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Preliminary Assessment of a Nearshore Nursery Ground for the Scalloped Hammerhead off the Atlantic Coast of Florida

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Abstract.—This study provides information regarding an open-ocean, nearshore nursery ground for the scalloped hammerhead *Sphyrna lewini* off the Atlantic coast of Florida near Cape Canaveral. Neonate scalloped hammerheads collected from this region ranged in size from 385 to 500 mm in total length (TL) and were observed during May and June, when water temperatures ranged from 26.1°C to 28.8°C. Although nearshore gill-net sampling during the study period encompassed the Florida Atlantic coastline from north of Cape Canaveral (latitude 28°40'N) south to the Jupiter Island area (latitude 27°04'N), neonate scalloped hammerheads were collected only in waters near the Cape Canaveral area. The nearshore waters near Cape Canaveral served as a nursery ground for scalloped hammerheads in 1994 and 1997. Extensive fisheries-independent gill-net sampling within the adjacent northern Indian River Lagoon system (Banana River Lagoon and Indian River Lagoon proper) did not collect scalloped hammerheads, indicating that this estuarine area does not serve as a nursery ground for this species. Other shark species collected in the overall study area included juvenile nurse sharks *Ginglymostoma cirratum* (620–1,219 mm TL); juvenile blacktip sharks *Carcharhinus limbatus* (630–885 mm TL); neonate, juvenile, and adult Atlantic sharpnose sharks *Rhizoprionodon terraenovae* (305–1,000 mm TL); juvenile and adult bonnethead *Sphyrna tiburo* (430–1,150 mm TL); and neonate and juvenile bull sharks *C. leucas* (754–1,460 mm TL). Human access to a portion of the open-ocean area near Cape Canaveral is currently prohibited due to security issues at the adjacent National Aeronautics and Space Administration's Kennedy Space Center and Cape Canaveral Air Force Station. This area closure has inadvertently created a marine reserve by eliminating fishing pressure on and significantly reducing vessel- or shore-based human interaction with this nearshore habitat. The effects, if any, of this marine reserve on shark populations in the region are unknown, and studies regarding these and other aspects of shark abundance and distribution in the Cape Canaveral area are currently ongoing.

Introduction

The scalloped hammerhead *Sphyrna lewini* is a circumglobal species that inhabits warm temperate and tropical seas. In the western Atlantic Ocean, this species occurs from New Jersey to Brazil, including waters of the Gulf of Mexico and Caribbean Sea (Bigelow and Schroeder 1948; Compagno 1984). Within United States waters, the scalloped hammerhead is classified as part of the large coastal shark species complex and is commercially landed in longline, gill-net, and driftnet fisheries. In the historical Florida commercial shark fishery, spanning from 1935 until 1950, they were considered among the most valuable species because they contained the highest potency liver oil among the common shark species available (Springer 1963). Although this species is currently caught in large numbers and its fins are of high value, it is typically considered less marketable than the more frequently landed blacktip shark *Carcharhinus limbatus* and sandbar shark *C. plumbeus* (Berkeley and Campos 1988; NMFS 1993, 2001). Recreational anglers in Florida routinely encounter the scalloped hammerhead. Although in Florida's state waters there is currently no size limit for this or any other shark species, there is a recreational bag limit of one per person per day or two per vessel per day, whichever is less (FWC 2007). This bag limit applies to all sharks, with the exception of currently protected shark species where no harvest or possession is allowed (FWC 2007).

Although information regarding nursery grounds for scalloped hammerhead is limited, nursery areas have been shown to include bays,

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sounds, and littoral zones (Sadowsky 1965; Clarke 1971; Branstetter 1987). Little is known about specific nursery grounds for this species off the U.S. Atlantic coast. In a review of shark nursery grounds in this region, Castro (1993) presented data on 16 neonate and small juvenile scalloped hammerheads (347–598 mm in total length [TL]) from Bulls Bay, South Carolina. He suggested that there is an extensive nursery for this species on the southeastern coast of the United States with the center possibly located off South Carolina. In Florida, a total of eight juveniles (479–695 mm TL) were collected in the Mosquito Lagoon basin of the northern Indian River Lagoon system on the Atlantic coast in May, August, and September 1977 (Snelson and Williams 1981). No other specimens, however, have been documented within the Indian River Lagoon system since then (Tremain and Adams 1995; Provancha et al. 1998; Kupschus and Tremain 2001). Additionally, Dodrill (1977) collected a free-swimming, 382-mm-TL neonate scalloped hammerhead in the surf zone of the Atlantic Ocean off Melbourne Beach, Florida, on 1 June 1975. Aubrey (2001) collected 11 scalloped hammerheads (457–969 mm stretched TL) in the Cape Canaveral, Florida nearshore area from 1995 to 1998. Three of these were classified as young-of-the-year individuals (457–481 mm stretched TL) and were collected in August 1996 (n = 2) and August 1997 (n = 1).

Estimates of large and rapid declines in the population of scalloped hammerheads in northwestern Atlantic waters have recently been proposed. Since 1986, the abundance of scalloped hammerheads in the northwest Atlantic has reportedly declined by an estimated 89% (Baum et al. 2003); however, critical evaluation of these results indicate that this estimate may be exaggerated based on incomplete analyses and dataset limitations (Burgess et al. 2005). Life history parameters indicate that scalloped hammerheads are potentially among the shark species most vulnerable to overexploitation (Branstetter 1990; Hoenig and Gruber 1990; Baum et al. 2003). Effective management and protection of coastal nursery habitats is critical for many shark species. Prior to developing effective management strategies for shark populations, additional information regarding these nursery grounds, how specific nursery habitats are used by individual species, and the interaction between juveniles and specific nursery environments is required (Pratt and Otake 1990; Pratt et al. 1998; NMFS 1999). This paper provides information regarding the occurrence of neonate scalloped hammerheads in an open-ocean, nearshore nursery off the Atlantic coast of Florida.

Methods

Study areas

The study area encompassed nearshore and estuarine waters of the Atlantic coast of Florida (Figure 1). Sampling of the nearshore component of the study occurred from north of Cape Canaveral (latitude 28°40'N) south to Jupiter Island (latitude 27°04'N). The inner continental shelf along Florida's Atlantic coast between Cape Canaveral and Jupiter Island is composed of between 9% and 21% hard-bottom habitat, with the remainder consisting of sand-shell and other bottom types (Perkins et al. 1997). Near Cape Canaveral, the nearshore area is characterized by a broad, sandy shelf with patchy hard-bottom that extends almost continuously from north of Cape Canaveral south to about 27°40'N. This area also includes an extensive sandy shoal (Southeast Shoal, 1–5 m deep) extending southeast from Cape Canaveral to approximately 28°25'N and a deeper area (Canaveral Bight, 6–10 m deep) to the south (Figure 1). Southeast Shoal is principally composed of sand-shell substrate while finer sediments (silt and clay) accumulate in the deeper waters of nearby Canaveral Bight (Meisburger and Duane 1971). Along shore south of Cape Canaveral, the patchy, hard-bottom reef structure is roughly 0.8 km wide and supports a diverse flora and fauna (Perkins et al. 1997). Continuing south to Jupiter Island, the continental shelf narrows and steepens such that the open sand and hard-bottom areas are confined to a narrow strip of shelf.

Sampling for the estuarine component of this study occurred within the Indian River Lagoon system, which is a narrow lagoon that extends along the east-central coast of Florida from Ponce de Leon Inlet (29°04'N) south to Jupiter Inlet (26°56'N) and consists of three shallow, interconnected basins (Mosquito Lagoon, Indian River Lagoon proper, and Banana River; Figure 1). The three basins are separated from the Atlantic Ocean by a series of narrow barrier islands and linked to ocean waters by five inlets (Ponce de Leon Inlet, Sebastian Inlet, Ft. Pierce Inlet, St. Lucie Inlet,

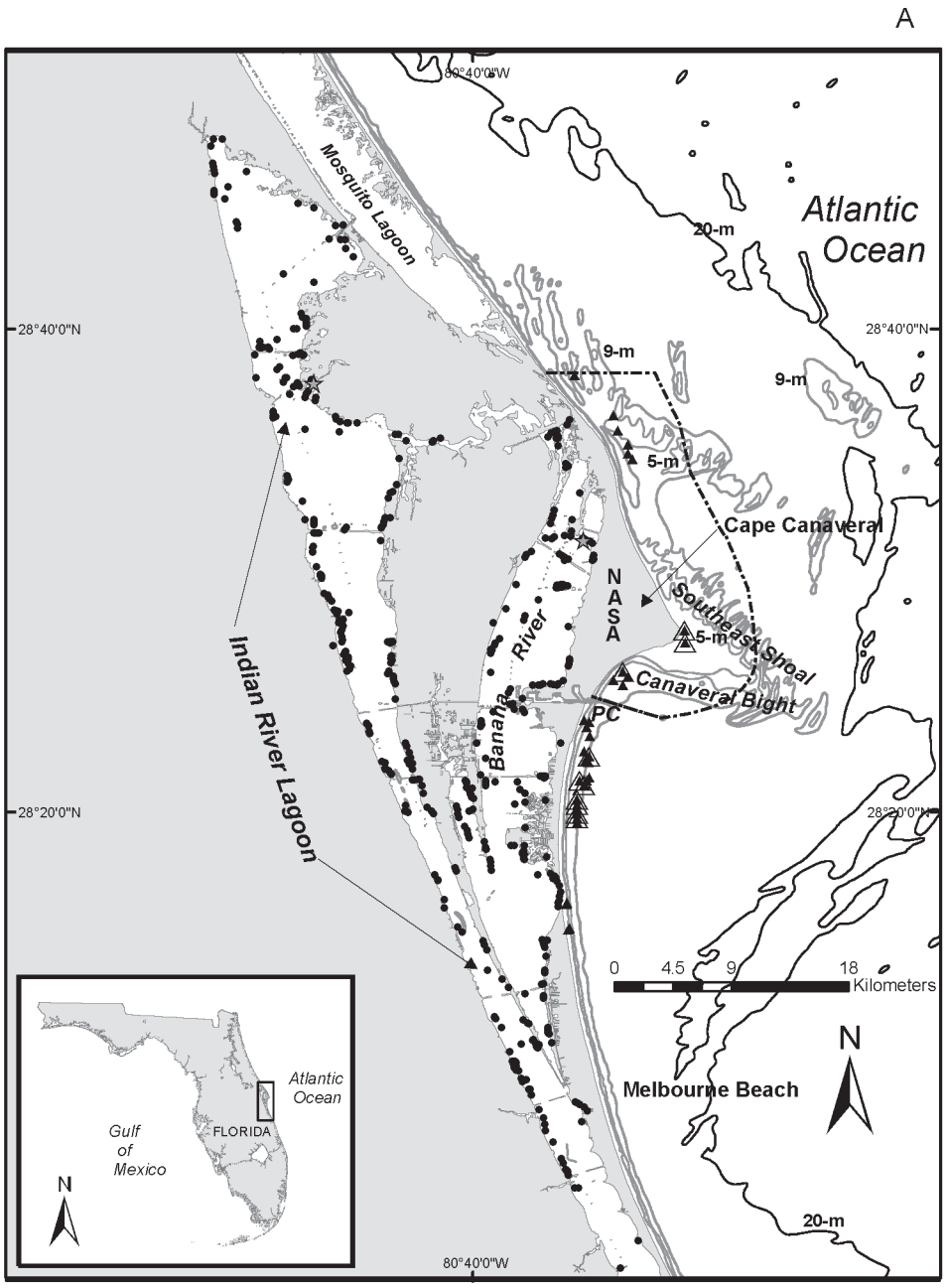

FIGURE 1. Map of the study area: A. Northern Indian River Lagoon and Cape Canaveral area south to Sebastian Inlet. PC = Port Canaveral; NASA = National Aeronautics and Space Administration, Kennedy Space Center and Cape Canaveral Air Force Station. —·— delineates the boundary of the NASA security area. B. Southern Indian River Lagoon and Ft. Pierce Inlet south to Jupiter Inlet. [●] Indian River Lagoon estuarine gill-net sets; [▲] FWRI observer and stratified-random nearshore gill-net sets; [⧋] locations of scalloped hammerheads *Sphyrna lewini* recorded from stratified-random nearshore gill-net sets; and [★] locations of FWRI fixed-station gill-net sets.

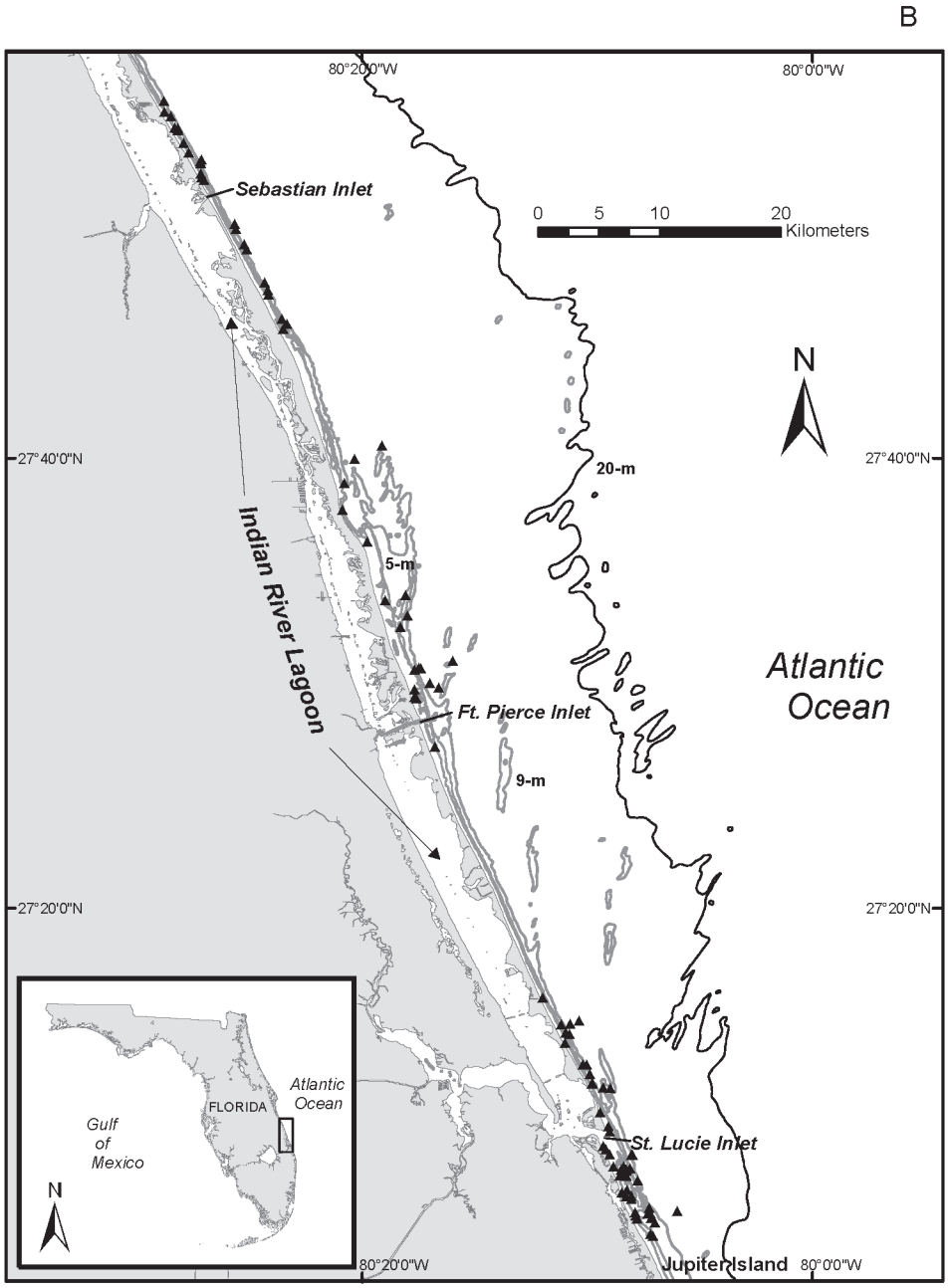

FIGURE 1. Continued.

and Jupiter Inlet) and one intermittently open series of locks at Port Canaveral. Detailed descriptions of the biotic and abiotic characteristics within the lagoon have been described by Snelson (1980), Gilmore et al. (1981), Tremain and Adams (1995), and Smith (2001).

Sampling design

During the late winter to early summer of 1994 (February–June), fisheries-independent and fisheries-dependent (observer trips) sampling was conducted in the nearshore coastal waters adjacent to

the Indian River Lagoon system from north of Cape Canaveral, Florida (latitude 28°40'N) south to Jupiter Island, Florida (latitude 27°04'N) as part of a study examining the fish catch composition and incidental sea turtle capture in the Florida Atlantic coast gill-net fishery (FMRI 1994). The fisheries-independent sampling used a stratified-random design in which the nearshore coastal waters (within ~1 nm from shore, ~3–10 m water depth) were stratified into four spatial zones, each centered around inlets (Port Canaveral, Sebastian Inlet, Ft. Pierce Inlet, St. Lucie Inlet) connecting the Atlantic Ocean to the Indian River Lagoon (Figure 1). Paired samples (0- and 30-min soak times) were collected at night at each randomly selected site. Samples classified as 0-min soak times referred to sets where gill-net recovery was initiated immediately after deployment with no additional unattended soak time. Monofilament gill nets were 548.6 m long and approximately 4 m deep, consisted of either 115-mm or 127-mm stretched mesh, and were set as a stab (or sinking) net that included half moon-, zig-zag-, and hook-shaped set patterns. The fisheries-dependent sampling involved stationing trained Florida Fish & Wildlife Conservation Commission-Fish and Wildlife Research Institute (FWC-FWRI) observers aboard commercial gill-net vessels operating within the nearshore coastal study area to document the targeted catch and all bycatch. These vessels were principally targeting Florida pompano *Trachinotus carolinus*, bluefish *Pomatomus saltatrix*, and Spanish mackerel *Scomberomorus maculatus*.

In addition to the nearshore sampling, the FWC-FWRI Fisheries-Independent Monitoring (FIM) program has been monitoring fish populations in the Indian River Lagoon since 1990. Within the estuarine waters of the Indian River Lagoon, the experimental design of the FIM program incorporated both stratified-random sampling and fixed-station sampling. Multipanel experimental gill nets (one 25-m panel of 51-mm stretch mesh and four 45.7-m panels of 76-mm, 102-mm, 127-mm, and 152-mm stretch mesh; all panels were 1.8 m deep) were set perpendicular to the shoreline with a minimum soak time of 1.5 h during stratified-random sampling and 1.0 h during fixed-station sampling.

Stratified-random gill-net sets in estuarine waters were conducted seasonally (spring and fall) between 1990 and 1995 and monthly thereafter, until March 1997. These sets were deployed within morning and evening crepuscular (defined as 1 h before to 1 h after sunrise or sunset) and nighttime periods. For each stratified-random set, two gill nets were deployed in the "regular" manner (i.e., smallest mesh on shore) and two gill nets were deployed in a "reverse" manner (i.e., largest mesh on shore), with a minimum distance of 45 m between nets. The order of initial mesh deployment was randomly selected.

Fixed gill-net stations in estuarine waters were sampled monthly between January 1991 and March 1996. Fixed station sets were deployed only during the evening crepuscular period. For each fixed-station set, three gill nets were deployed at each station, with the smallest mesh always on shore.

On all sampling trips, sharks that were collected were identified to species, counted, and sexed and their TLs (mm) were measured on a calibrated measuring board with the upper lobe of the caudal fin in a natural position. Umbilical scars were characterized as "umbilical remains," "fresh open," "partially healed," "mostly healed," "well healed," and "none" according to Pratt et al. (1998). Water depth and location (latitude and longitude) were recorded for all gill-net sets. Nearshore water temperatures were derived from unofficial sea-surface, surf-zone water temperatures from the National Oceanic and Atmospheric Administration's National Weather Service. Water temperatures and associated physical data were recorded at the beginning and end of each set for all sites within estuarine waters.

Results and Discussion

A total of 105 gill-net sets were completed from February to June 1994 during the nearshore gill-net portion of this study; water depths ranged from 3.5 to 11 m. A total of 40 neonate scalloped hammerheads were collected in nearshore gill nets. Neonates ranged in size from 385 to 500 mm TL, with a mean of 438 mm TL (±0.41 SE; Figure 2). Umbilical scars for all individuals examined were either partially healed or mostly healed. Although nearshore gill-net sampling during the study period encompassed the Florida Atlantic coastline spanning from northern Cape Canaveral (latitude 28°40'N) south to the Jupiter Island area (latitude 27°04'N), neonate scalloped hammerheads were collected only in waters adjacent to Cape Canaveral and directly southwest of

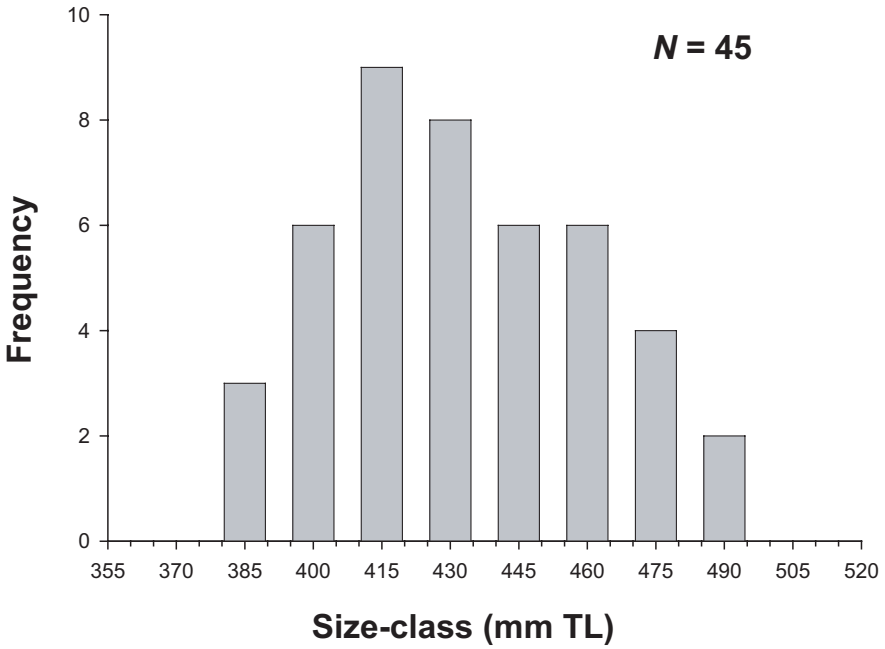

FIGURE 2. Size-frequency distribution of scalloped hammerheads *Sphyrna lewini* caught in the Cape Canaveral area between May and June 1994 and in June 1997.

Canaveral Bight (Figure 1). Water depths where scalloped hammerheads were collected ranged from 3.8 to 9.7 m. Neonates were collected from late May to early June, when surf-zone water temperatures recorded in the Cape Canaveral area ranged from 26.1°C to 26.6°C.

An additional five neonate scalloped hammerhead sharks were obtained from the recreational hook-and-line fishery directly off Cape Canaveral in late June 1997. These individuals ranged from 392 to 411 mm TL. The umbilical scars of these specimens were partially healed. The surf-zone water temperature was 28.8°C in the Cape Canaveral area when these neonates were collected.

Other shark species collected during gill-net sampling in the nearshore study area from February to June 1994 included juvenile nurse sharks *Ginglymostoma cirratum* (620–1,219 mm TL), juvenile blacktip sharks (630–885 mm TL), neonate, juvenile, and adult Atlantic sharpnose sharks *Rhizoprionodon terraenovae* (305–1,000 mm TL), and juvenile and adult bonnetheads *Sphyrna tiburo* (430–1,150 mm TL). Juveniles of all four of these additional shark species were collected in the Cape Canaveral area as well as other portions of the nearshore study area.

A total of 1,133 gill-net sampling sets were completed within the estuarine waters of the northern Indian River Lagoon from March 1990 to March 1997. Although an extensive 8-year sampling effort was made in this estuarine system over a wide variety of habitat types and environmental conditions using experimental gill nets capable of collecting scalloped hammerheads, none were collected from this area. The multipanel gill-net configuration used in this study has frequently collected neonate, small juvenile, and large juvenile sphyrnids and carcharhinids in other estuarine systems in Florida (e.g., Tampa Bay and Charlotte Harbor) during FWC-FWRI's Fisheries-Independent Monitoring Program sampling operations (FWC-FWRI, unpublished data). Additionally, Crabtree and Adams (1998) conducted extensive gill-net sampling in the Indian River Lagoon from the northernmost terminus of the Indian River Lagoon proper (approximately 28°47'N) south to Ft. Pierce, Florida (approximately 27°31'N) from September 1995 to January 1998, and no neonate or juvenile scalloped hammerheads were captured. During 1977, eight juveniles were collected in Mosquito Lagoon from large-mesh gill nets designed to collect sea turtles (Snelson and Williams 1981); however, subsequent sam-

pling in Mosquito Lagoon using similar gear types has not resulted in any additional captures of this species (Provancha et al. 1998; J. Provancha, Dynamac-NASA, personal communication). Extensive sampling elsewhere in the Indian River Lagoon system since that time has also not yielded any scalloped hammerhead sharks. The estuarine waters of the Indian River Lagoon proper and the Banana River Lagoon do not appear to serve as a nursery ground for the scalloped hammerhead.

Neonate and small juvenile bull sharks *Carcharhinus leucas* (754–1,460 mm TL) were collected within estuarine waters of the Indian River Lagoon during our sampling efforts and use this area as a primary and secondary nursery. Neonate and small juvenile bull sharks occur in all three basins of the Indian River Lagoon system (Mosquito Lagoon, Banana River Lagoon, and the Indian River Lagoon proper) (Snelson et al. 1984; Tremain and Adams 1995; Adams and McMichael 1999; Tremain et al. 2004).

Juvenile and adult scalloped hammerheads are frequently observed or caught year-round in waters off the Florida Atlantic coast (Dodrill 1977; Jennings 1985; Berkeley and Campos 1988; FWC-FWRI, unpublished data). During 1990–2002, lengths of scalloped hammerheads landed in the recreational fishery from within state waters off the Atlantic coast of Florida ranged from 458 to 2,726 mm TL (National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). Information regarding use of these waters by neonates or small juveniles is sparse. Neonates collected in this study were present in the nearshore waters off Cape Canaveral from late May to late June, with the majority (approximately 89%) being collected in late May and early June. The one neonate collected by Dodrill (1977) from the surf zone in Melbourne Beach, Florida was also observed in early June, and the eight juveniles observed in Mosquito Lagoon by Snelson and Williams (1981) were collected during May, August, and September. The three young-of-the-year scalloped hammerheads reported by Aubrey (2001) were observed in August. In coastal waters to the north, Castro (1993) observed five neonate scalloped hammerheads with open umbilical scars in Bulls Bay, South Carolina, from early to mid-June. Elsewhere within their range, parturition of this species is estimated to occur from May to July off Taiwan (Chen et al. 1988) and in late summer in North American waters (Castro 1996). In Kaneohe Bay, Hawaii, neonates with open umbilical scars occur from May to September, with abundance peaks in June and July (S. Kajiura, Florida Atlantic University, personal communication).

Size at parturition is estimated to be between 380 and 562 mm TL, based on the size of embryos in full-term litters or the size of free-swimming neonates (Clarke 1971; Compagno 1984; Chen et al. 1988; Castro 1996). In the northwestern Gulf of Mexico, back-calculated size at parturition for this species ranged from 450 to 600 mm TL with a mean of 503 mm TL (Branstetter 1987). Relatively small, free-swimming individuals have been recorded. The minimum size reported by Dodrill (1977) in the Melbourne Beach, Florida area was 382 mm TL, and Clarke (1971) reported a 395-mm-TL scalloped hammerhead from Hawaiian waters. Castro (1993) recorded a 347-mm-TL neonate from Bulls Bay, South Carolina. During this study, we collected three free-swimming individuals measuring less than 400 mm TL, with the smallest measuring 385 mm TL.

It is unknown if the scalloped hammerheads collected in this study were pupped within the study area; however, shark size and the umbilical scar condition of all specimens (either partially healed or mostly healed) indicate that some of these sharks were either born in the area or moved into the study area soon after parturition. Scalloped hammerheads used Cape Canaveral near-shore waters to some extent as a primary nursery area in 1994 and 1997. The presence of a limited number of larger juvenile scalloped hammerheads directly off Cape Canaveral observed in other studies (FWC-FWRI, unpublished data; Aubrey 2001) suggests that the area may also be a secondary nursery or may be temporarily utilized during migration.

Our sampling did not cover the entire Atlantic coast of Florida, but it did include representative areas along the central portion of this region. The Cape Canaveral area apparently provides suitable habitat for neonate scalloped hammerheads. Although little is known regarding the distribution and relative abundance of fishes or invertebrates in these nearshore waters, suitable prey types are likely available there. The stomach contents of neonates examined in this study included fresh, partially digested, and well-digested small fishes (e.g., menhaden *Brevoortia* spp.) and shrimp. Similarly, the most common prey items of juvenile scalloped hammerheads in Kaneohe Bay, Hawaii were

shrimp and small fishes (gobies; Bush 2003). The presence of fresh and partially digested prey items in stomachs of scalloped hammerheads examined during this study indicated that individuals from this population were actively feeding in nearshore Cape Canaveral waters. The extensive sand-shell plain of Southeast Shoal, the deeper waters of Canaveral Bight, and the shelf transition zone directly south of Canaveral Bight may provide important feeding areas for this species. The shallow waters and unique habitat of Southeast Shoal also may afford neonates an increased level of protection from large predators compared to adjacent deepwater habitats.

Additional research is required to better understand the status of the Cape Canaveral area as a nursery ground for the scalloped hammerhead and other shark species. A significant portion of Cape Canaveral waters, spanning from the surf-zone nearshore to the 3-mi state waters limit (Figure 1), are currently restricted for national-security issues related to the presence of NASA's Kennedy Space Center and Cape Canaveral Air Force Station. No unauthorized vessels have been allowed within this zone since approximately 11 September 2001, and access from shore is prohibited. This area closure has inadvertently created a marine reserve by eliminating fishing pressure in the area and significantly reducing vessel- or shore-based human interaction with this nearshore habitat. The effects, if any, of this marine reserve on shark populations in the region are currently unknown, and research regarding these and other aspects in the Cape Canaveral area is currently ongoing.

Conclusions

Although nearshore gill-net sampling encompassed a significant portion of the Florida Atlantic coastline, spanning from northern Cape Canaveral south to the Jupiter Island area, neonate scalloped hammerheads were collected only in waters directly adjacent to the Cape Canaveral area (Cape Canaveral and directly southwest of Canaveral Bight). In addition, despite extensive sampling effort, there was no indication that this species currently uses the estuarine waters of the adjacent Indian River Lagoon as a nursery ground. The nearshore area off Cape Canaveral, Florida served as a nursery habitat for the scalloped hammerhead in 1994 and 1997. Human access to a portion of this open-ocean area is currently prohibited, and the closure has inadvertently created a strictly enforced marine reserve. The potential effects of elimination of fishing pressure on and reduction in vessel- or shore-based human interaction with the nursery ground on scalloped hammerheads and other shark species are unknown at this time. Future research to assess the importance of this nearshore habitat will require comprehensive delineation of nursery areas; long-term, year-round fisheries-independent monitoring; life history studies; bioenergetics studies; and increased tagging efforts to better understand and effectively manage shark populations that use areas near Cape Canaveral and adjacent waters of the Atlantic coast of Florida.

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