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Was 2015 the Summer of the Shark? Evidence from the Coastal Carolina University Shark Project

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Abstract

Winyah Bay is a 65-km^2 estuary in northeast South Carolina and is considered essential habitat and nursery ground for several shark species of the western North Atlantic. As a result of a number of shark bites/attacks during the summer of 2015, many concluded there was higher abundance of sharks than in previous years. The objective of this study was to test this hypothesis using surveys of shark populations from Winyah Bay in the summer of 2015, and comparing the diversity and abundance of sharks from this survey to those of previous years from the same survey. From July to August in 2002-2006, 2013, and 2015, 169 bottom longlines (16/0 and 12/0 hooks) were set in Winyah Bay. A total of 243 sharks representing 11 species were captured in Winyah Bay. The sandbar shark (*Carcharhinus plumbeus*), finetooth shark (*Carcharhinus isodon*), blacktip shark (*Carcharhinus limbatus*) and Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) were the most abundant species caught. The average catch per unit effort (CPUE) for all sharks caught in Winyah Bay (1.306, 1.538, 1.706, 1.077, 1.375, 1.545, 1.846, for the periods above) was not significantly different among any of the study years ($F = 0.432$, $p > 0.05$, $df = 132$). However, the proportion of longlines that caught at least one shark (0.722, 0.385, 0.765, 0.538, 0.5, 0.727, and 1.0, for the periods above) was the highest in 2015. Bull sharks accounted for 16.7% of the 2015 total, and the most caught in the period examined for this paper. The prevalence of bull sharks and larger sharks, as well as a high longline index (1.0) could explain the increase in human-shark interactions and could be due to increased water temperatures, the lack of rainfall, or other factors.

Introduction

Sharks in the Media 2015

In the early summer of 2015, an atypically large number of shark bites and attacks occurred along the southeast U.S. coast (Mathewson 2016). The television, print, and digital media in the United States were consumed with these attacks for several weeks, leading the public to conclude that there had been a record number of shark attacks along its coasts and popular tourist beaches. Brian Howard (2016), for example, reported that 98 shark attacks (6 fatalities) occurred globally in 2015. He also stated that the U.S. had a record 59 shark attacks and high activity along the Carolinas and Florida. These attacks and bites have led to the belief that sharks were present in higher abundances in the summer of 2015 than previous years.

Shark Demographics of the Northwestern Atlantic

Recent studies have shown declines in shark populations globally as well as in the NW Atlantic (e.g., Baum *et al.* 2003; Myers *et al.* 2007; Fischer *et al.* 2012). Because many species of sharks are apex predators, which characteristically are among the least numerous organisms in ecosystems, these declines have led to concern by ecologists and increased research on this group.

Numerous studies have been conducted to determine the presence and abundance of shark species along the U.S. east coast as well as the environment factors that influence these populations (Table 1). These shark surveys have discovered that there are differences in offshore and coastal shark populations along the U.S. east coast. For example, the most common species captured in the Mid-Atlantic Bight were the sandbar shark *Carcharhinus plumbeus*, Atlantic sharpnose shark *Rhizoprionodon terraenovae*, dusky shark *Carcharhinus obscurus*, and tiger shark *Galeocerdo cuvier*, respectively, based on the 1994-2003 offshore bottom longline shark fishery survey (Morgan *et al.*, 2009). In contrast, Thorpe et al. (2004) determined that the most abundant species in the coastal southern North Carolina waters, which is part of the Mid-Atlantic Bight, were small sharks like the Atlantic sharpnose shark *Rhizoprionodon terraenovae* and dogfishes (*Mustelus canis* and *Squalus acanthias*). In the eastern Gulf of Mexico, the most abundant species in offshore waters were the sandbar, blacktip, Atlantic sharpnose, and blacknose sharks, respectively (Morgan *et al.,* 2009). Finally, in the southeast U.S. coastline, the most abundant species were the Atlantic sharpnose, sandbar, blacktip *Carcharhinus limbatus*, and tiger sharks, respectively (Morgan et al., 2009). A fishery dependent shark gill net survey concluded that the most abundant shark species in Georgia and Florida coastal waters were the blacknose *Carcharhinus acronotus*, Atlantic sharpnose, blacktip, finetooth *Carcharhinus isodon*, scalloped hammerhead *Sphyrna lewini*, bonnethead *Sphyrna tiburo*, spinner *Carcharhinus brevipinna*, and great hammerhead *Sphyrna mokarran* sharks, respectively (Trent *et al.*, 1997).

In coastal waters, the distribution of sharks is influenced by many environmental factors including salinity, temperature, depth, and dissolved oxygen. Grubbs and Musick (2007) determined that the most significant environmental factors affecting the distribution of sandbar sharks are salinity, depth, and dissolved oxygen, respectively. Heithaus *et al.* (2009) discovered that the abundance of bull sharks *Carcharhinus leucas* increased with salinity and dissolved oxygen. Finally, Abel *et al.* (2007) showed the diversity and abundance of sharks in Winyah Bay, South Carolina varied as a result of salinity differences in the system in rainy and dry years.

Shark Nursery Grounds

Essential habitat is defined as habitat that is required for spawning, breeding, feeding, or growth to maturity (Heithaus 2007). Shark nursery grounds are locations in which females give birth and/or juvenile sharks spend a significant part of their early life (Heithaus 2007). Typically, shark nursery grounds are found in protected coastal habitats like estuaries, which are ideal for nursery grounds because of an abundance of food sources for juvenile sharks and protection from predation (Harden Jones 1968). Belcher *et al.* (2009) confirmed that larger bonnethead sharks were found offshore and smaller ones were found in protected areas in Georgia. The separation between adult and juvenile sharks also limits competition between the two populations.

Several studies have led to the identification of shark nursery grounds globally and in the coastal waters of the western North Atlantic, as well (Table 2). Carlson *et al.* (2008) determined that Atlantic sharpnose sharks used a series of estuaries as nursery grounds rather than a single estuary, which is typical of most species. The most significant summer nursery ground for the sandbar shark is the Chesapeake Bay (Grubbs and Musick, 2007). Females migrate to the Bay to give birth in May or June, and the pups remain in the Bay until September or October, after which they migrate south. The juvenile sharks return to the area every summer for the first 4-10 years of life. The Delaware Bay and the coastal waters of South Carolina also include nursery grounds for sandbar sharks (Merson *et al.*, 2001). Sapelo Island National Estuarine Reserve, Georgia, is a primary and/or secondary nursery ground for multiple shark species, including Atlantic sharpnose, blacktip, finetooth, and bonnethead sharks (Gurshin, 2007). Thorpe *et al.* (2004) found that the southern North Carolina coastal waters have nursery grounds for dusky smooth-hound *Mustelus canis*, dusky, sandbar, Atlantic sharpnose, scalloped hammerhead, and bonnethead sharks. Bull sharks have been known to use estuaries or even rivers for nursery grounds (Heupel et al., 2010). However, they are usually confined to more southern coastal areas of the U.S., like Shark River Estuary in the Everglades National Park (Heithaus *et al.*, 2009).

Bonnethead shark nursery grounds are also typically found in more southern regions, like the Ten Thousand Islands Estuary in Florida (Steiner *et al.*, 2007).

Shark Studies of South Carolina

Multiple studies have focused on the shark populations and nursery grounds of the coastal waters of South Carolina. Ulrich *et al.* (2007) concluded that small coastal sharks, as defined by the National Marine Fisheries Service (NMFS) (1993), were the most abundant in South Carolina coastal waters. These species included the Atlantic sharpnose, finetooth, blacknose, and bonnethead sharks. The most abundant large coastal species (NMFS 1993) included the sandbar shark, blacktip shark, and scalloped hammerhead. Spiny dogfish *Squalus acanthias* and smooth dogfish *Mustelus canis* were captured during the colder months of the year, whereas most other species were caught during warmer months. For example, Driggers III *et al.* (2004) found that blacknose sharks were present in South Carolina waters only in the summer. In contrast, Atlantic sharpnose sharks were present in South Carolina during all seasons (Loefer *et al.*, 2003). Ulrich *et al.* (2007) also determined that Atlantic sharpnose sharks, finetooth sharks, sandbar sharks, blacktip sharks, and scalloped hammerheads make use of South Carolina's estuarine and nearshore habitats for nursery grounds. Atlantic sharpnose sharks use both estuarine and nearshore waters as primary nursery grounds. In contrast, finetooth sharks, sandbar sharks, blacktip sharks, and scalloped hammerheads use only estuarine waters as a primary nursery grounds.

In addition, Abel *et al.* (2007) studied the shark population of Winyah Bay and North Inlet, South Carolina in 2002 and 2003. Ten species were captured in Winyah Bay. A majority of these (79.6%) were immature. The most abundant species that were caught included the sandbar, Atlantic sharpnose, finetooth, and blacktip sharks, respectively. Five species were captured in

North Inlet. A majority of the sharks caught during 2003 in North Inlet were adults. Immature Atlantic sharpnose sharks were captured during both years, and immature finetooth, blacktip, and lemon sharks were captured during 2002. This study suggested that the coastal waters of South Carolina may be important shark nursery grounds.

Coastal Carolina University Shark Survey

Coastal Carolina University has been conducting an episodic longline survey starting in 2002 to study the shark community of Winyah Bay, South Carolina. Abel *et al.* (2007) published results from the first two years of this project. The study aimed to 1) identify the shark species present in the estuary, 2) identify whether Winyah Bay serves as a shark habitat and potential nursery ground, and 3) describe the shark population and distribution as it related to salinity.

This project was conducted to determine whether the diversity and abundance of the shark population of Winyah Bay, South Carolina was unusual during the summer of 2015. The goals of this study were 1) to identify the shark species presence and abundance in Winyah Bay in the summer of 2015, 2) to determine if the summer of 2015 differed from previous years, and 3) if there were any population changes, to hypothesize explanations for these changes.

Materials and Methods

Winyah Bay is a 22 km long coastal plain estuary formed by the confluence of the Black, Pee Dee, Sampit, and Waccamaw Rivers and is the third largest estuarine ecosystem in the United States, covering an area of 65-km^2 with a watershed of approximately 47,000 km^2 (Fig. 1). The combined river flow ranges from 0.03 to greater than 2,830 m^3s^{-1} , with an average of 500 m^3s^{-1} (Johnson 1972;Kjerfve et al. 1982). The longest axis of the bay is approximately 19 km long and runs from northwest to southeast. The width of the bay varies from 1.2 km at the entrances to 6.4 km near the center. The average depth of Winyah Bay is approximately 4 m. There is an 8.2 m-deep ship channel which is maintained by dredging that runs along most of the bay. Depths over 10 m occur along the channel and near the mouth of the bay. The dominant flora along the middle and lower bay is *Spartina alterniflora.* River-deposited sediment dominates the upper estuary, while the rest of Winyah Bay consists of mud, sand, silt, and clay (Patchineelam et al. 1999).

Winyah Bay acts as a partially mixed estuary during low to moderate flows, while the upper and middle bay act as a salt wedge estuary during high flows (Bloomer 1973). The average amplitude of semidiurnal times is approximately 1 m at the mouth of the bay and 1.4 m at the upper bay. Salinity differences between the surface and bottom waters range from 0 to 15 practical salinity units (psu) at the upper bay to greater than 30 psu at the mouth of the bay. Under average condition, salinity penetration is just north of the Highway 17 brides that crosses the upper bay about 19 km from the mouth.

Based on Abel *et al.* (2007), Winyah Bay was divided into three zones based on the salinity gradient along its axis (Fig. 1). Two principal sites with similar depths were selected within the middle and lower bay and were sampled randomly from July through August in 2002-2006 and 2013 and 2015. The sample sites were *Sandbar City* (as named in Abel *et al.*, 2007) in the middle bay and Mother Norton Shoals in the lower bay (Fig. 1). The period 2002-2006 were intensively studied as part of a demographic study, whereas in other years data were collected as part of other project or classes. Sampling in the summer of 2015 was done primarily for classes.

The capture methods followed those described in Abel *et al.* (2007). A total of 169 hand-deployed bottom longlines were set between July and August of 2002-2006, 2013, and 2015. Longlines consisted of 0.64-cm-diameter mainline (tarred, braided nylon), anchored at both ends.

Twenty five (50 in 2002) one-m long monofilament gangions with circle hooks were attached with tuna clips. Two types of longlines were used in this study to target different size classes of sharks. Longlines using 16/0 circle hooks were set to target adults and larger sharks. Longlines using 12/0 circle hooks were set to target juveniles, young of the year, and neonates. Lines with 16/0 hooks were set for 1 hour, while lines with 12/0 hooks were set for 30 minutes (in order to reduce mortality). Cut, thawed Atlantic mackerel *Scomber scombrus* was used to bait gangions.

Sharks were worked up either onboard or while tethered to the boat and were subsequently released. Captured sharks were identified by species, sexed, and measured for pre-caudal length, fork length, and total length (TL) to the nearest cm. The total length was measured from the tip of the snout to the tip of the longest lobe of the caudal fin. Sharks were assessed for health (nictitating reflex, responsiveness, coloration changes), and if deemed healthy, most were tagged with an M-type tag, dart tag, or rototag. Other data collected at each site included GPS coordinates, Secchi depth, water depth, surface and bottom salinity, temperature, and dissolved oxygen. Statewide precipitation conditions during the study periods were collected from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information and are summarized in Table 4.

For all longlines, the catch per unit effort (CPUE) was calculated as the # sharks $\times$ 25 hooks^{-1} $\times$ 30 min^{-1}. The average CPUE each year was calculated as the (# sharks $\times$ # lines^{-1}) $\times$ 25 hooks^{-1} $\times$ 30 min^{-1}. The CPUE were compared between years with analyses of variances (ANOVA).

Results

A total of 243 sharks representing 11 species were caught in Winyah Bay during the July-August study periods of 2002-2006, 2013, and 2015 (Table 3). The most abundant species were sandbar (n = 117), finetooth (32), blacktip (31), and Atlantic sharpnose sharks (26). Other species caught included spinner, bonnethead, scalloped hammerhead, lemon, bull, nurse, and blacknose sharks. *C. plumbeus* was the most abundant species captured every year (Figure 2). The other dominant species varied between *C. limbatus*, *R. terranovae*, *C. isodon*, and *C. leucas*.

C. plumbeus also had the highest average CPUE (1.047) over the entire duration of the study period (Figure 3), followed by *C. isodon* (0.189), *C. limbatus* (0.183), *R. terranovae* (0.154) and *C. leucas* (0.036).

Results Before 2015

In 2002, 94 sharks in 8 species were captured on 72 longline sets in Winyah Bay. In 2003, 20 sharks in three species were captured on 13 longline sets. In 2004, 29 sharks comprising five species were captured on 17 longline sets. Fourteen sharks representing four species were caught on 13 longline sets in 2005. In 2006, 11 sharks comprising three species were captured on 8 longline sets. In 2013, 51 sharks representing seven species were caught on 33 longline sets (Figure 4).

C. plumbeus was the most abundant species captured every year. In 2002, *C. isodon* and *C. limbatus* were additional dominant species. *R. terraenovae* was the second dominant species in 2003 and 2004. *C. limbatus* was the second significant species in 2005 and 2006. The second dominant species in 2013 was *R. terraenovae*. The average CPUE varied from 1.077 (S.E. =

0.348) in 2005 to 1.706 (S.E. = 0.427) in 2004 (Figure 5). The proportion of longlines with at least one shark ranged from 0.385 in 2003 to 0.765 in 2004 (Figure 6).

The average total length (TL) of all sharks caught in 2002 was 138.526 cm (Figure 7). The average TL was 76.520 cm in 2003. In 2004, the average total length of all sharks caught was 134.929 cm. The average TL of all sharks caught in 2005 was 88.009 cm. In 2006, the average TL was 152 cm. The average TL of all sharks caught was 85.875 cm in 2013.

Summer of 2015

In 2015, 24 sharks representing four species were captured on 13 longline sets (Figure 4). *C. plumbeus* was the dominant species in 2015. *C. isodon* and *C. leucas* were the additional dominant species during 2015. *C. limbatus* was the only other species caught in the summer of 2015. The average CPUE was 1.846 (S.E. = 0.274) in 2015 (Figure 5). The proportion of longlines with at least one shark was 1 in 2015, meaning that every longline set caught at least one shark (Figure 6). The average total length of all sharks caught in 2015 was 152.589 cm (Figure 7).

Comparison of 2015 to Previous Years

Statistically significant differences in the average CPUE were not found between any of the study years ($F = 0.432$, $p > 0.05$, $df = 132$). The average CPUE ranged from 1.077 (S.E. = 0.277) in 2005 to 1.846 (S.E. = 0.274) in 2015 (Table 3, Figure 5). The proportion of longlines with at least one shark varied from 0.385 in 2003 to 1 in 2015 (Figure 6). The average yearly proportion of longlines with at least one shark over all study years was 0.664.

The average total length in cm of all sharks caught varied among years (Figure 7). The highest average total length was 152.589 cm, which occurred in 2015. The lowest average total length was 76.520 cm in 2003. The average total length over the entire duration of the study was 118.350 cm.

Additional Findings

There was not a clear trend in the size distribution of significant shark species over the course of the study. *C. leucas* was the largest in the years that this species was present (Figure 8). *C. leucas* was also the only species to show a large change in the average size between the years that it was present. In 2002, the average size for *C. leucas* was 375 cm, whereas in 2015 it was 200 cm. In all other significant species there were only small yearly changes in the average size.

The overall CPUE of all species varied between sample sites. Sandbar City had and overall CPUE of 1.442 when all species were taken into consideration (Figure 9). Mother Norton Shoals had an overall CPUE of 1.410. The CPUE for each species varied between sites as well. *C. plumbeus* and *C. isodon* were the only species in which their CPUE was highest at Sandbar City (Figure 10). *R. terraenovae* had equal CPUE's at both sites. *C. limbatus* and *C. leucas* had higher CPUE's at Mother Norton Shoal than at Sandbar City. All other species were only captured at Mother Norton Shoal.

Discussion

CPUE

As anecdotal observations had suggested, the highest average CPUE occurred in 2015. However, as stated above, there was not a significant difference in the average CPUE among any of the study years. Therefore, this survey did not corroborate purported increase of sharks in Winyah Bay in the summer of 2015. However, 2015 was the only year in which every longline set caught at least one shark. While the significance of this is not entirely clear, it suggests a more even distribution of sharks in the summer of 2015 as compared to previous years. The average CPUE was fairly constant among the dominant species each year. The sandbar shark had the highest CPUE in every study year. The bull shark was the only species to have a large increase in the CPUE between study years (from 0.028 in 2002 to 0.308 in 2015)

Species Abundance

Over the entire study period, the most abundant species were the sandbar, finetooth, blacktip, and Atlantic sharpnose shark. This is similar to the results found by Abel *et al.* (2007). However, 2015 deviated somewhat from this pattern. Atlantic sharpnose sharks, which are typically very abundant in Winyah Bay, were not captured in the summer of 2015. Bull sharks were also much more prevalent in the summer of 2015. The only years in which this species was captured were 2002 and 2015. In 2002, only 2.1% of all captured sharks were bull sharks. However, in 2015, bull sharks were the second most dominant species, making up 16.7% of the catch.

Size Distribution

There appears to be a trend in the average TL of all sharks when related to the precipitation conditions of the corresponding year. The years 2002, 2006, and 2015 were all dryer than average years and had a higher average TL than other years. This could suggest that the increase in average TL during those years was caused by an increase in the salinity of the estuary. However, 2004 does not support this trend. The summer of 2004 was a wetter than average year, but had a higher average TL than the other wet years. The lesser average TL during 2003, 2005, and 2013 occurred because of the presence of the smaller shark species *S. lewini*, and *R. terraenovae*. A higher reliance on Winyah Bay for nursery grounds could be another possible explanation for the low average TL during 2003, 2005, and 2013. Because salinities were lower during these years, fewer adult sharks would have ventured into the estuary and juveniles would have had a higher abundance in the overall population.

Effect of Annual Precipitation

Precipitation patterns, which influence salinity, have an effect on the presence and abundance of sharks, as determined by multiple studies (e.g. Abel *et al.* 2007; Grubbs and Musick 2007; Heithaus *et al.* 2009). This study found similar patterns. Sandbar City's location in the middle bay, translates into lower surface to bottom salinities due to the increased flow of the rivers which feed the bay. Mother Norton Shoals is located near the mouth of the bay and therefore has a higher saltwater influence. The CPUE by location followed the precipitation pattern each year. Both 2002 and 2015 had a higher CPUE at Sandbar City than Mother Norton Shoals. Since both of these years experienced drought conditions, the salinity would be high enough for the presence of the more stenohaline shark species at Sandbar City. In all other study years, the CPUE was higher at Mother Norton Shoals. In 2003, which was a heavy rain year, no sharks were caught at Sandbar City. This was attributed to the increased freshwater input into the bay and the salinity would have been too low (Abel *et al.* 2007).

Bull sharks are known to travel into estuaries and rivers for, including for nursery grounds (Heupel et al. 2010). It is also known that the abundance of bull sharks increases with salinity (Heithaus et al. 2009). The presence of bull sharks in 2002 and 2015 could be caused by this trend. Since both years experienced drought conditions, the salinity would have be higher in Winyah Bay during those times. This could have been cause for an increased abundance of bull sharks during those study periods.

Hypothesized Explanations for the Shark Attacks of 2015

Although Winyah Bay is an estuary, and all of the observed bites and attacks occurred along ocean-front beaches, it is not unreasonable to expect that trends observed in Winyah Bay may reflect those occurring along the coastline since the mix of sharks, though not identical, is similar. Therefore, the results of this study can aid in hypothesizing explanations of the summer shark attacks and bites of 2015. Among these explanations are drought conditions, warmer waters, the early arrival of prey, and an increased number of beachgoers. As stated before, drought conditions in the early summer of 2015 would cause a higher salinity in Winyah Bay. However, salinities do not change drastically at beaches except during prolonged rainfall events or episodic deluges. In addition, though low salinities might deter sharks, high salinities (caused by droughts) will not necessarily attract sharks. Therefore, the presence and abundance of sharks along beaches would most likely not have been influenced by an increase in salinity. Water temperature is an environmental cue for the arrival of sharks, especially for pupping season (Merson and Pratt 2001). The high temperatures of the early summer of 2015 would have coincided with warmer water temperatures and therefore an earlier arrival of sharks. This can potentially explain the reason for an unusual number of shark attacks/bites in the early summer of 2015. High water temperatures also led to the early arrival of prey (sea turtles) and could have caused sharks to be present in close proximity to humans. And finally, the worldwide increase in beachgoers could be an explanation for the increased attacks and bites. The more people in the water and in close proximity to sharks, the higher the chance of an encounter.

Conclusions

The populations of sharks are important to understand due to many species roles as apex predators and vulnerability to declining numbers. Winyah Bay represents essential habitat and nursery ground for several shark species of the western North Atlantic. The most abundant species include the sandbar, finetooth, blacktip, and Atlantic sharpnose. Due to the media-claimed increase in shark attacks and bites along the U.S. coasts in the early summer of 2015, we hypothesized that there was an increase in the abundance of sharks in local waters. This study did not indicate a significant change in the abundance of sharks in Winyah Bay. However, the amount of sharks caught per longline set was more consistent in the summer of 2015 than previous years. In addition, bull sharks were more prevalent in 2015 than in previous years. These population changes could be due to rainfall-induced changes in salinity. A continuation of data collection in upcoming summers is needed to confirm whether the summer of 2015 was the summer of the shark.

References

Abel, D. C., R. F. Young, and J. A. Garwood. 2007. Survey of the shark fauna in two South Carolina estuaries and the impact of salinity structure. American Fisheries Society Symposium 50: 109-124.

Belcher, Carolyn N., Jennings, Cecil A. 2009. Use of fishery-independent trawl survey to evaluate distribution patterns of subadult sharks in Georgia. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science.* 1: 218-229.

Bloomer, D. R. 1973. A hydrographic investigation of Winyah Bay, South Carolina and the adjacent coastal waters. Master's thesis. Georgia Institute of Technology, Atlanta.

Carlson, J.K., Heupel, M.R., Bethea, D.M., Hollensead, L.D. 2008. Coastal habitat use and residency of juvenile Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*). *Estuaries and Coasts.* 31: 931-940.

Driggers III, William B., Carlson, John K., Cullum, Brian, Dean, John M., Oakley, Doug, and Ulrich, Glenn. 2004. Age and growth of the blacknose shark, *Carcharhinus acronotus*, in the western North Atlantic Ocean with comments on regional variation in growth rates. *Environmental Biology of Fishes.* 71: 171-178.

Fischer, Johanne, Erikstien, Karine, D'Offay, Brigitte, Guggisberg, Solen, and Barone, Monica. 2012. Review of the implementation of the international plan of action for the conservation and management of sharks. FAO Fisheries and Aquaculture Circular No. 1076, Rome.

Grubbs, R. Dean, Musick, John A. 2007. Spatial delineation of summer nursery areas for juvenile sandbar sharks in Chesapeake Bay, Virginia. *American Fisheries Society Symposium.* 50: 63-85.

Gurshin, Christopher W.D. 2007. Shark nursery grounds in Sapelo Island National Estuarine Research Reserve, Georgia. *American Fisheries Society Symposium.* 50: 141-151.

Harden Jones, F. R. 1968. Fish migration. St. Martin's Press, New York.

Heithaus, Michael R. 2007. Nursery areas as essential shark habitats: a theoretical perspective. American Fisheries Society Symposium 50: 3-13.

Heithaus, Michael R., Delius, Brian K., Wirsing, Aaron J., and Dunphy-Daly, Meagan M. 2009. Physical factors influencing the distribution of top predator in a subtropical oligotrophic estuary. *Limnol. Oceanogr.* 54(2): 472-482.

Heupel, M.R., Yeiser, B.G., Collins, A.B., Ortega, L., Simpfendorfer, C.A. 2010. Long-term presence and movement patterns of juvenile bull sharks, *Carcharhinus leucus*, in an estuarine river system. *Marine and Freshwater Research.* 61: 1-10.

Howard, Brian C. 2016. 2015 had a record number of shark attacks. Here's why. National Geographic.

Johnson, F. A. 1972. A reconnaissance of the Winyah Bay estuarine zone, South Carolina. South Caroina Water Resources Commission Report No. 4, Columbia.

Kjerfve B., A. Proehl, F. B. Schwing, H. E. Seim, and M. Marozas. 1982. Temporal and spatial considerations in measuring estuarine water fluxes. Pages 37-51 in V. S. Kennedy, editor. Estuarine comparisons. Academic Press, New York.

Loefer, Joshua K., and Sedberry, George R. 2003. Life history of the Atlantic Sharpnose Shark Rhizoprionodon terraenovae (Richardson, 1836) off the Southeastern United States. *Fishery Bulletin.* 101: 75-88.

Mathewson, Samantha. 2016. Shark attacks: New record set in 2015 with 98 attacks worldwide. Nature World News.

Merson, Rebeka R., Pratt Jr., Harold L. 2001. Distribution, movements, and growth of young sandbar sharks, *Carcharhinus plumbeus,* in the nursery grounds of Delaware Bay. *Environmental Biology of Fishes*. 61: 13-24.

Morgan, Alexia, Cooper, Peter W., Curtis, Tobey, Burgess, George H. 2009. Overview of the U.S. east coast bottom longline shark fishery, 1994-2003. *Marine Fisheries Review* 71(1): 23-38.

NMFS (National Marine Fisheries Service). 1993. Fishery management plan for sharks of the Atlantic Ocean. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Marine Fisheries Service, Silver Spring, Maryland.

Patchineelam, S. M., B. Kjerfve, and L.R. Gardner. 1999. A preliminary sediment budget for the Winyah Bay estuary, South Caroina, USA. *Marine Geology* 162: 133-144.

Steiner, P.A., Michel, M., O'Donnell, P.M. 2007. Notes on the occurrence and distribution of elasmobranchs in the Ten Thousand Island Estuary, Florida. *American Fisheries Society Symposium*. 50: 237-250.

Thorpe, Teresa, Jensen, Christopher F., Moser, Mary L. 2004. Relative abundance and reproductive characteristics of sharks in southeastern North Carolina coastal waters. *Bulletin of Marine Science*. 74(1): 3-20.

Trent, L., Parshley, D.E., Carlson, J.K. 1997. Catch and bycatch in the shark drift gillnet fishery off Georgia and east Florida. *Marine Fisheries Review*. 59(1): 19-28.

Ulrich, Glenn F., Jones, Christian M., Driggers, III, William B., Drymon, J. Marcus, Oakley, Douglas, and Riley, Catherine. 2007. Habitat utilization, relative abundance, and seasonality of sharks in the estuarine and nearshore waters of South Carolina. *American Fisheries Society Symposium* 50: 125-139.

Study	Location	Species
Morgan *et al.* 2009	Mid-Atlantic Bight	Sandbar Atlantic sharpnose Dusky Tiger
Morgan *et al.* 2009	Eastern Gulf of Mexico	Sandbar Blacktip Altantic sharpnose Blacknose
Morgan *et al.* 2009	Southeast U.S.	Atlantic sharpnose Sandbar Blacktip Tiger
Thorpe *et al.* 2004	Southern North Carolina	Atlantic sharpnose Dogfishes
Trent *et al.* 1997	Georgia and Florida	Blacknose Atlantic sharpnose Blacktip Finetooth Scalloped hammerhead Bonnethead Spinner Great hammerhead
Ulrich *et al.* 2007	South Carolina	Atlantic sharpnose Finetooth Blacknose Bonnethead Sandbar Blacktip Scalloped hammerhead Spiny dogfish Smooth dogfish
Abel *et al.* 2007	Winyah Bay	Sandbar Atlantic sharpnose Finetooth Blacktip

Table 1. Most abundant species (in descending order) in locations across the western North Atlantic as found by previous studies.

Study	Location	Species
Belcher *et al.* 2009	Georgia	Bonnethead
Grubbs and Musick 2007	Chesapeake Bay	Sandbar
Gurshin 2007	Sapelo Island	Atlantic sharpnose Blacktip Finetooth Bonnethead
Heithaus *et al.* 2009	Shark River Estuary	Bull
Merson *et al.* 2001	Delaware Bay	Sandbar
Steiner *et al.* 2007	Ten Thousand Islands estuary	Bonnethead
Thorpe *et al.* 2004	Southern North Carolina	Dusky smooth-hound Dusky Sandbar Atlantic sharpnose Scalloped hammerhead Bonnethead
Ulrich *et al.* 2007	South Carolina	Atlantic sharpnose Finetooth Sandbar Blacktip Scalloped hammerhead

Table 2. Shark species that use nursery grounds in locations along the western North Atlantic, as found by previous studies.

Species	n	CPUE	Average size TL (cm)
C. brevipinna			
Total	11	0.065	74.773
2002	0	0	
2003	0	0	
2004	0	0	
2005	0	0	
2006	0	0	
2013	11	0.333	74.773
2015	0	0	
C. limbatus			
Total	31	0.183	131.799
2002	21	0.292	131.794
2003	0	0	
2004	1	0.059	156
2005	4	0.308	130
2006	2	0.25	154
2013	2	0.061	73
2015	1	0.077	146
C. plumbeus			
Total	117	0.692	123.091
2002	36	0.5	121.914
2003	17	1.308	113.559
2004	15	0.882	112.047
2005	7	0.538	136.786
2006	8	1	150
2013	19	0.576	106.474
2015	15	1.154	120.857
R. terranoave			
Total	26	0.154	49.477
2002	5	0.069	48.2
2003	2	0.154	61
2004	10	0.588	37.1
2005	2	0.154	40.25
2006	1	0.125	
2013	6	0.182	60.833
2015	0	0	
S. tiburo			
Total	13	0.077	106.773

2002	2	0.028	101.5
2003	0	0	
2004	0	0	
2005	0	0	
2006	0	0	
2013	11	0.333	112.045
2015	0	0	
C. isodon			
Total	32	0.189	139.267
2002	26	0.361	117.8
2003	0	0	
2004	2	0.118	156.5
2005	0	0	
2006	0	0	
2013	0	0	
2015	4	0.308	143.5
S. lewini			
Total	4	0.024	51.875
2002	1	0.014	57.5
2003	1	0.077	55
2004	0	0	
2005	1	0.077	45
2006	0	0	
2013	1	0.030	50
2015	0	0	
N. brevirostris			
Total	1	0.006	213
2002	0	0	
2003	0	0	
2004	1	0.059	213
2005	0	0	
2006	0	0	
2013	0	0	
2015	0	0	
C. leucas			
Total	6	0.036	287.5
2002	2	0.028	375
2003	0	0	

2004	0	0	
2005	0	0	
2006	0	0	
2013	0	0	
2015	4	0.308	200
G. cirratum			
Total	1	0.006	154.5
2002	1	0.014	154.5
2003	0	0	
2004	0	0	
2005	0	0	
2006	0	0	
2013	0	0	
2015	0	0	
C. acronotus			
Total	1	0.006	124
2002	0	0	
2003	0	0	
2004	0	0	
2005	0	0	
2006	0	0	
2013	1	0.030	124
2015	0	0	
All Sharks			
Total	243	1.438	118.350
2002	94	1.306	138.526
2003	20	1.538	76.520
2004	29	1.706	134.929
2005	14	1.077	88.009
2006	11	1.375	152
2013	51	1.545	85.875
2015	24	1.846	152.589

Table 3. Abundance, CPUE, and size data for sharks caught on longlines in Winyah Bay. Accurate size data were missing for some individuals because some sharks escaped immediately after identification and sharks in poor shape were released before measurement.

Year	Precipitation Condition
2002	Drought

2003	Wetter than average
2004	Wetter than average
2005	Wetter than average
2006	Dryer than average
2013	Wetter than average
2015	Dryer than average

Table 4. The precipitation condition for South Carolina during the study years.

Figure 1. Map of Winyah Bay. SBC (Sandbar City) and MNS (Mother Norton Shoals) represent the two primary sites with in the middle and lower bays, respectively.

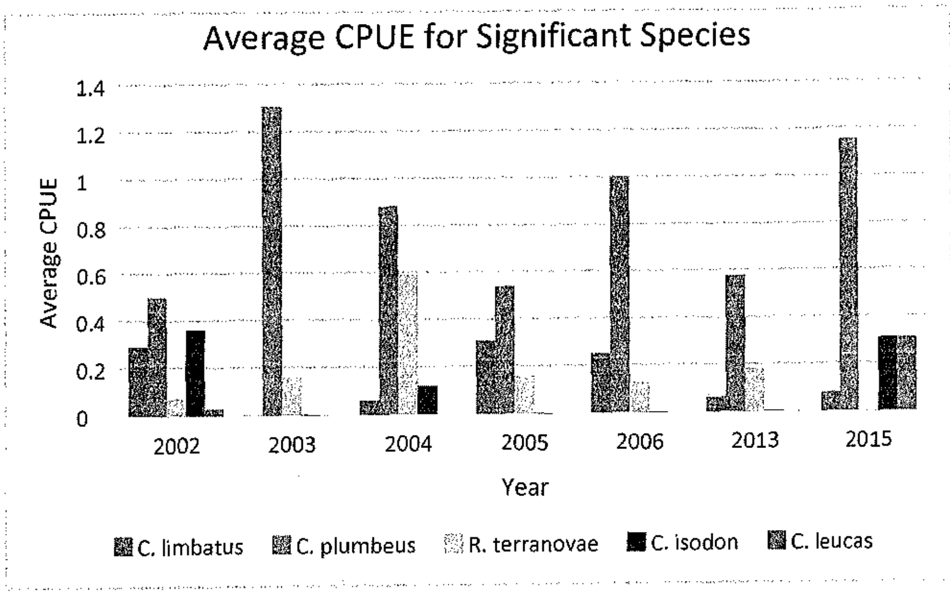


Figure 2. Average yearly CPUE for the significant species caught in Winyah Bay.

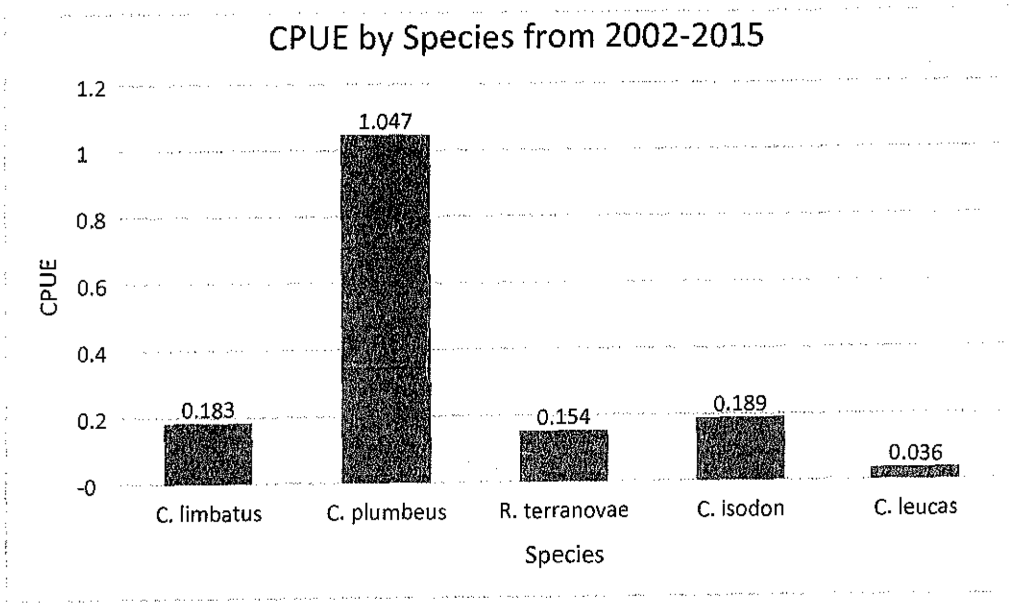
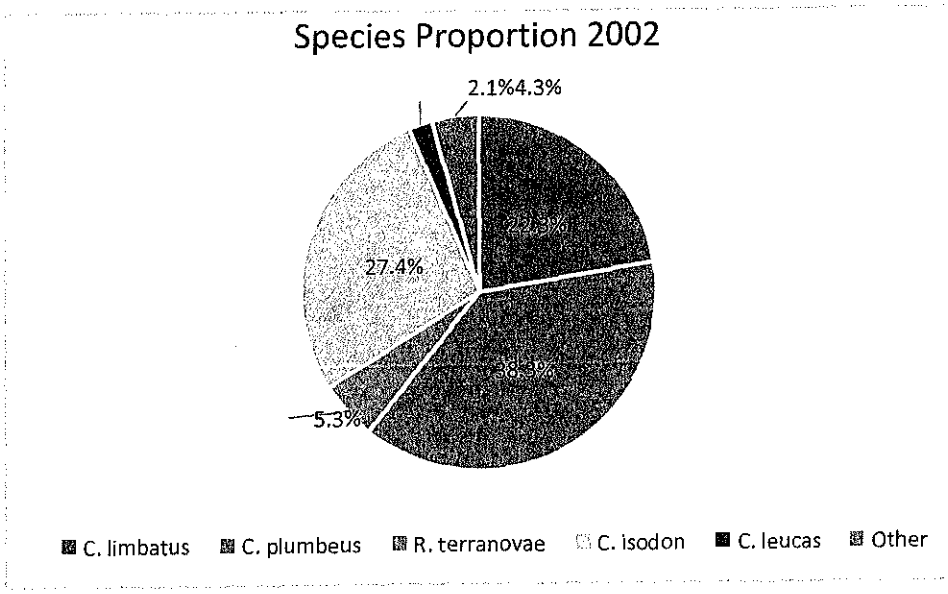
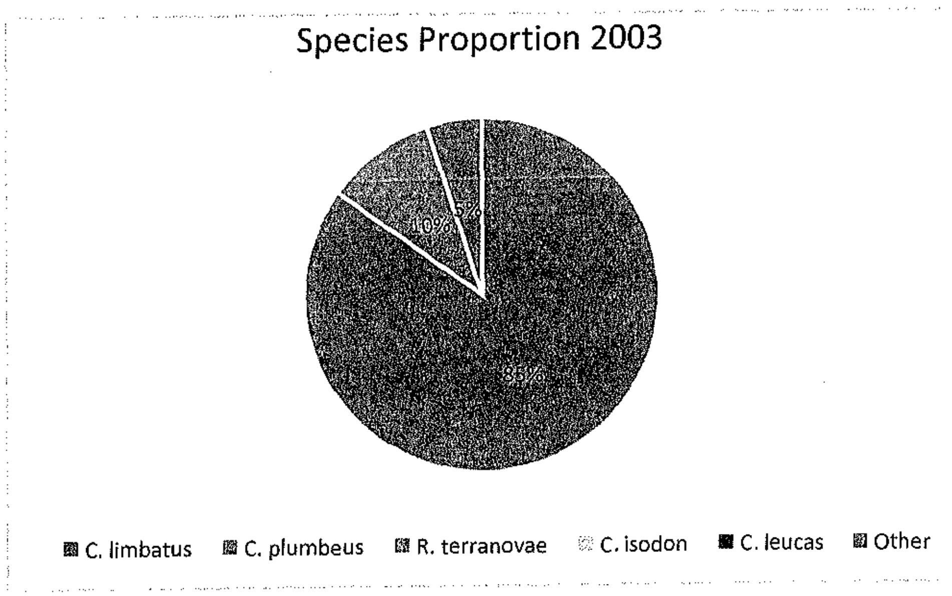


Figure 3. Average CPUE for the significant species caught in Winyah Bay over the entire duration of the study.


Species Proportion 2002
2.1%
4.3%
22.3%
27.4%
38.3%
5.3%
C. limbatus
C. plumbeus
R. terranovae
C. isodon
C. leucas
Other


Species Proportion 2003
10%
5%
85%
C. limbatus
C. plumbeus
R. terranovae
C. isodon
C. leucas
Other

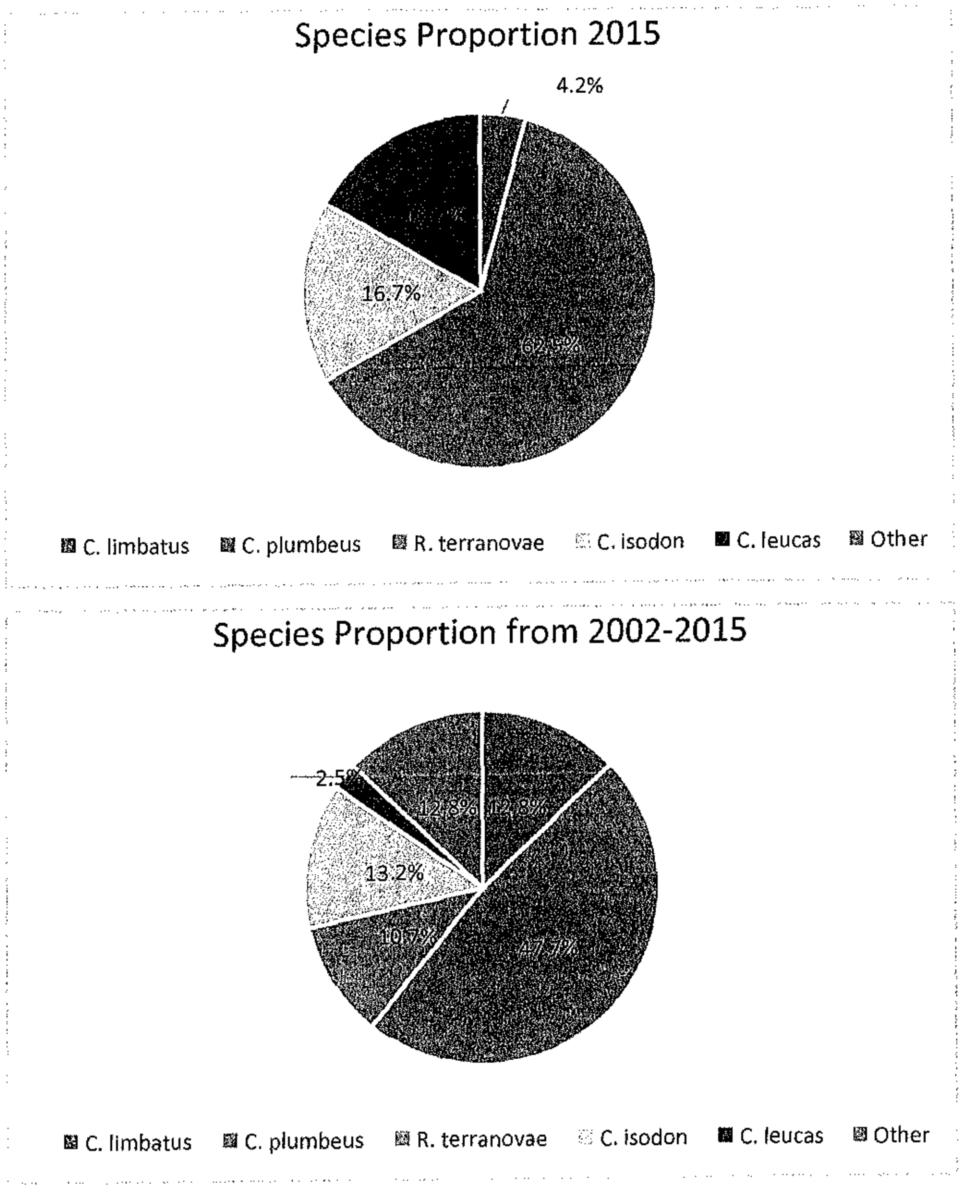


Figure 4. Species composite of total catch on all longlines in Winyah Bay.

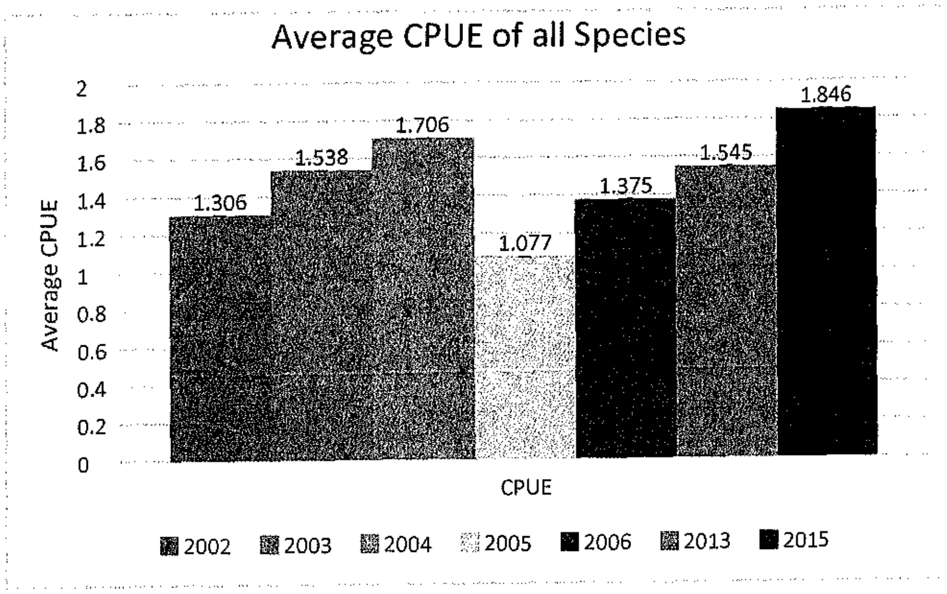


Figure 5. Average CPUE of all longlines in Winyah Bay.

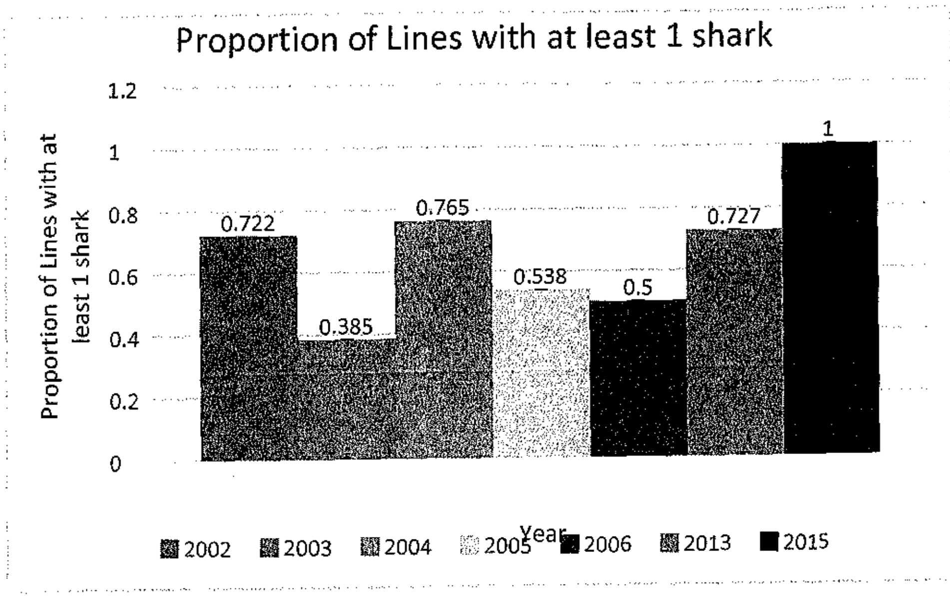


Figure 6. Proportion of all longlines with at least 1 shark caught in Winyah Bay.

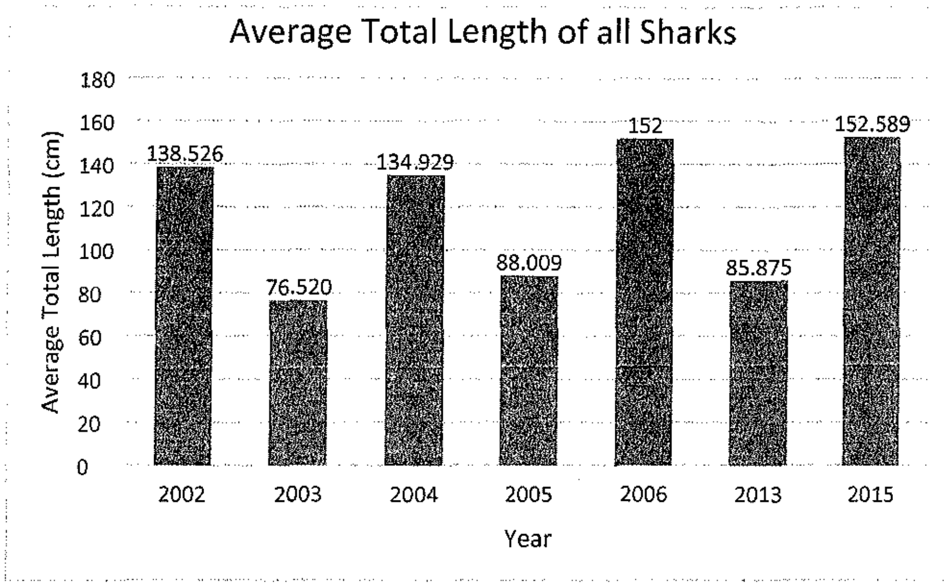


Figure 7. The average total length of all sharks caught each year in Winyah Bay. Accurate size data were missing for some individuals because some sharks escaped immediately after identification and sharks in poor shape were released before measurement.

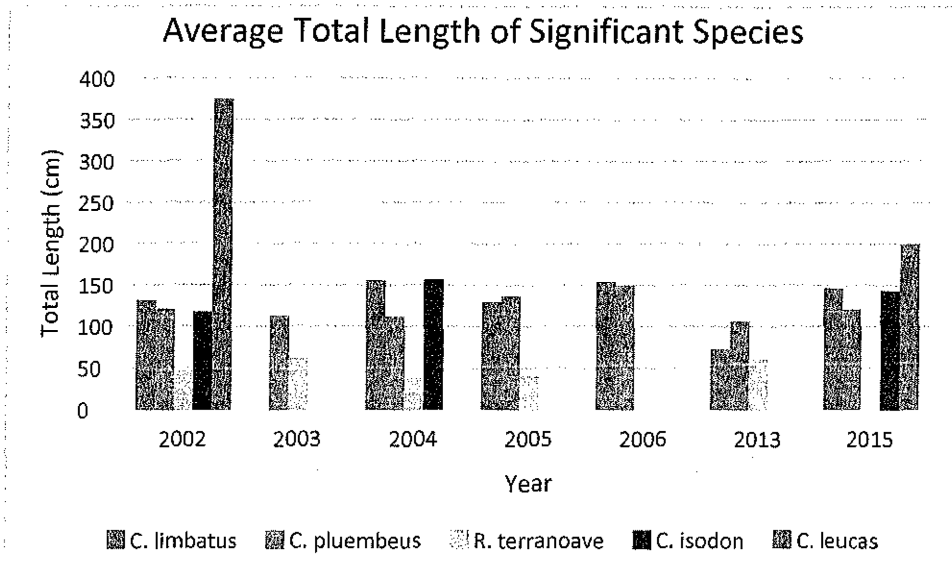


Figure 8. The average total length in cm of the significant species caught each year in Winyah Bay. Accurate size data were missing for some individuals because some sharks escaped immediately after identification and sharks in poor shape were released before measurement.

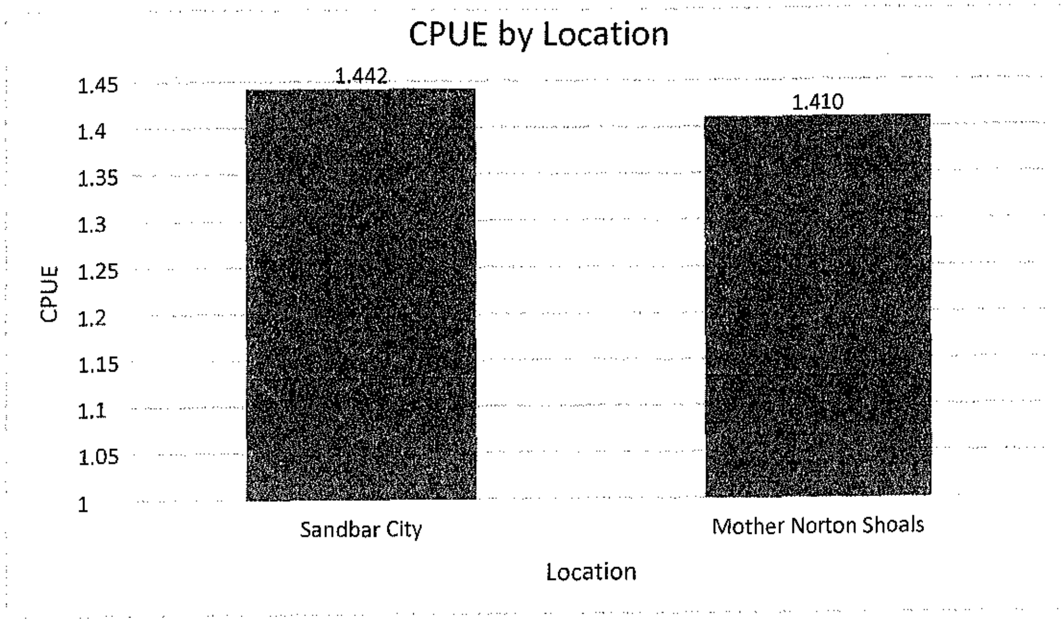


Figure 9. The overall CPUE for the study sites in Winyah Bay.

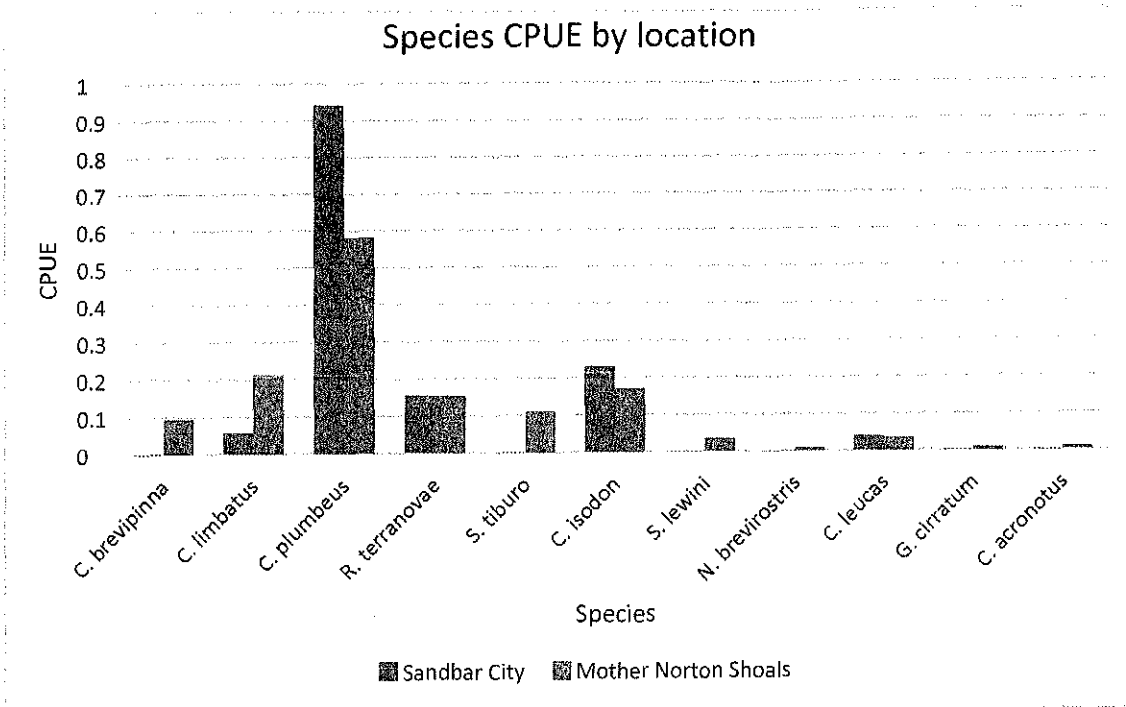


Figure 10. The overall CPUE by location for each species caught in Winyah Bay.