Evidence of a Bull Shark Nursery in the Altamaha River Estuary, Georgia

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Abstract: The National Marine Fisheries Service (NMFS) has developed fishery management plans for sharks that require delineation of nursery areas, monitoring of relative abundance of juveniles in these areas, and identification of habitat relationships between juvenile sharks and the nursery environment. Netting surveys conducted during 2008 and 2009 in the Altamaha River Estuary suggested that the estuary served as both a primary and secondary nursery for bull sharks (*Carcharhinus leucas*) in 2008 and limited use as a secondary nursery in 2009. Variation in spatial distribution also suggested that bull sharks in the Altamaha River Estuary partitioned habitat based on size. This study represents the first documentation of a bull shark nursery in Georgia waters, but further monitoring is needed to determine the importance of this nursery and to identify factors influencing its use through time.

Key words: primary nursery, secondary nursery, estuary, neonate, young-of-the-year

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Sharks exhibit unique life history strategies that have allowed them to be evolutionarily successful (Castro 1983). Unlike most bony fishes that produce large numbers of externally fertilized eggs, sharks typically produce small numbers of well-developed young that are both conceived and reared internally. Many sharks are also characterized by slow growth, delayed age at maturity, large size, and long lifespan (Castro 1983). This combination of life-history traits results in a low reproductive potential, and hence, low resilience to fishing mortality (Hoenig and Gruber 1990). Despite this vulnerability, sharks have been increasingly exploited in recent decades, both as bycatch in pelagic longline fisheries (Bonfil 1994) and as targeted species in directed fisheries (Rose 1996). The combined effects of poor management and overfishing have lead to several well-documented population collapses of several species including porbeagle (*Lamna nasus*) (Anderson 1990), soupfin shark (*Galeorhinus galeus*) (Olsen 1959), spiny dogfish (*Squalus acanthias*) (Hoff and Musick 1990), and basking shark (*Cetorhinus maximus*) (Parker and Stott 1965).

Because of growing concerns regarding overfishing of many Atlantic coast shark species, the National Marine Fisheries Service (NMFS) developed the first fishery management plan for U.S. shark populations in 1993. The goal of this plan was to prevent further population declines, and it categorized the various species into three distinct management groups (i.e., large coastal, small coastal, and pelagic) dependent on fishery characteristics as opposed to traditional approaches based on biology (NMFS 1993). Subsequent surveys revealed that many species within the large coastal group were already overfished by the time the plan was implemented (Camhi 1998). Consequently, the NMFS determined that a single management strategy for large coastal sharks was inappropriate because of the different life-history characteristics and varying exploitation rates among the different species within the group (NMFS 2008). Although stock assessments have been completed for several populations of these large coastal shark species, including sandbar sharks (*Carcharhinus plumbeus*) and blacktip sharks (*Carcharhinus limbatus*), current population data are lacking for many other species because they are rarely encountered in either commercial fisheries or fisheries-independent surveys.

Unlike teleosts, the relationship between the numbers of adults and young in a population is direct for most shark species (Holden 1974, Carlson and Brusher 1999, Helfman 2007); however, juvenile abundance estimates and identification and assessment of nursery habitats are completely lacking for most shark species. Consequently, several recent fishery management plans have specifically identified studies of juvenile nursery habitats as a critical research priority. These plans also recommend monitoring of juvenile abundance within nursery habitats in addition to research designed to better understand the linkages between habitat supply and the growth and survival of juvenile sharks within nursery environments (NMFS 1993, 2003, 2006).

Nursery grounds are critically important for successful reproduction of many shark species. Typically, they are located in protected coastal or estuarine areas (Castro 1993, McCandless et al. 2007) where large gravid females can give birth before returning to marine waters. Depending on species, the young remain in the protection of these nursery habitats for several weeks, months, or years after their birth (Springer 1967). Shark nursery habitats can be classified as either primary or secondary depending on which juvenile stages are present (Bass 1978). Primary nursery areas are defined as any area where birth occurs or where young-of-the-year

(YOY) are present. Secondary nursery areas are those areas used by juveniles at any time during their first few years of life (Bass 1978). Regardless of category, shark nursery areas generally provide juveniles with abundant food resources and protection from predators to help maximize growth and survival (Springer 1967, Branstetter 1990, Simpfendorfer and Milward 1993).

Few shark nursery areas have been identified or described in the coastal waters of Georgia. However, many Georgia estuarine and nearshore waters are known to be productive primary and secondary nurseries for several shark species including Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*), bonnethead sharks (*Sphyrna tiburo*), blacktip sharks, and sandbar sharks (Belcher 2008). Although confirmatory studies are needed, recent surveys by Belcher (2008) suggest that Georgia estuaries may also serve as important nurseries for scalloped hammerheads (*Sphyrna lewini*), finetooth sharks (*Carcharhinus isodon*), spinner sharks (*Carcharhinus brevipinna*), bull sharks (*Carcharhinus leucas*), lemon sharks (*Negaprion brevirostris*), and blacknose sharks (*Carcharhinus acronotus*).

The bull shark is a large, coastal, euryhaline species that is found worldwide in subtropical and tropical coastal and estuarine habitats (Thorson et al. 1973, Compagno 1984). Young bull sharks commonly inhabit nursery areas located in brackish water bays and estuaries of large rivers (Springer 1967, Snelson and Williams 1981, Simpfendorfer and Milward 1993). On the U.S. Gulf Coast, bull shark nurseries have been identified in the estuarine waters of Texas (Hueter and Tyminski 2007), Louisiana (Blackburn et al. 2007, Neer et al. 2007), Mississippi and Alabama (Parsons and Hoffmayer 2007), and Florida (Carlson 2002, Hueter and Tyminski 2007, Steiner et al. 2007). Along the U.S. Atlantic Coast, however, only the Indian River Estuary in Florida has been confirmed as a bull shark nursery ground (Snelson et al. 1984, Adams and Paperno 2007). The goal of this study was to evaluate the use of the Altamaha River Estuary in Georgia by bull sharks to determine whether the estuary is an important nursery area for the species. The specific objectives of this study were to (1) document the seasonal occurrence of different life stages of bull shark in the Altamaha River Estuary and (2) identify key environmental variables that may affect temporal and spatial variation in the distribution of bull sharks.

Methods

Study Site

This study was conducted in the Altamaha River Estuary, located near Darien, Georgia (Figure 1). The estuary spans approximately 67 km^2 and is one of the largest, minimally impacted estuaries on the Atlantic coast (NOAA 1996). Freshwater flows into the estuary are generally greatest during spring and lowest during the summer months. The estuary is characterized by substrates consisting of sand and mud, large expanses of salt marsh, numerous tidal creeks, and large tidal fluctuations of up to 2.1 m (Johnson et al. 1974). For the purposes of this study, the Altamaha River Estuary (ARE) refers to the entire study area. The portion of the ARE downstream of river kilometer five (rkm 5) is referred to hereafter as Altamaha Sound (AS). All portions of the estuary above rkm-5 are referred to as upstream sites with rkm referenced as appropriate (Figure 1).

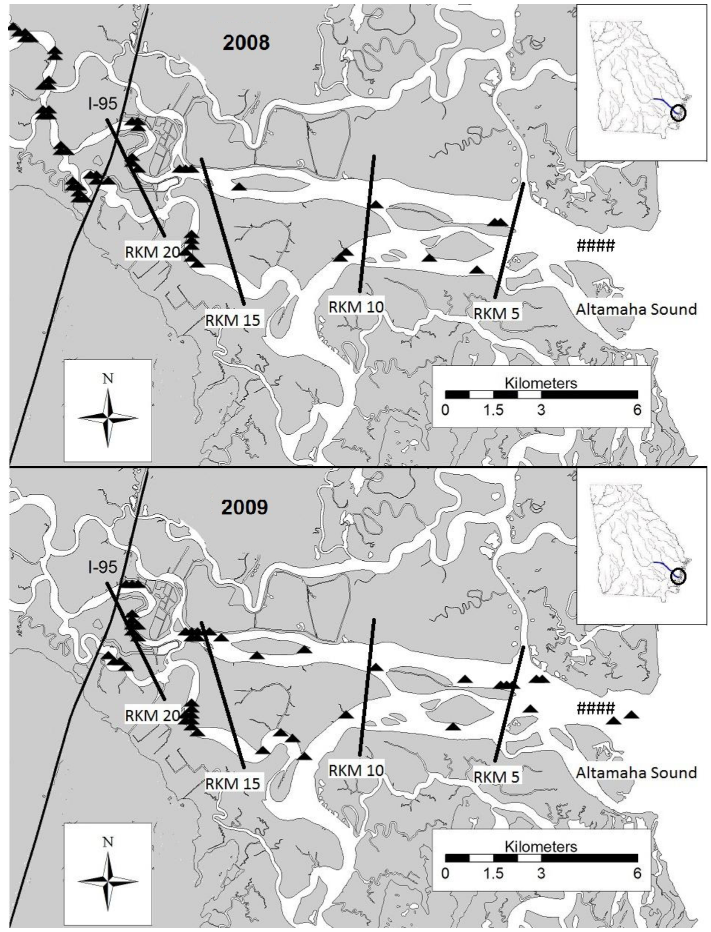

Figure 1. Netting locations of trammel and experimental gill nets (triangles) and drift nets (####) in the Altamaha River Estuary, Georgia, 2008–2009. River kilometers are depicted in 5-km intervals (black bars; RKM = river kilometer).

Fish Sampling

Bull sharks were collected in the ARE from May–July of 2008 and 2009. In 2008, bull sharks were obtained from an ongoing sturgeon (*Ascipenser* spp.) research project using large-mesh drifted gill nets (drift nets) in combination with anchored experimental gill nets and trammel nets. Drift nets were 30.5 m long and 7.6 m deep and constructed of braided nylon webbing. Drift nets consisted of a single panel of stretch mesh sizes of 30.5 cm, 35.6 cm, or 40.6 cm and were usually attached to two other nets of different mesh size to minimize size-selective sampling. Soak times were approximately 3 hrs, beginning 1 h before slack tide and ending 1 h after slack tide. Drift nets were deployed only within the AS and were monitored continuously.

Experimental gill nets consisted of three 30.5-m panels of 7.6-cm, 10.2-cm, or 15.2-cm stretch monofilament mesh. Trammel nets were constructed of a 7.6-cm stretch mesh inner panel and two 30.5-cm stretch mesh outer panels of monofilament mesh. Both trammel nets and experimental gill nets were 91.4-m long and 3.1-m deep and were fished only during slack tidal periods. Soak times ranged from 30 to 60 min depending on tidal conditions. After nets were deployed, temperature and salinity were recorded using a YSI 85 multi-meter in the immediate vicinity of the nets. In 2008, experimental gill nets and trammel nets were deployed only at upstream sites within the ARE.

Because shark sampling in 2008 was secondary to safe capture and release of federally protected sturgeons, bull sharks were often released before accurate counts or biological data (i.e., life stage, see 2009 sampling below) could be recorded. Additionally, drift nets were not used after 15 June 2008. Therefore, Altamaha Sound was not sampled during the last half of the sampling period in 2008. In 2009, bull sharks were sampled using the same gear as in the previous year; however, drift nets were deployed once each week for the duration of the sampling period (May–July). As in 2008, experimental gill nets and trammel nets were deployed at upstream sites, but in 2009, these gears were also deployed in AS.

In accordance with the NMFS Apex Predator Program's Cooperative Atlantic States Pupping and Nursery (COASTSPAN) survey protocol, all sharks were identified to species, sexed, measured for both fork and total lengths (cm FL and TL), and weighed (kg). Similar to Merson (1998), umbilical scar condition was recorded as "umbilical remains," "fresh open," "partially healed," "mostly healed," "well healed," or "none." Prior to release, all sharks were tagged with a NMFS roto tag, and sharks larger than 1 m TL were tagged with a NMFS dart-type M-tag. For the purpose of classifying the Altamaha River Estuary as a primary or secondary nursery, life stage of captured bull sharks was classified as either "neonate" (umbilical remains present, scar open), "YOY" (umbilical scar healed but visible), "large juvenile" (no umbilical scar present; male: claspers soft, not calcified; female: <225 cm TL (Branstetter and Stiles 1987)), or "adult" (male: claspers calcified; female: ≥225 cm TL (Branstetter and Stiles 1987)).

Results

In 2008, a total of 50 gill net sets, 26 trammel net sets, and 16 drift net sets captured 22 bull sharks consisting of neonates, YOY, large juveniles, and adults. Of these fish, seven were large juveniles or adults, and 15 were either neonates or YOY. Large juveniles and adults ($n = 7$) were captured in AS only during the month of May at water temperatures of 25.5 to 27.3 C (mean = 25.1 C) and salinities of 17.3 to 30.0 ppt (Figure 2). Neonates and YOY ($n = 15$) were captured at upstream sites (rkm 14–18) during June and July at water temperatures ranging from 28.8 to 31.4 C (mean = 30.1 C) with salinities of 10.4 to 12.4 ppt (Figure 2).

Approximately 30 additional large juvenile (>120 cm) and adult bull sharks (>225 cm) were captured in AS in 2008 but, because of the large number of sturgeon and/or sharks in the catch, many of these fish were released before detailed data could be recorded. Approximately 15 additional YOY bull sharks and approximately five additional neonates with umbilical remains were captured at upstream sites (~rkm 14–18), but again, these fish were released before detailed biological data could be recorded. In addition to the bull sharks captured, we also captured blacktip sharks, finetooth sharks, Atlantic sharpnose sharks, and bonnethead sharks within the AS (Table 1).

In 2009, a total of 124 gill net sets, 31 trammel net sets, and 12

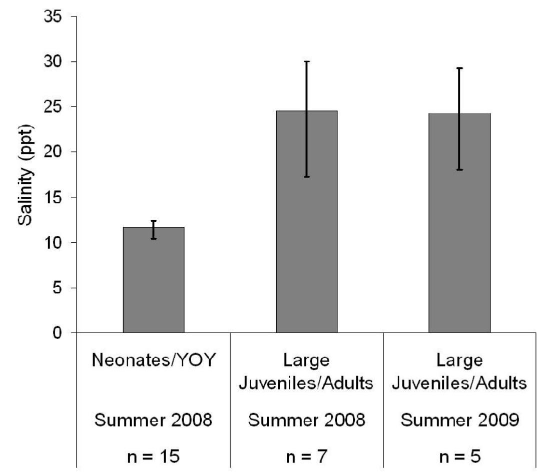

Figure 2. Salinity at capture for bull sharks 2008–2009. Columns represent mean salinity for group, and error bars represent the range of salinities bull sharks were captured. No neonates or YOY were collected in 2009.

Table 1. Shark captures by species in the Altamaha River Estuary for both years of this study. In 2008, additional sharks were captured but not recorded.

Species	2008	2009
Blacktip Shark	3	36
Bonnethead Shark	1	15
Atlantic Sharpnose	1	13
Finetooth Shark	2	6
Bull Shark	22	5

drift net sets captured 75 sharks comprised of five species. Blacktip sharks were the most abundant species ($n = 36$), and bull sharks were the least abundant species ($n = 5$). Other species captured included bonnethead sharks, Atlantic sharpnose, and finetooth sharks (Table 1). Five large juvenile bull sharks ranging in size from 173.0 to 197.5 cm TL (mean TL = 189.5 cm; SD = 9.9 cm) were captured at water temperatures of 28.5 to 30.0 C (mean = 29.1 C) and salinities of 18.0 to 29.3 ppt (Figure 2). All five large juvenile bull sharks captured in 2009 were captured in AS between late June and late July. No neonates or YOY were captured in 2009. No large juveniles or adults were captured upstream of the AS, and no neonate or YOY bull sharks were captured below rkm 14 in either summer (Figure 3).

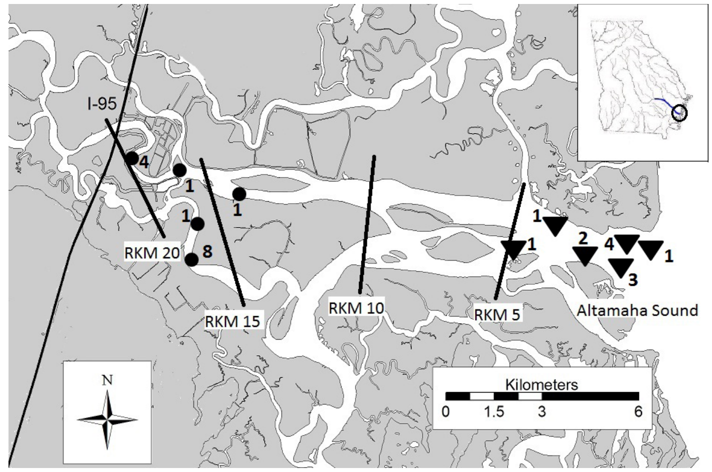

Figure 3. Locations of 27 bull shark captures from May–July 2008 and 2009. Twelve large juveniles (inverted triangles) were captured in Altamaha Sound, while 15 neonates and YOY (circles) were captured at upstream sites. Numbers represent number of sharks captured in sampling event.

Discussion

Since fishery management plans prioritized the identification and delineation of shark nursery areas, multiple bull shark nurseries have been identified in estuarine areas along the U.S. Gulf Coast; however, on the U.S. Atlantic Coast, only the Indian River Lagoon system in Florida has been identified as an important nursery for the bull shark (McCandless et al. 2007). Results of our study provide evidence that the Altamaha River Estuary is a nursery area for bull sharks; however, the relatively low number of neonates, YOY, and large juveniles collected (particularly during the second year of our study) may indicate that it is a limited-use nursery. Presence of large juvenile bull sharks in AS during 2008 indicated that bull sharks used this habitat as a secondary nursery area. Presence of neonate and YOY bull sharks at sites upstream of the AS suggested these areas served as a primary nursery during that same summer. However, the majority of the sampling conducted that year was allocated at sites upstream from where neonate and YOY bull sharks were captured. Hence, abundance of neonates and YOY life stages may have been much higher in the study area than the data suggested. Conversely only five bull sharks were captured in 2009, despite implementation of a more intensive sampling effort within the lower ARE during that summer. Although some juvenile bull sharks were captured from this area in 2009, the youngest animals captured were large juveniles, suggesting that the ARE had limited use as a secondary nursery in 2009.

Despite the limited sample sizes obtained in our study, the distribution of bull shark captures during the summer of 2008 and 2009 suggested that bull sharks within the ARE partitioned habitat based on life stage. Similar results were reported by Simpfendorfer et al. (2005) in the Caloosahatchee River-Pine Island Sound system in southwest Florida. In that system, the smallest individuals were collected in the Caloosahatchee River, with neonates collected only in June and July. Larger bull sharks were found in the more open areas of San Carlos Bay and Pine Island Sound (Simpfendorfer et al. 2005). In the ARE, neonate and YOY bull sharks were collected at upstream sites from early June–July during the summer 2008, but large juveniles were never captured in waters upstream of the AS. The fact that juvenile and adult bull sharks were never collected in nets at upstream sites in either year suggests that large bull sharks do not frequently inhabit these areas of the ARE.

Several previous studies have shown that many shark species may select specific nursery areas that provide abundant food resources and increased protection from large predators (Springer 1967, Branstetter 1990, Simpfendorfer and Milward 1993, Simpfendorfer et al. 2005). As such, habitat partitioning may play a key role in the spatial separation of neonates and YOY life stages from larger juveniles and adults. Because large bull sharks are known to be cannibalistic (Snelson et al. 1984), and several other large coastal shark species were captured during our study, habitat selection by neonate and YOY bull sharks within the ARE may be a critical factor in determining their recruitment to successive life stages. Although confirmatory studies are needed, these inferences are supported by the spatial separation of life stages we observed in our study. Future studies with similar gear types and sampling regimes conducted for several consecutive years should be initiated within the ARE to better understand how spatial and temporal segregation of bull shark life stages affects annual recruitment of this large coastal species. Likewise, studies of habitat selection based on food availability are also needed to better understand the ecology of this species.

Water temperatures did not appear to affect the occurrence of bull sharks within the ARE during this study. This observation is in accordance with the findings of Heupel and Simpfendorfer

(2008) who evaluated summer distribution of bull sharks within the Caloosahatchee River-Pine Island Sound system in southwest Florida. Although bull sharks can tolerate prolonged exposure to freshwater (Thorson et al. 1973), recent studies have demonstrated that salinity is an important factor in determining occurrence and seasonal distributions of bull shark life stages (Simpfendorfer et al. 2005, Heupel and Simpfendorfer 2008). For example, small juveniles and neonates in the Caloosahatchee River were most common at salinities of 7.0 to 17.5 ppt (Simpfendorfer et al. 2005), and tracking of neonate and YOY bull sharks outfitted with acoustic transmitters revealed avoidance of salinities less than 7.0 ppt and affinity for salinities of 7.0 to 20.0 ppt (Heupel and Simpfendorfer 2008). Use of moderate salinities by bull sharks is thought to minimize the metabolic costs of osmoregulation (Simpfendorfer et al. 2005, Heupel and Simpfendorfer 2008). Similarly, neonate and YOY bull sharks in the ARE were captured at salinities of 10.4 to 12.4 ppt, further supporting the hypothesis that mid-range salinities may facilitate more efficient osmoregulation in bull sharks. In this study, large juvenile bull sharks were captured in approximately the same mean salinity (24.5 ppt) and range (17.3 to 30.0 ppt) of salinities in both years, suggesting that they may select more saline habitats than those preferred by neonates and YOY. Further studies of salinity preferences of different life stages will provide new information regarding ontogenetic changes in bull shark physiology.

Like most estuarine systems, salinity in the ARE is largely influenced by freshwater inflow (Sheldon and Alber 2002). Historically, flows in the Altamaha River are typically highest in May and decrease as summer progresses. In 2008, river flows were approximately 30% of the historical average (USGS 2010), resulting in mid-range salinities (i.e., 7.0 to 20.0 ppt) at protected upriver sites where neonates and YOY were captured in early summer. Conversely, higher than average flows in 2009 created low salinities (i.e., <7.0 ppt) extending all the way downriver to the entrance of AS through early July, and no neonates or YOY were captured. Thus, availability of primary nursery habitat in estuarine systems like the ARE may vary depending on annual patterns of precipitation and flow.

Results of this study suggest that the ARE serves limited use as a nursery for bull sharks. Additionally, our findings support the previous work of Simpfendorfer et al. (2005) who suggest that bull sharks may partition habitat based specific salinity preferences of specific life stages. Annual variation in abundance and distribution of bull shark life stages documented in our study also suggests that habitat availability within specific estuaries may vary depending on annual fluctuations in flow that alter the salinity gradients within estuarine habitats. We emphasize, however, that additional studies are needed to better understand how these dynamics interact with other biological variables such as food availability and interactions with other large coastal shark species. Regardless, successful reproduction in bull sharks requires access to nursery habitat within large estuaries. Unfortunately, most of these areas are situated in close proximity to dense human populations. Consequently, bull sharks may be at greater risk from anthropogenic habitat alterations (i.e., flow alteration) compared to other large coastal shark species. A better understanding of the relationship between juveniles and the nursery environment will allow managers to predict how particular human actions may impact bull shark populations. Therefore, continued studies focusing on bull shark ecology, physiology, and the identification of critical habitat—especially nurseries—will be vital to the development of species-specific management practices that better protect the species.

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