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Distribution, movements and growth of young sandbar sharks, *Carcharhinus plumbeus*, in the nursery grounds of Delaware Bay

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Synopsis

During the spring and summer months of 1995, 1996 and 1997, gillnet and longline surveys were conducted in conjunction with tag and recapture experiments to outline spatial and seasonal distribution of young sandbar sharks, *Carcharhinus plumbeus*, in Delaware Bay for essential fish habitat mapping, to assess abundance of young sandbar sharks, and to quantify growth during the summer nursery season. Sandbar sharks ($n = 943$) ranging from 40 to 120 cm fork length (48 to 130 cm total length) were captured; yearly totals were 199, 314 and 430 in 1995, 1996 and 1997, respectively. Individuals were captured between June and October in water temperatures ranging from 15.4° to 28.5°C and salinities ranging from 22.8 to 30.3 ppt. Presence of neonates and catch per unit effort data indicate that pupping begins in late June near the southwestern coast of the Bay. Juveniles were present from early June through September and their spatial distribution in the Bay appeared uniform. Of 782 sandbar sharks tagged and released during the three years, 50 were recaptured. Mean distance from tag to recapture location and mean days-at-liberty of sandbar sharks recaptured in Delaware Bay during the year of tagging were 10 km and 18 days, respectively. Some sharks were recaptured as far as 957 km from the release location. Length distributions show young-of-the-year sandbar sharks grow about 2–3 cm in length during the nursery season.

Introduction

Several species of viviparous sharks migrate into coastal bays to give birth to their young (Castro 1993, Simpfendorfer & Milward 1993). Studies suggest that inshore nursery grounds offer the selective advantages of low predation rates, high prey abundance and appropriate habitat during early life history in teleosts (Gibson 1994, Malloy et al. 1996) and elasmobranchs (Branstetter 1990, Rountree & Able 1996). Additionally, Springer (1967) hypothesized that population size is limited through density-dependent mechanisms by the quantity of suitable nursery area.

The sandbar shark, *Carcharhinus plumbeus*, is distributed in warm-temperate and tropical oceans (Compagno 1984). They are highly migratory and have been reported to travel over 2900 km (National Marine Fisheries Service[1]). Nevertheless, many allopatric populations exist; for example, in the China Sea (Taniuchi 1971), off Hawaii (Wass 1973), and in the Red Sea (Baranes & Wendling 1981). Heist et al. (1995) concluded from a genetic study that sandbar sharks from the western North Atlantic and Gulf of Mexico comprise one interbreeding population.

Primary nursery grounds, defined as areas where parturition occurs, of the western North Atlantic/Gulf of Mexico sandbar shark population extend from South Carolina (Castro 1993) to New Jersey

[1] National Marine Fisheries Service. 1991. The shark tagger. Annual report of the NMFS Cooperative Shark Tagging Program. Apex Predators Program, Narragansett, Rhode Island. 14 pp.

(Merson & Pratt,[2] Merson 1998). Evidence of pupping in the northern (Springer 1960) and eastern Gulf of Mexico (Carlson 1999) exists, but to date few neonates have been captured in the Gulf. Young-of-the-year sandbar sharks have been documented in Great Bay, New Jersey (Merson & Pratt[2]), in Virginia bays along the Delmarva Peninsula (Colvocoresses & Musick[3]), including Chincoteague Bay (Medved et al. 1988), Wachapreague estuary (Hoese 1962) and Great Machipongo Inlet (Casey et al. 1985), Chesapeake Bay (Schwartz 1960, Musick et al. 1993), and Bulls Bay, South Carolina (Castro 1993). There are no contemporary first-hand accounts of western North Atlantic sandbar shark pupping grounds north of New Jersey or south of South Carolina. The contribution of open coastal areas (outside of the bays) as pupping grounds for the sandbar shark is not known.

Sandbar shark pupping season is reported to occur in May and June (Colvocoresses & Musick[3], Castro 1993). Following birth, young-of-the-year remain in primary nursery grounds (areas where pupping occurs) for the remainder of the summer and then migrate south to warmer waters (Springer 1960). Juveniles (ages 1 and older) migrate from overwintering areas to both primary and secondary nurseries (defined as geographically broader areas utilized by juveniles where no parturition occurs) in the spring. Some juveniles up to 150 cm total length (TL) are captured in primary nursery grounds (Hoese 1962, Casey et al. 1985, Castro 1993, Musick et al. 1993). Using all age and growth estimates, the lengths reported in these studies correspond to sandbar sharks up to ages between 5 and 17 years (Casey et al. 1985, Casey & Natanson 1992, Sminkey & Musick 1995).

Chesapeake Bay has been identified as the major primary nursery ground for sandbar sharks in the western North Atlantic (Musick & Colvocoresses[4], Musick et al. 1993). Sandbar sharks were reported in Delaware Bay (Price 1977) and juveniles are regularly tagged and released there by participants in the U.S. National Marine Fisheries Service Cooperative Shark Tagging Program, although the extent of utilization of the Bay as a pupping and nursery ground remained unreported until the present study.

The sandbar shark is a commercially important species and has been managed since 1993 by the National Marine Fisheries Service (NMFS) under the Fishery Management Plan for Atlantic Tuna, Swordfish and Sharks (National Marine Fisheries Service[5]). Information about the ecology of nursery areas contributes to understanding shark reproduction, knowledge requisite to fisheries management (Pratt & Otake 1990). The Magnuson-Stevens Fishery Conservation and Management Act[6] requires that NMFS facilitate collection of data related to essential fish habitat (defined as waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity) and report findings to regional management councils. Nursery grounds qualify as essential fish habitat. The Act specifically requests information about the geographical distribution of essential fish habitat, habitat related densities, growth, reproduction and survival rates within habitats, and production rates. Identifying the geographical extent and seasonal utilization of shark nurseries is necessary to define essential habitat and evaluate effects of commercial and recreational fisheries and other anthropogenic activities on juvenile sharks.

The purposes of this study were to describe the spatial and seasonal distribution of young sandbar sharks in Delaware Bay, to delineate essential fish habitat, to assess abundance, and to quantify growth over the nursery season.

Methods

Study site

Extensive shoals 1–4 m in depth cover most of Delaware Bay. The average depth of the Bay is 7.4 m and the total area is 1989 km^2 (National Oceanic and

[2] Merson, R.R. & H.L. Pratt, Jr. 1997. Northern extent of the pupping grounds of the sandbar shark, *Carcharhinus plumbeus*, on the U.S. East Coast. The 77th Annual Meeting of the American Society of Ichthyologists and Herpetologists, University of Washington, Seattle, 26 June–2 July 1997. 240 pp. (abstract).

[3] Colvocoresses, J.A. & J.A. Musick. 1989. Reproductive biology of the sandbar shark, *Carcharhinus plumbeus*, in the Chesapeake Bight. The 69th Annual Meeting of the American Society of Ichthyologists and Herpetologists, San Francisco State University, San Francisco, 17–23 June 1989. 78 p. (abstract)

[4] Musick, J.A. & J.A. Colvocoresses. 1988. Seasonal recruitment of subtropical sharks in Chesapeake Bight, U.S. A. Workshop on recruitment in tropical coastal demersal communities, Campeche, Mexico, 21–25 April, 1986, FAO/UNESCO, I.O.C. Workshop report no. 44. 323 pp.

[5] National Marine Fisheries Service. 1999. Final fishery management plan for Atlantic tuna, swordfish, and sharks. Highly Migratory Species Management Division, Office of Sustainable Fisheries, Silver Spring Volumes 1–3. 1199 pp.

[6] Magnuson-Stevens Fishery Conservation and Management Act. 1996. Public Law 94-265, Amended 11 October 1996.

Atmospheric Administration 1985). Sloughs and channels (5–9 m deep) run from the shallows into the main shipping channel (9–46 m deep), which transects the center of Delaware Bay from the bay mouth to the Delaware River (National Ocean Service 1987). Suspended sediments render Bay waters highly turbid (Sharp 1998) thereby reducing underwater visibility to less than 0.5 m. Salinities range from 33 parts per thousand (ppt) at the entrance of the Bay to 8 ppt in the upper estuary off Woodland Beach. Tidal and wind driven mixing produce a relatively homogeneous temperature profile ranging from 20° to 28°C (Michels[7]) during the summer months. The tidal range in Delaware Bay is about 1.4 meters.

Sampling

A total of 31 stations in Delaware Bay were sampled with gillnet and longline gear. An anchored bottom-set nylon monofilament gillnet (length 233 m, height 3.1 m, 10.6 cm stretch mesh) with additional buoys and weights on the floatline and leadline, respectively, was used in July and August 1995, monthly from June to October 1996 and May, July and August 1997. The net was set for 1.5 to 6.5 h (mean 3.5 h) and continuously tended for sharks and bycatch to reduce mortality and ensure the best condition for release. Gillnet catch per unit effort (CPUE) was the number of sandbar sharks captured divided by set duration (sharks h^{1}). A 50 hook, bottom-set longline was also used in July and August 1997. Gangions made of 1.5 m braided nylon (4 mm diameter) and 0.5 m stainless steel leaders were attached to a 280 m long braided nylon (12 mm diameter) mainline. Circle hooks (12/0) were baited with menhaden, *Brevoortia tyrannus*, and set for one hour. Longline CPUE was calculated by dividing the number of sandbar sharks captured by the number of hooks set and multiplying by 100 (sharks 100 $hooks^{-1}$). Surface temperature, measured with a bucket thermometer and salinity, measured with a hand held refractometer, were recorded at the beginning and end of each sampling set.

Captured sharks were examined for an umbilical scar, measured, weighed, sexed, tagged and released within three minutes of being removed from the gillnet or unhooked from the longline. Fork length (FL) and total length (TL) were measured to the nearest centimeter with a measuring board and sharks were placed in a tared bucket and weighed with a hand held spring scale to the nearest 0.1 kg. Young-of-the-year sharks (age 0+) included neonates (sharks with open umbilical scars) and sharks with well healed umbilical scars within the expected length and weight range of neonates. Sharks were classified as juveniles (ages 1 and older) if they had well healed umbilical scars and were captured before the pupping season began, were larger than the length and weight range of neonates, or had no visible umbilical scar. Live sharks were tagged with either a small, yellow, nylon dart tag in the dorsal musculature or a small, blue, plastic tag attached to the first dorsal fin. These individually numbered tags requested information about the date of recapture, location and length.

[7] Michels, S. F. 1996. Coastal finfish assessment survey. Annual Report Federal Aid in Fisheries Restoration Project F-42-R-7, Delaware Division of Fish and Wildlife, Dover. 129 pp.

Results

Sandbar sharks were captured in Delaware Bay from June to October at depths of 1.5 to 8.3 m (mean 3.4 m) where surface temperatures ranged from 15.4° to 28.5°C (Figure 1) and where salinity ranged from 22.8 to 30.3 ppt. No sandbar sharks were captured during the earliest sampling period (6 to 9 May), when water temperatures ranged from 13.0° to 14.4°C. Only juveniles were captured during sampling on 3 and 4 June (15.4° to 17.5°C). Neonates were first captured on 29 June when water temperatures were 21.2° to 23.1°C. Juveniles were captured throughout the summer until 5 September and young-of-the-year sandbar sharks were captured from their birth to 2 October (Figure 1). The latest capture by our gillnet sampling in Delaware Bay was a young-of-the-year on 2 October when water temperature was 21.0°C. There was no difference in salinity ($n = 60$), depth ($n = 63$) or surface temperature ($n = 63$) (during the nursery season, June through September) between sampling sets where sandbar sharks were present and absent (t-test, $p > 0.05$). Tidal cycle (ebb or flood) during gillnet sets was not a significant factor in the presence or absence, number captured, or CPUE during the nursery season (t-test, $p > 0.05$, $n = 48$).

Over the three year project 943 sandbar sharks were captured in Delaware Bay. The sex ratio of the total collection was slightly male-biased (54%). Totals of 199, 314 and 430 sharks were captured in 1995, 1996 and 1997, respectively (Table 1). The overall (gillnet and longline) sandbar shark catch per set ranged from 0 to 125 sharks. The mean catch ± one standard error was 11 ± 3 sharks. Gillnet sets captured from 0 to 125

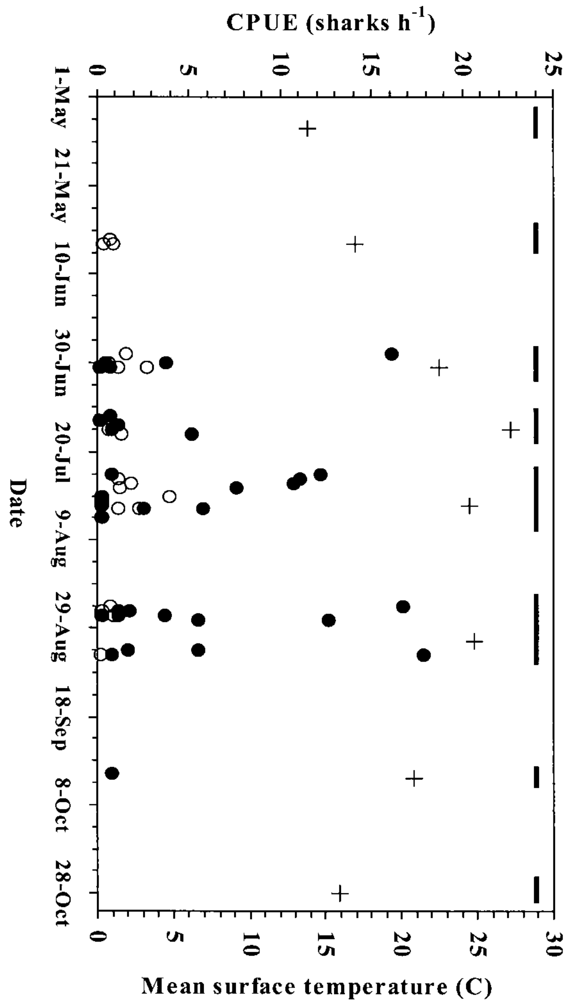

Figure 1. Gillnet sandbar shark catch per unit effort (CPUE), sampling and mean surface temperature by date. Closed circles are young-of-the-year CPUE, open circles are juvenile CPUE, bars indicate gillnet sampling dates, and crosses are mean surface temperature during each sampling interval. CPUE zero values are not shown.

(mean 13 ± 3) sharks and the 50 hook longline sets captured from 0 to 19 (mean 4 ± 1) sharks.

Sandbar sharks were captured at 20 of 31 sampling stations (Figure 2) in Delaware Bay but were most abundant along the southwest coast of the Bay. There was no difference in gillnet CPUE between sampling years (ANOVA, $p > 0.05$, $n = 35$). Catch per unit effort by station for the entire nursery season (catch pooled over all sampling intervals at individual gillnet stations divided by total sampling time at the station) ranged from 0 to 13.4 young-of-the-year and 0 to 4.7 juvenile sandbar sharks h^1 (Figure 3). The sandbar shark (all age groups) gillnet CPUE was significantly lower (t-test, $p < 0.05$, $n = 57$) in the central and northeast areas (mean 1.5 ± 0.9) than the southwestern coast (mean 4.2 ± 0.9) during the nursery season (June through September). Despite this difference there was one gillnet set made in the northeast area on 2 August 1997 that yielded 20 young-of-the-year sharks. Juveniles were uniformly distributed in Delaware Bay; there was no difference in juvenile sandbar shark gillnet CPUE or number of sharks between the northeastern and southwestern parts of the Bay (t-test, $p > 0.05$, $n = 57$). However, there were significant differences in young-of-the-year sandbar shark gillnet CPUE and numbers of young- of-the-year caught between the southwestern and northeastern stations (t-test, $p < 0.01$, $n = 57$).

Captured sandbar sharks ranged from 40 to 120 cm FL (48 to 130 cm TL). Neonates were 40 to 59 cm FL (48 to 71 cm TL) and the largest young-of-the-year was 60 cm FL (70 cm TL) (Table 2). Juveniles measured 57 to 120 cm FL (63 to 130 TL). Young-of-the-year weight ranged from 0.7 to 2.4 kg (mean 1.4 ± 0.0) and juveniles weighed 1.3 to 9.0 kg (mean 4.6 ± 0.3) (Figure 4). The FL distribution of young-of-the-year sandbar sharks significantly increased (ANOVA, $p < 0.01$) between July and August in 1995 ($n = 174$), July and August 1997 ($n = 357$), and July and September 1996 ($n = 237$) (means shown in Table 2).

During this project three tagged sharks were recaptured and measured by biologists. In August 1995, we recaptured and measured a young-of-the-year sandbar shark which we had measured, tagged and released in July (40 days-at-liberty). This individual grew from 45 cm to 48 cm FL. In August 1996, a young-of-the-year sandbar shark, recaptured by biologists from the Delaware Division of Fish and Wildlife during their annual trawl survey, measured 1 cm longer than at the time of release 47 days earlier. In June 1996, personnel from the National Aquarium at Baltimore recaptured and measured a sandbar shark we released in Delaware Bay as a young-of-the-year in August 1995. This individual grew from 58 cm to 68 cm FL.

Of the 782 sandbar sharks tagged and released during the three years, 50 have been recaptured (6.4%) (Table 1). The recapture rate of dart tags was 6% and fin tags was 9%. The recapture rate of sharks in the same year that they were tagged was 5.2%, 6.1%, and 5.7% in 1995, 1996 and 1997, respectively. All but 4 shark recaptures were made by recreational fishermen and all but 2 of the recaptured sharks were tagged as

Table 1. Summary of Delaware Bay sampling effort, sandbar shark catch, age group composition, and tag and recapture data.

Year	Gear type	Number of stations sampled	Sets	Hours sampling	Total catch	% young-of-the-year	% juveniles	Total sharks tagged	Young-of-the-year recaptured	Juveniles recaptured	Recapture rate (%)
1995	Gillnet	12	15	59	199	90	10	154	8	0	5.2
1996	Gillnet	10	31	107	314	86	14	244	15	0	6.1
1997	Gillnet	11	23	75	362	88	12				
1997	Longline	17	19	19	68		66	34			
1997	All gear combined	21	42	94	430	84	16	383	21	1	5.7
1998									3		
1999									1	1	
	Overall	31	88	260	943	86	14	781	48	2	6.4

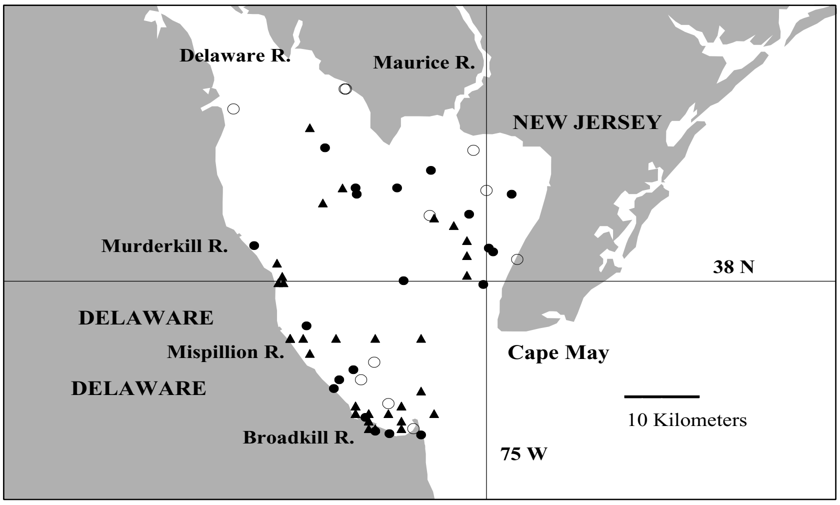

Figure 2. Location of sandbar sharks in Delaware Bay. Closed circles are sampling station locations where sandbar sharks were present, open circles are sampling station locations where sandbar sharks were absent, and closed triangles indicate the locations of sandbar shark tag recaptures.

young-of-the-year. The age 1 juvenile (tagged in early June, 1997, at 59 cm FL) was recaptured after 14 days-at-liberty 2 km from the tagging location in Delaware Bay during 1997. The larger juvenile (89 cm FL at release) was recaptured just outside of Delaware Bay three years after it was released. Sharks were at liberty from 2 to 1121 days and were recaptured between 0 and 957 km from the release location. One tagged as a young-of-the-year was recaptured the next year approximately 2 km from the 1995 tagging location. A shark tagged in 1996 was recaptured 39 km from the tagging location in 1997, and another was recaptured 2 years later 11 km from release location in Delaware Bay. Seven sharks were recaptured outside of Delaware Bay (Figure 5).

Mean distance from tag to recapture location ($n = 38$) and mean days-at-liberty ($n = 39$) of sandbar sharks recaptured in Delaware Bay during the year they were tagged were 10 km and 18 days, respectively. Sixty percent were recaptured within 7 km of release location and over 80% of these sharks were recaptured within 15 km (Figure 6). Although most recaptures were from the southwest coast of the Bay (Figure 6, inset), sandbar sharks were captured throughout the Bay (Figure 2). Seven sharks tagged along the southwestern coast were recaptured in the central and northwest areas of the bay. Days-at-liberty in Delaware Bay ranged from 2 to 62 days, and the latest date in the calendar year of a recapture in the Bay was 27 September.

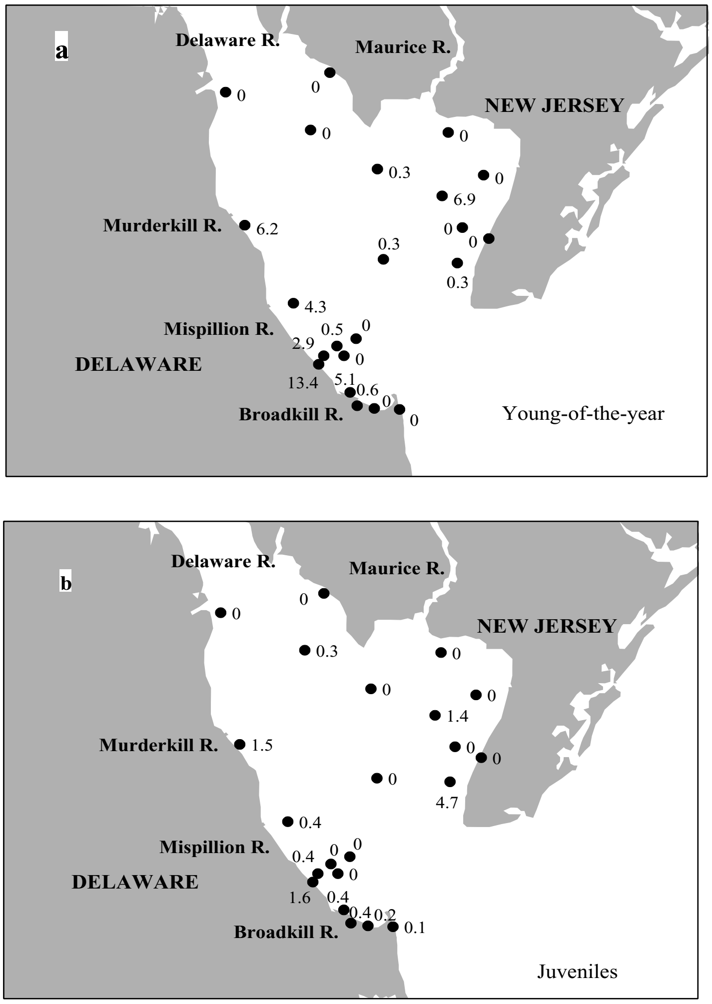

Figure 3. Delaware Bay nursery season young-of-the-year (a) and juvenile (b) sandbar shark gillnet catch per unit effort by location. Numbers are pooled CPUE by station (total catch at station divided by total hours of sampling at the station) during the nursery season (June through September).

Table 2. Summary of Delaware Bay young-of-the-year sandbar shark mean length by month [all values (except n) are in cm].

Year	n	Mean fork length			Net change in mean fork lenght	95% confidence interval (pooled variance)	Range of growth	
		July	August	September			lower	upper
1995	174	48.9	52.2	—	3.3	1.1	2.2	4.4
1996	254	49.2	49.1	51.9	2.7	1.4	1.3	4.1
1997	357	49.9	51.2	—	1.3	0.5	0.8	1.8
All years combined	785	49.5	51.8	51.9	2.4	0.5	1.9	2.9
n		373	296	116				

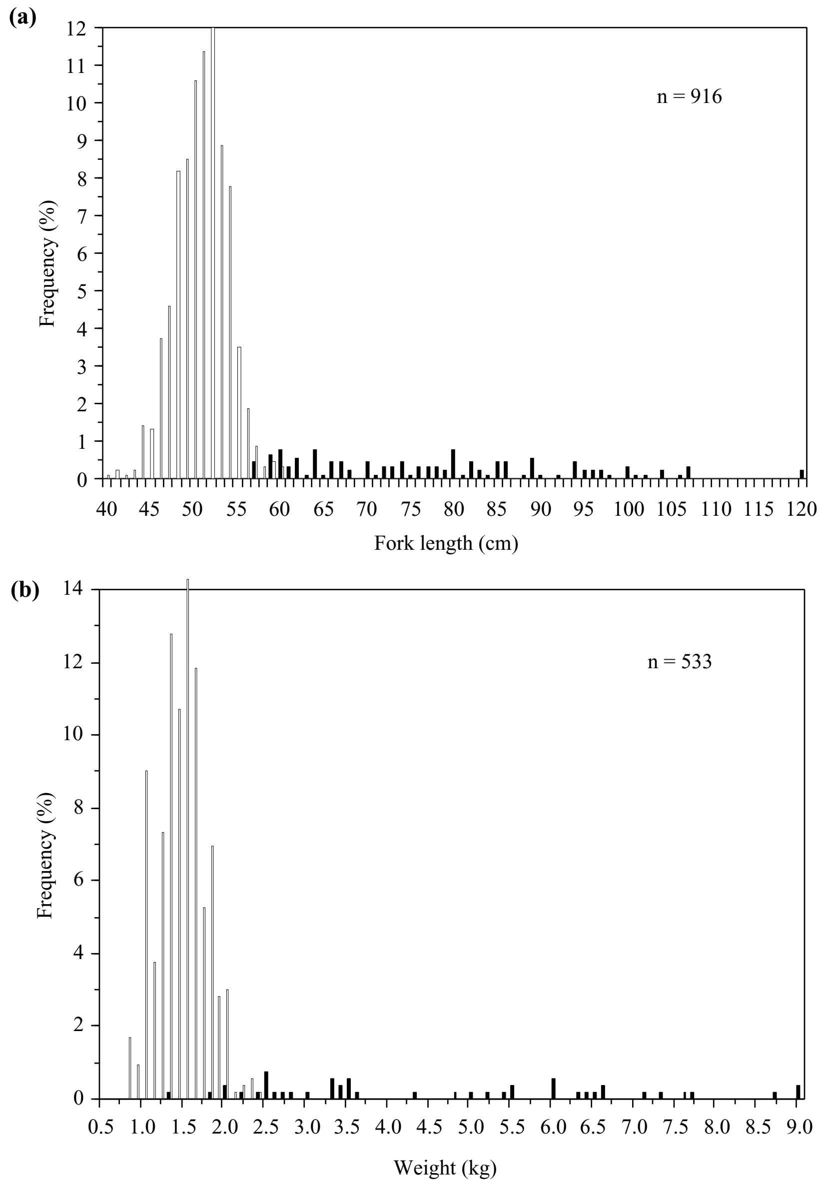

Figure 4. Delaware Bay sandbar shark (a) length frequency distribution by age group, n = 916, and (b) weight frequency distribution by age group, n = 533. Open columns are young-of-the-year (age 0+). Solid columns are juveniles (ages 1 and older).

Discussion

Pupping season

Juvenile sandbar sharks enter the Delaware Bay nursery in early June. Neonates (sharks with open umbilical scars) appeared at the end of June and the number of sandbar sharks with no indication of external healing of the umbilical scars, indicating recent birth, was low by August. Medved & Marshall (1981) captured young sandbar sharks in Chincoteague Bay, Virginia as early as the first week in June. Musick & Colvocoresses[4] report pupping in May and June in Chesapeake Bay, Virginia. Colvocoresses & Musick[3] state that pregnant females are captured there no later than June. Castro (1993) captured term pregnant females in Bulls Bay,

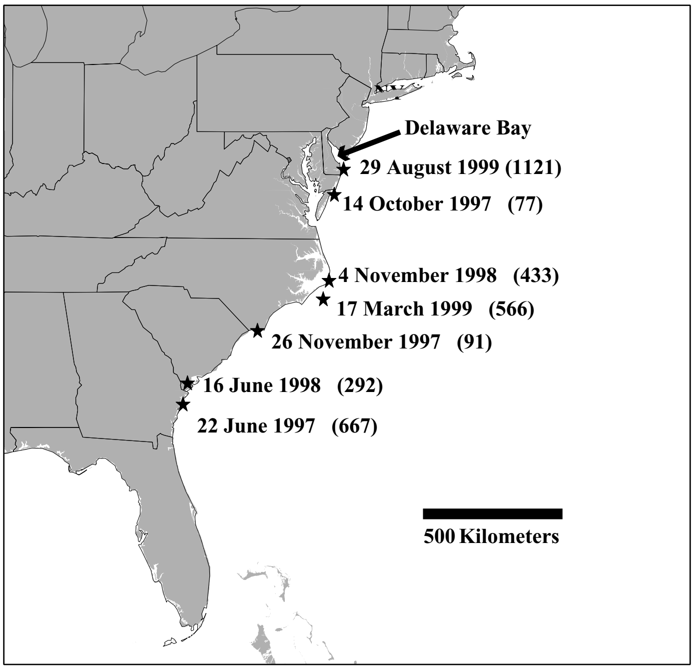

Figure 5. Locations and dates of sandbar sharks recaptured outside of Delaware Bay (n = 7). Number in parentheses indicates days-at-liberty.

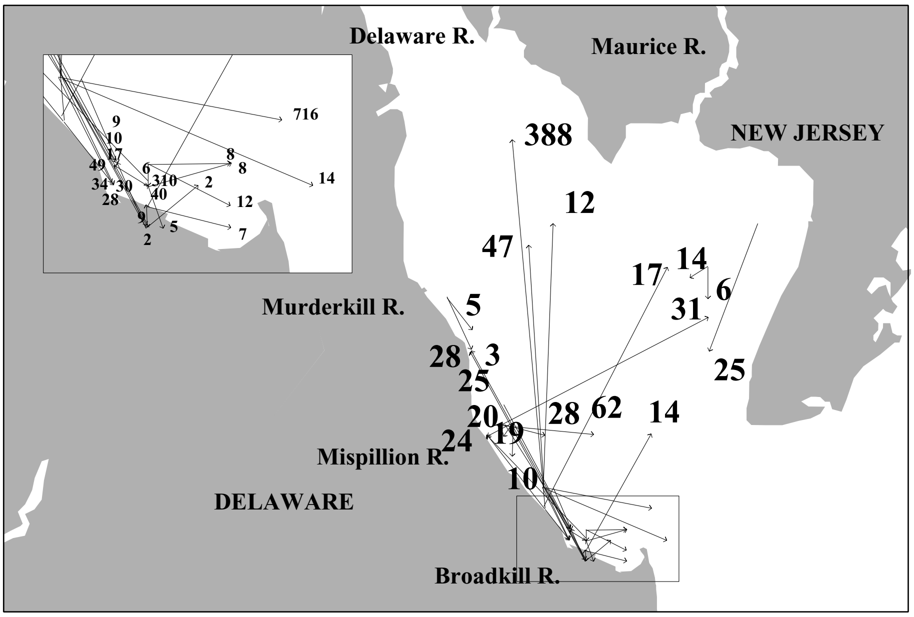

Figure 6. Delaware Bay sandbar shark tag-release and recapture locations (n = 41). Arrowhead indicates recapture location and number indicates days-at-liberty. Inset figure is zoom of area indicated by square.

South Carolina in May and June. The pupping season begins and ends later in Delaware Bay than Virginia and South Carolina. This shift may be due to the lag in spring seawater warming in the north and possibly the later arrival of term females into the northern pupping grounds because of their longer migration from the southern overwintering areas (Springer 1960).

Juvenile sandbar sharks arrive in Chesapeake Bay when surface temperatures are above 18°C, in late May and June (Grubbs[8]). The earliest capture of juvenile and neonate sandbar sharks in Delaware Bay coincided with temperatures of 15.4° and 23.1°C, respectively. The latest sandbar shark capture occurred in October when the water temperature was 21.0°C. The occurrence of juvenile and neonate sandbar sharks in Delaware Bay is consistent with other studies suggesting that water temperature is the cue to the onset and conclusion of the sandbar shark pupping and nursery season. Interannual variation of the nursery season may be explained by differences in seawater warming in the spring and cooling in the fall.

Spatial distribution

Distribution of elasmobranchs on their nursery grounds has been attributed to prey distribution (Casey & Pratt 1985, Castro 1993, Holland et al. 1993), salinity, temperature, direction of tidal flow (Medved & Marshall 1983), turbidity (Clarke 1971, Holland et al. 1993), and refuge from predators (Holland et al. 1993, Morrissey & Gruber 1993). Salinity appears to direct sandbar shark distribution toward eastern and southeastern Chesapeake Bay (Grubbs[8]). From our results, these parameters do not appear to influence distribution of sandbar sharks in Delaware Bay. Depth and environment may influence the distribution of sandbar sharks in other coastal nursery grounds where these parameters may be more heterogeneous than Delaware Bay. A study of short-term movements of individuals using telemetry may reveal more concerning the factors influencing distribution of sandbar sharks in Delaware Bay.

Higher abundance of neonate sharks along the southwestern coast of Delaware Bay relative to their abundance in central and northeastern areas may indicate that parturition occurs in close proximity to the southwestern coast. The location of parturition might be explained by the migratory route of females entering Delaware Bay from southern overwintering areas (Springer 1960); the southwestern coast would be the first suitable area encountered by a shark entering the bay. Further, there are numerous sloughs running from deep water to the shallow waters along the southwest coast where presumably the females give birth.

Aggregating behavior of young sharks in nurseries has been shown by Simpfendorfer & Milward (1993) in *Carcharhinus tilstoni* and *Rhizoprionodon taylori*, in *Sphyrna lewini* by Clarke (1971) and Holland et al. (1993), and *Negaprion brevirostris* by Morrissey & Gruber (1993) and was suggested to be a predator avoidance behavior. Holland et al. (1993) observed a dispersed distribution pattern of young *S. lewini* at night, further suggesting that daytime aggregation is a refuging behavior. On several occasions our net caught sandbar sharks in high numbers, suggesting aggregating behavior of sandbar sharks in our daytime gillnet sampling in Delaware Bay. We did not sample at night so cannot conclude that this aggregating behavior is a daytime refuging phenomenon. It seems unlikely however, that a daytime refuge is necessary for avoidance of visual predation because Delaware Bay is highly turbid, rendering daytime benthic visibility to night-like conditions.

Predation of young sandbar sharks may occur in Delaware Bay. During our three-year study we observed three young-of-the-year (48, 49 and 50 cm FL) and one juvenile (78 cm FL) with fresh and healing shark bite marks on the posterior dorsal flank. By the size and pattern of these marks, we surmise that they were made by larger sandbar sharks and young sandtiger sharks, *Odontaspis taurus*. All but one of the bitten sandbar sharks was captured by our gillnet sampling. Although it is possible that some of the sharks were attacked while caught in the gillnet, most wounds were partially healed, indicating that these sharks were previously bitten. One young sandbar shark captured on our longline had a fresh bite mark with a scraping pattern, consistent with the jagged teeth of a sandtiger shark. On that same longline set we captured a 97 cm FL sandtiger shark. Results from our gillnet catch and tag-recapture data show that the primary nursery area is along the southwest coast of Delaware Bay between the Broadkill and Murderkill rivers, but young-of-the-year disperse through the bay during the nursery season.

[8] Grubbs, R. D. 1996. Recruitment patterns and nursery ground delineation for *Carcharhinus plumbeus* in Chesapeake Bay. Proceedings of the 12th Annual Meeting of the American Elasmobranch Society, Hotel InterContinental, New Orleans, 13–19 June 1996. 343 p. (abstract).

Juveniles are uniformly distributed in the bay as evidenced by equal catch abundance between New Jersey and Delaware stations. Young sandbar sharks have the potential for long distance movement in a short time period (Medved & Marshall 1983), however most of the Delaware Bay recaptures (59%) were made less than 5 km from the release location and only seven individuals crossed the bay. These data suggest that although there is some dispersal through Delaware Bay during the nursery season, the young-of-the-year tend to remain along the southwestern coast.

The recaptures of 4 sandbar sharks tagged in Delaware Bay after one (n = 2), 2 (n = 1), and 3 (n = 1) years at liberty suggest that there is either a limited availability of suitable nursery grounds or that natal nursery homing occurs. Some juvenile sandbar sharks return to Chesapeake Bay (R.D. Grubbs personal communication). Other recapture evidence does not support the natal nursery homing hypothesis; two sandbar sharks tagged as a young-of-the-year in Delaware Bay were recaptured 2 years later in mid- to late June in the Okatee River, South Carolina, and St. Catherine's Sound, Georgia. The presence of young sharks suggest these areas are summer nursery grounds, but more sampling is necessary to determine the significance of these areas to the sandbar shark. These are important findings because if suitable nursery habitat is limiting, density-dependent factors may curtail population growth (Springer 1967).

The recaptures of 3 sandbar sharks off North Carolina between November and March are consistent with Springer's (1960) description of their overwintering nursery ground. When sandbar sharks were no longer captured in Delaware Bay, they were captured off Virginia in mid-October and then off North Carolina in November and March. Additionally, Merson & Pratt[2] reported recaptures of age 0+ sandbar sharks (tagged in New Jersey in July) off North Carolina in March.

Abundance

To evaluate the relative importance of coastal nursery grounds, sampling methods must be consistent. Few studies quantifying abundance of sharks in nursery grounds have been published and comparison of studies is difficult given differences in capture methods. The number of neonate sandbar sharks reported in this study is unequaled by any published account of sandbar shark nursery grounds. However, there are no published quantitative gillnet surveys targeting sharks along the US East Coast.

Comparing our study to a longline survey for juvenile sharks in Chesapeake Bay (Musick et al. 1993) suggests similarities in relative abundance of young sandbar sharks. In Chesapeake Bay, longline CPUE of young sandbar sharks 42 to 83 cm FL (50 to 100 cm TL) between May and October was approximately 6 sharks 100 hooks^{-1} (Musick et al. 1993). Overall longline CPUE in Delaware Bay (sandbar sharks 43 to 106 cm FL) was just over 7 sharks 100 hooks^{-1}.

Delaware Bay is a pupping ground for the sandbar shark and a nursery ground for juveniles that return seasonally. The total number of juveniles captured during this study was lower than that of young-of-the-year sandbar sharks. This difference can be explained by the cumulative mortality that reduces the abundance of older age classes, the design of our gillnet gear which targeted smaller individuals, and the ability of juvenile sharks to utilize a more extensive nursery range outside the Bay than young-of-the-year sharks. Our longline gear captured a larger percentage of juvenile sharks suggesting that either the gillnet or longline selectively sample the population. A combination of gear types should be used to reduce bias in describing the length distribution of sharks in a nursery ground.

Another explanation for lower juvenile abundance (relative to young-of-the-year sharks) in Delaware Bay is that juvenile nursery grounds (secondary nursery grounds) are geographically more extensive than pupping areas and therefore the densities of sharks ages 1 and older in a given nursery are lower. Sandbar sharks larger than 84 cm FL are distributed as far north as Cape Cod, Massachusetts (G. Skomal personal communication). The largest juvenile we captured in Delaware Bay measured 120 cm FL. Casey et al. (1985) reported juveniles up to 136 cm FL in a Virginia nursery ground. The length of the largest juvenile we captured in Delaware Bay corresponds to a minimum age of 8 (Sminkey & Musick 1995) and a maximum age of 16 (Casey & Natanson 1992) years. These data and the recaptures of sandbar sharks in Delaware Bay during the years following their initial release indicate that the Bay is used as a nursery for 8 to 16 years.

Growth

Young-of-the-year sandbar sharks grow 2–3 cm in length over the nursery season. Results of our length frequency analysis are consistent with lengths measured on recaptured sharks during this study. Additionally, Casey et al. (1985) reported that a young-of-the-year sandbar shark measured by them at tag and recapture had grown 3 cm between mid-July and mid-September in Great Machipongo.

Sminkey & Musick (1995) report von Bertalanffy model parameters for sandbar sharks that yield a growth increment of 11 cm between ages 0 and 1 and suggested that 75% of the yearly growth occurred between July and September. Casey et al. (1985) and Casey & Natanson (1992) report von Bertalanffy parameters that produce 10 and 6 cm growth increments, respectively, from age 0 to age 1. During this project, a sandbar shark tagged as young-of-the-year and recaptured at age 1 had grown 10 cm (measured by biologists at release and recapture). Although growth in the first year is consistent with Sminkey & Musick (1995) and Casey et al. (1985), our best estimate of growth between July and September is 2 to 3 cm. This growth is only about 33% of the age 0 to 1 growth increment, and is less than half Sminkey & Musick's hypothesized proportion of growth during the nursery season. The growth increment during the nursery season is probably not as high as 75%. Investigations of prey abundance and growth in overwintering nursery areas will clarify the proportions of growth during the year and possibly yield information about habitat related growth rates.

Essential fish habitat

As stated in the Magnuson-Stevens Fishery Conservation and Management Act[6], essential fish habitat is defined as waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. As a nursery ground, Delaware Bay is essential habitat for the sandbar shark. Young sandbar sharks are present from June to October. Sandbar sharks use the southwestern Bay as a pupping ground and the entire Bay as a summer feeding nursery for young-of-the-year and juvenile sharks. Some sharks return to Delaware Bay from their overwintering nursery grounds and the presence of large juveniles (120 cm FL) in Delaware Bay shows this nursery is utilized for 8 to 16 years (Casey & Natanson 1992, Sminkey & Musick 1995). The southwestern coast of the Bay appears to support a higher abundance of sandbar sharks than the central and northeastern areas. However, the entire Bay should be considered a sandbar shark nursery ground. The estimated growth in Delaware Bay is consistent with reports of summer growth in other US East Coast nursery grounds, indicating this area provides the necessary resources for young sandbar sharks.

Ferreira (1997) reported an average of 12 044 sandbar sharks were landed annually by recreational fishers in Delaware Bay and that commercial fisheries operating within and adjacent to Delaware Bay were also catching sandbar sharks. Further studies should be conducted to evaluate the impacts that fisheries may have on this essential habitat.

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