Assessing The Variability In Distribution Of Four Shark Species Within The Mississippi Sound

Daniel Crear
University of New England

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Assessing the variability in distribution of four shark species within the Mississippi Sound

An Honor Thesis Presented to
The Faculty of the Department of Marine Sciences
University of New England

In partial fulfillment of the
requirements for the Degree of
Bachelor of Science with Honors in Marine Biology

By

Daniel Crear
Undergraduate Honors Marine Biology Student
University of New England
Biddeford, Maine
May 2, 2012

Thesis Examination Committee:

James Sulikowski, Ph.D. (Department of Marine Sciences (MAR), UNE)
William Driggers III, Ph.D. (National Marine Fisheries Service; MAR)
Eric Hoff Mayer, Ph.D. (National Marine Fisheries Service; MAR)
Abstract

Global declines in shark populations have been observed, including several species indigenous to the northwest Atlantic Ocean and the Gulf of Mexico (GOM). Attributing to these declines is a lack of abundance and distribution data of early life stages, particularly within essential habitats such as nursery grounds. Previous research has defined the Mississippi Sound as a multispecies shark nursery, therefore determining how abundance and distribution patterns change will aid in verifying where these species are throughout the year within this shark nursery. Thus, the objectives of the current study were to describe the variability in distributions of four shark species in the Mississippi Sound. From March 2009 to October 2011, 1,309 sharks including, 737 Atlantic sharpnose, *Rhizoprionodon terraenovae*, 332 finetooth, *Carcharhinus isodon*, 151 blacktip, *Carcharhinus limbatus*, and 89 bonnethead, *Sphyrna tiburo*, sharks were collected within the Mississippi Sound. Male Atlantic sharpnose were present in the sound throughout all life stages where as females left the sound once maturity was reached. Immature finetooth and blacktip utilized the Mississippi Sound as a nursery and left before maturity was reached. Low abundances of bonnethead suggested that this area is not as important for this species. All species preferred the Central and East Areas within the Mississippi Sound in 2010 and 2011, demonstrating the possible effect of environmental parameters such as temperature, salinity, and dissolved oxygen on shark distribution. Relatively higher abundances were observed in the summer compared to spring and fall for all species of sharks. This study confirms that the Mississippi Sound is an important nursery ground for Atlantic sharpnose, finetooth, and blacktip sharks.
Introduction

It is well documented that global shark populations have been declining since 1970 (Myers et al., 2007; Baum & Blanchard, 2010). For example, within the North Atlantic Ocean the relative abundance of several pelagic species including mako, *Isurus oxyrinchus*, oceanic whitetip, *Carcharhinus longimanus*, and blue sharks, *Prionace glauca*, has declined by 34, 50, and 53%, respectively over the last 20 years (Baum & Blanchard, 2010). Decreasing coastal shark populations have been observed as well. For example, the blacktip, *C. limbatus*, sandbar, *C. plumbeus*, and bull sharks, *C. leucas*, have each suffered an estimated 55% decline in their relative abundance (Baum & Blanchard, 2010). Contributing to this collapse is a lack of accurate life history, abundance, and distribution data of early life stages occurring within essential fish habitats (EFH) particularly within nursery grounds (Rechisky & Wetherbee 2003; Heithaus 2007; Parsons & Hoffmayer 2007; Ulrich 2007; Kinney & Simpfendorfer 2009).

Previous studies have reported several multispecies shark nursery grounds along the coasts of the northwest Atlantic Ocean and Gulf of Mexico (GOM), including the Mississippi Sound (MS Sound) (Castro 1993; Parsons & Hoffmayer 2007). The MS Sound is located in northern GOM and is bordered by the Mississippi/Alabama coastline to the north and by a string of barrier islands to the south. Within these shallow, estuarine waters, large assemblages of several juvenile sharks including blacktip, *C. limbatus*, Atlantic sharpnose, *Rhizoprionodon terraenovae*, and finetooth, *C. isodon* sharks have been observed, supporting the hypothesis that this area serves as an important nursery ground for at least these shark species.

Despite the importance of nursery grounds to the survival of a number of shark species, very little is known about how abundance and distribution patterns change within these areas. For example, no studies have examined how age distributions within nursery areas vary on a
temporal, spatial or seasonal scale (Parsons & Hoffmayer 2007). Gaining a detailed understanding on how multiple cohorts of different shark species utilize these areas is extremely important in the establishment of effective management practices. In addition, by identifying discrete species specific habitats and how distributions change overtime could be the first step in ensuring these essential habitats are conserved and rehabilitated (Heithaus, 2007; Parsons & Hoffmayer, 2007). The goals of this study were to build upon previous studies that have shown the MS Sound to be an important shark nursery ground by identifying the age and size classes, spatial distribution, developmental stages, and seasonal distribution of the blacktip, sharpnose finetooth, and bonnethead, *Sphyrna tiburo*, sharks within the MS Sound over a three year period.

**Methods**

*Field Sampling*

This study was conducted from 2009 to 2011 from March through October within the waters of the Mississippi Sound (MS Sound) extending from Cat Island east to Petit Bois Island (Fig. 1). Following Parsons and Hoffmayer (2007), sharks were captured using a 182.9 x 3 m gillnet, which consisted of six 30.5 m panels of the following sizes: 4.5, 5.1, 5.7, 6.7, 7.0, and 10 cm square mesh. The net was typically fished between 0800 and 2000 hrs. Depending on the rate of capture and environmental conditions prevalent, the net was checked every 0.5-1.0 hr. The gillnet sampling employed a random stratified block design, with ten 10.6 km² blocks selected throughout the MS Sound. Each month from March to October, stations were randomly selected within each block (Fig. 1).

Latitude and longitude were recorded for the beginning, middle, and end of each set. A Niskin bottle and Yellow Springs Instruments (YSI) were used at each site to measure environmental parameters including temperature, salinity and dissolved oxygen at the surface,
middle, and bottom of the water column. In addition, water depth, turbidity, and sea state were recorded at each station.

After capture, sharks were identified, sexed and measured for pre-caudal length (PCL), fork length (FL), stretch total length (STL), and weight. Sharks in good physical condition were individually marked with either a roto tag (Premier One Supplies) on the dorsal fin or a dart tag (Hallprint, Inc.) inserted in the dorsal musculature, and were released. Catch per unit effort (CPUE) was calculated as number of sharks per hour. A sub sample of sharks, mainly those in poor physical condition or dead, were retained for age determination.

*Preparation of vertebral samples and band counts*

Vertebral samples were taken from below the dorsal fin from 258 Atlantic sharpnose, 51 blacktip, 43 bonnethead, and 18 finetooth sharks. Preparation of vertebra followed the protocol from Cicia et al. (2009). Briefly, after being frozen, samples were thawed, cleaned of excess tissue and air dried. Three individual centra were removed from each specimen and a sagittal section was cut using a Raytech Jem Saw with 5” saw blades (Raytech Industries, Middletown, CT) to generate a thin bowtie-like cross section. Cross sections were mounted on glass microscope slides using Cytoseal 60 (Fisher Scientific, Pittsburg, PA). Mounted vertebrae were digitally photographed with a Nikon SMZ-U Stereoscopic Zoom camera (Nikon Inc, USA) and SPOT Basic™ Image Capture Software for Microscopy (Diagnostic Instruments, Inc.). An annulus (annual ring) was defined as one opaque and one hyaline zone.

*Precision and bias*

Each vertebra was read twice by two readers, without any previous knowledge of the shark’s length or previous counts (Cailliet et al., 2006). If ages differed by more than two years
they were discarded. Count precision was measured using the index of average percent error (IAPE) equation (Beamish and Fournier, 1981).

\[
\text{IAPE} = \frac{1}{N} \sum \frac{1}{R} \sum \left( \frac{|X_{ij} - X_j|}{X_j} \right) \times 100,
\]

Where \( N \) = the number of sharks age; \( R \) = the number of readings; \( X_{ij} \) = the \( i \)th age determination of the \( j \)th fish; and \( X_j \) = the average calculated for the \( j \)th fish.

Vertebrae with IAPE indexes of less than 15% were used to determine growth rates in each shark. In addition, to evaluate bias between the two readers an age bias plot was utilized (Sulikowski, 2005). Once ages were determined, the subsample of ages were applied to sharks captured within the MS Sound over the course of this study. Each shark was then given a developmental stage based on the age selected. For each species, young-of-the year (YOY) was represented from age 0 to 1. Sharpnose, blacktip, finetooth, and bonnethead were considered juveniles from age 1 to 2, 5, 5, and 2 respectively. Individuals older than corresponding ages were considered adults (Carlson & Barmore, 2003; Carlson, 2003; Carlson, 2006; Lombardi-Carlson, 2007).

**Statistics**

To investigate specific distribution patterns of sharks, the MS Sound was divided up into three areas: West (89.149-88.903°W), Central (88.903-88.654°W), and East (88.654-88.396°W) (Fig. 2). To determine the effect of area and developmental stage on CPUE, a two way analysis of variance (ANOVA) was run for each species, with area of the MS Sound and developmental stage as the factors. Additionally, the effect of season and developmental stage on CPUE was determined for each shark species using a two way ANOVA. If the data did not meet the assumptions of normality and homogeneity of variances, then they were transformed. If data
transformations were not successful, then the non-parametric Kruskal-Wallis test was utilized. Since there is no non-parametric equivalent to the two way ANOVA, several Kruskal Wallis tests were performed. Following ANOVA tests, Fisher’s LSD post hoc test was used to separate mean ranks.

**Results**

From 2009 to 2011, 1,309 sharks representing the four most common species were caught within the waters of the Mississippi Sound (MS Sound). The Atlantic sharpnose shark was the most abundant species (n=737, 28.4-83.9 cm FL), followed by finetooth (n=332, 35.0-103.3 cm FL), blactktip (n=151, 42.0-118.0 cm FL), and bonnethead (n=89, 35.9-81.6 cm FL) sharks (Table 1). Three-hundred-forty total sharks from all species were collected in 2009, 592 in 2010, and 377 in 2011, and the CPUE was 3.47, 4.89, and 3.15 sharks per soak time (hr) for 2009, 2010, and 2011, respectively. The catch was dominated by immature sharks (79%) representing 67%, 99%, 91%, and 27% of Atlantic sharpnose, finetooth, blacktip, and bonnethead sharks, respectively.

**Size and age distribution**

Comparison of band counts between two readers indicated no appreciable bias (Fig. 3) and minimal error (mean IAPE of 7.4%) for all sampled vertebrae (N=370). Sixty three percent of the counts agreed, 36% were within 1 year, and 1% were within 2 years. Atlantic sharpnose (SN) females were present in MS Sound up until they reached maturity (1.6 years); however, males were present from age 0 through 5 and older (Fig. 4a, 5a). Unlike SN, the majority of finetooth (FT) caught were age 0 or young of the year (YOY) sharks (Fig. 4b). Similar to FT, the majority of blacktip (BT) caught was between ages 0 and 2 (Fig. 4c). The majority of BH
captured in this study were 3 years or older (Fig. 4d). Finetooth, BT, and bonnethead (BH) were not caught at ages older than 5, 6, 5 years respectively (Fig. 5b,c,d).

Size frequencies of sharks captured in the MS Sound varied depending on species. The ratio of male to female SN was approximately equal until the sharks reached 50 cm FL, at which point males dominated the catch (Fig. 6a). Most of the FT caught were immature, with the majority less than 60 cm FL (Fig. 6b). Similar to FT sharks, the majority of the BT sharks were immature (Fig. 6c). The ratio of male to female were relatively even across all the size classes for FT and BT (Fig. 6b,c). Similar to SN, BH males made up the majority of the catch. Larger BH (60-79 cm FL) demonstrated the highest frequency captured, (Fig. 6d) which corresponded with the age data.

Environmental parameters and presence/absence of species

The trend in surface and bottom salinity varied in each year of the study. Salinities were highest in the West in 2009 (surface: 23.9±4.12; bottom: 25.0±4.63) compared to 2010 (surface: 19.5±1.04; bottom: 21.5±1.08) and 2011 (surface: 19.2±1.74; bottom: 22.7±1.73). In 2010, surface and bottom salinities were higher in the Central (surface: 21.4±0.96; bottom: 24.7±1.17) and East (surface: 23.1±0.89; bottom: 24.2±0.84) compared to the West (surface: 19.5±1.04; bottom: 21.5±1.08) Area. However, in 2011 salinities were highest in the East (surface: 22.3±1.17; bottom: 25.0±1.29) compared to the Central (surface: 18.7±1.65; bottom: 22.7±1.66) and West (surface: 19.2±1.74; bottom: 22.7±1.73). Bottom dissolved oxygen levels in the West Area were lowest in 2011 (4.8±0.50) when compared to 2010 (5.8±0.56) and 2009 (5.2±0.56). No distinct trends were observed between years or areas for surface or bottom temperatures during the study (Table 2).
Sites where each shark species were present displayed higher surface and bottom temperatures compared to sites where each shark species were absent. In particular BT displayed the greatest difference between surface and bottom temperatures. Atlantic sharpnose, FT and BT were caught at higher surface and bottom salinities and lower surface and bottom dissolved oxygen levels. However, SN and BT were caught at the highest surface (SN: 22.9±0.55; BT: 23.2±0.82) and bottom (SN: 25.2±0.52; BT: 25.6±0.64) salinities. Bonnethead did not display any specific trends (Table 3).

**Distribution and abundance**

In 2009, the distribution of all four shark species combined was slightly skewed to the western portion of the MS Sound; however, statistical analysis revealed no significant differences were evident ($H_2 = 0.451, P = 0.798$). In 2010, CPUE was significantly influenced by Area ($H_2 = 7.36, P = 0.025$), with the East (6.89±1.58) being significantly greater than the Central (3.37±1.17) and West (1.75±0.47) Areas (Fig. 7). A similar trend was observed in 2011, with a significant effect of Area on CPUE ($H_2 = 23.42, P < 0.001$), revealing that catch was significantly higher in the East (6.80±1.88) compared to the West (0.45±0.26) and Central (0.19±0.14) Areas.

**Sharpnose (SN)**

In 2009, no significant effect of Area on CPUE was evident for SN ($H_2 = 0.866, P = 0.648$); however, in 2010 the relationship between Area and CPUE was approaching significance ($H_2 = 5.874, P = 0.053$). A significant relationship was observed between Area and CPUE in 2011 for SN ($H_2 = 21.744, P < 0.001$). In particular, 2011 CPUE for the East Area (5.12±1.57) was significantly greater compared to Central (0.031±0.031) and West (0.28±0.17) Areas. Although not significant the same trend was seen in 2010, with the East Area (3.77±1.07)
displaying a greater CPUE compared to Central (1.23±0.43) and West (1.07±0.31) (Fig 8a).
Developmental stage did not have a significant effect on CPUE for SN during any sampling
year; 2009 (H² = 0.939, P = 0.625), 2010 (H² = 2.065; P = 0.356), and 2011 (H² = 2.944, P =
0.230); however, juveniles displayed higher CPUE than YOY and adult for all three years (Fig
9a).

Finetooth (FT)

No significant relationships were evident between Area in the MS Sound and FT CPUE
during any year (2009: H² = 0.109, P = 0.947; 2010: H² = 0.642, P = 0.725; 2011: H² = 2.497, P =
0.287), however higher CPUE was seen in the East Area compared to Central and West in 2010
and 2011 (Fig. 8b). No significant relationship between CPUE and developmental stage
occurred during any sampling year; 2009 (H² = 0.109, P = 0.947), 2010 F²,179 = 1.91, P = 0.157),
and 2011(H² = 2.971, P = 0.226); however, adult CPUE (2009: 0.02±0.01; 2010: 0.0±0.0;
2011:0.0±0.0) was lower than YOY (2009: 0.48±0.26; 2010: 1.13±0.14; 2011: 0.17±0.14) and
juvenile (2009: 0.34±0.16; 2010: 0.14±0.03; 2011: 0.05±0.03) for all years (Fig. 9b).

Blacktip (BT)

Blacktip CPUE did not show any significant relationship with Area of the MS Sound
during any year (2009: H² = 0.0975, P = 0.952; 2010: H² = 1.155, P = 0.561; 2011: H² = 4.637, P
= 0.098). However, CPUE was highest in the Central Area in 2010, whereas in 2011 it was
lowest (Fig. 8c). No significant relationships were observed between CPUE and developmental
stage for BT in any of the years of the study, however, adult BT had lower CPUEs (0.0-0.01)
than YOY (0.02-0.30) and juvenile (0.21-0.32) BT in all three years (Fig. 9c).
**Bonnethead (BH)**

No significant relationship was evident between Area in the MS Sound and BH CPUE in any year of the study; however in 2011 the relationship was approaching significance (2009: $H^2 = 0.535$, $P = 0.765$; 2010: $H^2 = 1.180$, $P = 0.554$; 2011: $F_{2,176} = 2.82$, $P = 0.063$). Trends were observed in 2009 and 2011 when BH CPUE was highest in the Central Area in 2009 and the East Area in 2011 (Fig. 8d). Higher adult (0.29±0.23) CPUE was observed in 2009 compared to YOY (0.01±0.01) and juvenile (0.02±0.02); however, the relationship between CPUE and developmental stage was not significant ($H^2 = 3.769$, $P = 0.152$). The relationship between developmental stage and CPUE appeared to be approaching significance in 2010 ($F_{2,179} = 2.71$, $P = 0.069$). During this year, juvenile (0.10±0.04) and adult BH (0.07±0.03) displayed a higher CPUE than YOY (0.01±0.01) sharks. In 2011, there was no significant relationship between CPUE and developmental stage ($F_{2,176} = 0.032$, $P = 0.968$) (Fig. 9d).

**Seasonal Distribution**

There was a significant effect of season on SN CPUE ($H^2 = 12.873$, $P = 0.002$), with CPUE being significantly higher during summer (1.01±0.20) compared to spring (0.57±0.10) and fall (0.32±0.11). Finetooth shark CPUE was highest in fall (0.39±0.21) and summer (0.38±0.17) compared to spring (0.06±0.02); however, there was no statistical difference between season and CPUE ($H^2 = 4.063$, $P = 0.131$). Although not statistically significant ($H^2 = 1.456$, $P = 0.483$), BT displayed a higher CPUE during summer (0.19±0.07) compared to spring (0.13±0.06) and fall (0.10±0.04). No significant relationship was evident between season and BH CPUE ($F_{2,425} = 2.31$, $P = 0.100$); however, CPUE was highest in spring (0.11±0.04) compared to summer (0.08±0.04) and fall (0.003±0.003) (Fig. 10).
Discussion

Size and age distribution

The importance of nursery areas for the conservation and maintenance of shark populations is becoming recognized by fishery management agencies (Heupel et al., 2007). Shark nursery areas have been identified along the US east coast and the Gulf of Mexico (Castro, 1993; Merson & Pratt, 2001; Carlson, 2002; Parsons & Hoffmayer, 2007), however past studies have only focused on the abundance and species distributions within these areas. Limited information is available on the age structure of sharks within nursery grounds and how this changes over time. Given that age information forms the basis for estimating the risks associated with population exploitation of immature sharks, in addition understanding this life history parameter in the context of nursery grounds is vital to effective management of shark stocks.

Depending on species, a high degree of variability existed between the sizes and ages that utilize the Mississippi Sound (MS Sound). For example, a significant amount of Atlantic sharpnose (SN) were caught at a wide variety of ages (0 to 5+) during all sampling months. However, it appeared that females of this species are using this area only as a nursery ground, while male SN occupy the MS Sound before and after reaching sexual maturity. Previous studies by Parsons and Hoffmayer (2005) found a similar relationship between sexes in the MS Sound suggesting that SN undergo a geographic segregation between sexes after maturity.

In contrast to SN, both finetooth (FT) and blacktip (BT) were almost exclusively captured at sizes less than 89 cm FL and almost none were over two or three years of age. Previous research has suggested that the size at 50% maturity for FT is 94.7 to 98.1 cm FL and from 3.9 to 4.3 years of age for males and females, respectively (Carlson et al., 2003), while size at 50% maturity for BT is approximately 103 to 117 cm FL and from 4.5 to 5.7 years of age for males
and females, respectively (Carlson et al. 2006). Thus based on this information, it would appear that both FT and BT are leaving the MS Sound prior to or during the onset of sexual maturity. However, the gear selectivity of the gillnet may not have been able to catch adult FT and BT, making it difficult to determine if larger numbers of adult BT and FT were present in the MS Sound. With that said, higher abundances of immature FT and BT were still captured, suggesting that these species are utilizing this area as a nursery ground, which supports previous work by Parsons and Hoffmayer (2007). In addition, the lack of difference in distribution between sexes within the sound reveals that both sexes for FT and BT are utilizing this area until the onset of maturity is reached.

The lack of any significant distribution pattern of sharks within the MS Sound in 2009 suggests that shark species do not prefer any specific area (West, Central, East) within the MS Sound. The low abundance of immature bonnethead (BH) sharks suggests that this area might not be an important nursery habitat for BH in this region. Lower abundances in BH compared to other species in the MS Sound were also observed by Parsons and Hoffmayer (2007). They suggested that the scarcity and loss of sea grass within the MS Sound may not make the area as appealing for BH. Based on Lombardi-Carlson et al. (2007); BH mature between 2 to 3 years of age. With that in mind, it appears that BH in the current study may be utilizing the MS sound after maturity is reached. The higher numbers of males caught compared to females for all ages of BH indicate that males may be utilizing this area more than females. Carlson (2002) observed higher numbers of immature BH (<60 cm TL) in northwest Florida waters, particularly within Crooked Island Sound suggesting that this area may be a more important nursery ground for this species.

**Distribution and abundance within the MS Sound**

The lack of any significant distribution pattern of sharks within the MS Sound in 2009 suggests that shark species do not prefer any specific area (West, Central, East) within the MS
Sound. In 2010, it appeared that sharks preferred the East Area within the MS Sound. A number of parameters determine the distribution of fish within a habitat, for example environmental factors, food abundance, predation, and various anthropogenic changes (Heithaus, 2007; Parsons & Hoffmayer, 2007; Jennings et al., 2008). The Deepwater Horizon oil spill which occurred on April 20th, 2010 could be a partial explanation for the shift towards the East Area of the MS Sound. The shark abundance shifted to the East Area in 2011, enough that a significant difference between CPUE and the area within the MS Sound occurred. A shift in distribution this dramatic within an area suggests that something may be influencing this shift. In May 2011, the Bonnet Carre Spillway released thousands of cubic meters per sec of freshwater in the Gulf of Mexico to reduce water levels in New Orleans. Based on previous studies it can be assumed that the addition of excess freshwater flowing into the northern Gulf of Mexico in 2011 decreased the dissolved oxygen and salinity levels in the MS Sound (Rabalais & Turner, 2001). According to Rabalais and Turner (2001) the northern Gulf of Mexico has become the largest zone of oxygen depleted coastal water in the United States due to the largest influx of freshwater from the Mississippi River. Although statistical comparisons were not conducted between environmental parameters and shark distribution in the current study, it is still notable to mention that surface salinity decreased from 2009 to 2011 in the West area (23.9±4.12 to 19.2±1.74 ppt). Given the fact that previous studies have demonstrated that environmental parameters can alter the distribution of shark species, the anecdotal observation of environmental changes observed in this study, may explain the distribution shifts in the MS Sound in 2011 (Parsons & Hoffmayer, 2005; 2007).

Atlantic Sharpnose (SN)
No changes in the distribution were observed for SN in 2009, suggesting that this species did not prefer any specific area. However in 2010 and 2011, the CPUE in the East was over twice that of Central and West. Parsons and Hoffmayer (2007) observed that SN were captured at significantly higher salinities, suggesting that this species may be less euryhaline than previously thought. Additionally, they hypothesized that females may be more stenohaline than males providing a possible explanation for why mature females were not found in the MS Sound. The bottom and surface salinities SN were captured in during this study corresponded with bottom and surface salinities observed in the East Area in 2011 supporting Parsons and Hoffmayer (2007) study that salinity may be a driving force for SN distribution. Juvenile SN displayed the highest abundances during each year of the study however it is more important to note all developmental stages where present.

**Finetooth (FT)**

No significant changes in FT CPUE were observed throughout areas in any year while the study was conducted. However, although not significant, a trend was observed where higher abundances of FT were caught in the East and Central compared to the West in 2010 and 2011, suggesting that something may have produced a shift in this species distribution. The bottom and surface temperature FT were captured in during this study corresponded with bottom and surface temperatures observed in the East Area in 2010 and 2011 supporting Parsons and Hoffmayer (2007) who found that FT were present in a mean surface and bottom temperatures of 29.4±0.4 and 28.7±0.3°C respectively. It may be possible that temperature assists in influencing FT distribution. It appeared that for each year there were low abundances of FT adults captured compared to YOY and juvenile, however no significance was observed. Based on the size and age data, FT are utilizing the sound as a nursery.
**Blacktip (BT)**

Similar to SN and the overall trend, the BT distribution in 2009 did not vary in area, suggesting that this species did not prefer any specific area. In contrast, BT were more abundant in the Central and East Areas in 2010 than in the West. The current study found trends similar to what Parsons and Hoffmayer (2007) found, where BT catch was strongly correlated to increased temperatures within the MS Sound. The Central and East Areas within the MS Sound had higher bottom and surface temperatures than the West Area in 2010 where BT were captured in higher abundances. However, the Central Area in 2011 displayed the lowest bottom and surface temperatures where no BT were captured, possibly explaining the BT shift in distribution seen in the Central Area. The abundance of developmental stages were not statistically different in 2009, 2010, or 2011 for BT suggesting that all life stages were occupying the MS Sound during those years. However it should be noted that although not statistically significant, very low abundances of adults were observed throughout all of the years. Again, it may also be possible however, that the smaller size range that the gillnet selects may not be able to capture the larger BT, therefore it is difficult to determine whether adult BT are utilizing the MS Sound.

**Bonnethead (BH)**

Bonnethead did not display any significantly higher abundances in any area within the MS Sound during any year of the study; however, in 2011 BH were more abundant in the East Area. According to Ubeda et al. (2009) BH can tolerate salinities from 15 to 35 ppt which may support the idea that BH were not affected by the drop in salinity observed in West Area in 2010. The presence of adults suggests that this area is important for BH after maturity however, the overall low abundances observed for BH introduces a large amount of variability when determining any meaningful trends. The low numbers of immature BH caught supports Parsons
and Hoffmayer (2007) findings that this area may not be an important nursery ground for this species.

*Seasonal Distribution of combined years*

The significantly higher SN and BT abundances during summer may be due to higher temperatures and salinities. This observation for SN contrasts Parsons and Hoffmayer’s (2005) observations that suggest abundances of adult male SN were less in the summer months compared to spring and fall. However, research by Parsons and Hoffmayer (2007), support the link between temperature and abundance observed in the current study. FT, did exhibit higher abundances in the summer and fall months compared to spring suggesting that they prefer seasonal conditions of the summer and fall over the spring within the sampling area of the MS Sound. Bonnethead exhibited higher abundances in the spring and summer however the low sample size of BH made it difficult to accurately evaluate seasonal abundance of this species. It must be noted that this current study did not run any statistics on the environmental parameters measured; in addition this study did not take into account the presence of predators or food availability within the MS Sound which may also affect the distribution of shark species. Further research needs to be conducted in order to fully evaluate the distribution of shark species within the MS Sound.

**Acknowledgements**

We’d like to thank the Gulf Coast Research Laboratory, but in particular, W. Dempster, G. Gray, J. Tilley, C. Butler, J. Higgs, J. McKinney, and A. Karels for the collection of our samples. We further extend our gratitude to Jill Hendon who assisted in organizing our samples and data after collection. This project was supported by a UNE Honors Program, College of Arts and Sciences Dean Office and Marine Science Department.
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Table 1. Sharks caught during each year for SN= Atlantic sharpnose, BT= blacktip, BH= bonnethead, FT= finetooth. Numbers in parenthesis represents % of the catch that were immature.

<table>
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<th># sharks 2010</th>
<th># sharks 2011</th>
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<td>SN</td>
<td>158 (63)</td>
<td>282 (61)</td>
<td>297 (74)</td>
<td>737 (67)</td>
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<td>BT</td>
<td>48 (94)</td>
<td>80 (93)</td>
<td>23 (83)</td>
<td>151 (91)</td>
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<tr>
<td>BH</td>
<td>36 (89)</td>
<td>24 (79)</td>
<td>29 (86)</td>
<td>89 (84)</td>
</tr>
<tr>
<td>FT</td>
<td>98 (98)</td>
<td>206 (100)</td>
<td>28 (100)</td>
<td>332 (99)</td>
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</table>

Table 2. Mean environmental data collected at all sampling sites in the Mississippi Sound within each area (West, Central, East) from 2009 to 2011.

<table>
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<th>2010</th>
<th>2011</th>
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<tr>
<td>(°C)</td>
<td>27.4±0.78</td>
<td>22.9±1.92</td>
<td>26.4±1.22</td>
</tr>
<tr>
<td>Bottom Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(°C)</td>
<td>27.3±0.85</td>
<td>22.7±1.89</td>
<td>26.1±1.16</td>
</tr>
<tr>
<td>Surface Salinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppt)</td>
<td>23.9±4.12</td>
<td>17.7±2.90</td>
<td>21.9±2.68</td>
</tr>
<tr>
<td>Bottom Salinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppt)</td>
<td>25.0±4.63</td>
<td>19.2±3.17</td>
<td>23.0±2.45</td>
</tr>
<tr>
<td>Surface DO (mg/L)</td>
<td>5.9±0.34</td>
<td>6.5±0.48</td>
<td>6.3±0.49</td>
</tr>
<tr>
<td>Bottom DO (mg/L)</td>
<td>5.2±0.56</td>
<td>6.0±0.46</td>
<td>6.0±0.54</td>
</tr>
</tbody>
</table>
Table 3. Mean environmental data collected at all sampling sites where each shark species were collected and where each shark species were not collected in the Mississippi Sound from 2009 to 2011.

<table>
<thead>
<tr>
<th></th>
<th>Surface Temperature (°C)</th>
<th>Bottom Temperature (°C)</th>
<th>Surface Salinity (ppt)</th>
<th>Bottom Salinity (ppt)</th>
<th>Surface DO (mg/L)</th>
<th>Bottom DO (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN</td>
<td>Present 27.9±0.44</td>
<td>27.2±0.45</td>
<td>22.9±0.55</td>
<td>25.2±0.52</td>
<td>6.8±0.10</td>
<td>5.1±0.20</td>
</tr>
<tr>
<td>SN</td>
<td>Absent 25.5±0.56</td>
<td>24.8±0.53</td>
<td>19.1±0.83</td>
<td>21.5±0.94</td>
<td>7.2±0.19</td>
<td>5.5±0.30</td>
</tr>
<tr>
<td>FT</td>
<td>Present 28.1±0.41</td>
<td>27.5±0.48</td>
<td>21.1±1.03</td>
<td>23.7±0.86</td>
<td>6.6±0.19</td>
<td>5.0±0.26</td>
</tr>
<tr>
<td>FT</td>
<td>Absent 26.3±0.45</td>
<td>25.5±0.43</td>
<td>20.8±0.61</td>
<td>23.2±0.68</td>
<td>7.1±0.13</td>
<td>5.4±0.22</td>
</tr>
<tr>
<td>BT</td>
<td>Present 28.7±0.44</td>
<td>28.0±0.41</td>
<td>23.2±0.82</td>
<td>25.6±0.64</td>
<td>6.7±0.15</td>
<td>4.8±0.33</td>
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<tr>
<td>BT</td>
<td>Absent 25.9±0.45</td>
<td>25.2±0.45</td>
<td>20.1±0.64</td>
<td>22.6±0.71</td>
<td>7.1±0.14</td>
<td>5.5±0.21</td>
</tr>
<tr>
<td>BH</td>
<td>Present 28.1±0.53</td>
<td>27.1±0.52</td>
<td>19.9±1.00</td>
<td>23.6±0.77</td>
<td>7.3±0.25</td>
<td>5.0±0.35</td>
</tr>
<tr>
<td>BH</td>
<td>Absent 26.3±0.44</td>
<td>25.6±0.43</td>
<td>21.1±0.62</td>
<td>23.3±0.69</td>
<td>6.9±0.12</td>
<td>5.4±0.21</td>
</tr>
</tbody>
</table>
Figure 1. Map of the Mississippi Sound. Random stratified block design, with ten 10.6 km² blocks were made for sampling. Each month from March to October, stations were randomly selected within each block.

Figure 2. Map of the Mississippi Sound. The study area was divided up in 3 equal sections: West, Central, and East. For the purpose of the study sampling sites were randomly selected throughout the study area.

Figure 3. Combined Age bias graph for pair-wise comparison of sharpnose (258), Blacktip (51), Finetooth (18) and Bonnethead (43) vertebral counts by two independent readers. Each error bar represents the 95% confidence interval for the mean age assigned by reader 2 to all fish assigned a given age by reader 1. The diagonal line represents the one-to-one equivalence line. Sample sizes are given above each corresponding age. Sample sizes for each corresponding age are above the line.

Figure 4. Age-frequency distribution of Atlantic sharpnose, *Rhizoprionodon terraenovae*, (a), finetooth, *Carcharhinus isodon*, (b), blacktip, *C. limbatus*, (c), and bonnethead, *Sphyrna tiburo*, (d) captured within the Mississippi Sound from 2009 to 2011.

Figure 5. Size at age keys for Atlantic sharpnose, *Rhizoprionodon terraenovae*, (a), finetooth, *Carcharhinus isodon*, (b), blacktip, *C. limbatus*, (c), and bonnethead, *Sphyrna tiburo*, (d) sharks within the Mississippi Sound from 2009 to 2011.

Figure 6. Length-frequency distribution of Atlantic sharpnose, *Rhizoprionodon terraenovae*, (a), finetooth, *Carcharhinus isodon*, (b), blacktip, *C. limbatus*, (c), and bonnethead, *Sphyrna tiburo*, (d) sharks captured within the Mississippi Sound from 2009 to 2011. Red line indicates size at sexual maturity.

Figure 7. Catch per unit effort (CPUE) of all species caught within each area (West, Central, East) in 2009, 2010, and 2011. In the above figures A indicates significance over B and bars with no letters denote no significance between groups.

Figure 8. Catch per unit effort (CPUE) of Atlantic sharpnose, *Rhizoprionodon terraenovae*, (a), finetooth, *Carcharhinus isodon*, (b), blacktip, *C. limbatus*, (c), and bonnethead, *Sphyrna tiburo*, (d) caught within each area (West, Central, East) in 2009, 2010, and 2011. In the above figures A indicates significance over B and bars with no letters denote no significance between groups.

Figure 9. Catch per unit effort (CPUE) of young of the year (YOY), juvenile (JUV), and adult (ADU) for Atlantic sharpnose, *Rhizoprionodon terraenovae*, (a), finetooth, *Carcharhinus isodon*, (b), blacktip, *C. limbatus*, (c), and bonnethead, *Sphyrna tiburo*, (d) caught within the Mississippi Sound in 2009, 2010, and 2011. In the above figures A indicates significance over B and bars with no letters denote no significance between groups.

Figure 10. Catch per unit effort (CPUE) of Atlantic sharpnose, *Rhizoprionodon terraenovae*, (SN), finetooth, *Carcharhinus isodon*, (FT), blacktip, *C. limbatus*, (BT), and bonnethead, *Sphyrna tiburo*, (BH) caught within the Mississippi Sound for each season (Spring, Summer, and Fall) during the study. In the above figures A indicates significance over B and bars with no letters denote no significance between groups.
Figure 3

The figure illustrates the comparison of the number of bands observed by two readers. The y-axis represents the number of bands of reader two with 95% CI, while the x-axis represents the number of bands of reader one. The data points are marked with values, and the two lines indicate the trend for Reader 1 (blue) and Reader 2 (red).
Figure 4.

(a) Frequency distribution of males and females by age group. (b) Similar distribution for a different age range. (c) Frequency distribution by size class for males and females. (d) Frequency distribution by size class for another group.
Figure 6

a

![Histogram of size classes with frequency for Males and Females.]

b

![Histogram of size classes with frequency for Males and Females.]

c

![Histogram of size classes with frequency for Males and Females.]

d

![Histogram of size classes with frequency for Males and Females.]

Legend:

- Males
- Females
Figure 7

Distribution within the MS Sound

CPUE (#sharks/hour)

West Central East

2009 2010 2011

Area

West Central East

A B B A A

2009 2010 2011
Figure 10

Seasonal Distribution of shark species for all years

[Bar chart showing seasonal distribution with categories Spring, Summer, and Fall, and species indicated by colors: SN, BT, BH, FT]