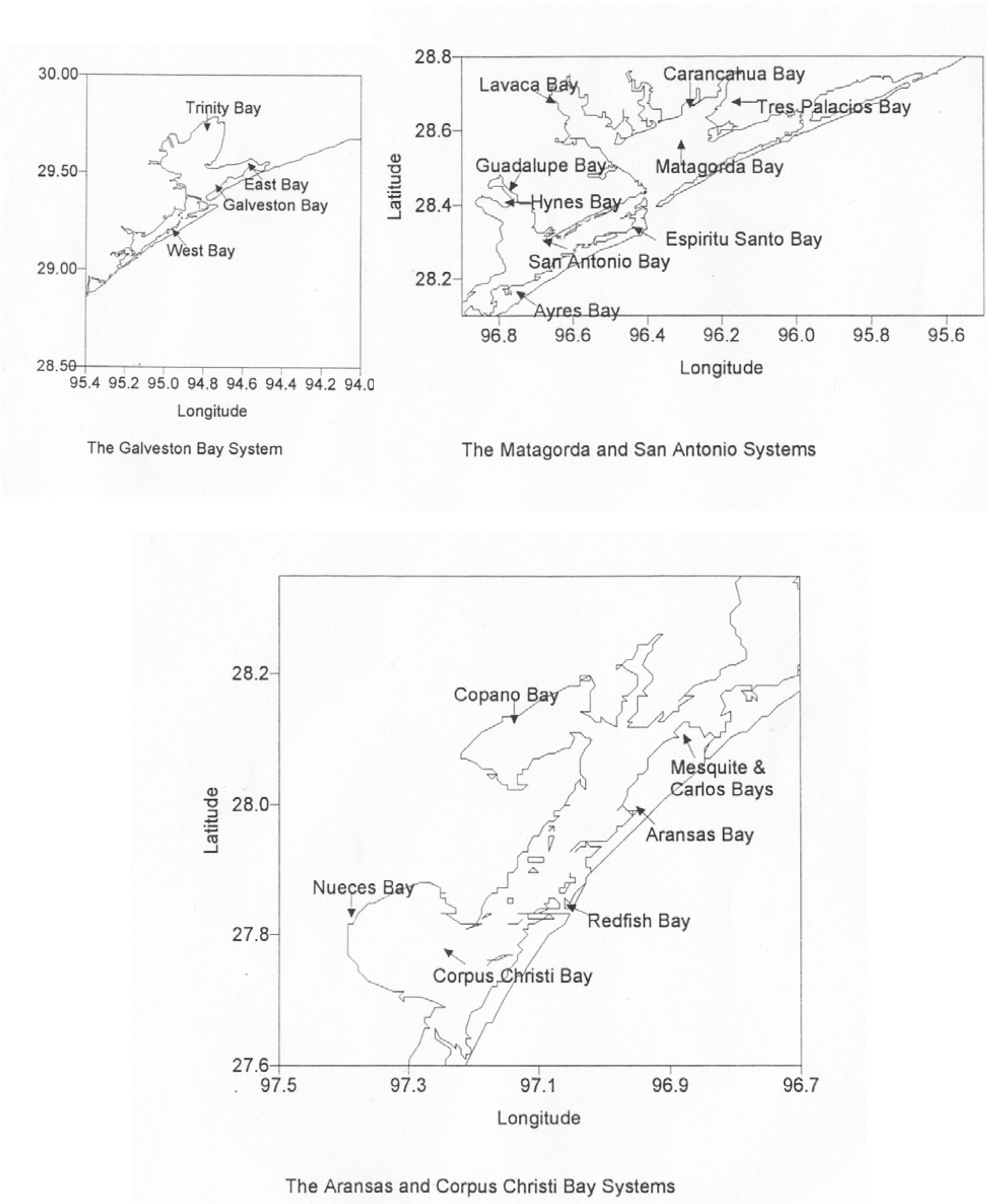

Figure 2. **Galveston, Matagorda, San Antonio, Aransas, and Corpus Christi bay systems and their component minor bays**

hereafter referred to as series 1 and series 2). Relative abundance in terms of CPUE by species was analyzed for series 1 and for months in common between the two time series.

YOY sharks were captured in all major Texas bay systems. CPUEs for all YOY sharks were the highest in the Matagorda and San Antonio systems and lowest in Sabine Lake and the Upper Laguna Madre systems for both time series (Figures 3 and 4). The minor bays in the Galveston and Matagorda systems and Espiritu Santo Bay in the San Antonio System had the overall highest CPUEs and highest species diversity for the entire coast (Figures 5 and 6). These bay systems are characterized by environmental conditions that more closely fit those described for a typical Gulf of Mexico estuarine system (Britton and Morton 1989), in contrast to the more extreme conditions that can be found in the northern (more hyposaline) and southern (hypersaline) bay systems.

Overall, assessment of seasonal distribution revealed a general trend of higher relative abundance in the spring and summer months for series 1 (April, June, July, and August) for all YOY sharks combined. CPUEs were markedly lower in winter months for series 1 with an absence of captures or very few captures from December through February. This pattern fits well with known life-history characteristics and seasonal environmental variation.

Species Profiles

Bull sharks, *Carcharhinus leucas*

Bull sharks (*Carcharhinus leucas*) were the most abundant species with captures in all major bays. Adult bull sharks were captured in Matagorda and San Antonio systems, but gear selectivity probably affected capture of larger specimens (Figure 1). Juveniles (age 1+) and YOY specimens were captured in all bay systems.

For both time series, YOY bull sharks were most abundant in the Matagorda, San Antonio and Aransas systems (Figure 1). Within the Matagorda system, YOY bull sharks were most abundant in the minor bays Tres Palacios, Matagorda, Lavaca, and Carancahua (Figure 2). Within the San Antonio system, YOY bull sharks were most abundant in the minor bays San Antonio, Ayres, and Espirito Santo (Figure 2). Within the Aransas system, YOY bull sharks were most abundant in minor bays Aransas, Mesquite, and Carlos (Figure 2). It should also be noted that the Matagorda and San Antonio major bay systems, where YOY bull sharks were relatively abundant, are contiguous via passes and channels between the bay systems (Figure 2).

Analysis of seasonal distribution for YOY bull sharks using catch data from series 1 indicates that YOY bull sharks are captured in relatively high numbers beginning in April and increase through July and then decrease through December. No captures of YOY bull sharks occurred during January and February during series 1. This distribution fits well with previous studies that suggest bull sharks are born in inshore nursery areas in late spring and summer along the east coast of the U.S. (Snelson et al. 1984, Castro 1993a) and with Nelson's (1992) reported seasonal distribution of bull sharks in these bay systems. YOY-sized bull sharks captured in March and April range in size from 833 - 975 mm TL. Branstetter and Stiles (1987) suggested that due to variable growth rates, large neonates captured in spring may have been born the previous year. Captures of bull sharks that fit within the reported range of size at birth are reported in May and are present through summer and into fall. Linear regression analysis yielded a statistically significant decreasing trend in CPUE over the period 1975 –1995 ($r^2 = 0.43$; $p \leq 0.002$) (Figure 7), but explanations for this decrease are not evident from the data elements collected.

Salinity and temperature ranges at locations for YOY bull shark captures (Table 2) fit well with the bull shark's described ability to adapt to a wide range of temperature and salinities (Compagno 1984, Grace and Henwood 1997), and may help to account for the abundance of YOY bull sharks in Texas bay systems.

Blacktip sharks, *Carcharhinus limbatus*

Blacktip sharks (*Carcharhinus limbatus*) were the second most abundant species and captures occurred in all major bay systems. Adult blacktips were captured in Galveston, Matagorda, San Antonio, Corpus Christi, and Lower Laguna Madre major bay systems (Figure 1). Again, gear selectivity may have excluded captures of larger specimens. Juvenile (age 1+) blacktips were captured in all bay

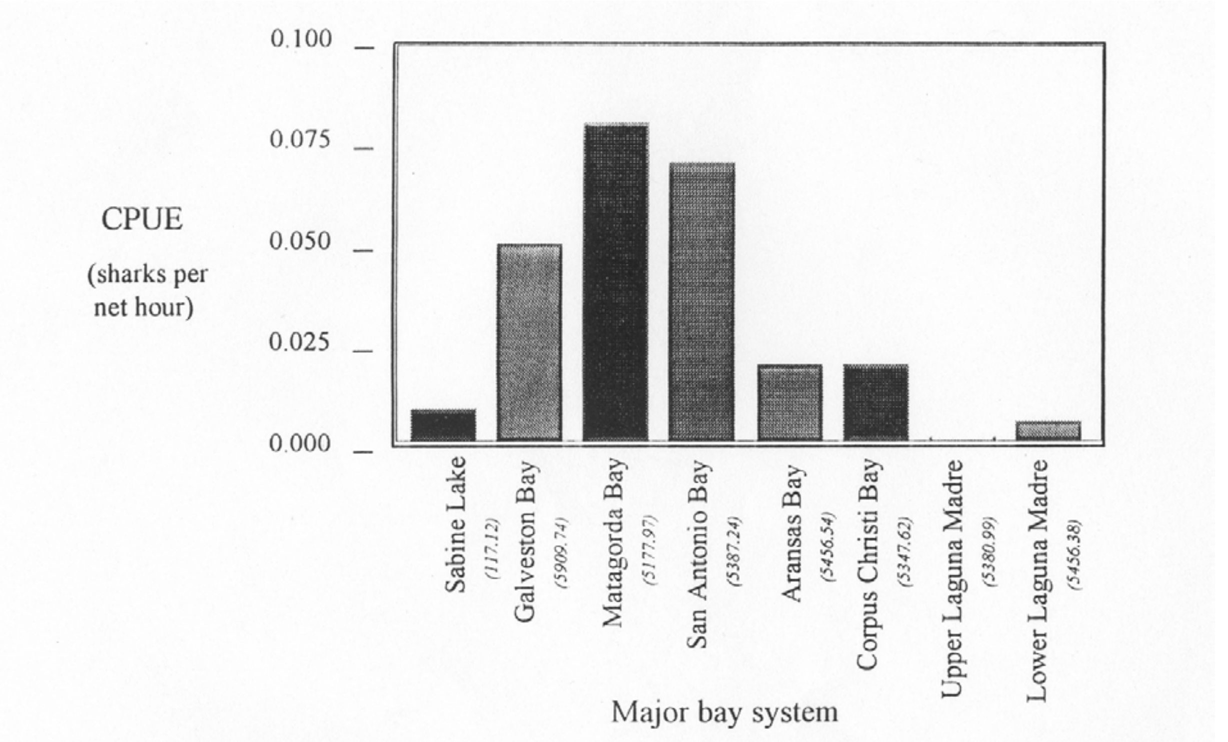

Figure 3. **YOY CPUE by major bay system, 1975 – 1982. Numbers in italics indicate in net hours**

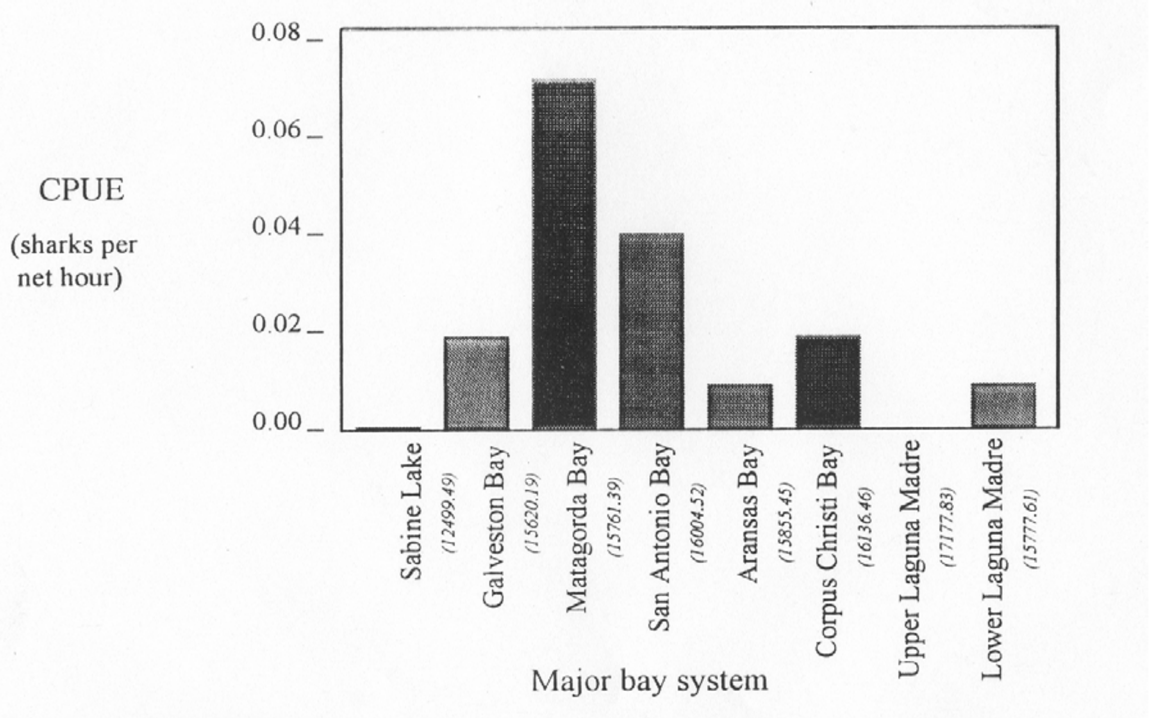

Figure 4. **YOY CPUE by major bay system, 1983 – 1995. Numbers in italics indicate in net hours**

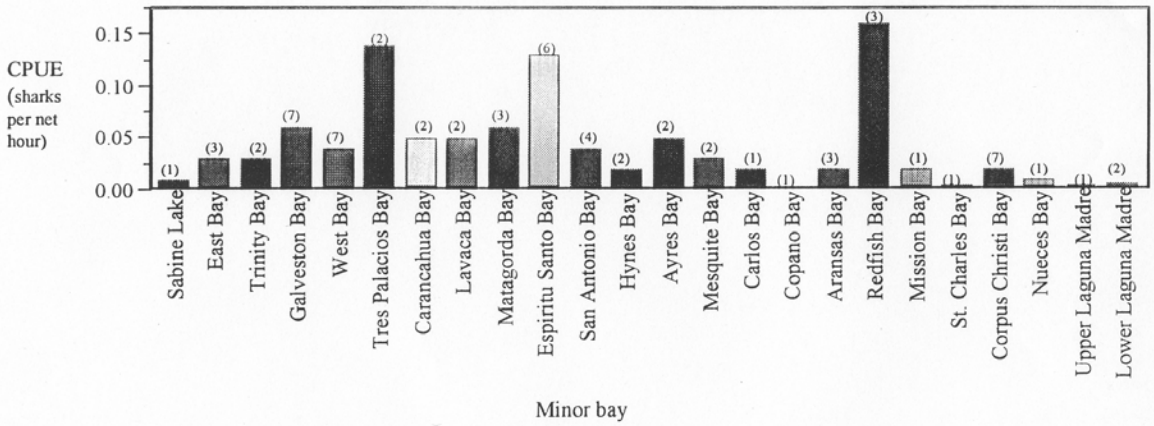

Figure 5. **YOY CPUE by minor bay, 1975 – 1982. Numbers in parentheses indicate number of species present.**

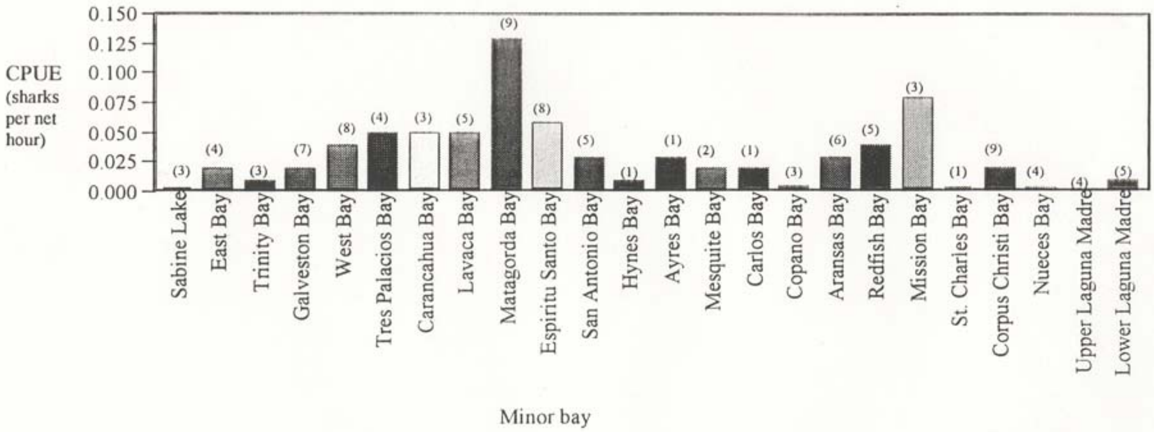

Figure 6. **YOY CPUE by minor bay, 1983 – 1995. Numbers in parentheses indicate number of species present.**

Table 2. **YOY temperature (ºC) and salinity (ppt) ranges at shark capture locations for the six most abundant species**

Species	Temperature range (ºC)	Salinity range (ppt)
Carcharhinus leucas	18.6 - 33.5	0.0 - 51.0
Carcharhinus limbatus	16.7 - 34.0	0.0 - 54.0
Sphyrna tiburo	18.0 - 33.5	0.0 - 39.0
Rhizoprionodon terraenovae	16.7 - 32.0	10.0 - 38.0
*Carcharhinus isodon**	19.2 - 30.6	16.0 - 36.0
Negaprion brevirostris	22.5 - 33.2	9.9 - 39.0

* Due to a lack of published data only neonates were included in the YOY class for this species

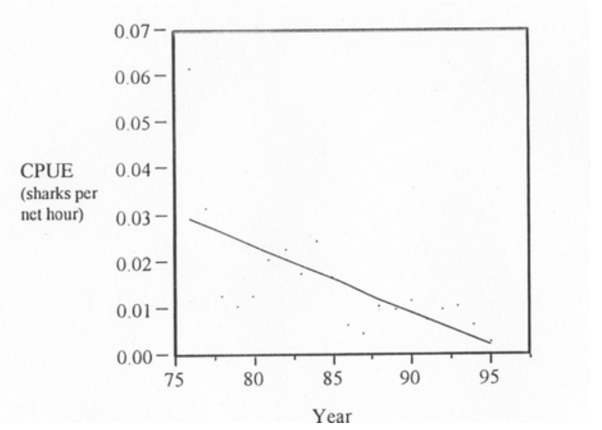

Figure 7. Linear regression analysis of YOY bull shark CPUE. $r^2 = 0.43$; $p \leq 0.002$.

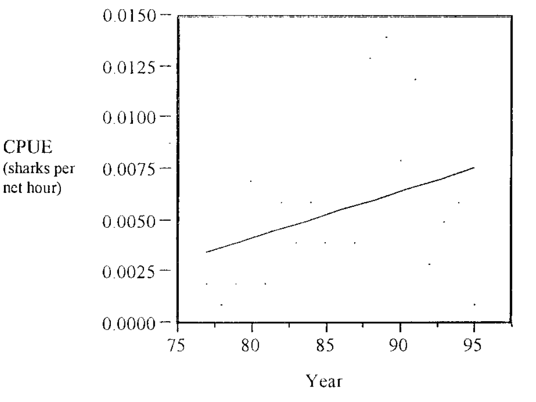

Figure 8. Linear regression analysis of YOY blacktip shark CPUE. $r^2 = 0.43$; $p \leq 0.002$.

systems except for Sabine Lake and the Corpus Christi major bay system (Figure 1). YOY specimens were captured in all major bay systems.

For series 1, YOY blacktip sharks were most abundant in the Galveston and Corpus Christi major bay systems (Figure 1). For series 2, YOY blacktips were most abundant in the Matagorda, Galveston, Corpus Christi, and San Antonio major bay systems (Figure 1). Within the Galveston system, YOY blacktips were most abundant in the minor bays West, Trinity, and Galveston (Figure 2). Within the Corpus Christi system, YOY blacktips were most abundant in the minor bay Corpus Christi Bay (Figure 2). Within the Matagorda system, YOY blacktips were most abundant in the minor bays Matagorda and Carancahua (Figure 2). In addition, YOY blacktips were relatively abundant in Espiritu Santo Bay in the San Antonio system and Redfish Bay in the Aransas system (Figure 2).

Analysis of seasonal distribution for YOY blacktip sharks using catch data from series 1 indicates YOY blacktips were captured as early as February and captures increase to highs in June, July, and August. No captures occurred during December and January. This distribution fits well with Castro's (1996) study that suggests blacktips pup in May and June in shallow coastal waters off the east coast of the U.S. YOY blacktips captured prior to May are larger than the size range reported for size at birth and may have been born in the previous year. Blacktip captures within the reported range of size at birth occurred in May and continued into September.

Although linear regression analysis of CPUE for common months for both time series revealed an apparent increasing trend in relative abundance for YOY blacktip sharks, it was not statistically significant ($r^2 = 0.11$; $p \leq 0.18$) (Figure 8). CPUE values for 1976 and 1986 were considered outliers and were omitted from the regression analysis. No explanation for the variability in CPUE is apparent from data analysis. Although the increasing trend lacks statistical significance, it may have biological significance, especially in light of the decreasing trend noted for bull sharks.

Salinity and temperature ranges (Table 2), reflect the reported ability of blacktip sharks to adapt to a fairly wide range of temperatures and salinities (Compagno 1984, Castro 1996, Grace and Henwood 1997). This may help to account for the relatively high abundance of blacktips in Texas bay systems.

Percent composition analysis of catch for YOY bull and blacktip sharks showed that bull shark captures accounted for 60 - 88% of the YOY catch prior to 1986, except for 1976 when YOY bull sharks accounted for 23% of the catch (Figure 9). Beginning in 1986, the percentage of YOY bull shark captures began to decrease, accounting for less than 60% of shark captures in all subsequent years except for 1992 (75%) (Figure 9). YOY blacktips accounted for lower percentages of the total YOY catch in the years 1976 - 1985 (5 - 31%) and then, although variable, increased and even dominated in some years beginning in 1986 (Figure 9). This analysis supports the results of the CPUE regression analysis.

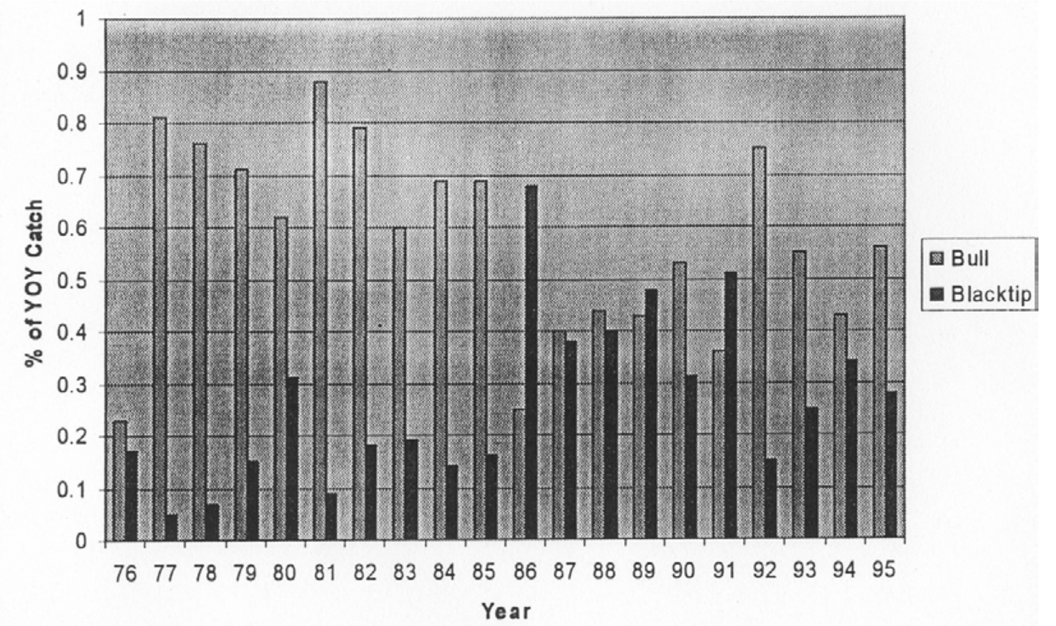

Figure 9. **Percent of YOY catch per year for bull and blacktip sharks.**

Bonnethead sharks, *Sphyrna tiburo*

Bonnethead sharks (*Sphyrna tiburo*) of all age classes were captured in all major bay systems. The capture of higher numbers of adults of this species is probably related to the ability of the gear to sample the entire size range of this small coastal species.

For both time series, YOY bonnethead sharks were most abundant in the San Antonio major bay system (Figure 1). Within this system, YOY bonnetheads were most abundant in minor bay Espiritu Santo Bay (Figure 2). CPUEs for all other bay systems were relatively low.

Seasonal distribution analysis for YOY bonnethead sharks using catch data from series 1, indicated that YOY bonnetheads were most abundant in April. No captures of YOY bonnetheads occurred in July or September through December, and only six YOY were caught in August in 1976 and 1977. Insufficient numbers of captures of neonate-sized specimens (only 12 from 1976-1994) prevent the identification of a probable pupping season for this species in these bays; although parturition has been reported to occur in the fall in other areas (Parsons 1993, Marquez-Farias et al. 1998).

Salinity and temperature ranges for capture locations are shown in Table 2. These ranges suggest this species is also able to tolerate at least moderate fluctuations in temperature and salinity although the overall range is somewhat less than the bull and blacktip sharks.

Atlantic sharpnose sharks, *Rhizoprionodon terraenovae*

Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) were captured in all major bay systems except Sabine Lake. Adults were captured in the Matagorda, San Antonio, Corpus Christi, and Lower Laguna Madre major bay systems (Figure 1). Juveniles (age 1+) and YOY Atlantic sharpnose were captured in all major bay systems except for Sabine Lake (Figure 1).

For series 1, YOY Atlantic sharpnose were most abundant in the Galveston major bay system (Figure 1). Within this system, YOY Atlantic sharpnose were captured in minor bays West and Galveston Bays (Figure 2). For series 2, YOY Atlantic sharpnose were most abundant in the Matagorda major bay system (Figure 1). Within this system, the majority of YOY Atlantic sharpnose captures occurred in minor bays Tres Palacios and Matagorda Bays (Figure 2).

Analysis of seasonal distribution for YOY Atlantic sharpnose sharks using catch data from series 1 indicated they are present in Texas bay systems from May through November with greatest numbers present from July to September. Captures of Atlantic sharpnose that fell within the range of TL reported for size at birth were captured in July and August; falls within the range for the reported pupping season of late May to July in other areas (Parsons 1983, Parsons 1985, Castro and Wourms 1993, Marquez-Farias and Castillo-Geniz 1998).

Salinity and temperature ranges at locations for YOY Atlantic sharpnose shark captures are shown in Table 2. While the overall temperature and salinity range are comparable to those for bull, blacktip, and bonnethead sharks, a reduced tolerance to abrupt variations could be a factor influencing the low observed relative abundance for a species considered to be very common in the Gulf of Mexico. Other factors could include predation by larger species and sampling bias (mesh size too large for neonates) for younger age classes for this small coastal shark.

Finetooth sharks, *Carcharhinus isodon*

Finetooth sharks (*Carcharhinus isodon*) were captured in all major bay systems except for Sabine Lake and the Upper Laguna Madre, with YOY specimens captured in all systems except for Sabine Lake, San Antonio Bay and the Upper Laguna Madre (Figure 1).

For series 1, YOY finetooth sharks were most abundant in the Galveston system and for series 2 were most abundant in the Corpus Christi and Galveston systems (Figure 1).

Analysis of seasonal distribution using catch data from series 1 establishes YOY finetooth sharks are present in Texas bays from April into November. All YOY finetooth captures were neonates. Castro (1993b) reported a pupping season from May to June for finetooth sharks off the east coast of the U.S. The salinity and temperature ranges for YOY finetooth sharks are shown in Table 2

Lemon sharks, *Negaprion brevirostris*

Lemon sharks (*Negaprion brevirostris*) were captured in all bay systems except for the Upper Laguna Madre (Figure 1). Gear selectivity may have precluded the capture of larger specimens; however, one adult was captured in Matagorda Bay (Figure 1). Juveniles (age 1+) were captured in all systems except the Upper Laguna Madre; YOY specimens were captured in all systems except Sabine Lake and the Upper Laguna Madre (Figure 1).

YOY lemon sharks were most abundant in the San Antonio system for series 1 and in the Matagorda system for series 2 (Figure 1). Within these bay systems, YOY lemon sharks were most abundant in Espiritu Santo and Matagorda Bays (Figure 2). Analysis of seasonal distribution using catch data form series 1 indicates that YOY lemon sharks are present from April through July and in October with highest numbers occurring from May through July. The salinity and temperature ranges for YOY lemon sharks are shown in Table 2.

Scalloped hammerhead sharks, *Sphyrna lewini*

YOY scalloped hammerhead sharks (*Sphyrna lewini*) were captured in all bay systems except for the Upper Laguna Madre (Figure 1). For series 1, YOY scalloped hammerheads were most abundant in the Galveston and Corpus Christi systems (Figure 1). For series 2, YOY scalloped hammerheads were most abundant in the Lower Laguna Madre and Matagorda systems (Figure 1). Highest relative abundance by minor bays was in Galveston and Aransas Bays (Figure 2). Analysis of seasonal distribution using catch data from series 1 indicates YOY scalloped hammerheads are present from April through September with greatest numbers in July.

Spinner sharks, *Carcharhinus brevipinna*

Spinner sharks (*Carcharhinus brevipinna*) were captured in all bay systems except for Sabine Lake and the Upper Laguna Madre (Figure 1). Juveniles (age 1+) were captured in the Galveston, Matagorda, and San Antonio systems (Figure 1). For series 1, YOY spinners were captured only in the San Antonio and Matagorda systems (Figure 1). For series 2, YOY spinners were most abundant in the Galveston and Corpus Christi systems (Figure 1). Spinner sharks occurred in relatively low abundance throughout the survey period although it is considered a common shark in the Gulf of Mexico. Analysis of seasonal distribution for YOY spinner sharks indicates they are present in the bays in April, May and October.

Other Species

Low numbers of YOY-sized specimens were reported for smalltail sharks (*Carcharhinus porosus*), dusky sharks (*Carcharhinus obscurus*), silky sharks (*Carcharhinus falciformis*), and smooth dogfish sharks (*Mustelus canis*). Numbers of captures for these species were so small that analysis for relative abundance or seasonal distribution was not attempted.

Other species reported captured, but for which no YOY-sized specimens were recorded, were sandbar sharks (*Carcharhinus plumbeus*), great hammerhead sharks (*Sphyrna mokarran*), smalleye hammerhead sharks (*Sphyrna tudes*), and blacknose sharks (*Carcharhinus acronotus*).

Preliminary Findings

The gill net survey data indicate that some Texas bay systems serve as important nursery areas for several species of sharks including the bull shark, blacktip shark and possibly the bonnethead and Atlantic sharpnose sharks. In a general sense, the area from the Galveston Bay system to Espiritu Santo Bay in the San Antonio system (Figures 1 and 2) provides habitats for the highest number and species diversity of sharks found along the Texas coast. There are specific areas within bay systems that are utilized by a number of species as nursery areas. For example, within an area encompassing the southern section of Matagorda Bay and most of Espiritu Santo Bay (approximately 50 km linear distance; Figure 2) eight species (of the 12 species reported to occur from this survey) use this area as a nursery ground. Areas of extreme salinities and temperatures seem to affect the distribution of some species. Additional biological investigations and assessments and continuation of the time series analysis would be useful for identifying critical factors that make these bays attractive as shark nursery habitats.

Acknowledgments

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END OF CHAPTER SECTION

SPECIES SPECIFIC SHARK NURSERY SUMMARY TABLES

These tables summarize the information contained in the text of the chapters and in the data provided by contributing authors in addition to the databases donated by SEAMAP and the Florida Department of Environmental Protection. For purposes of this report primary and secondary nursery areas are defined as: primary nursery habitat where neonate and/or young-of-the-year occur (based on size and umbilical scar condition when available), and secondary nursery habitat where age 1+ juveniles occur.

LIST OF TABLES

Table 1. Atlantic sharpnose

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Inshore and nearshore waters from Cape Hatteras to Holden Beach, NC	summer primary nursery (pupping May-July)	no data	no data	no data	no data	Jensen et al, SEAMAP
	SC estuarine and nearshore waters	summer primary nursery (pupping May-June), remain in nursery until Oct	21-29	no data	24-37	no data	Ulrich and Riley, SEAMAP
	GA estuarine and coastal waters	summer primary nursery (April-Sept)	26.4-30.8	4.3-7.4	21.6-36.4	2.7-13.1	Belcher and Shierling, Gurshin, SEAMAP
	Yankeetown to 10,000 Islands on the west coast of FL, the northern coast of FL to Cape Canaveral on the east coast, and the Florida Keys	summer primary nursery (May-Nov), pupping May-July, FL Keys – overwintering grounds	18.4-30.7	4.75-8.56	22.8-33.7	0.9-4	Hueter and Tyminski, Michel and Steiner, SEAMAP
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer primary nursery	19.5-31.2	3.6-7.7	24-37	0.7-6.2	Carlson
	From the mouth of St Louis Bay, MS to the tip of Fort Morgan, AL	summer primary nursery	B 29.2 S 30.1	B 5.5 S 6.5	B 20.6 S 18.5	6.9	Parsons (env. parameters are average values)
	Terrebonne/Timbalier Bay System, LA	summer primary nursery (June-Sept)	no data	no data	no data	no data	Neer et al
	All major bay systems along the Gulf coast of TX from Galveston Bay to Lower Laguna Madre and coastal TX waters	summer primary nursery (May-Nov)	16.7-32	no data	10-38	no data	Jones and Grace, Hueter and Tyminski
Juvenile	Inshore and nearshore waters from Cape Hatteras to Holden Beach, NC	summer secondary nursery	17.3-33	no data	no data	1.4-16.5	Jensen et al., SEAMAP
	SC estuarine and nearshore waters	summer secondary nursery (May-Oct)	21-29	no data	24-37	no data	Ulrich and Riley, SEAMAP
	GA estuarine and coastal waters	summer secondary nursery (May-Oct)	26.4-30.8	4.3-7.4	21.6-36.4	2.7-13.1	Belcher and Shierling, Gurshin, SEAMAP
	Yankeetown to 10,000 Islands on the west coast of FL, the northern coast of FL to Cape Canaveral on the east coast, and the Florida Keys	summer secondary nursery, FL Keys – overwintering grounds	17.2-33.3	2.9-8.71	22.8-37.4	0.6-43.9	Hueter and Tyminski, Michel and Steiner, SEAMAP
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	16-32.4	4.5-8.3	19-38	1.7-6.4	Carlson
	Coastal AL off Dauphin Island and Mobile Point	summer secondary nursery (June-Oct)	B 24.5-28.9 S 28.9-31.5	B 0.3-4.5 S 4.3-7.2	B 31.4-36.3 S 28.6-31.5	2.7-14	Gurshin
	MS, LA, and TX coastal waters in the Gulf of Mexico	summer secondary nursery					Hueter and Tyminski
	From the mouth of St Louis Bay, MS to the tip of Fort Morgan, AL	summer secondary nursery	B 27.1 S 28	B 6.5 S 7.3	B 20.4 S 19.7	8.2	Parsons (env. parameters are average values)
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery (April-Nov)	22.6-32.4	no data	23-37.3	1.5-4.9	Neer et al
	All major bay systems along the Gulf coast of Texas from Galveston Bay to Lower Laguna Madre	summer secondary nursery	no data	no data	no data	no data	Jones and Grace

Table 2. Blacknose shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Off Holden Beach, NC	summer primary nursery (pupping May-July)	no data	no data	no data	no data	Jensen et al, SEAMAP
	SC nearshore waters	summer primary nursery	no data	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA nearshore waters	summer primary nursery	no data	no data	no data	no data	SEAMAP
	Neonates found along Gulf beaches in Tampa Bay area in June. YOY found along Gulf beaches in Tampa Bay area and in the estuarine areas of Tampa Bay and Charlotte Harbor and migrate out in late Oct; many YOY overwinter in Florida Keys	summer primary nursery (June-Oct) FL Keys – overwintering grounds	27-34	3.25-7.07	26.5-37	0.9-9	Hueter and Tyminski, Michel and Steiner, SEAMAP
	Northeast Gulf of Mexico (Apalachee Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer primary nursery	24.7-33.2	4.6-7.4	29-35	1-6.3	Carlson
	North central Gulf of Mexico (N=1)	summer primary nursery	B 29 S 32	B 7 S 7.2	B 26.2 S 17.2	4.6	Parsons
Juvenile	Coastal waters from Cape Lookout to Holden Beach, NC - none seen north of Cape Hatteras	summer secondary nursery	20.3-33	no data	no data	3.3-11.9	Jensen et al., SEAMAP
	SC nearshore waters	summer secondary and overwintering nursery (May-Dec)	18-22	no data	no data	no data	Ulrich and Riley, SEAMAP
	Coastal waters from Yankeetown to Charlotte Harbor, FL and the Florida Keys	summer secondary nursery (March-Oct); in FL Keys year round	17.3-32.5	4.76-8.71	25.6-37	0.9-60.4	Hueter and Tyminski, Michel and Steiner,
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	20.8-33.6	2-8.3	27-38	0.7-5	Carlson
	North central Gulf of Mexico	summer secondary nursery	B 27.7 S 24.8	B 5.4 S 8.2	B 20.3 S 24.5	4.6	Parsons (env. parameters are average values)

Table 3. Blacktip shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Off Yaupon and Holden Beaches, NC	summer primary nursery	no data	no data	no data	no data	Jensen et al
	SC estuarine and nearshore waters	summer primary nursery, pupping late May/early June to early July	no data	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine waters	summer primary nursery (June-Sept)	21-30.4	4.35-6.08	22-36.1	0.5-11.6	Belcher and Shierling, Gurshin
	Yankeetown to 10,000 Islands on the west coast of Florida, Cape Canaveral on the east coast of FL and the Florida Keys. Also found in the Marquesas Islands west of the Florida Keys	summer primary nursery (June-Oct); FL Keys – found year round; Marquesas Islands – overwintering grounds	19.1-33.6	3.28-10.26	15.8-41.1	0.9-12.5	Hueter and Tyminski, Michel and Steiner
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer primary nursery	22.5-31.4	3.6-7	19-38	2.1-6	Carlson
	From the mouth of St Louis Bay, MS to the tip of Fort Morgan, AL	summer primary nursery	B 29.3 S 30.6	B 6.6 S 6.6	B 20.3 S 17.8	3.4	Parsons (env. parameters are average values
	Terrebonne/Timbalier Bay System, LA	summer primary nursery (May-Sept)	22.6-32.4	no data	18-34.7	1.2-5.2	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre	summer primary nursery (May-Sept)	16.7-34	no data	0-54	no data	Jones and Grace
Juvenile	Nearshore and inshore waters from Cape Hatteras and Core Sound to Holden Beach, NC	summer secondary nursery	no data	no data	no data	no data	Jensen et al.
	SC estuarine and nearshore waters	secondary nursery (May-Dec)	18-24	no data	no data	no data	Ulrich and Riley, SEAMAP, Hueter and Tyminski
	GA estuarine waters	summer secondary nursery (June-Sept)	21-30.4	4.35-6.08	22-36.1	0.5-11.6	Belcher and Shierling, Gurshin
	Yankeetown to 10,000 Islands on the west coast of Florida, Cape Canaveral on the east coast of FL and the Florida Keys	summer secondary nursery (March-Nov); warm water effluents of Tampa Bay and Yankeetown power plants during winter months	20.8-33.6	2-8.3	27-38	0.7-5	Hueter and Tyminski, Michel and Steiner
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay) north central Gulf of Mexico	summer secondary nursery	16-32.5	1.9-8.3	19-38	0.7-6.4	Carlson
	Coastal Alabama off Dauphin Island and Mobile Point	summer secondary nursery	B 27.3-28.1	B 3.2-6.2	B 34.3-37	5.8-7.6	Gurshin
	From the mouth of St Louis Bay, MS to the tip of Fort Morgan, AL	summer secondary nursery	B 28 S 28.8	B 6.3 S 6.9	B 19.4 S 17.7	3.1	Parsons (env. parameters are average values)
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery (April-Nov)	22.6-32.4	no data	18-34.7	1.2-5.2	Neer et al
	All major bay systems along the Gulf coast of Texas from Galveston Bay to Lower Laguna Madre, except Corpus Christi Bay	summer secondary nursery	no data	no data	no data	no data	Jones and Grace

Table 4. Bonnethead shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Coastal waters from the tip of GA to Cape Canaveral, FL	summer primary nursery	no data	no data	no data	no data	SEAMAP
	Estuarine and shallow coastal waters from Yankeetown to Charlotte Harbor, FL and the Florida Keys	summer primary nursery	16.1-31.7	4.96-8.21	15.4-35.6	0.6-5.5	Hueter and Tyminski,
	10,000 Islands Estuary, FL	summer primary nursery (May-Oct)	no data	no data	no data	no data	Michel and Steiner
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer primary nursery	16-32.5	1.9-8.3	19-38	0.7-6.4	Carlson
	North central Gulf of Mexico (near the mouth of St. Louis Bay, MS), N=1	summer primary nursery	B 28 S 29.5	B 7.8 S 8.8	B 24 S 15.5	6	Parsons
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre	summer primary nursery	18-33.5	no data	0-39	no data	Jones and Grace
Juvenile	Inshore and nearshore waters from Cape Hatteras to Holden Beach, NC	summer secondary nursery	19-33	no data	no data	0.6-11.6	Jensen et al., SEAMAP
	SC estuarine and nearshore waters	summer secondary nursery	no data	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine and nearshore waters	summer secondary nursery	23-30.1	4.23-6.85	22-36.6	0.5-13.1	Belcher and Shierling, Gurshin, SEAMAP
	Coastal waters from the tip of GA to Cape Canaveral, FL	summer secondary nursery	no data	no data	no data	no data	SEAMAP
	Estuarine and shallow coastal waters from Yankeetown to Charlotte Harbor, FL and the Florida Keys	summer secondary nursery; also found in warm water effluents of Tampa Bay power plants and in the Florida Keys in the winter months	15.9-33	2.88-10.46	16.5-36.9	0.6-4.9	Hueter and Tyminski,
	10,000 Islands Estuary, FL	summer secondary nursery	20-32.1	2.7-7.6	16.4-41.8	0.8-4	Michel and Steiner
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	16-32.5	1.9-8.3	19-38	0.7-6.4	Carlson
	North central Gulf of Mexico (near the mouth of St. Louis Bay, MS and north of Horn Island, MS)	summer secondary nursery	28-30.1	5.7-8.8	15.5-24	3-3.4	Parsons
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery (May-August)	28.4-31.4	no data	25.3-34.3	1.8-2.4	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre and coastal TX waters	summer secondary nursery	no data	no data	no data	no data	Jones and Grace, Hueter and Tyminski

Table 5. Bull shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Off Yaupon Beach, NC (low number of sharks)	summer primary nursery (few specimens)	no data	no data	no data	no data	Jensen et al
	Coastal and estuarine waters from Yankeetown to Charlotte Harbor, FL and the Florida Keys	summer primary nursery (May-Nov); also found in warm water effluents of Tampa Bay and Yankeetown power plants during the winter months	21.5-34	2.83-8.4	3-33.3	0.6-4.6	Hueter and Tyminski
	10,000 Islands Estuary, FL	summer primary nursery	no data	no data	no data	no data	Michel and Steiner
	From Bon Secour Bay, AL to the mouth of St. Louis Bay, MS	summer primary nursery	B 29 S 30	B 9.1 S 9	B 14.5 S 14	no data	Parsons (env. parameters are average values)
	Terrebonne/Timbalier Bay System, LA	summer primary nursery (April-Sept)	22.6-32.4	18-34.7	29-35	1.2-5.2	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre and coastal waters off TX	summer primary nursery	18.6-33.5	no data	0-51	no data	Jones and Grace, Hueter and Tyminski
Juvenile	Off Ocracoke Inlet and Yaupon Beach and in Core Sound, NC	summer secondary nursery	20.3-33	no data	no data	3.3-11.9	Jensen et al.
	St. Helena Sound, SC (N=1)	summer secondary nursery	no data	no data	no data	no data	Ulrich and Riley
	Indian River Lagoon, FL	summer secondary nursery	22.8-34.1	5-9.2	11.8-30.7	0.2-1.5	FL DEM
	Coastal and estuarine waters from Yankeetown to Charlotte Harbor, FL and the Florida Keys	summer secondary nursery; also found in warm water effluents of Tampa Bay and Yankeetown power plants during the winter months	21-33.6	2.56-7.43	14.3-36.8	0.9-6.4	Hueter and Tyminski
	10,000 Islands Estuary, FL	summer secondary nursery	19.7-32.1	2.8-5.2	12.8-41.7	0.8-2.5	Michel and Steiner
	Estuarine waters of Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, St. Joseph Bay, and Crooked Island Sound)	summer secondary nursery	20.7-31.8	4.5-6.6	25-36	2.5-5	Carlson
	From Bon Secour Bay, AL to the mouth of St. Louis Bay, MS	summer secondary nursery	B 29.7 S 30.6	B 6.3 S 7.3	B 17.1 S 14.9	2.8	Parsons (env. parameters are average values)
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery (March-Nov)	22.6-32.4	no data	18-34.7	1.2-5.2	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre	summer secondary nursery					Jones and Grace

Table 6. Dusky shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Nearshore waters from Cape Hatteras to Bogue Banks and off Holden Beach, NC	Oct and Nov; pupping April and May off Holden beach	no data	no data	no data	no data	Jensen et al, SEAMAP
	SC coastal waters	transient or overwintering nursery (Nov)	18	no data	no data	no data	Ulrich and Riley
Juvenile	In the coastal waters of Martha's Vineyard, MA (off East and South Beaches of Chappaquiddick Island)	summer secondary nursery	17-24	no data	no data	4.8-19.2	Skomal
	Exposed nearshore waters in Virginia, rarely enter the estuaries (one juvenile female, 79cm PCL, caught in lower Chesapeake Bay in August of 1990)	summer secondary nursery	no data	no data	no data	no data	Grubbs and Musick
	Nearshore waters from Cape Hatteras to Holden Beach, NC	summer secondary and overwintering nursery grounds	18.1-22.2	no data	no data	4.3-15.5	Jensen et al, SEAMAP
	SC coastal waters	transient or overwintering nursery (Nov)	18	no data	no data	no data	Ulrich and Riley

Table 7. Finetooth shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	SC estuarine waters	summer primary nursery (June - Sept), pupping early to mid June	no data	no data	no data	no data	Ulrich and Riley
	GA estuarine and coastal waters	transient or overwintering nursery (Nov)	above 25	no data	23-26	0.5-5	Belcher and Shierling, Gurshin, SEAMAP
	Northeast Gulf of Mexico (Apalachicola Bay and Crooked Island Sound)	summer primary nursery	26.4-31.4	4.5-5.6	25-36	3.3-5	Carlson
	Terrebonne/Timbalier Bay System, LA	summer primary nursery (May-Aug)	25.3-32.1	no data	19-34.3	0.6-4.9	Neer et al
	Galveston, Matagorda, Aransas, Corpus Christi and the Lower Laguna Madre major bay systems of Texas	summer primary nursery (April-Nov)	19.2-30.6	no data	no data	16-36	Jones and Grace
Juvenile	Cape Hatteras to Holden Beach, NC	summer secondary nursery for older juveniles	22-30.6	no data	no data	3.1-10.7	Jensen et al
	SC estuarine (primarily early juveniles) and nearshore coastal waters (primarily late juveniles)	summer secondary nursery (May-Oct)	20-28	no data	no data	no data	Ulrich and Riley
	GA estuarine waters	summer secondary nursery	25-28.2	6.21	23-32.1	0.5-4.3	Gurshin
	Northeast Gulf of Mexico (Apalachicola Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	19.5-31.4	3.6-6.8	19-38	2.3-5.3	Carlson
	Coastal Alabama off Dauphin Island and Mobile Point (N=3)	summer secondary nursery	B 26.1-27.5 S 28.8-31.5	B 0.3-2.4 S 5.3-7.3	B 33.3-36.3 S 23.5-32.4	4.9-7.6	Gurshin
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery	25.3-32.1	no data	19-34.3	0.6-4.9	Neer et al
	All major bay systems along the Gulf coast of Texas from Galveston Bay to Lower Laguna Madre, except Upper Laguna Madre	summer secondary nursery	no data	no data	no data	no data	Jones and Grace
	Along the beaches of the lower TX coast	spring and fall migrations	33.8	8.5	11.5	2.1-5.5	Hueter and Tyminski

Table 8. Florida smoothound shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	no data	no data	no data	no data	no data	no data	
Juvenile	Tampa Bay and Charlotte Harbor, FL	overwintering nursery (Dec-April)	16.1-23.6		1.5-2.7	30.9-33.5	Hueter and Tyminski
	Northeast Gulf of Mexico (Apalachee Bay, St Joseph Bay, Crooked Island Sound, and St Andrew Bay)	summer secondary nursery	16-22	6-8.2	3-5	27-35	Carlson

Table 9. Great hammerhead shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Yankeetown, Tampa Bay, and Charlotte Harbor, FL	summer primary nursery (only YOY, June-Oct)	23.9-31.1	5-5.3	21.9-34.9	1.5-6.1	Hueter and Tyminski
Juvenile	Yankeetown, Tampa Bay, Charlotte Harbor, and 10,000 Islands, FL	summer secondary nursery (March-Oct)	20.9-32.9	3.6-7.1	15.8-41.4	1-33	Hueter and Tyminski, Michel and Steiner
	TX estuarine and offshore waters in the Gulf of Mexico	summer secondary nursery	no data	no data	no data	no data	Jones and Grace, Hueter and Tyminski

Table 10. Lemon shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Shallow grass flats of Tampa Bay, FL and also in the 10,000 Islands Estuary and the Florida Keys	summer primary nursery	19.6-31.6	5.9-9.6	25.8-34.7	0.3-1.8	Hueter and Tyminski, Michel and Steiner
	Terrebonne/Timbalier Bay System, LA (low numbers and no GIS data available)	summer primary nursery	29-32	no data	26-28.6	no data	Neer et al
	All major bay systems along the Gulf coast of Texas from Galveston Bay to Lower Laguna Madre, except Upper Laguna Madre	summer primary nursery (April-July and Oct)	22.5-33.2	no data	9.9-39	no data	Jones and Grace
Juvenile	North Edisto Estuary, SC (N=2)	summer secondary nursery	no data	no data	no data	no data	Ulrich and Riley
	St Andrews Sound, GA (N=2)	summer secondary nursery	27.6	4.7	32.9	13	Belcher and Shierling
	Coastal and estuarine waters of Tampa Bay, the 10,000 Islands Estuary and the Florida Keys	summer secondary nursery, year round in FL Keys	19.1-33	2.5-7.3	18.4-38.5	0.6-3.3	Hueter and Tyminski, Michel and Steiner
	Northeast Gulf of Mexico (Apalachicola Bay and St. Joseph Bay	summer secondary nursery	27.2-34	2-8.1	26-39	0.7-6.3	Carlson
	Terrebonne/Timbalier Bay System, LA (low numbers)	summer secondary nursery	29-32	no data	26-28.6	no data	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre, except Upper Laguna Madre	summer secondary nursery	no data	no data	no data	no data	Jones and Grace

Table 11. Nurse shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Charlotte Harbor, FL and the Florida Keys	primary nursery	31.7	7.01	33.9	2.1	Hueter and Tyminski
Juvenile	Tampa Bay, Charlotte Harbor, 10,000 Islands Estuary and the Florida Keys	secondary nursery (April-Nov)	17.5-32.9	3.1-9.7	28-38.5	0.6-2.9	Hueter and Tyminski, Michel and Steiner
	Dry Tortugas, FL	summer secondary nursery	no data	no data	no data	no data	Pratt and Carrier
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, and Crooked Island Sound)	summer secondary nursery	22.6-28.1	5-8.3	27-37	3.5-6	Carlson

Table 12. Sandbar shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Great Bay, NJ	summer primary nursery (pupping early July)	23.8	7.01	26.5	2.4	Merson and Pratt
	Delaware Bay (DE & NJ waters)	summer primary nursery (June-Oct with majority of pupping from late June to early July)	18-29.9	no data	18.3-30.4	0.9-16.6	McCandless et al
	Lower Chesapeake Bay, VA and the tidal creeks and lagoons along Virginia's Eastern Shore	summer primary nursery	17-28	no data	no data	no data	Grubbs and Musick
	In coastal waters from Cape Hatteras to Bogue Banks, off Holden Beach and in Pamlico Sound, NC	summer primary nursery (May-July); overwintering grounds off Cape Hatteras, NC (catches increase greatly in Oct and Nov)	no data	no data	no data	no data	Jensen et al, SEAMAP
	SC estuarine and nearshore coastal waters	summer primary nursery (May-Sept), with coastal waters also serving as overwintering grounds	no data	no data	no data	no data	Ulrich and Riley
	GA estuarine waters	summer primary nursery (June-Sept)	26.9-30.1	4-5.9	29.6-30.1	3.7-13.1	Belcher and Shierling
	Off Yankeetown, FL (N=3)	summer primary nursery	25-29	no data	20.4-25.4	2.4-3.7	Hueter and Tyminski
	Northeast Gulf of Mexico (Apalachicola Bay and Crooked Island Sound)	summer primary nursery	26.6-30.8	5-7.3	19-39	3-5.2	Carlson
Juvenile	Cape Poge Bay, MA, around Chappaquiddick Island, MA (East and South Beaches), and off the south shore of Cape Cod, MA	summer secondary nursery (June -Oct)	20-24	no data	no data	2.4-6.4	Skomal
	Delaware Bay (DE & NJ waters)	summer secondary nursery (May-Oct)	15.5-30	no data	18.3-31.4	0.8-23	McCandless et al
	Lower Chesapeake Bay, VA and the tidal creeks and lagoons along Virginia's Eastern Shore	summer secondary nursery (May-Oct)	17-28	no data	no data	no data	Grubbs and Musick
	Coastal NC waters	summer secondary nursery; overwintering grounds off Cape Hatteras, NC	22.6-28.1	no data	no data	no data	Jensen et al, SEAMAP
	SC estuarine and coastal waters	summer secondary (April - Sept) and overwintering grounds (Dec)	15-28	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine waters	summer secondary nursery (June-Sept)	26.9-30.1	4-5.9	29.6-30.1	3.7-13.1	Belcher and Shierling
	Northeast Gulf of Mexico (Apalachicola Bay and Crooked Island Sound)	summer secondary nursery	19.8-30.8	5-7.3	19-36	2.1-5.2	Carlson
	North central Gulf of Mexico (just north of Cat and Horn Islands, MS) (N=4)	summer secondary nursery	23.3-24.4	8-8.3	13.4-14.8	2.1	Parsons
	Upper Texas coast, LA coast, and Bulls Bay, SC	spring/summer secondary nursery	no data	no data	no data	no data	Hueter and Tyminski

Table 13. Sand tiger shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	South of Cape Cod, MA, in coastal waters off East Beach, Chappaquiddick Island, MA, and bays north of Cape Cod from Quincy to Salem, MA (N=5)	summer primary nursery	no data	no data	no data	no data	Skomal
	Occasional pupping in Virginia estuaries, primarily transient in Virginia coastal waters (low numbers)	summer primary nursery	no data	no data	no data	no data	Grubbs and Musick
	YOY present in the vicinity of Cape Hatteras, NC	Oct/Nov	19.1-20.2	no data	no data	11.3-13.7	Jensen et al, SEAMAP
Juvenile	Cape Poge Bay, MA, around Chappaquiddick Island, MA (East and South Beaches), and off the south shore of Cape Cod, MA (N=4)	summer secondary nursery	no data	no data	no data	no data	Skomal
	Delaware Bay (DE & NJ waters)	summer secondary nursery	19-25	no data	23.1-29.8	2.8-7.0	McCandless et al
	Chesapeake and Magothy Bays, primarily transient in Virginia coastal waters (low numbers)	summer secondary nursery	no data	no data	no data	no data	Grubbs and Musick
	Broad coastal region of North Carolina from Cape Hatteras to Holden Beach, particularly between Cape Hatteras and Cape Lookout	summer secondary nursery	19.1-27.2	no data	no data	8.2-14.6	Jensen et al, SEAMAP
	SC estuarine and coastal waters (N=1)	summer secondary nursery	no data	no data	no data	no data	SEAMAP

Table 14. Scalloped hammerhead shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Occasionally, females pup along the coast of Virginia and offspring move into adjacent estuaries	summer primary nursery	no data	no data	no data	no data	Grubbs and Musick
	Cape Hatteras to Holden Beach with the majority found below Cape Fear, NC	summer primary nursery	no data	no data	no data	no data	Jensen et al, SEAMAP
	SC estuarine and coastal waters	summer primary nursery	17-19	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine and coastal waters	summer primary nursery	no data	no data	no data	no data	Belcher and Shierling, SEAMAP
	In the bays and nearshore areas of Yankeetown, Tampa Bay, and Charlotte Harbor on the west coast of FL and from the northern tip to Cape Canaveral, FL on the east coast	summer primary nursery	23.2-30.2	5.09-5.92	27.6-36	0.9-6.1	Hueter and Tyminski, SEAMAP
	10,000 Islands Estuary, FL (N=1)	summer primary nursery (July)	no data	no data	no data	no data	Michel and Steiner
	Northeast Gulf of Mexico (Apalachicola Bay, Crooked Island Sound and St Andrew Bay)	summer primary nursery	25.5-31.2	4.6-6.2	25-39	2.3-7	Carlson
	Mississippi Sound, MS and AL in the north central Gulf of Mexico, especially around Dauphin Island	summer primary nursery	B 29.1 S 29.2	B 5.6 S 7.1	B 19.9 S 18.9	3.4	Parsons (env. parameters are average values
	Terrebonne/Timbalier Bay System, LA (N=4)	summer primary nursery	28.4-32.4	29.5-34.3	no data	1.5-2.4	Neer et al
	All major bay systems along the Gulf coast of Texas from Sabine Lake to Lower Laguna Madre, except Upper Laguna Madre and off the beaches of the lower coast of Texas (April-Sept)	summer primary nursery	no data	no data	no data	no data	Jones and Grace, Hueter and Tyminski
Juvenile	Coastal NC waters from Oregon Inlet to Holden Beach, NC	summer secondary nursery	19-30	no data	no data	3.1-13.5	Jensen et al, SEAMAP
	SC coastal waters	summer secondary nursery (April-Nov)	17-19	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine waters (N=2)	summer secondary nursery	no data	no data	no data	no data	Belcher and Shierling
	On the east coast of FL from the northern tip to Cape Canaveral, FL, and occasionally in the Tampa Bay, FL area	summer secondary nursery	no data	no data	no data	no data	Hueter and Tyminski, SEAMAP
	10,000 Islands Estuary, FL (N=1)	summer secondary nursery (July)	30.6	6.23	37.3	no data	Michel and Steiner
	Northeast Gulf of Mexico (Apalachee Bay, Apalachicola Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	20.4-31.4	4.5-6	25-39	2.3-6	Carlson
	Mississippi Sound, MS and AL in the north central Gulf of Mexico	summer secondary nursery	B 29.3 S 30	B 6 S 6.1	B 18.8 S 17.6	2.9	Parsons (env. parameters are average values
	Terrebonne/Timbalier Bay System, LA	summer secondary nursery (July)	30.1	20.1	no data	1.2	Neer et al

Table 15. Silky shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	no data	no data	no data	no data	no data	no data	
Juvenile	Offshore waters of the Florida and Texas Gulf coasts	summer secondary nursery; FL – Aug and TX – April and May	no data	no data	no data	no data	Hueter and Tyminski

Table 16. Smalleye hammerhead shark

Life Stage	**Location**	**Season**	**Temp (°C)**	**DO (mg/l)**	**Salinity (ppt)**	**Depth (m)**	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	no data	no data	no data	no data	no data	no data	
Juvenile	Corpus Christie Bay, Texas (N=3)	secondary nursery (Sept)	no data	no data	no data	no data	Jones and Grace

Table 17. Smalltail shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Matagorda and Corpus Christie Bays, Texas	primary summer nursery (June-Aug)	no data	no data	no data	no data	Jones and Grace
	Corpus Christie Bay, Texas	overwintering grounds (Nov, Feb, and March)	no data	no data	no data	no data	Jones and Grace
Juvenile	no data	no data	no data	no data	no data	no data	

Table 18. Smooth dogfish

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Buzzards Bay, MA, Nantucket Sound, MA, Vineyard Sound, MA, and their associated bays and estuaries	summer pupping grounds (late May - early June), remain in primary nursery until October	no data	no data	no data	no data	Skomal
	Delaware Bay (DE & NJ waters)	summer primary nursery ground	no data	no data	no data	no data	McCandless et al
	Lower Chesapeake Bay, VA and the tidal creeks and lagoons along Virginia's Eastern Shore	summer primary nursery ground	no data	no data	no data	no data	Grubbs and Musick
	NC coastal waters from Oregon Inlet to Holden Beach	primary nursery ground, April – July and October - November	no data	no data	no data	no data	Jensen et al, SEAMAP
Juvenile	Delaware Bay (DE & NJ waters)	summer secondary nursery grounds	no data	no data	no data	no data	McCandless et al
	Lower Chesapeake Bay, VA and the tidal creeks and lagoons along Virginia's Eastern Shore	summer secondary nursery grounds	no data	no data	no data	no data	Grubbs and Musick
	NC coastal waters from Cape Hatteras to Holden Beach	secondary nursery ground, April – June and October – November	16.5-28.3	no data	no data	1.9-17.7	Jensen et al, SEAMAP
	SC estuarine and coastal waters	secondary nursery (April and May)	no data	no data	no data	no data	Ulrich and Riley, SEAMAP

Table 19. Smooth hammerhead shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Off Broadkill Beach, DE in Delaware Bay (N=2), neonates with umbilical remains still attached	summer primary nursery	25.5	no data	30.3	3.6	McCandless et al
Juvenile	Coastal waters off Cape Hatteras and Holden Beach, NC	summer secondary nursery	17.8-20.2	no data	no data	5.1-15.5	Jensen et al

Table 20. Spinner shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	Source (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Off Cape Hatteras and Holden Beach, NC	May-September primary nursery, (pupping from May to July)	no data	no data	no data	no data	Jensen et al
	SC estuarine and nearshore coastal waters	summer primary nursery	no data	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA coastal waters	summer primary nursery	no data	no data	no data		SEAMAP
	In the coastal areas of Yankeetown, Tampa Bay, Charlotte Harbor and Cape Canaveral, FL	summer primary nursery (May-Oct)	24.7-31.7	4.6-7.07	21-37	0.6-38.4	Hueter and Tyminski
	Northeast Gulf of Mexico (Apalachicola Bay and Crooked Island Sound)	summer primary nursery	22.5-30.5	5.4-6	25-35	2.7-5	Carlson
	North central Gulf of Mexico from Perdido Bay, AL to St. Louis Bay, MS	summer primary nursery	B 27.5-28.5 S 29.4-31.5	B 0.3-7 S 5.7-7.4	B 27-36.3 S 23.5-26.6	6-7	Parsons, Gurshin
	Terrebonne/Timbalier Bay System, LA	summer primary nursery (July-Sept)	28.2-30.3	24-29	no data	4.6-5.2	Neer et al
	San Antonio and Matagorda major bay systems along the Gulf coast of Texas and TX coastal waters	summer primary nursery	no data	no data	no data	no data	Jones and Grace, Hueter and Tyminski
Juvenile	Coastal waters from Oregon Inlet to Holden Beach, NC	summer secondary nursery (May-Sept)	18.1-33	no data	no data	3.1-16.5	Jensen et al, SEAMAP
	SC estuarine and nearshore coastal waters	summer secondary nursery	no data	no data	no data	no data	Ulrich and Riley, SEAMAP
	GA estuarine (N=1) and coastal waters	summer secondary nursery	28.2	6.21	32.1	3.8	Belcher and Shierling, SEAMAP
	In the coastal areas of Tampa Bay, Charlotte Harbor and Cape Canaveral, FL and associated with nearshore oil rigs on the upper Texas coast, as well as in the coastal waters of Mississippi and Louisiana	summer secondary nursery	21.9-30.1	3-9.84	17.1-36.2	2.1-53	Hueter and Tyminski
	Northeast Gulf of Mexico (Apalachicola Bay, St. Joseph Bay, Crooked Island Sound and St Andrew Bay)	summer secondary nursery	20.9-31.2	4.9-8.3	19-38	2-6	Carlson
	North central Gulf of Mexico from Perdido Bay, AL to St. Louis Bay, MS	summer secondary nursery (Aug-Sept)	B 27.9 S 28.7	B 5.8 S 6.7	B 22.4 S 20.9	4.6	Parsons
	Galveston, San Antonio and Matagorda major bay systems along the Gulf coast of Texas	summer secondary nursery	no data	no data	no data	no data	Jones and Grace

Table 21. Spiny dogfish

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	Near Bogue Banks, NC (N=2)	May primary nursery	no data	no data	no data	no data	SEAMAP
Juvenile	Coastal waters from Oregon Inlet to Cape Fear, NC	May secondary nursery	no data	no data	no data	no data	Jensen et al, SEAMAP

Table 22. Thresher shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	YOY off Cape Hatteras and south of Ocracoke Inlet, NC	May, Oct and Nov	18.2-20.9	no data	no data	4.6-13.7	Jensen et al, SEAMAP
Juvenile	Coastal NC and SC	April, May, Oct and Nov	18.2-20.9	no data	no data	4.6-13.7	Jensen et al, SEAMAP, Ulrich and Riley

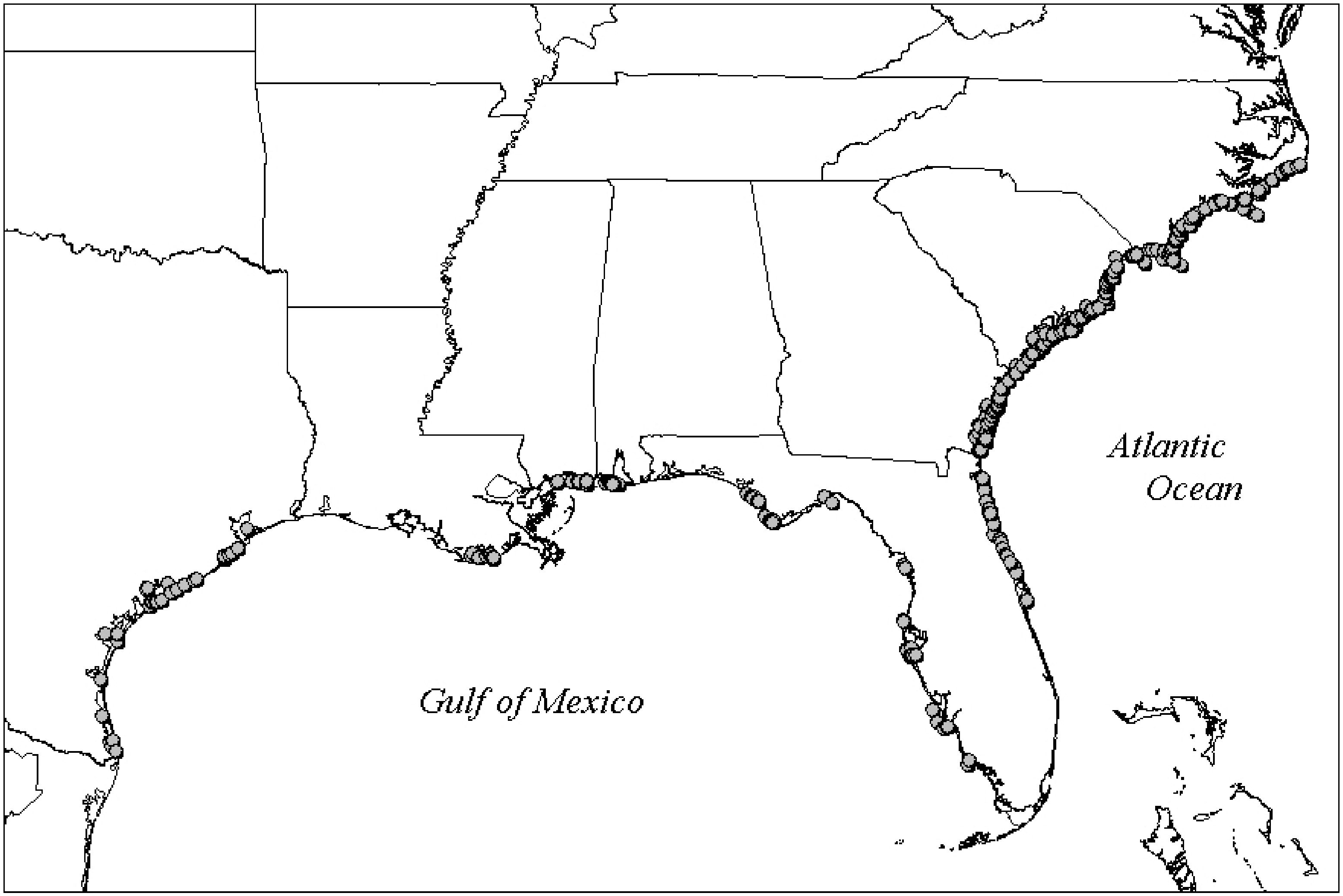
Table 23. Tiger shark

Life Stage	Location	Season	Temp (°C)	DO (mg/l)	Salinity (ppt)	Depth (m)	**Source** (from chapter text and/or data provided for this report)
			B = bottom and S = surface				
Neonate & YOY	SC nearshore coastal waters	summer primary nursery	no data	no data	no data	no data	Ulrich and Riley
	Along the LA, Mississippi, Alabama, and Florida coasts	summer primary nursery (YOY)	30.8	4.9	31.8	20.1-49.4	Hueter and Tyminski
Juvenile	NC coastal waters (no GIS data available)	summer secondary nursery	30	no data	no data	no data	Jensen et al
	SC nearshore coastal waters	summer secondary nursery & overwintering (July-Dec)	23.4-30.2	4.9-6.9	32-38.3	1.8-58.5	Ulrich and Riley
	Coastal waters off Tampa Bay and the 10,000 Islands Estuary in FL and off Mississippi	summer secondary nursery	no data	no data	no data	no data	Hueter and Tyminski. Michel and Steiner

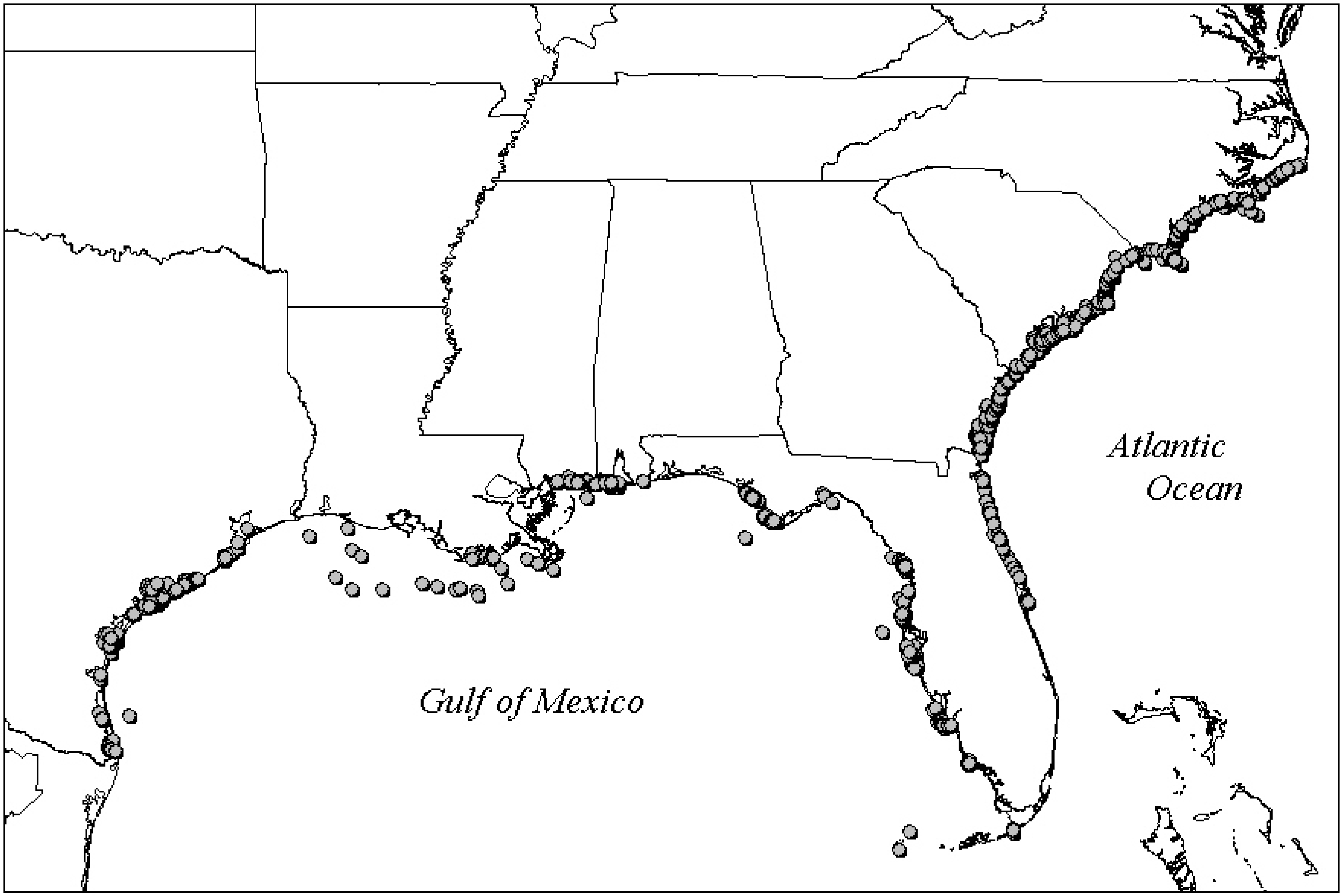
SPECIES SPECIFIC SHARK NURSERY SUMMARY MAPS

These maps display the data provided by contributing authors in addition to the databases donated by SEAMAP and the Florida Department of Environmental Protection. See Species Specific Shark Nursery Summary Tables for descriptions. For purposes of this report primary and secondary nursery areas are defined as: primary nursery habitat where neonate and/or young-of-the-year occur (based on size and umbilical scar condition when available), and secondary nursery habitat where age 1+ juveniles occur.

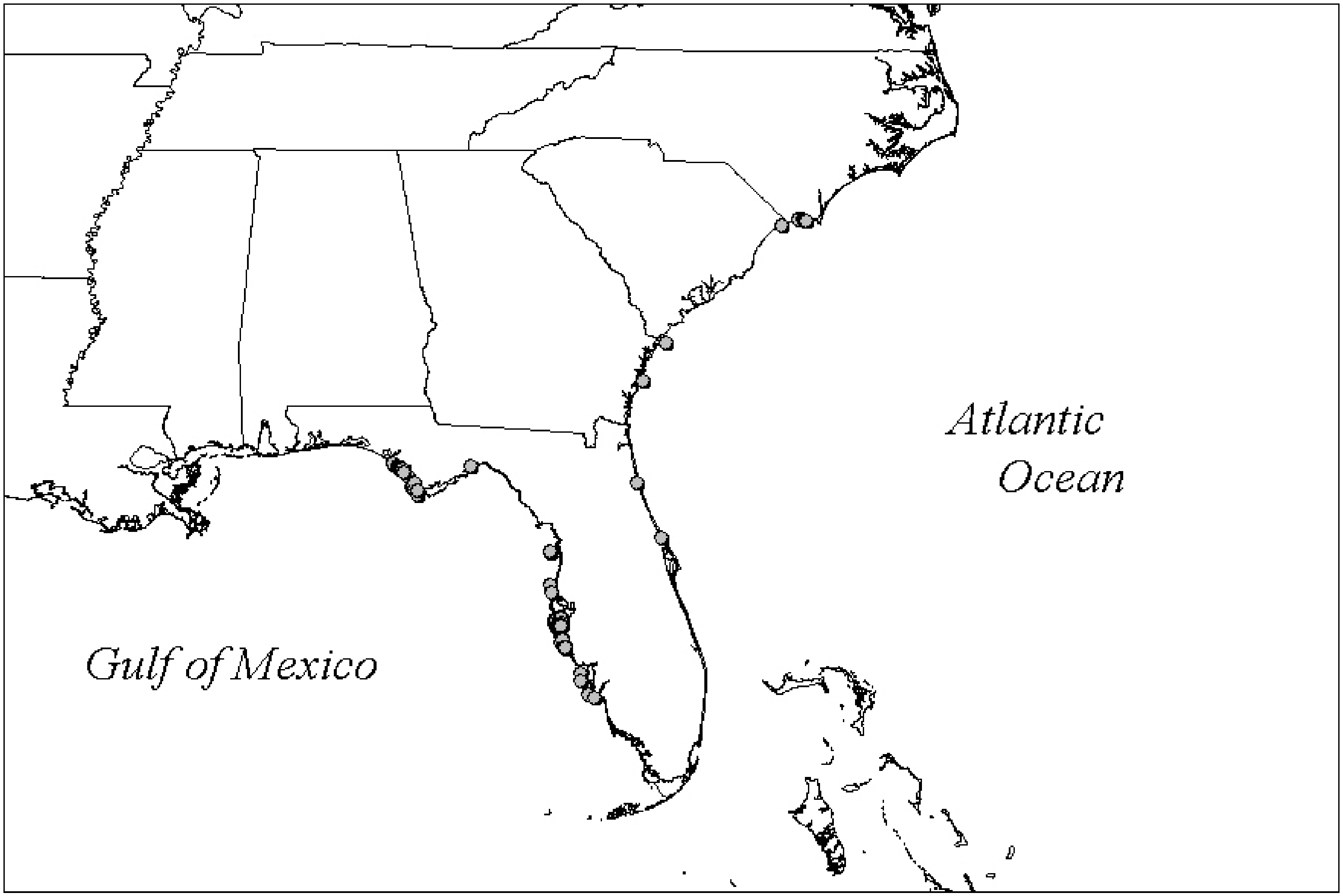
LIST OF MAPS



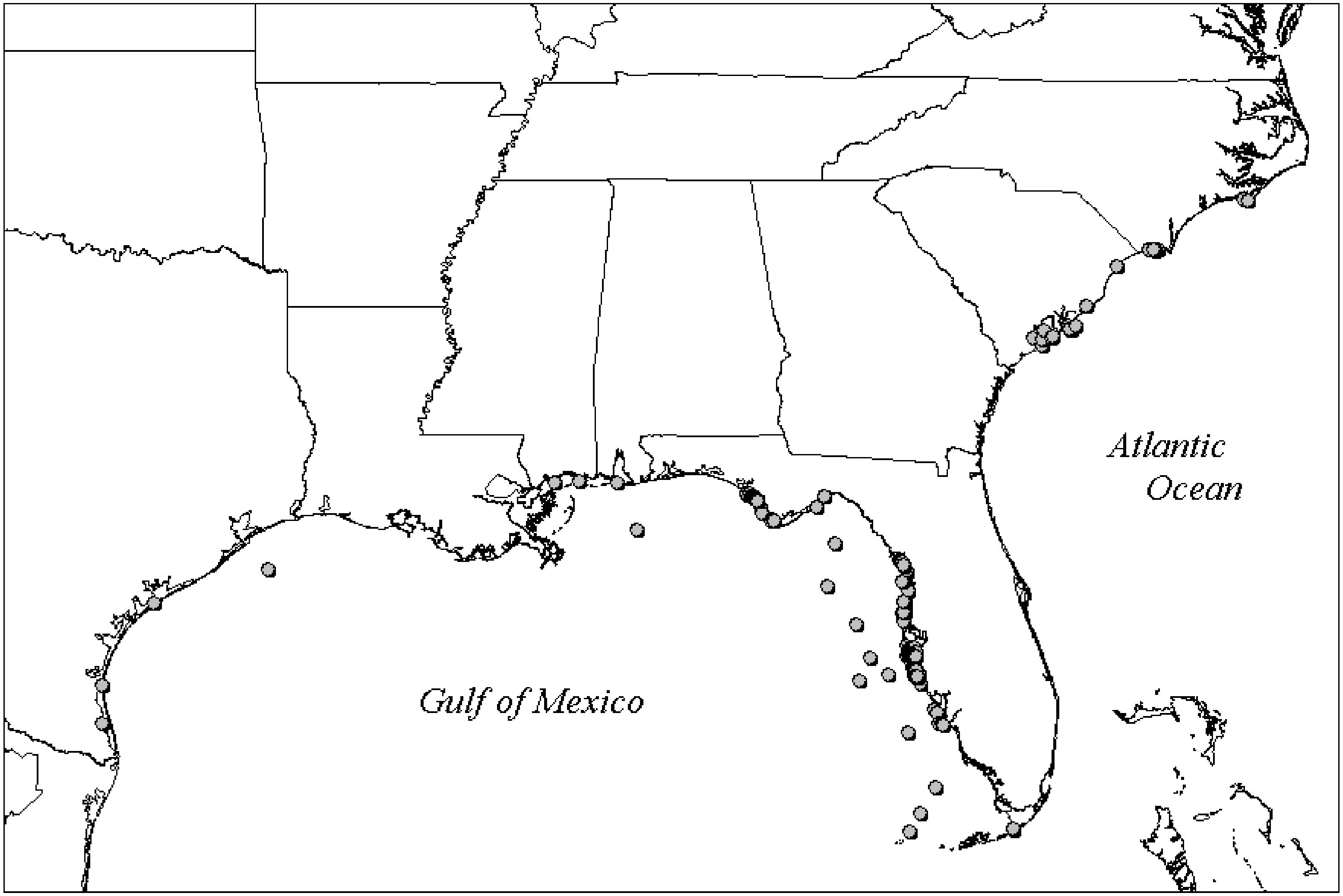
Map 1. Primary nursery areas for Atlantic sharpnose sharks indicated by shark capture locations for neonates and young-of-the-year



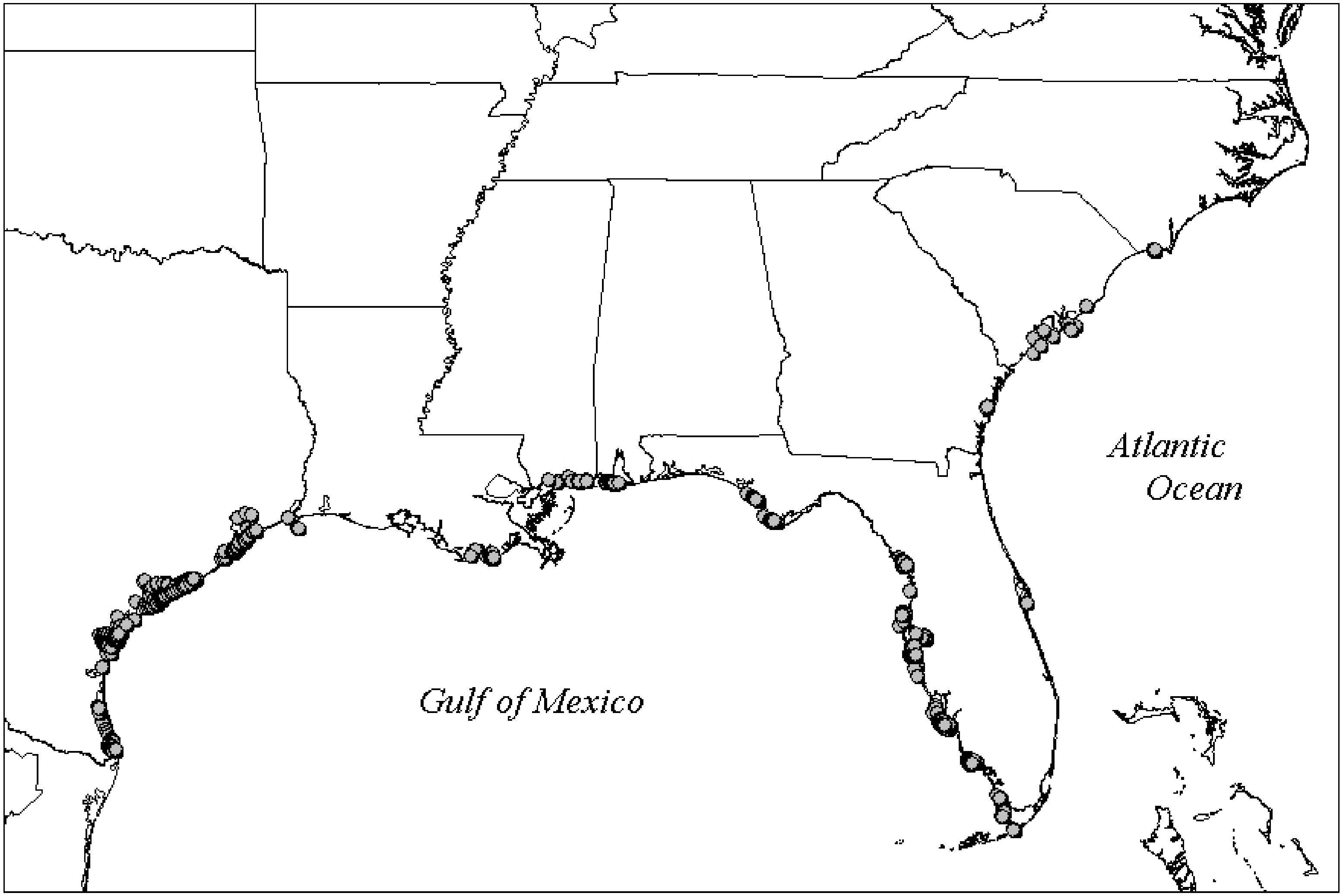
Map 2. Secondary nursery areas for Atlantic sharpnose sharks indicated by shark capture locations for juveniles (age 1+)



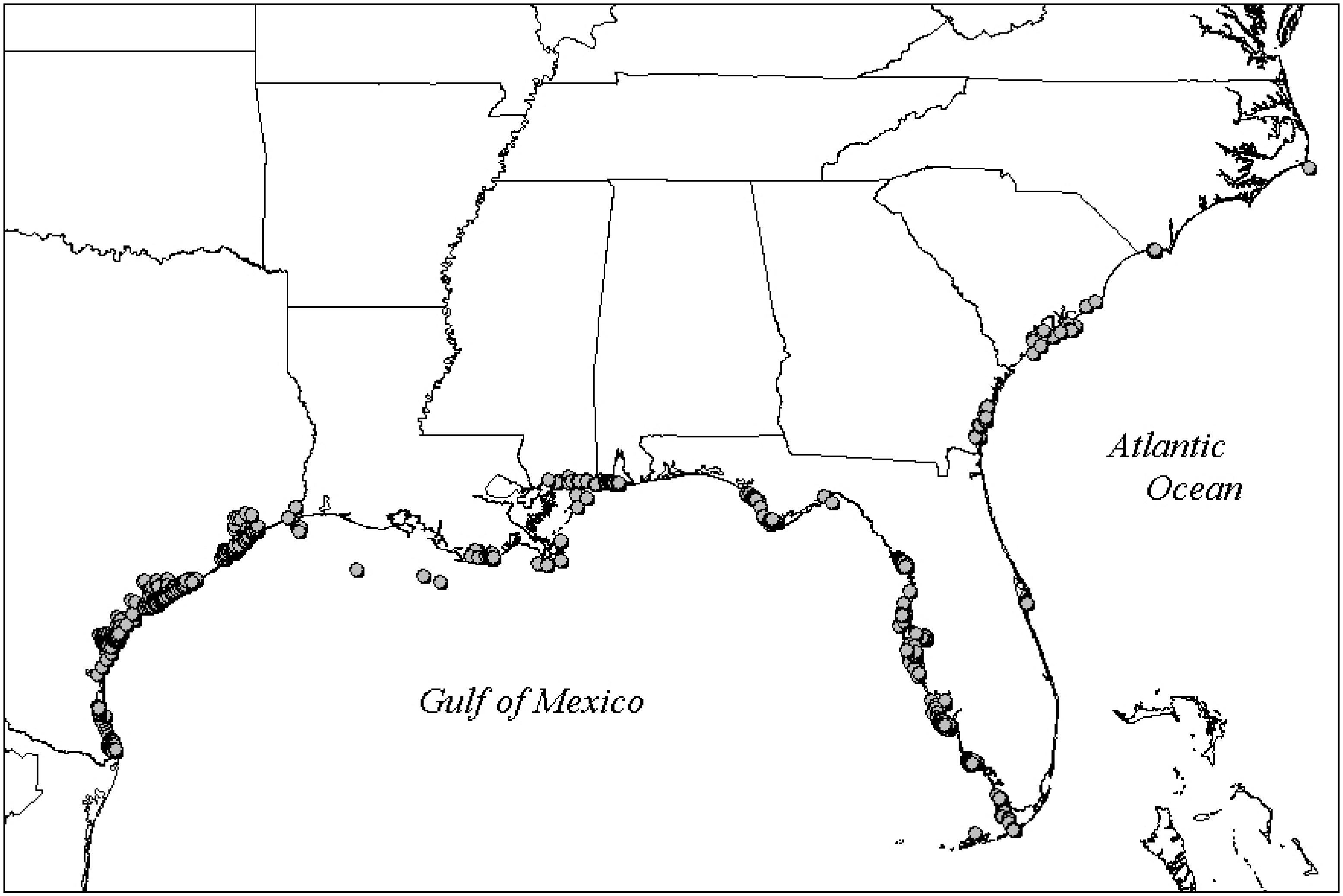
Map 3. Primary nursery areas for blacknose sharks indicated by shark capture locations for neonates and young-of-the-year



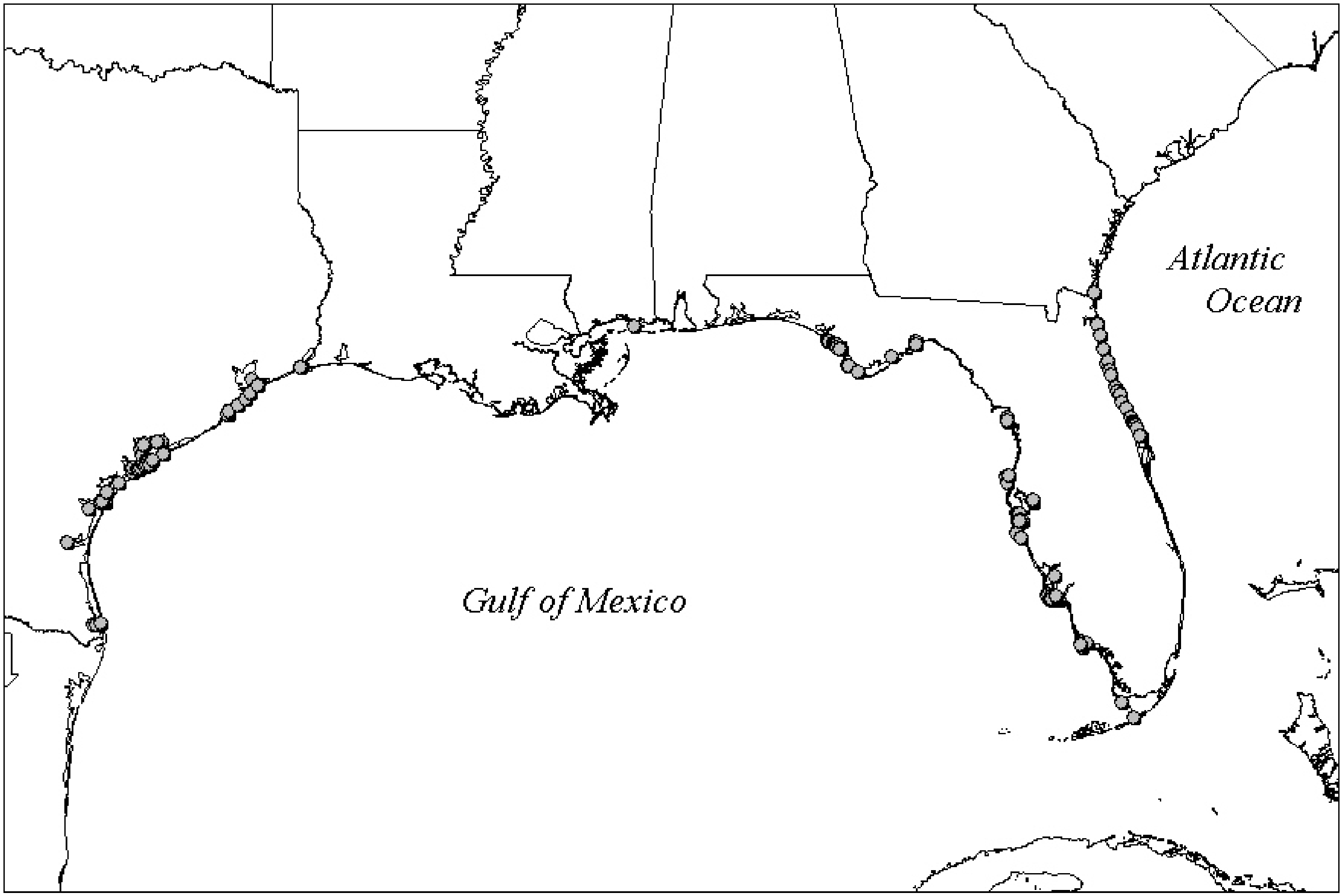
Map 4. Secondary nursery areas for blacknose sharks indicated by shark capture locations for juveniles (age 1+)



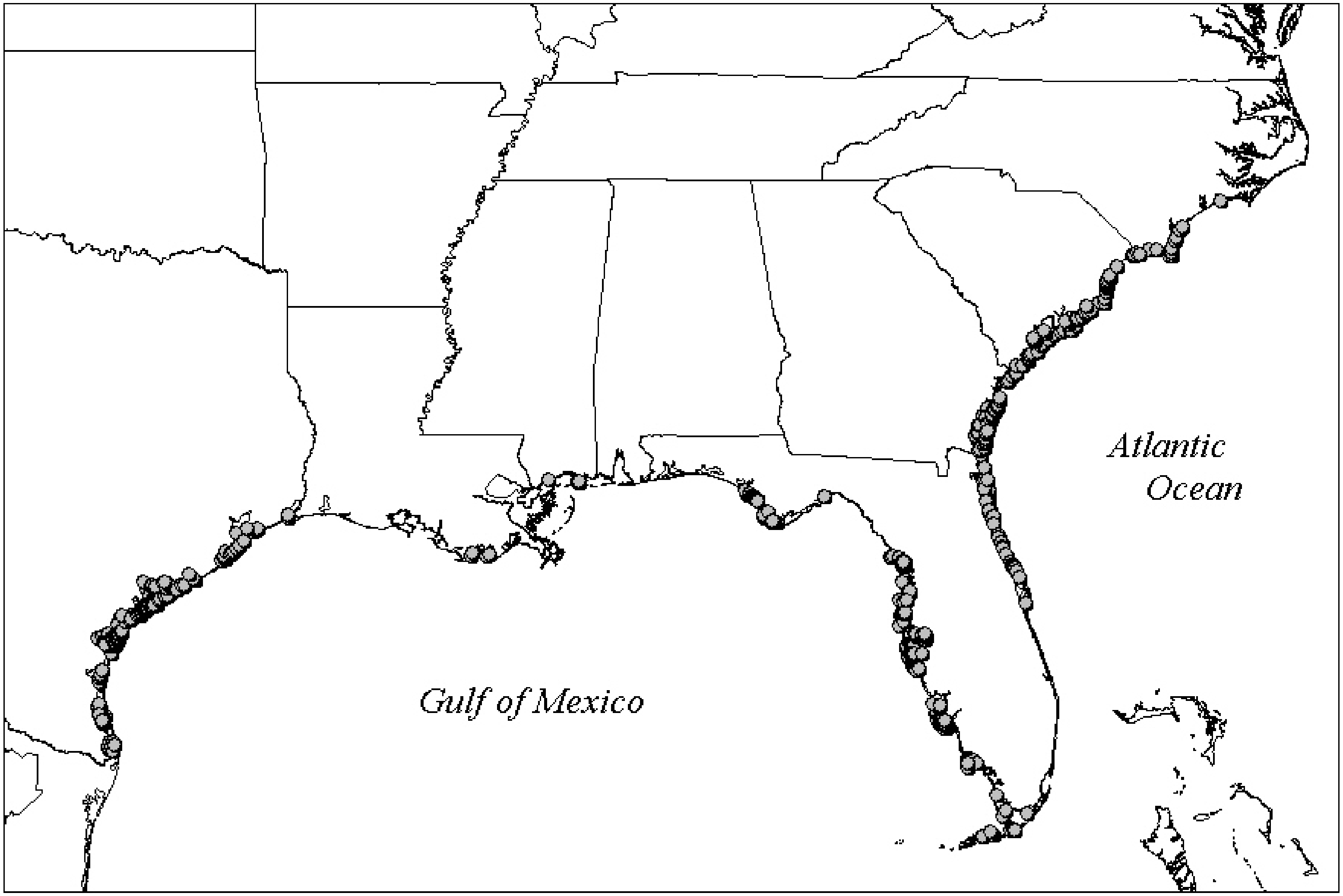
Map 5. Primary nursery areas for blacktip sharks indicated by shark capture locations for neonates and young-of-the-year



Map 6. Secondary nursery areas for blacktip sharks indicated by shark capture locations for juveniles (age 1+)

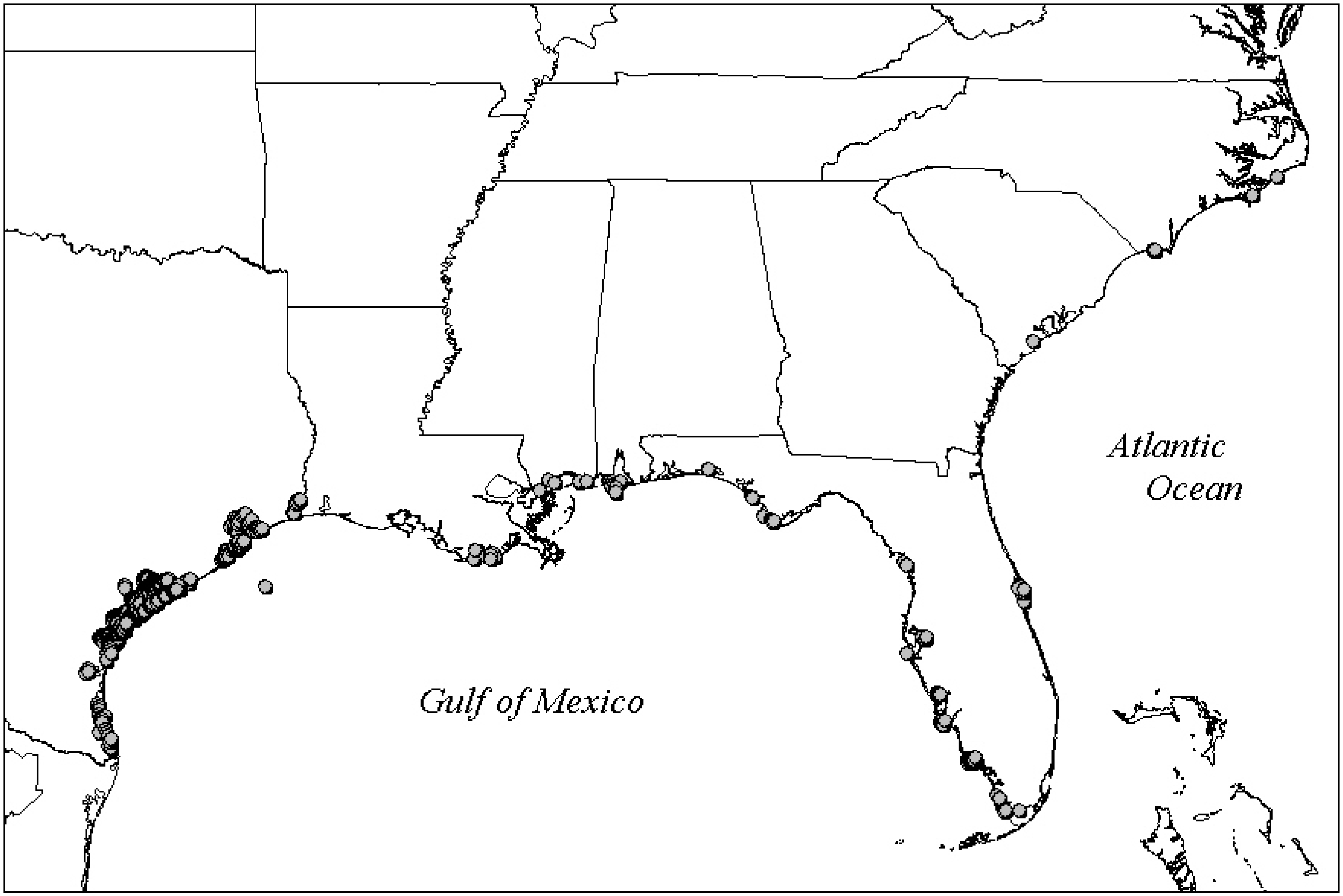


Map 7. Primary nursery areas for bonnethead sharks indicated by shark capture locations for neonates and young-of-the-year

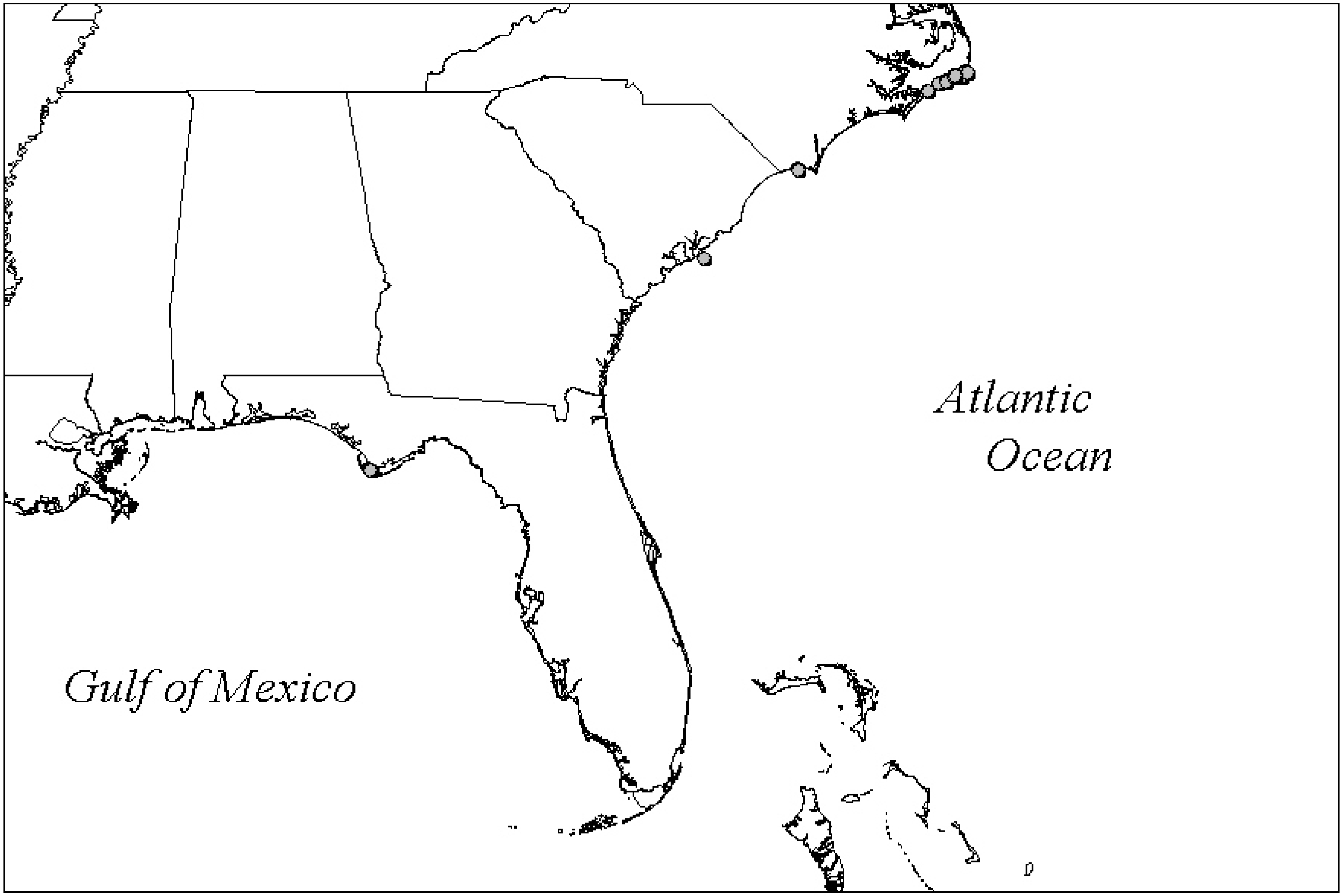


Map 8. Secondary nursery areas for bonnethead sharks indicated by shark capture locations for juveniles (age 1+)

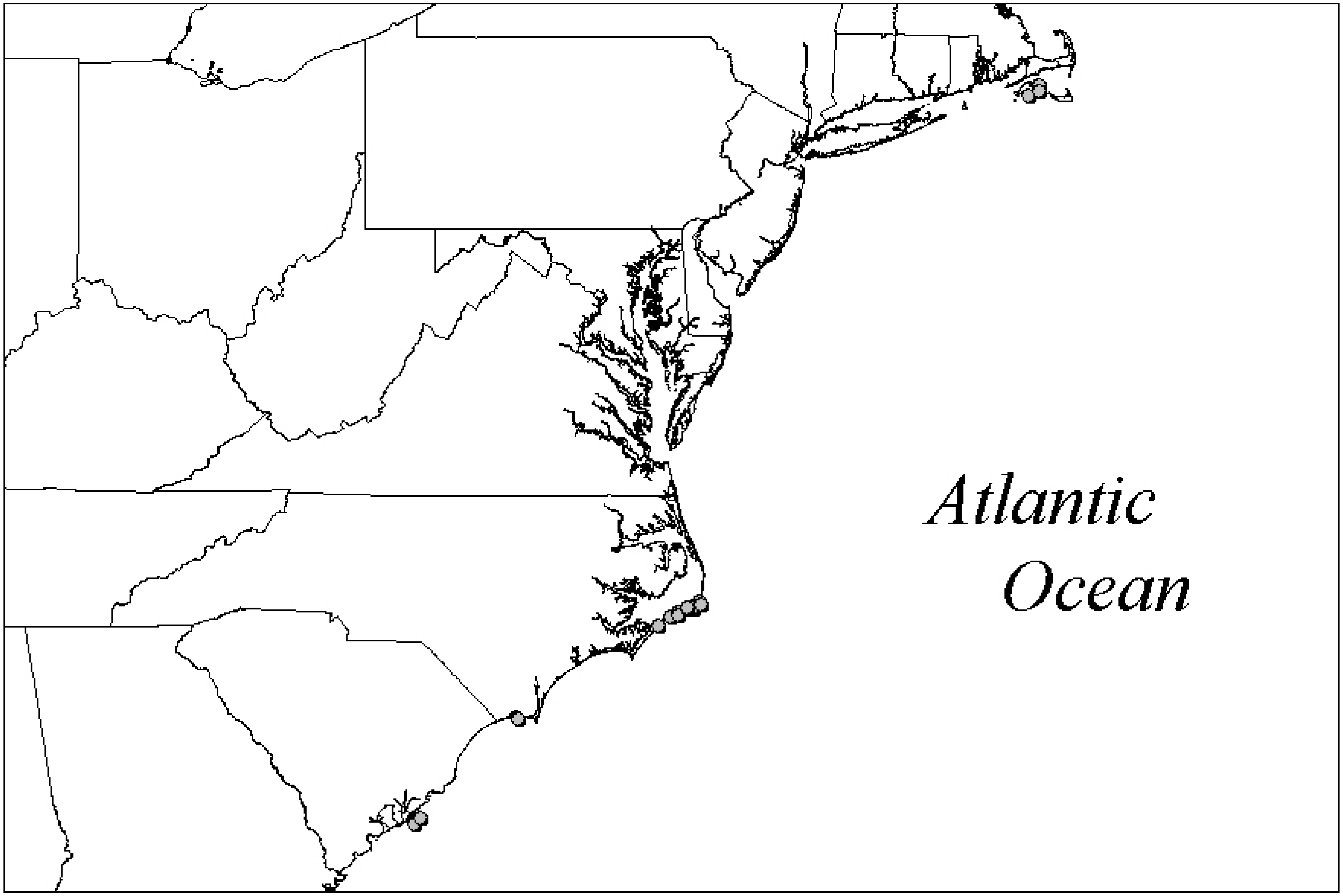
Map 9. Primary nursery areas for bull sharks indicated by shark capture locations for neonates and young-of-the-year



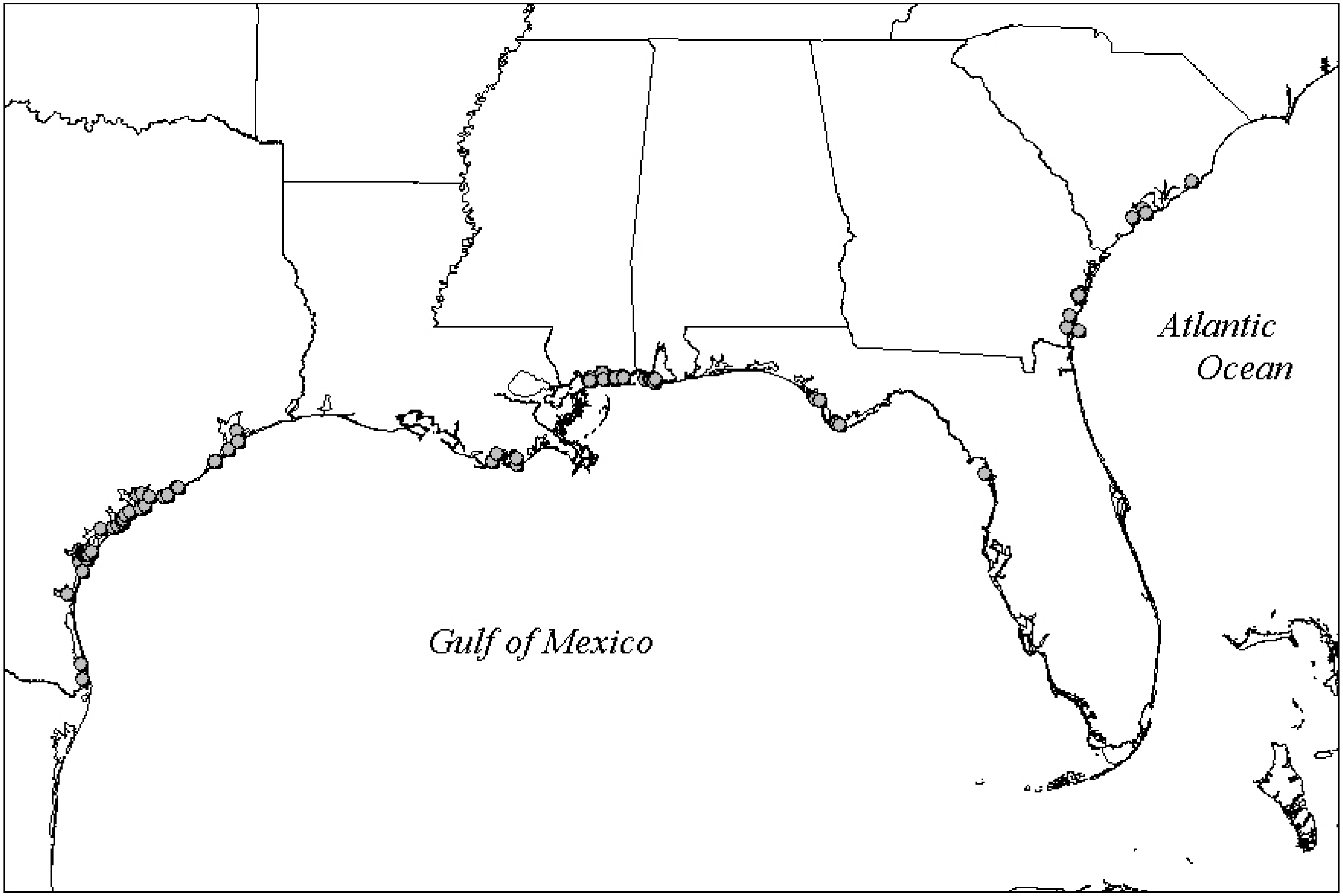
Map 10. Secondary nursery areas for bull sharks indicated by shark capture locations for juveniles (age 1+)



Map 11. Primary nursery areas for dusky sharks indicated by shark capture locations for neonates and young-of-the-year



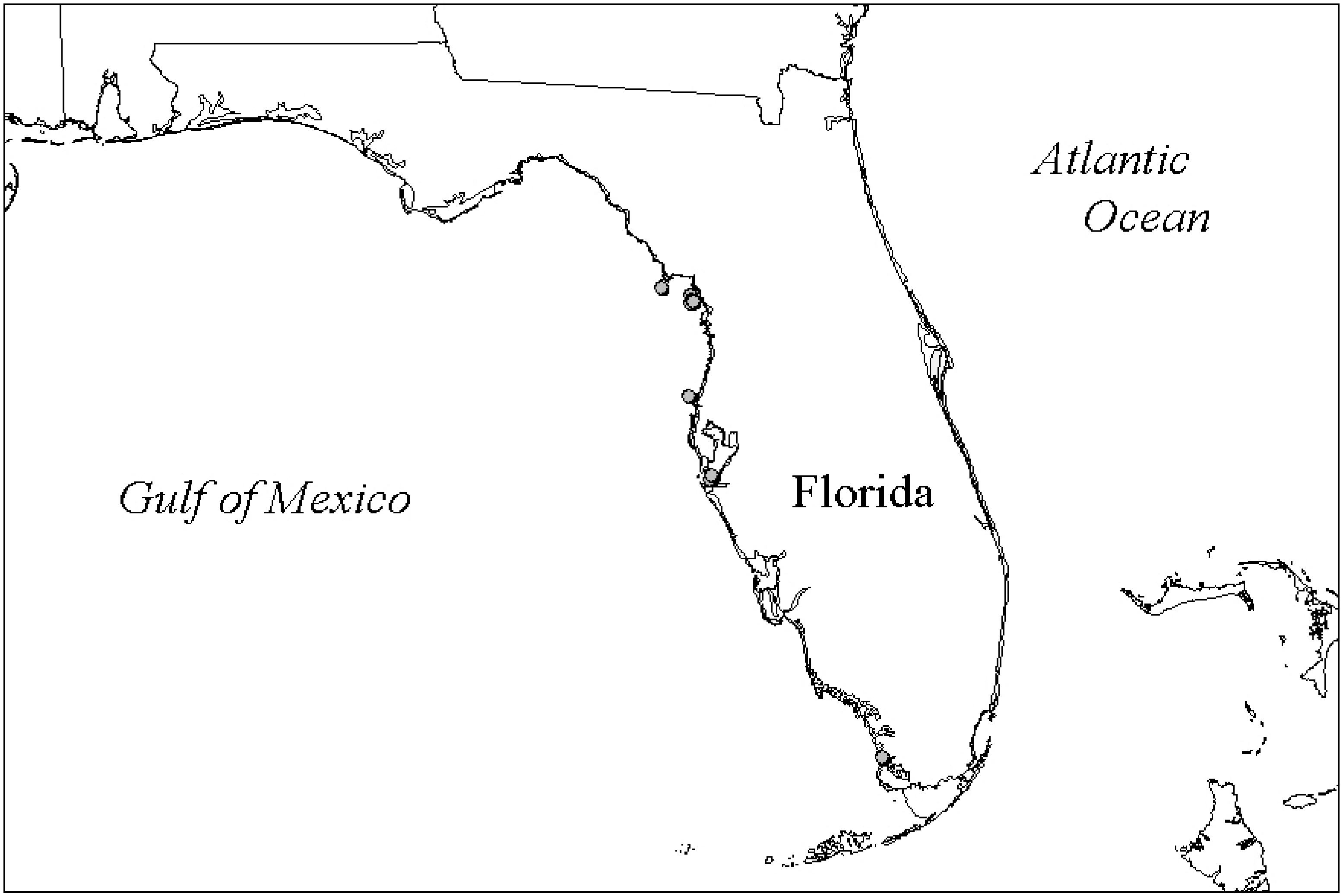
Map 12. Secondary nursery areas for dusky sharks indicated by shark capture locations for juveniles (age 1+)



Map 13. Primary nursery areas for finetooth sharks indicated by shark capture locations for neonates and young-of-the-year

Map 14. Secondary nursery areas for finetooth sharks indicated by shark capture locations for juveniles (age 1+)

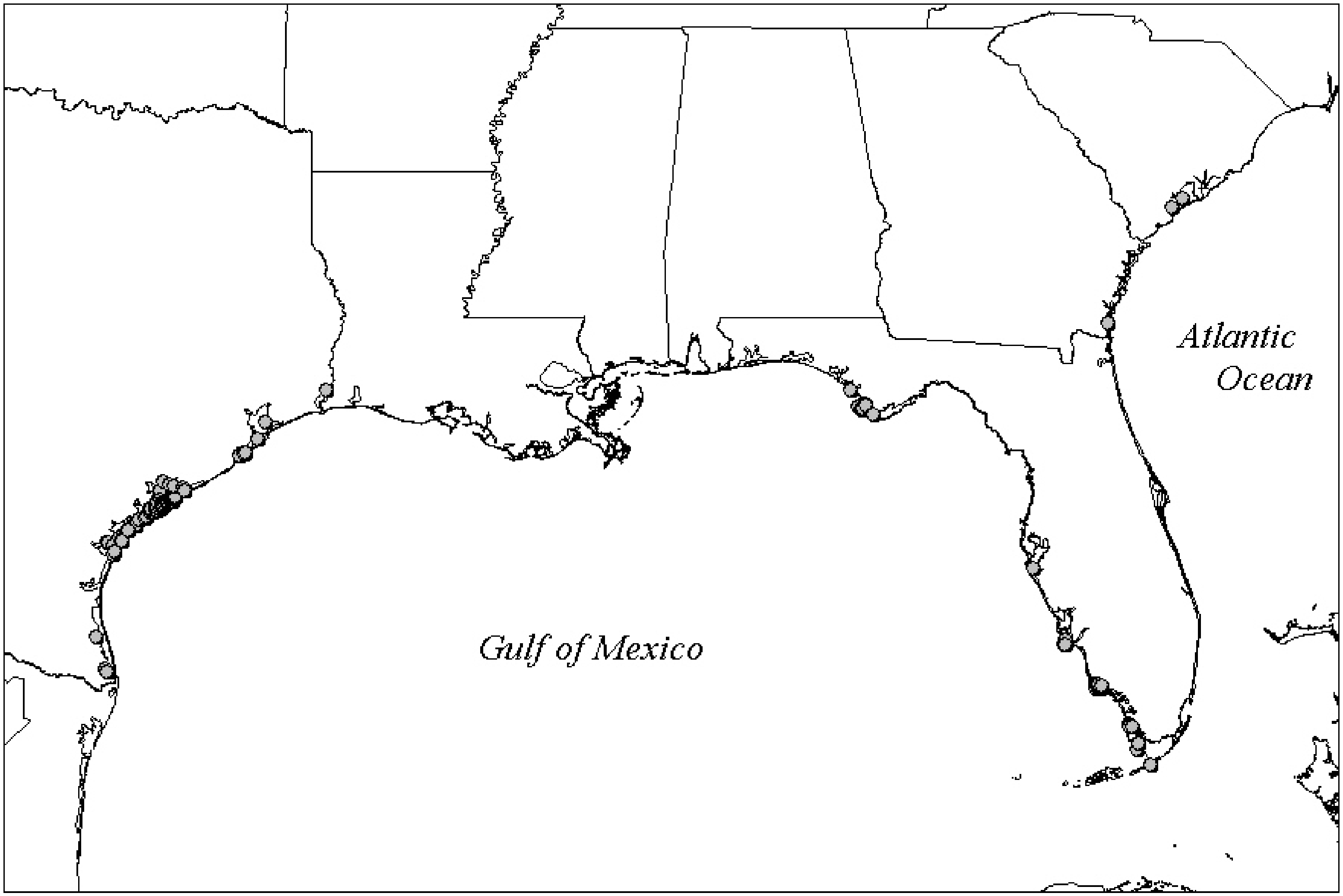
Map 15. Secondary nursery areas for Florida smoothounds indicated by shark capture locations for juveniles (age 1+)



Map 16. Primary nursery areas for great hammerhead sharks indicated by shark capture locations for neonates and young-of-the-year

Map 17. Secondary nursery areas for great hammerhead sharks indicated by shark capture locations for juveniles (age 1+)

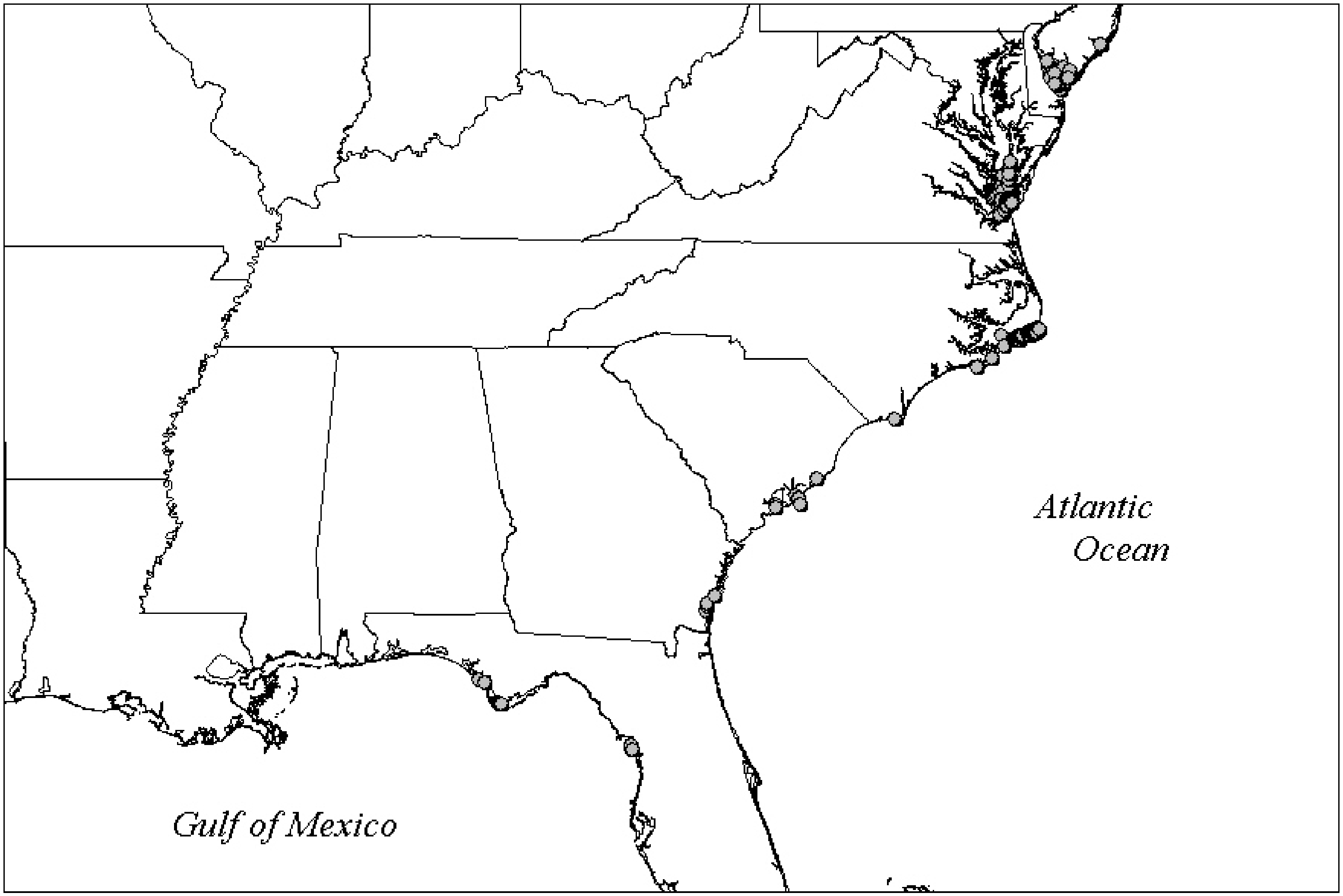
Map 18. Primary nursery areas for lemon sharks indicated by shark capture locations for neonates and young-of-the-year



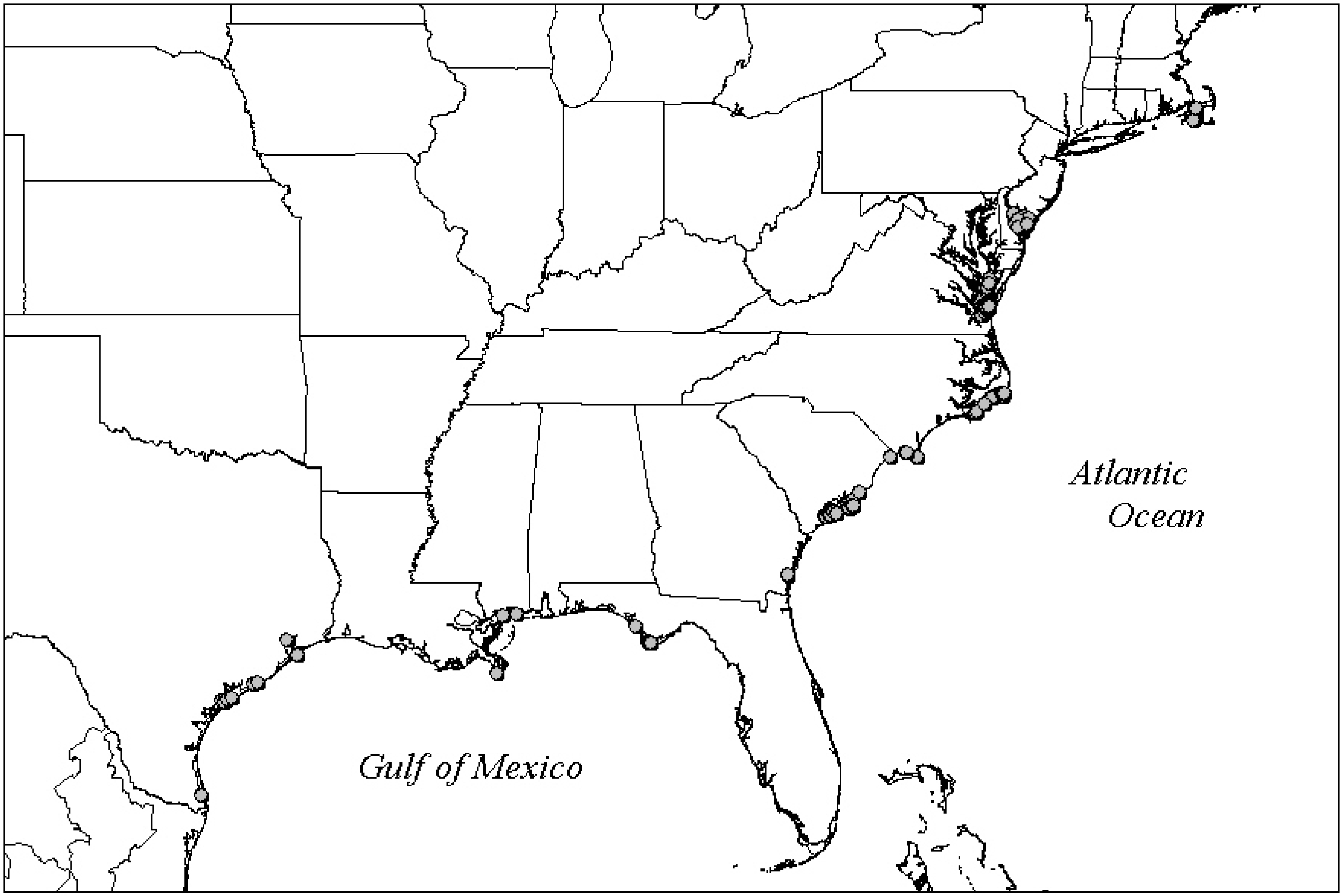
Map 19. Secondary nursery areas for lemon sharks indicated by shark capture locations for juveniles (age 1+)

Map 20. Primary nursery areas for nurse sharks indicated by shark capture locations for neonates and young-of-the-year

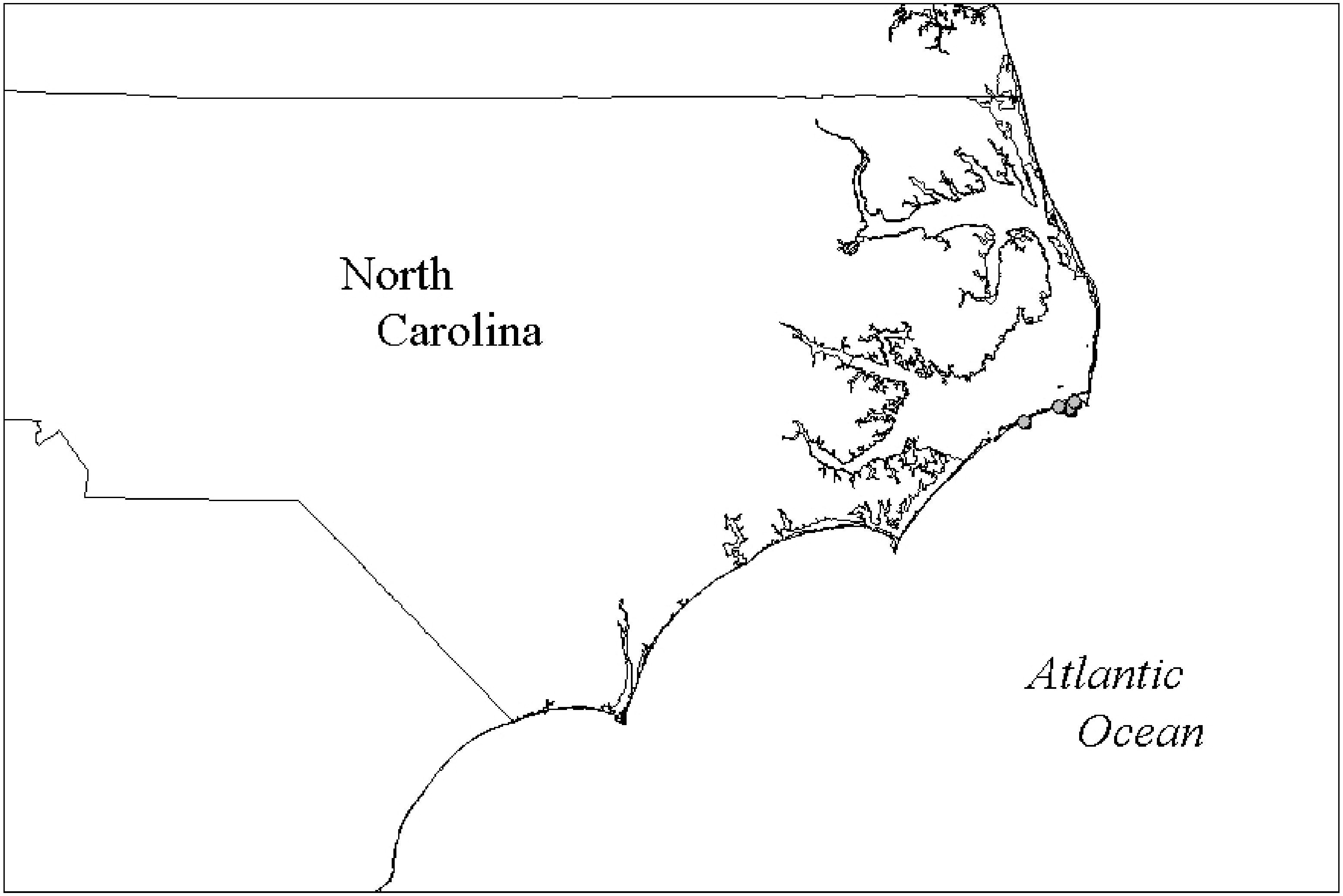
Map 21. Secondary nursery areas for nurse sharks indicated by shark capture locations for juveniles (age 1+)



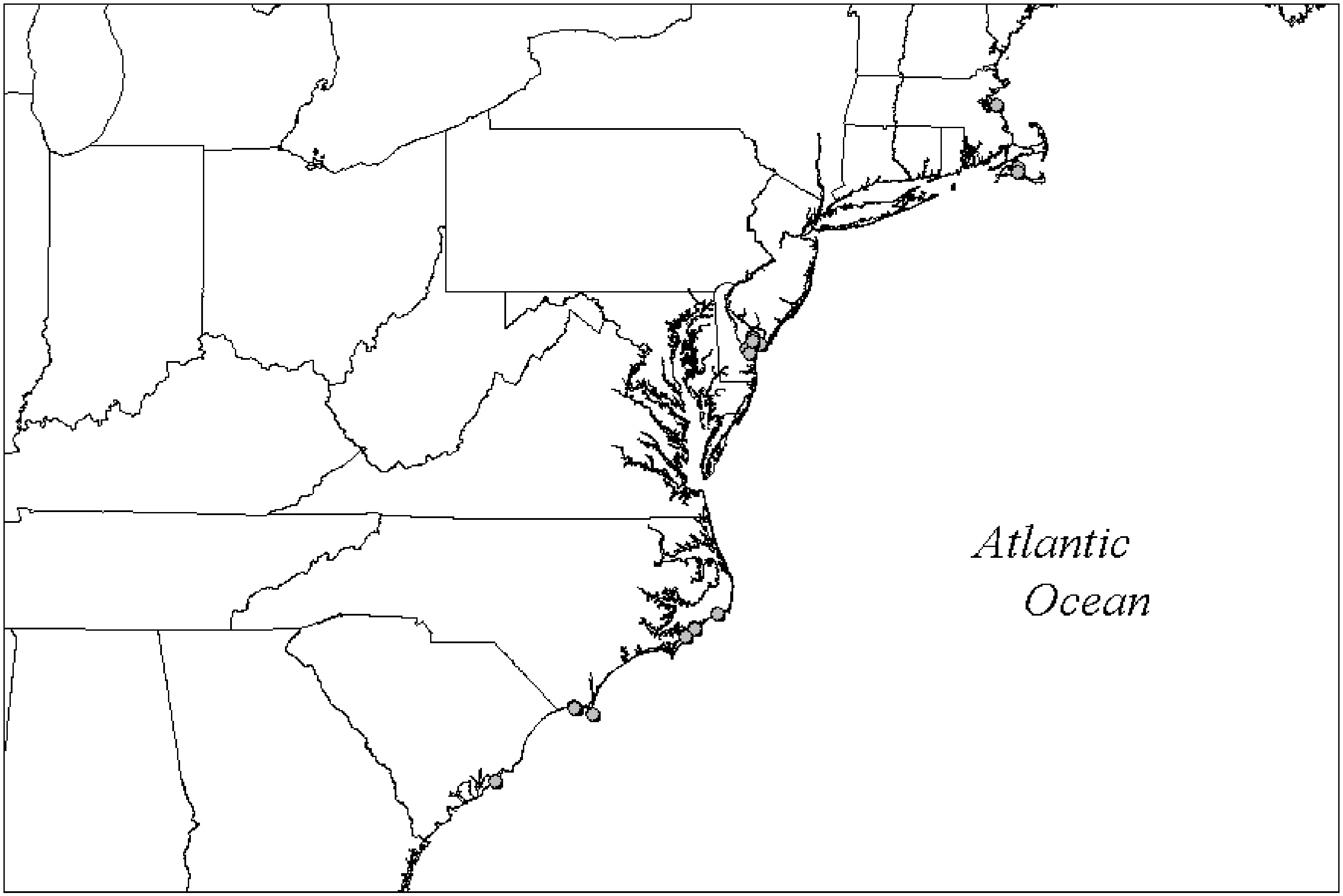
Map 22. Primary nursery areas for sandbar sharks indicated by shark capture locations for neonates and young-of-the-year



Map 23. Secondary nursery areas for sandbar sharks indicated by shark capture locations for juveniles (age 1+)



Map 24. Primary nursery areas for sand tiger sharks indicated by shark capture locations for neonates and young-of-the-year

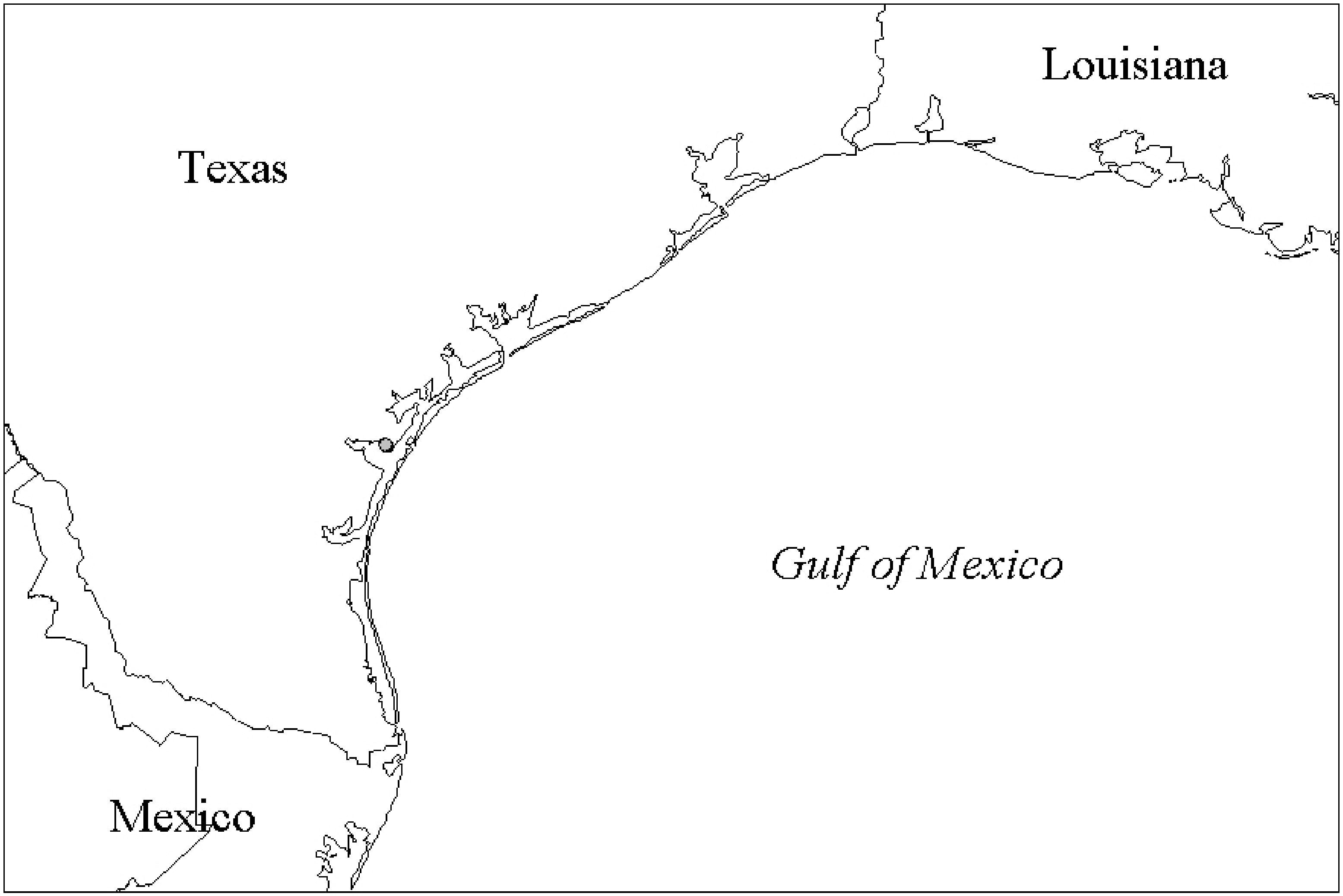


Map 25. Secondary nursery areas for sand tiger sharks indicated by shark capture locations for juveniles (age 1+)

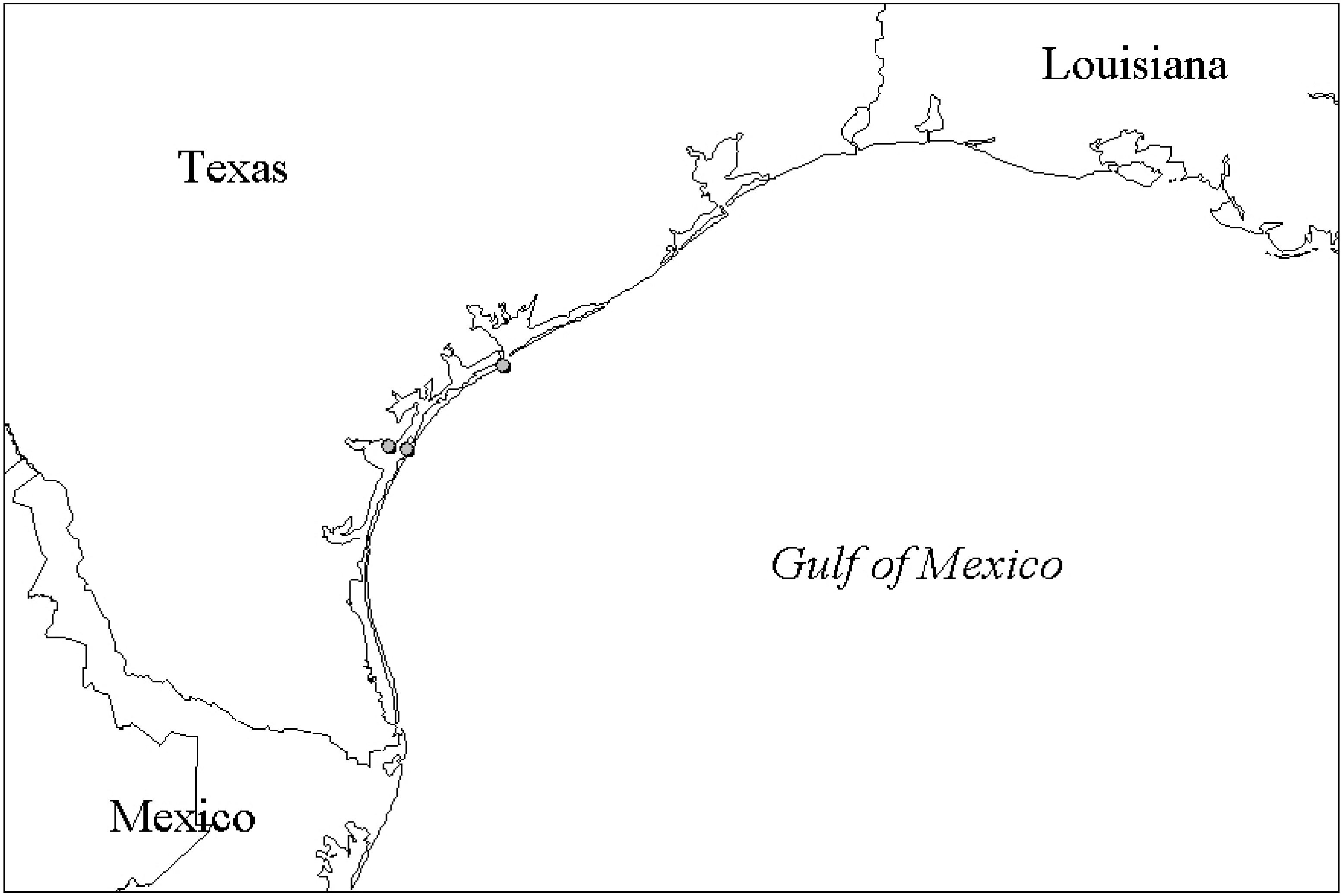
Map 26. Primary nursery areas for scalloped hammerhead sharks indicated by shark capture locations for neonates and young-of-the-year

Map 27. Secondary nursery areas for scalloped hammerhead sharks indicated by shark capture locations for juveniles (age 1+)

Map 28. Secondary nursery areas for silky sharks indicated by shark capture locations for juveniles (age 1+)

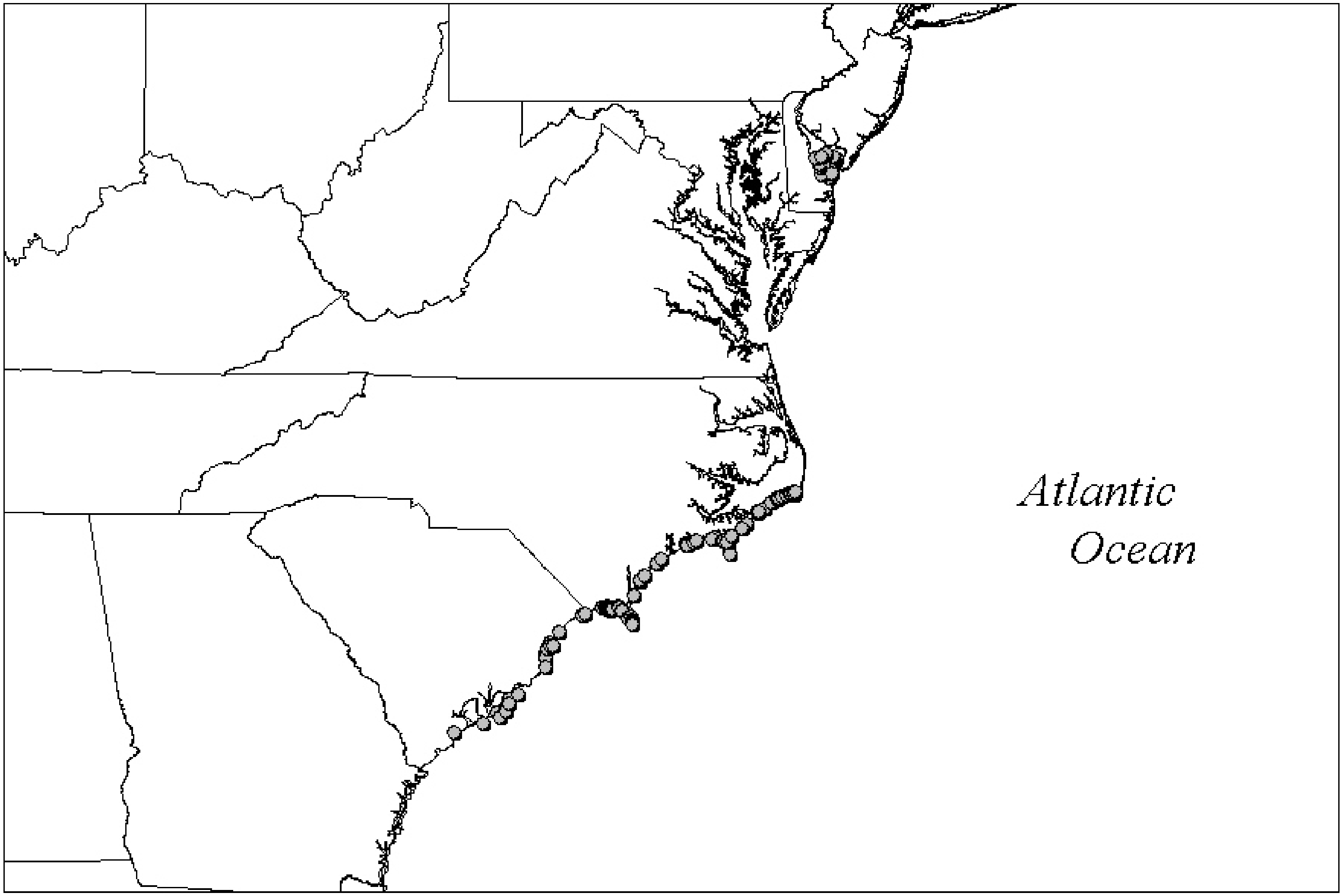


Map 29. Secondary nursery areas for smalleye hammerhead sharks indicated by shark capture locations for juveniles (age 1+)

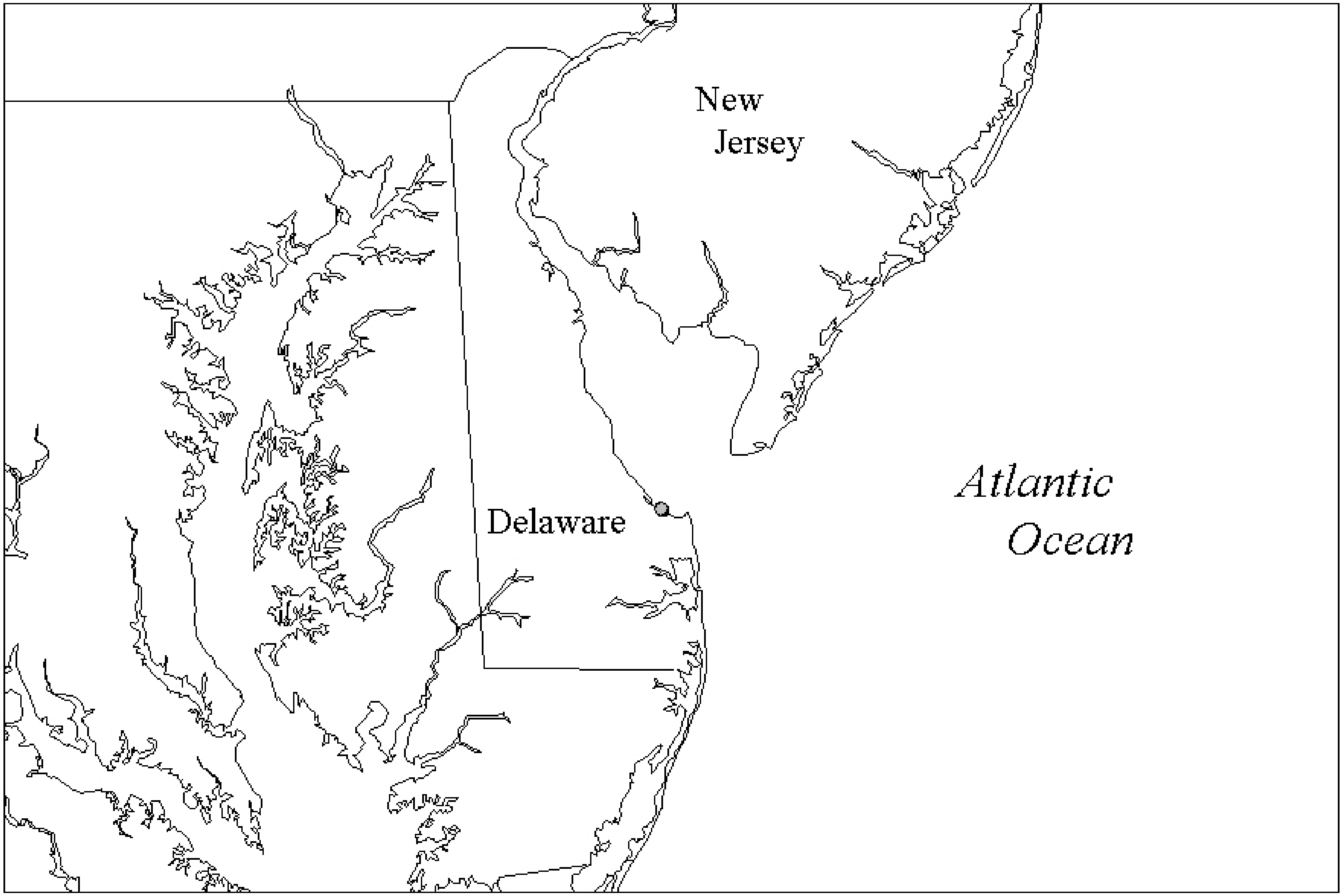


Map 30. Primary nursery areas for smalltail sharks indicated by shark capture locations for neonates and young-of-the-year

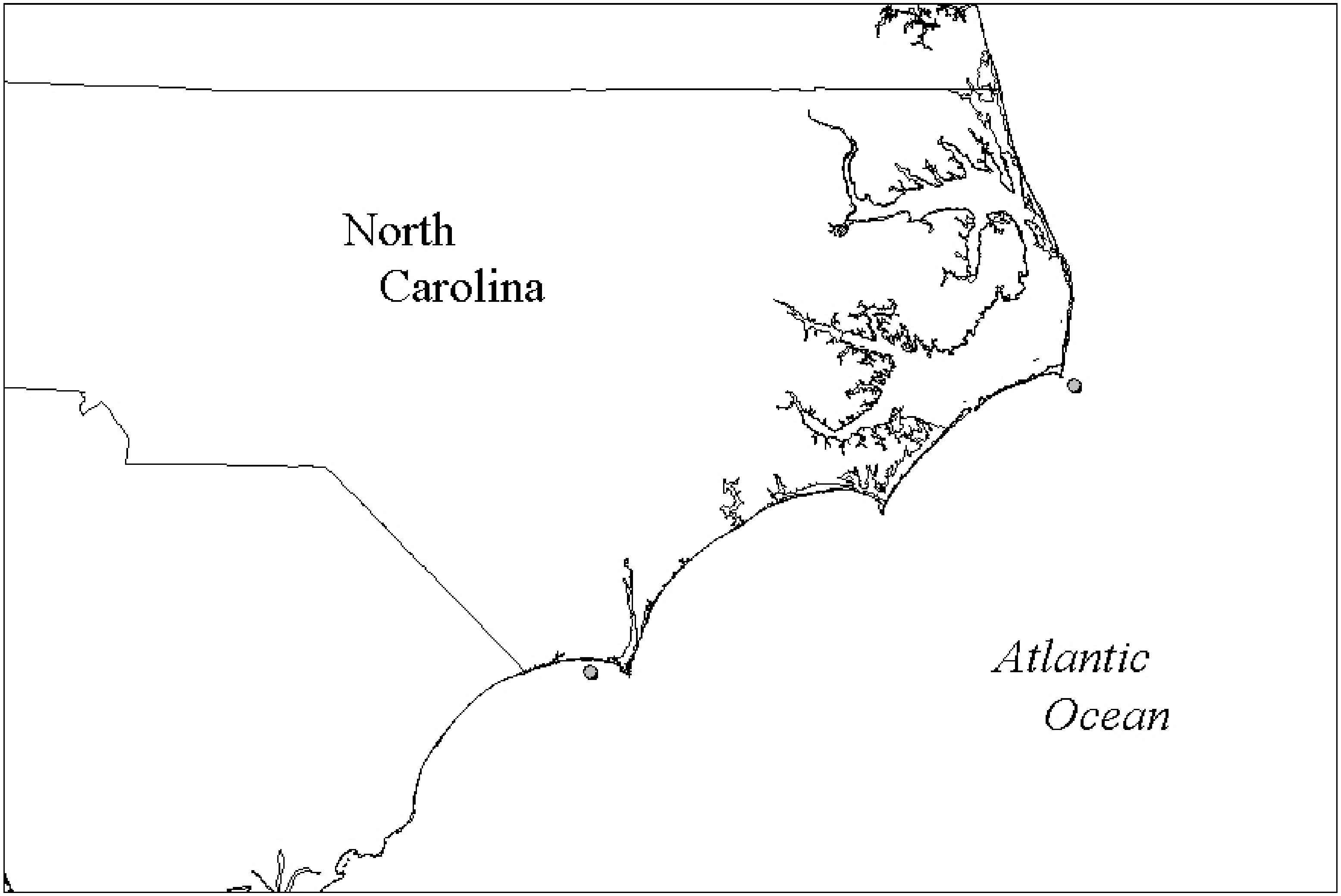
Map 31. Primary nursery areas for smooth dogfish indicated by shark capture locations for neonates and young-of-the-year



Map 32. Secondary nursery areas for smooth dogfish indicated by shark capture locations for juveniles (age 1+)

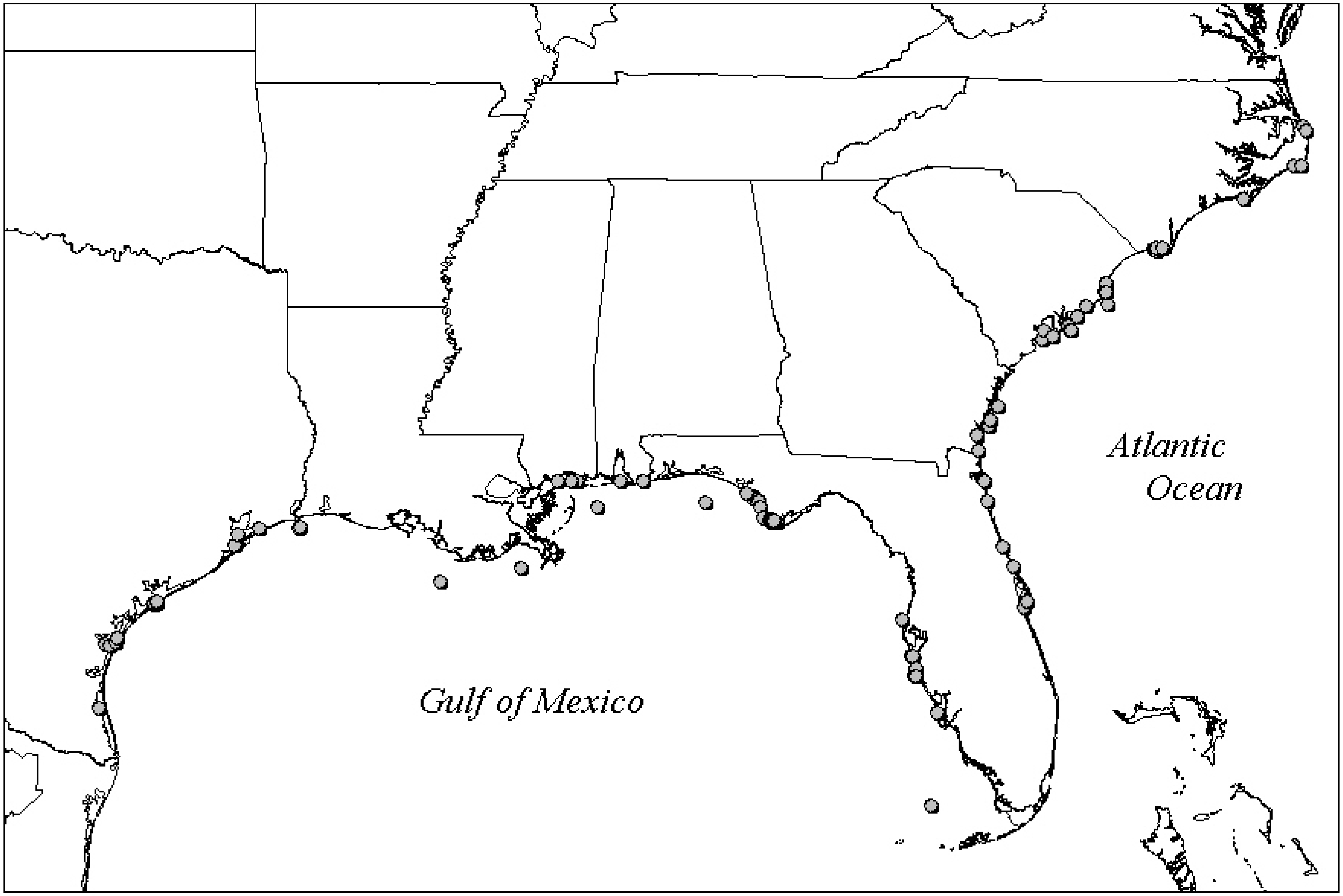


Map 33. Possible primary nursery area for smooth hammerhead sharks indicated by shark capture location for two neonates

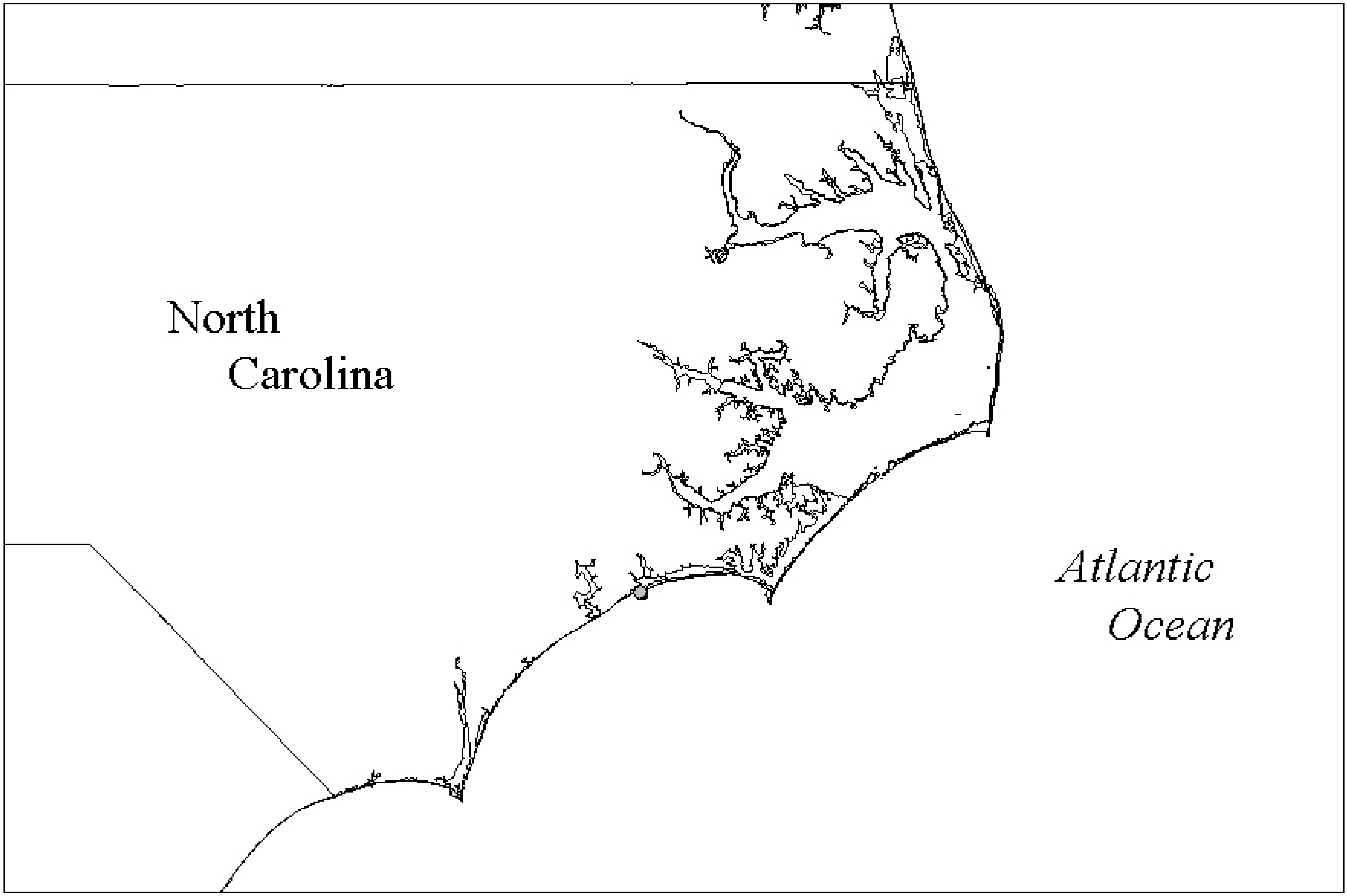


Map 34. Secondary nursery areas for smooth hammerhead sharks indicated by shark capture locations for juveniles (age 1+)

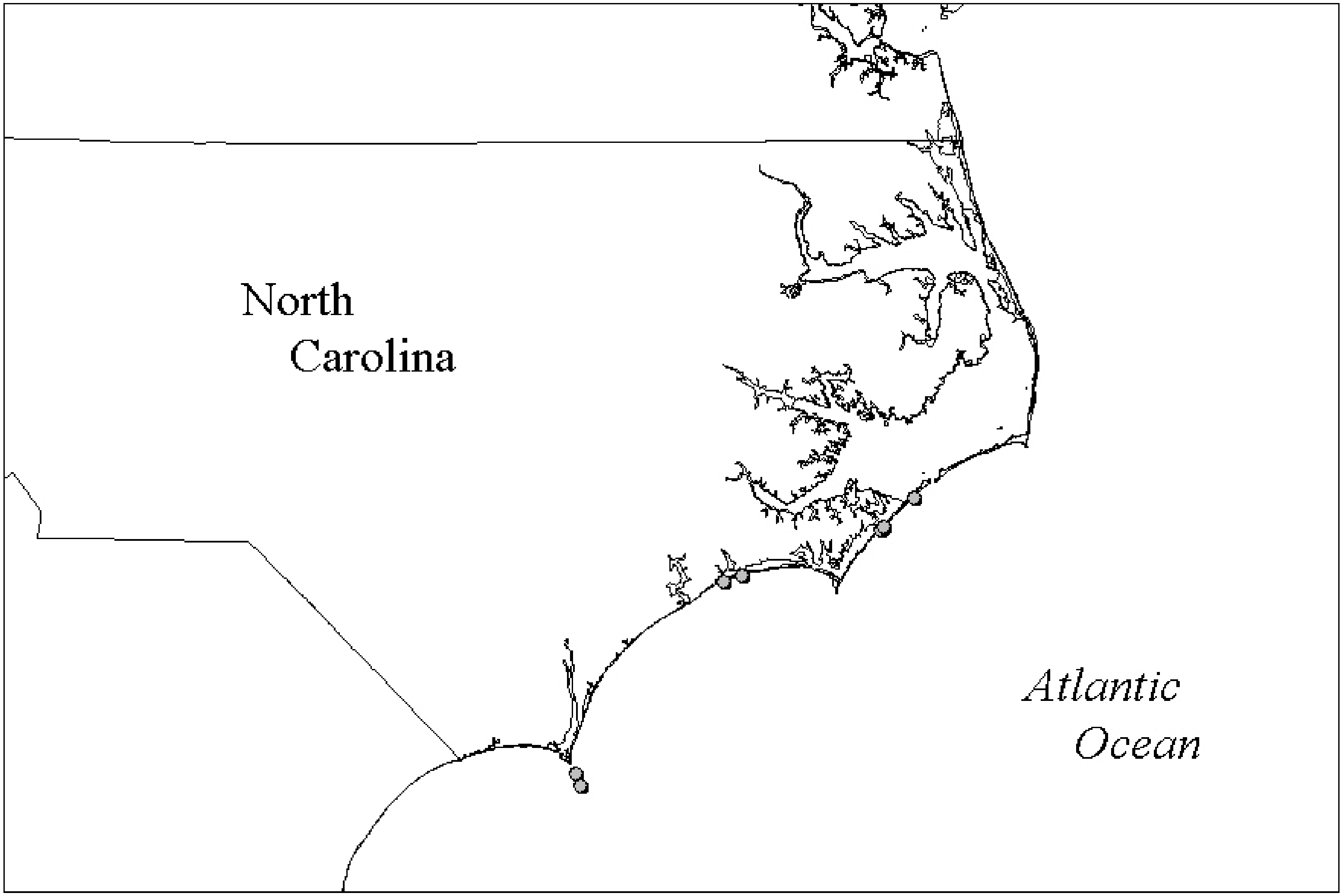
Map 35. Primary nursery areas for spinner sharks indicated by shark capture locations for neonates and young-of-the-year



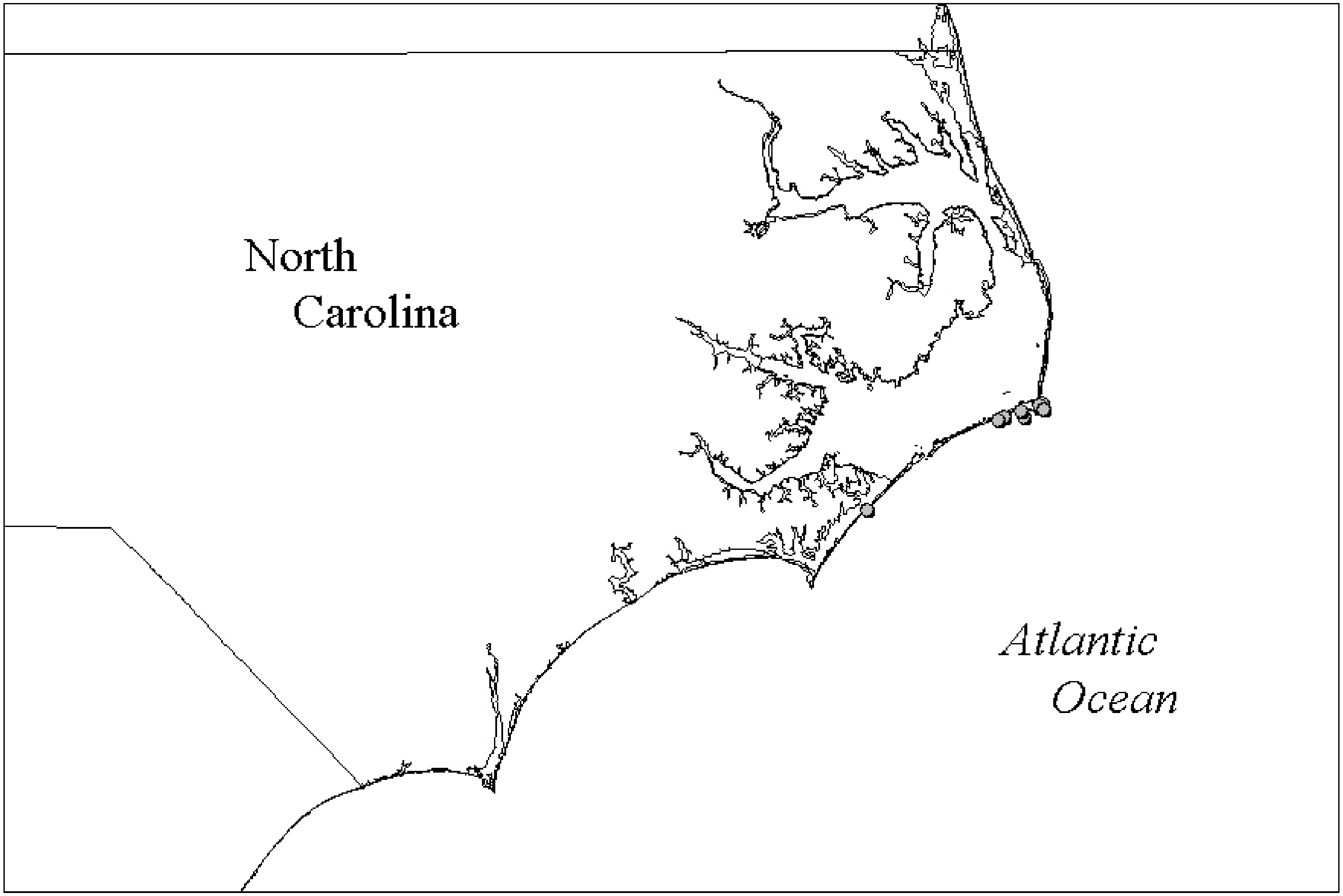
Map 36. Secondary nursery areas for spinner sharks indicated by shark capture locations for juveniles (age 1+)



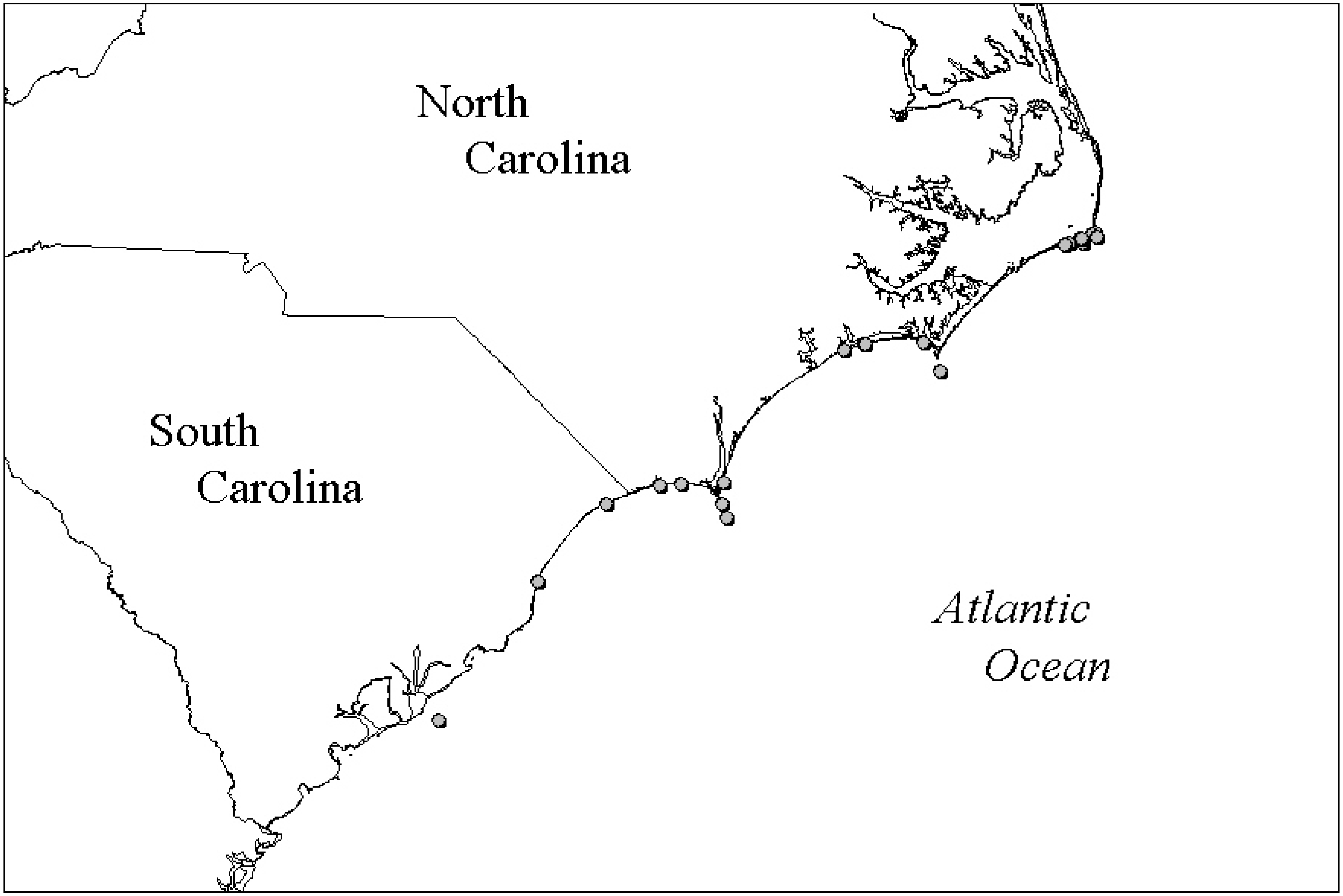
Map 37. Possible primary nursery area for spiny dogfish indicated by shark capture location for two young-of-the-year



Map 38. Secondary nursery areas for spiny dogfish indicated by shark capture locations for juveniles (age 1+)



Map 39. Primary nursery areas for thresher sharks indicated by shark capture locations for neonates and young-of-the-year



Map 40. Secondary nursery areas for thresher sharks indicated by shark capture locations for juveniles (age 1+)

Map 41. Primary nursery areas for tiger sharks indicated by shark capture locations for neonates and young-of-the-year

Map 42. Secondary nursery areas for tiger sharks indicated by shark capture locations for juveniles (age 1+)