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Shark Community Structure in Winyah Bay, SC

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BY

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Introduction

Overfishing of several shark species has led to serious worldwide declines in stocks. Baum (2003) examined data from the Northwest Atlantic using the U.S. pelagic longlining fleet and concluded that several species showed declines of as much as 90% from historic levels. Campana (2006) studied fishing records for the blue shark (*Prionace glauca*) worldwide and found similar patterns of decline. Myers (2007) also noted signs of decline in the Northwest Atlantic and attributed it to overfishing, sport fishing, and finning-directed catch (Meyers 2007; Thorpe et al. 2004). Declines from 90-95% have been observed in shark populations in the Gulf of Mexico (Baum 2004). Some of these estimates may underestimate declines of sharks because the commercial fisheries frequently undercount sharks to avoid penalties for excessive by-catch.

Several studies from the eastern US coast provide further evidence for decline. Abel (2007) conducted a survey of Winyah Bay and North Inlet, South Carolina, and Heithaus (2007) conducted a similar assessment in Florida. Both showed declines in local populations, although Abel (2007) showed a year-to-year difference with a few species lower than expected. Meyers et al. (2007) illustrates how a loss or decline of a local apex predator affects the local human population in the form of a population increase of an undesired species. Berkeley et al. (1988) showed how by-catch in the sword fishing industry in Florida has led to population declines of several shark species as most catches were either female or neonate.

Hisano (2011) used data for fishing levels and natural mortality rates and ran several models of shark stocking in fished and non-fished scenarios. The models indicated that only a few changes are necessary to keep these populations healthy. Baum (2007) describes methods for conservation on a global scale which are applied by Heupel and Bennett (2007) on a small scale in an Australian reef. Loss of sharks results in changes in ecosystems (Stevens et al. 2000). As Baum showed in 2004, loss of 90% of the population can cause extensive ecological issues and the knowledge of these declines allows for more focused conservation methods. Burgess et al. (2005) provided a data review for several papers covering roughly 9 years and found that as more recent data comes in, shark stocks seem to be on the rise as a whole. This provides positive reinforcement to continue studying population fluctuations.

Assessments of local shark stocks are vital to understand population trends and their causes. Local data are incomplete despite many studies over many years. The first published study listed all of the shark species found off the coast of SC (Bearden 1965). Following Bearden's work, Schwartz (2003) used a 30 year data set to describe the elasmobranchs found in NC and SC. In 2004, a survey of coastal habitats in southeast NC helped to identify the nursery habitat for *C. acronotus*, *C. brevipinna*, *C. limbatus*, *C. obscurus*, *C. plumbeus*, *M. canis*, *R. terraenovae*, *S. tiburo*, and *S. lewini* (Thorpe *et al*. 2004). Yednock (2005) and Maxwell (2008) described the elasmobranch fauna of North Inlet. Then, in 2007, Abel *et al.* collected 12 species of shark around the Winyah Bay area and 5 species in North Inlet using both longlines and trammel nets. Ulrich *et al.* (2007) also caught 12 shark species and identified the primary nursery areas for five in estuarine and near-shore zones of SC. The elasmobranch fauna of North and Murrell's Inlet were then compared by McDonough (2008).

Coastal Carolina University began its own long-lining population survey in 2002 of Winyah Bay and monitored consistently until 2006. Many new findings came out of the first few years including 12 new species, the shark distribution, and salinity structure of the bay (Abel et al. 2007). This data set (Pankow and Abel Unpublished data), along with UNC's public data for 2006-2010 and data from Gary (2009) are the basis of this study. By examining size and diversity for recent years, important trends in the elasmobranch population can be identified and used to create management strategies on a local scale.

Methods

All sampling took place in Winyah Bay. Winyah Bay is a coastal plain estuary 90 km northeast of Charleston, SC, and is part of a two-estuary system along with North Inlet. North Inlet is separated by a full marsh system so samples were only collected from Winyah itself.

132 long-lines, anchored at both ends, were deployed between July and September of 2013. Sample sites were rather consistent at two locations at the mouth of the estuary with a few sites off the jetties at Georgetown, SC. Sampling was conducted on high tides, in the morning to late afternoon, up to 14 days per month. Three sets of two hand long-lines each were made on sampling days. Each line consisted of 25 gangions and was allowed to set for thirty minutes. At the end of the soak time each line was brought in. Sharks less than 130 cm were brought on board and sharks greater than 130 cm were tied to the side of the boat. Once restrained the animal was processed. Processing included: identification, determining sex, measuring fork length, precaudal length, and total length, and more for another study. Finally, the hook was removed either by hand or cut and the shark released.

Pankow and Abel (Unpublished data)

Data were organized in Excel and all graphical representations were produced using Excel and the statistical freeware R. Richness, total catch, and species diversity were calculated using the Shannon-Weiner Diversity Index. Any observation that did not have an associated sex or fork length was omitted for statistical analysis. One way ANOVAs were used to compare length, richness, and diversity for the data set as a whole as well as individually for the most abundant species between years and studies. All ANOVAs that showed a significant difference were analyzed using a Tukey's HSD procedure with a 95% familywise level of confidence.

Gary (2009) Data

All statistical analyses were identical to those for Pankow and Abel (Unpub.).

UNC Data

A single Welch's two sample t-test was run on average lengths of *C. plumbeus* as it was absent from the data from UNC. The remaining statistical analyses were identical to those for Pankow and Abel (Unpub.).

Results

Size

Average fork length was determined for each study overall and for the three major (highest abundance) species, *C. brevipinna, R. terraenovae, and C. plumbeus* (Fig. 1). Mean fork length for all species was significantly different between studies ($p < 0.001$). Tukey's HSD indicates that the mean length for Pankow and Abel (Unpub.) was between 16 and 28 cm smaller than the average fork length for Gary (2009), and average fork length for UNC was between 16 and 24 cm smaller than for Gary (2009) (Table 1). Many significant differences were found for average fork length by year for all species; the average fork length for 2013 was significantly different than that for all data from 2006 – 2010. The greatest difference was between 2013-2010 with 2013 being between 25 and 52 cm shorter than 2010 (Table 2).

Average fork length for *C. brevipinna* was significantly different between studies ($p < 0.001$). Post- hoc comparisons indicated that significant differences existed between Pankow and Abel (Unpub.) and Gary (2009) with Pankow and Abel (Unpub.) being 38 and 94 cm shorter, and between Pankow and Abel (Unpub.) and UNC with the average fork length for UNC between 18 and 36 cm longer. *C. plumbeus* was caught in only two studies and the average fork length was significantly different ($p < 0.001$). Average fork length for *C. plumbeus* for Pankow and Abel (Unpub.) was between 14 and 34 cm shorter than for Gary (2009). Mean fork length for *R. terraenovae* was also significantly different between studies (p < 0.001). There were significant differences between both Gary (2009) and Pankow and Abel (Unpub.), and UNC . UNC was longer than both Gary (2009) and Pankow and Abel (Unpub.) by 8 – 18 cm and 12 – 31 cm, respectively (Table 3).

Diversity and Richness

Mean diversity and mean richness were found by study (Fig. 3, Fig. 4).The average number of species caught was significantly different between years (p= 0.002), but not between months (p= 0.326). Significant differences in average catch between years were found using Tukey's HSD procedure (Table 4). Average richness between studies was significantly different (p < 0.001). Both Gary (2009) and UNC were significantly different from Pankow and Abel (Unpub.) . Catches from Pankow and Abel (Unpub.) were between 3 – 9 species more speciose than both Gary (2009) and UNC (Table 5).

Average diversity is not significantly different between years (p= 0.074), while average diversity is different between months, although only between September and July. Average diversity was also significantly different between studies (p = 0.005). UNC and Gary (2009) were both different from Pankow and Abel (Unpub.) but not each other (Table 6). The major species represented in Pankow and Abel (Unpub.) are *C. brevipinna*, *C. plumbeus* , and *R. terraenovae* (Fig. 5a). The major species represented by the UNC data set are *C. brevipinna*, *C. acronatus*, and *R. terraenovae* (Fig. 5b). *C. isodon*, *C. plumbeus*, and *R. terraenovae* were the major species for Gary (2009)(Fig. 5c). Compared to both data sets, the dominant community structure changes most notably with a severe drop in *R. terraenovae* and an increase in *C. brevipinna*. Other species also experience these trends, but *R. terraenovae* and *C. brevipinna* represent all three data sets and both show signs of change.

The total catch per species per month for each data set shows a visual record of the community structure varying between studies. It depicts the large amount of *R. terraenovae* caught in previous studies when compared to the lack of *R. terraenovae* in recent data (Fig. 6&7).

Discussion

The most prominent differences between the data of previous studies and the data from Pankow and Abel (Unpub.) indicate changes in community structure through significant differences in average for length length (particularly for three major species), diversity, richness, and total number of species caught by study.

Size

The average fork length of all sharks per study was significant between Gary (2009) and the other two. Gary (2009), which also took place in Winyah Bay, had sharks 16 and 28 cm longer than the recent data. The average fork length of all sharks per year was significant across many years, most notably between 2013 and each year between 2006 and 2010. The average shark fork length from this study has decreased within the past 5 years. This decrease in size can be explained in a few possibilities; overfishing, time of year, and change in equipment. Larger sharks are targets for fisheries and sport fisherman. Removal of larger sharks from the population results in a shift in size toward small. Bradshaw et al. (2008) observed how the overfishing of whale sharks in the Indian Ocean has resulted in a decrease in average size by 2 meters, and a decrease in abundance by 40%.

Time of year is very important in migration, mating, and nurseries. Pankow and Abel (Unpub.) data only covered from July to September which is a limited time frame and allows for variability. Sharks move due to the change of season. Some sharks are more tolerant to colder/warmer temperatures which determine when they leave an area. Movement to and from mating sites and nursery grounds are could be a possibility. Nursery grounds exhibit a distinct increase in activity during mating times of the year followed by large populations of neonates and juveniles. A study by Dean Grubbs et al. (2005) showed the migration patterns of *C. plumbeus* in Winyah as they come into the area around September and breed, and the juveniles stay until the following May. Gary (2009) sampled all year round and has the best representative sample of size trends. The decline in size could be due to a high population of juveniles staying in the bay longer than usual. Equipment type selects for different kinds of fish so it is reasonable to believe that differences in gear type between studies could account for variation in size and specie.

C. brevipinna, *C. plumbeus*, and *R. terraenovae* were all tested against themselves as they were the most abundant and most changed. *C. brevipinna* was smaller than both UNC and Gary (2009) by 18-36cm and 38-94cm respectively, *C. plumbeus* was also smaller then Gary (2009) by 14 and 34 cm, and *R. terraenovae* was smaller than UNC by 12 and 31 cm. All three major species experienced significant reductions in size compared to previous data. Explanations range from overfishing, time of year, and gear type as before.

Diversity & Richness

The average number of species caught between years is significantly different only between 2013 and the previous studies. Average richness by study was also significant with increases for 3 to 9 species more for this study than previous. The observed increase in number of species can be explained by gear type or high food volume. Gear and bait type have not been formally shown to affect catch diversity, but Pankow and Abel (Unpub.) used both mackerel and sardines while sampling and experienced a higher catch rate of Ray species while using sardines. This change in bait and positioning in the mouth of the estuary could be the reason for the increase. Food availability directly influences the capacity of species Winyah can accommodate. An increase in productivity and prey fish populations could result in a higher diversity of sharks needed to maintain the ecosystem.

Average species diversity between studies was significant. An increase was apparent between this study and both Gary (2009) and UNC. This increase in overall diversity could be due to gear type again, or the leaving of *R. terraenovae*, which has been consistently high until this study. Bonfil (1997) states that migrations of southeast species are not well defined, so it is possible that R. terraenovae left for migration early. Species diversity shows a significant trend between the months of August and September, while not being significant at all between years. Reasons for this drop include: Migration and competition. Competition can be explained the same way as for the drop in number of species. Migration of sharks occurs seasonally for many species for feeding and mating, which require nursery grounds. Nursery grounds are important for their protection for juveniles. The use of Winyah as a nursery ground by any species will increase numbers significantly over the summer and decrease quickly as winter sets in. This could explain why the data shows a significant drop in diversity and total catch (Fig. 2) for every September of all years.

There has been a noticeable change in the dominate species caught. The three major species for each data set varied, suggesting shifts in community structure. The three major species that persist in at least two data sets were *C. brevipinna*, *R. terraenovae*, and *C.plumbeus*. *C. brevipinna* was found in both Pankow and Abel (Unpub.) and UNC's data with significantly more catches and size distribution in the former data set. *C.plumbeus* was present in our data and the data from Gary (2009) data with a serious decline between the two. Excluding all months but July, August, and September, there is a decline of *R. terraenovae* between the data from UNC and Pankow and Abel (Unpub.) as there is also a large increase between the data from UNC and the data from Gary (2009). This excludes time of year influencing prevalence of each of these species, as all catches are compared to the same month in which they were caught. The increase in *C. brevipinna* catches could be due to an influx of prey items, a more favorable temperature later into the year, or gear type. *C. plumbeus* may be more susceptible to salinity than the other species which could drive them out with a relatively small shift. Short term weather scales play a role as in a rainy year will discourage the sharks from entering the bay as the salinity is too low to survive, although the current study was during a normal – dry summer. Other causes could be from loss of food source or equipment type. *R. terraenovae* has a peak in catches between 2005 and 2010 and a decrease in 2013. The peak consisted of hundreds being caught over the 5 year study. Influences of high food availability and favorable water conditions most likely set up the area for the mass influx of *R. terraenovae*. *R. terraenovae* is known for using enclosed bays as nursery grounds, so Winyah could have been a nursery over the study by Gary (2009). The decline in numbers was either the system returning to normal, the species being driven out by competition of *C. brevipinna* as it moved into the system, or equipment use.

Conclusions

This study found evidence for a change in shark community structure within Winyah Bay. Sharks as a whole have decreased in size and there has been a statistically significant increase in diversity which indicates that *R. terraenovae* may have been a damper on diversity in previous years. As they left diversity bounced back, but the decrease in size and change in dominate species, to *C. brevipinna*, can be seen differently. These changes are the result of large scale processes and reflect a combination of outside factors like overfishing, migration patterns, and food availability.

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Tables

P&A = Pankow and Abel (Unpub.)
UNC = UNC
Gary = Gary (2009)

Study	Difference	Lower Limit	Upper Limit	P-value
P&A-Gary	-22.669	-28.74244	-16.5955	0
UNC-Gary	-20.3246	-24.44277	-16.20642	0
UNC-P&A	2.344379	-3.425578	8.114335	0.606545

Table 1: Tukey HSD of an ANOVA for differences in average length by study.

Year	Lower Limit	Upper Limit	P-value	Significant
2013-2006	-33.37978	-14.32507	0	Yes
2013-2007	-29.36362	-4.043522	0.001275	Yes
2013-2008	-28.03748	-5.572761	0.000102	Yes
2013-2009	-34.74825	-3.43582	0.004578	Yes
2013-2010	-52.10086	-25.09751	0	Yes

Table 2: Tukey HSD of an ANOVA for difference in average length by year (all species).

Species	Study	Difference	Lower Limit	Upper Limit	P-value
C. brevipinna	P&A-Gary	-66.4057	-94.2136	-38.59772	9E-07
	UNC-Gary	-39.3077	-67.8969	-10.71848	0.004468
	UNC-P&A	27.09797	18.57144	35.6245	0
***C. plumbeus* ***	P&A-Gary	-	14.83118	34.08333	4.73E-06
R. terraenovae	P&A-Gary	-8.60849	-19.03829	1.821309	0.128678
	UNC-Gary	12.78773	7.64164	17.933813	0
	UNC-P&A	21.39622	11.87137	30.921071	5E-07

Table 3: Tukey HSD of an ANOVA for difference in average length by study.

* = Welch two sample t-test used instead as it only appears in two studies.

Year	Difference	Lower Limit	Upper Limit	P-value
2013-2002	54	1.064683	106.93532	0.043247
2013-2003	56.33333	3.398016	109.26865	0.03132
2013-2004	62.33333	9.398016	115.26865	0.013358
2013-2005	54.33333	1.398016	107.26865	0.041314
2013-2007	70	17.064683	122.93532	0.004378
2013-2008	69.33333	16.398016	122.26865	0.004826
2013-2009	72.33333	19.398016	125.26865	0.00311
2013-2010	68.33333	15.398016	121.26865	0.005587

Table 4: Tukey HSD of an ANOVA for difference in average number caught per year.

Study	Difference	Lower Limit	Upper Limit	P-value
P&A-Gary	5.933333	2.958287	8.908379	0.000102
UNC-Gary	0.183333	-1.638503	2.00517	0.966307
UNC-P&A	-5.75	-8.786394	-2.713606	0.000198

Table 5: Tukey HSD of an ANOVA for difference in average richness by study.

Month (a)	Difference	Lower Limit	Upper Limit	P-value
July-August	0.4454308	-0.1445021	1.0353637	0.166187
September-August	-0.3417392	-0.9316721	0.2481938	0.337037
September-July	-0.78717	-1.3771029	-0.1972371	0.00727
Study (b)	Difference	Lower Limit	Upper Limit	P-value
P&A-Gary	1.0732053	0.2601197	1.8862908	0.00794
UNC-Gary	-0.1146388	-0.61255	0.3832724	0.836647
UNC-P&A	-1.1878441	-2.017696	-0.3579921	0.003982

Table 6: (a) Tukey HSD of an ANOVA of average diversity by month.
(b) Tukey HSD of an ANOVA of average diversity by study.

Figures & Graphs

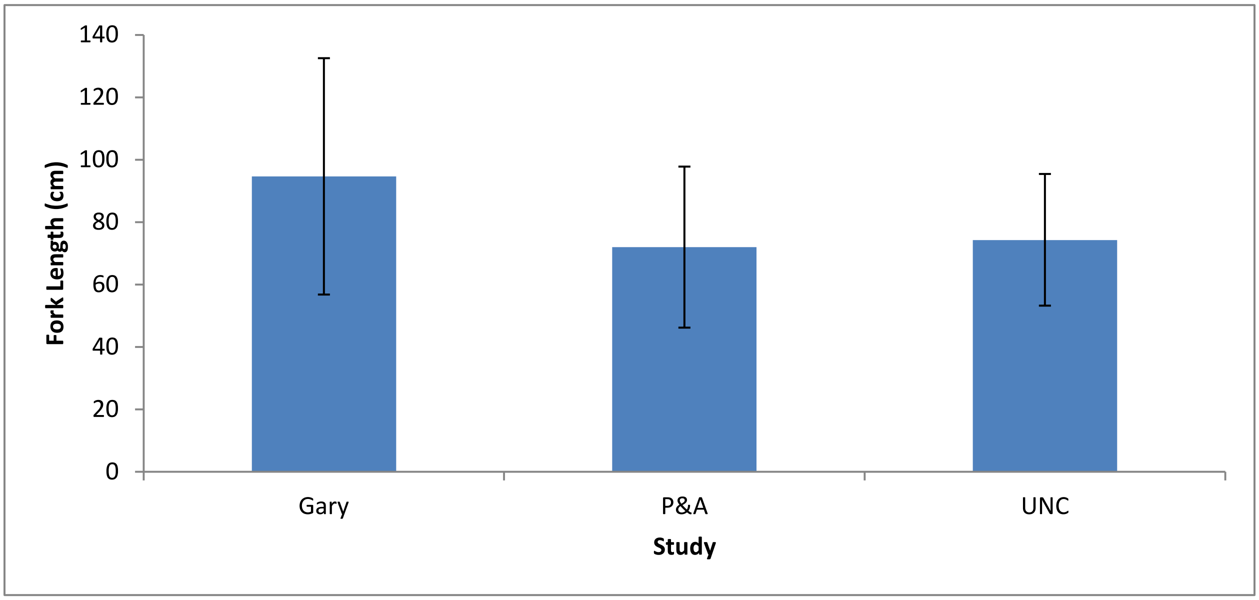

Figure 1: Mean fork length (cm) by study.

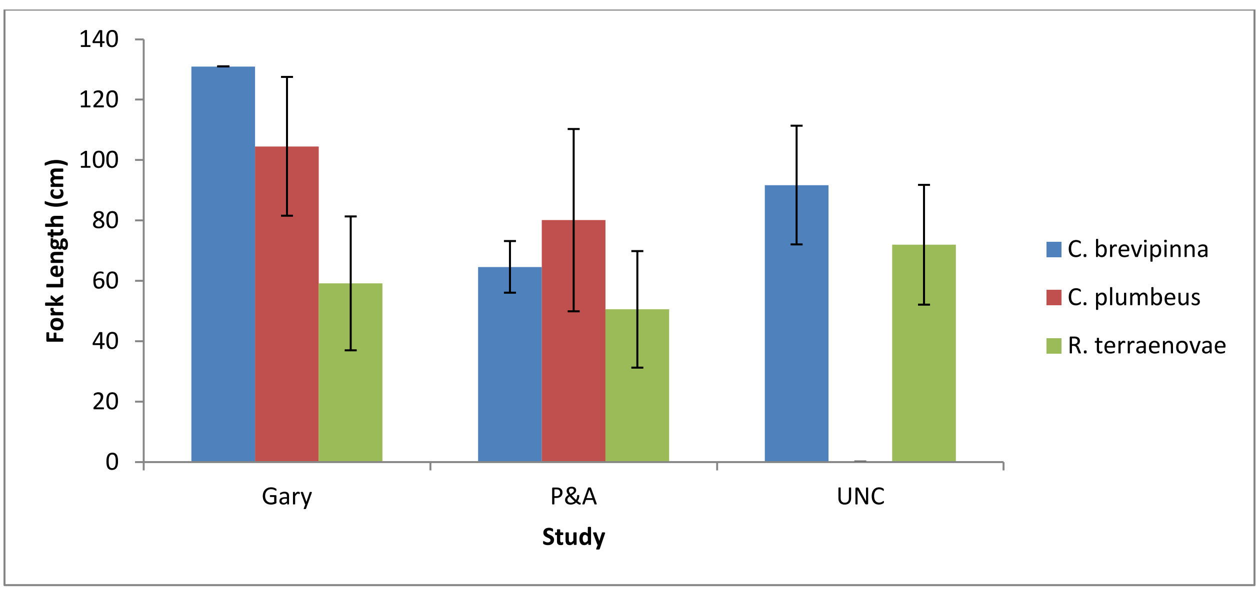

Figure 2: Mean fork length for *C. brevipinna*, *C. plumbeus*, and *R. terraenovae*.
Note: Gary – n=1 for *C. brevipinna*.

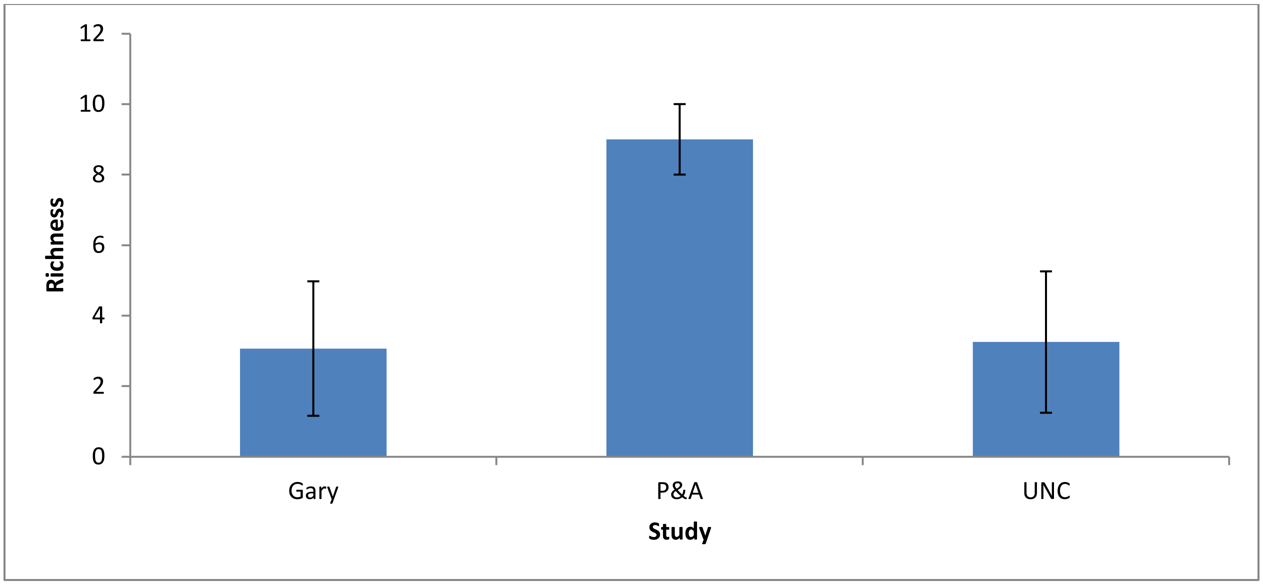

Table 3: Mean richness by study.

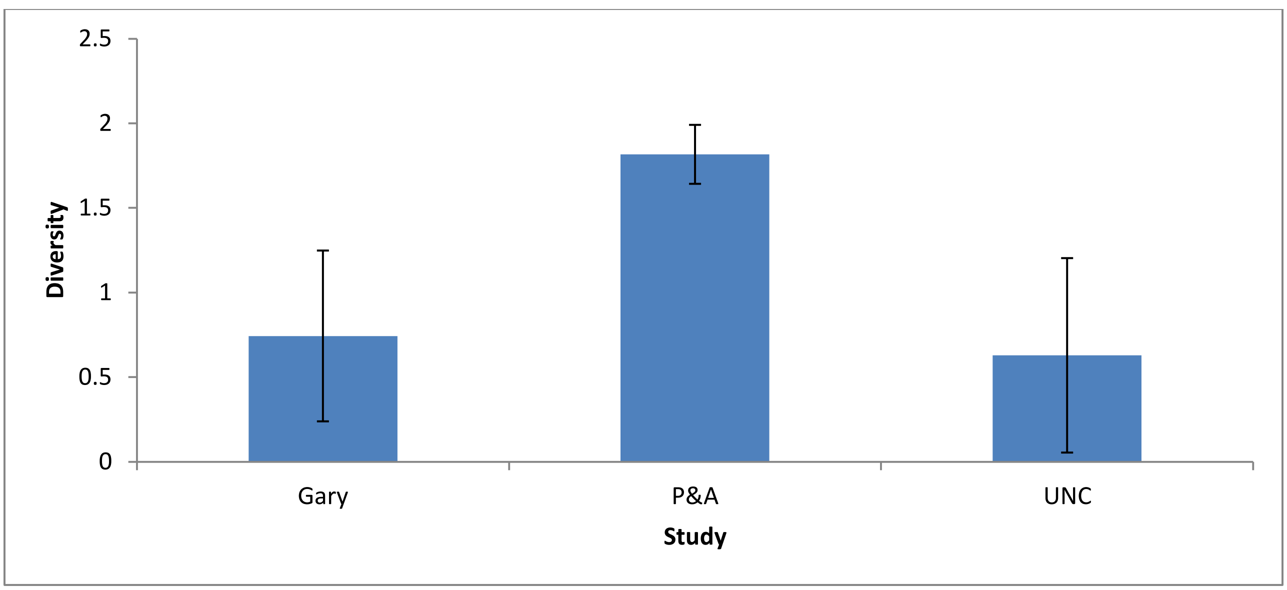

Figure 4: Mean diversity by study.

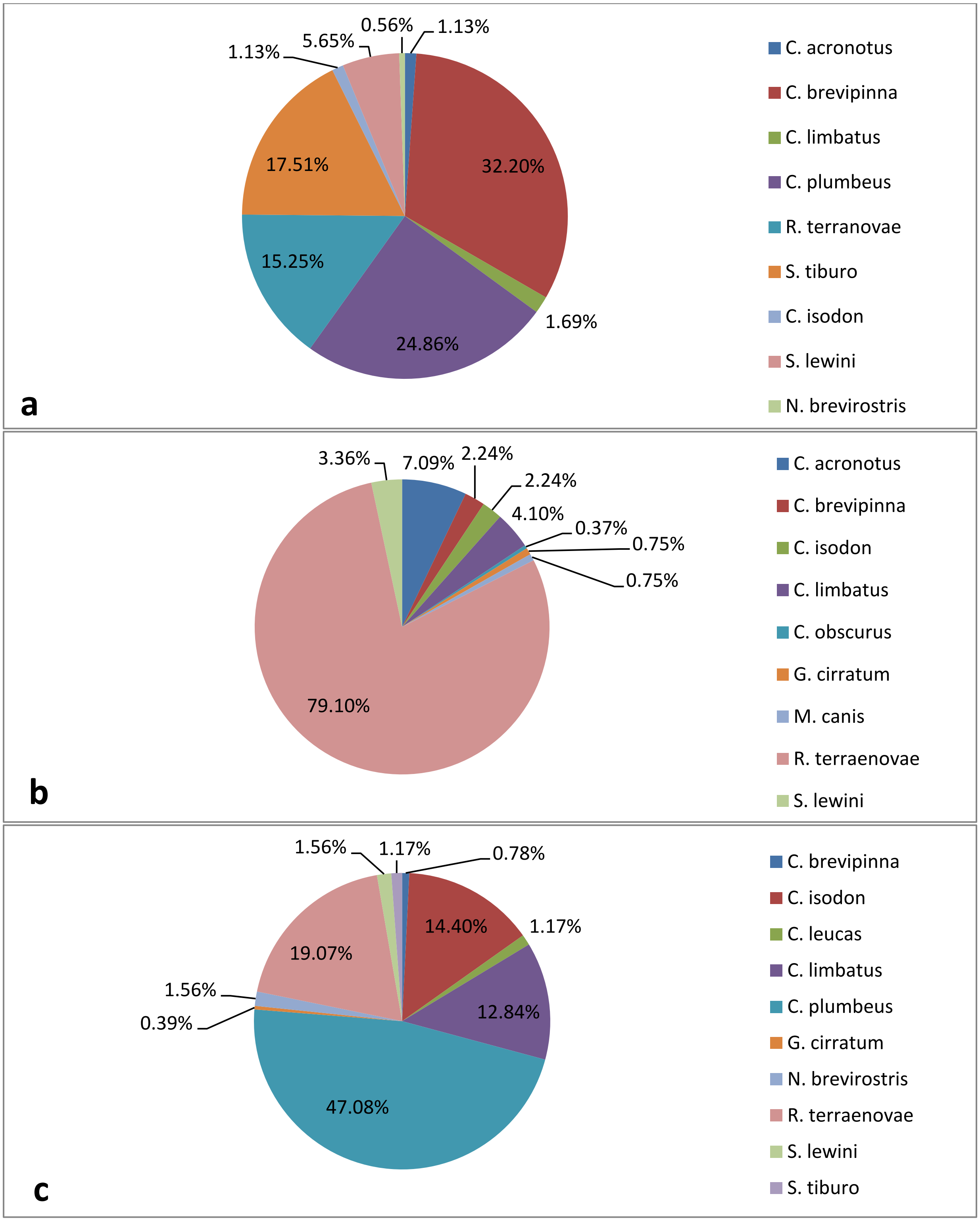

Figure 5: Species composition by percentage for this study (a), UNC (b), and Gary (2009) (c)

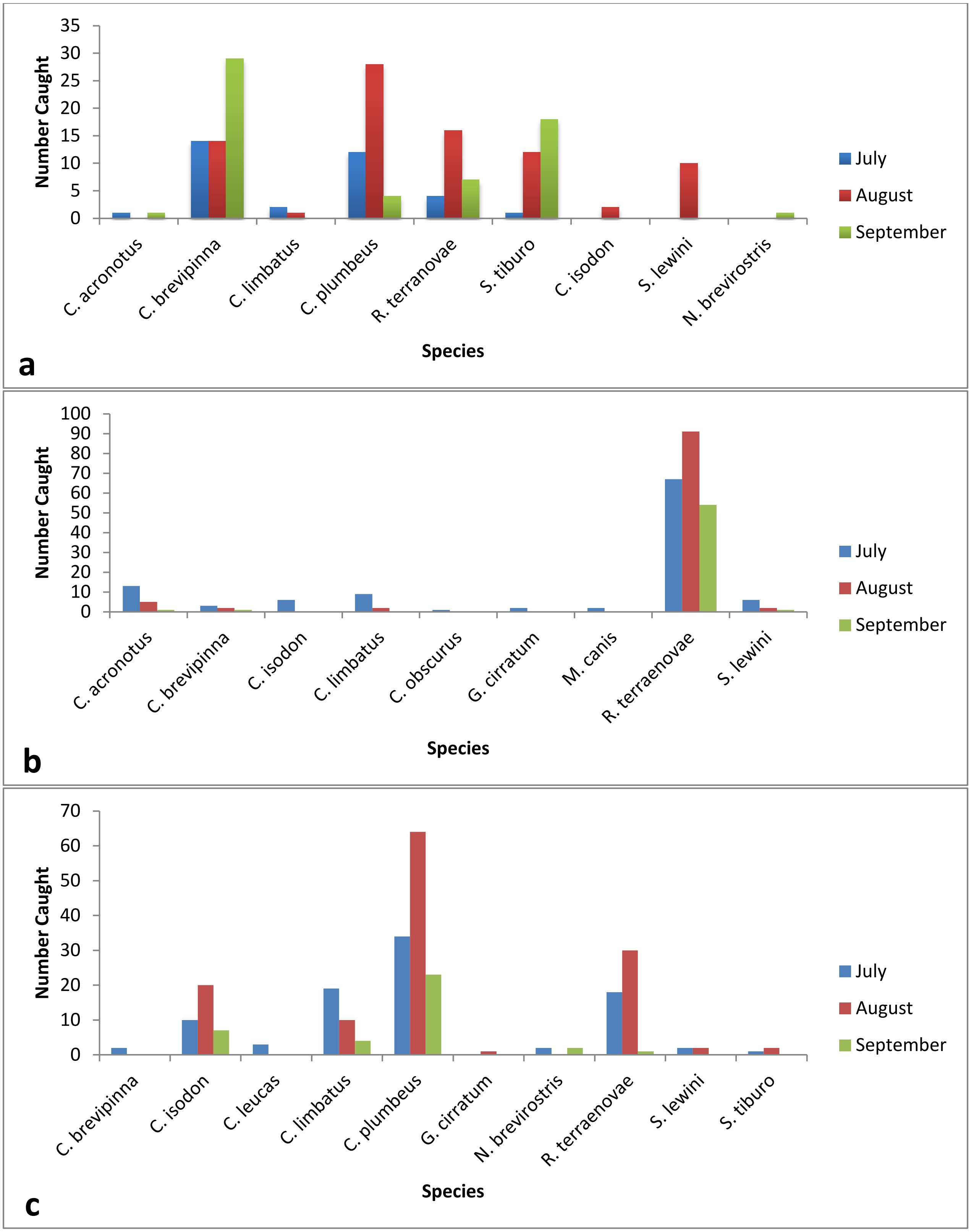

Figure 6: Number caught of each species over three months per species for this study (a), UNC (b), and Gary (2009) (c).

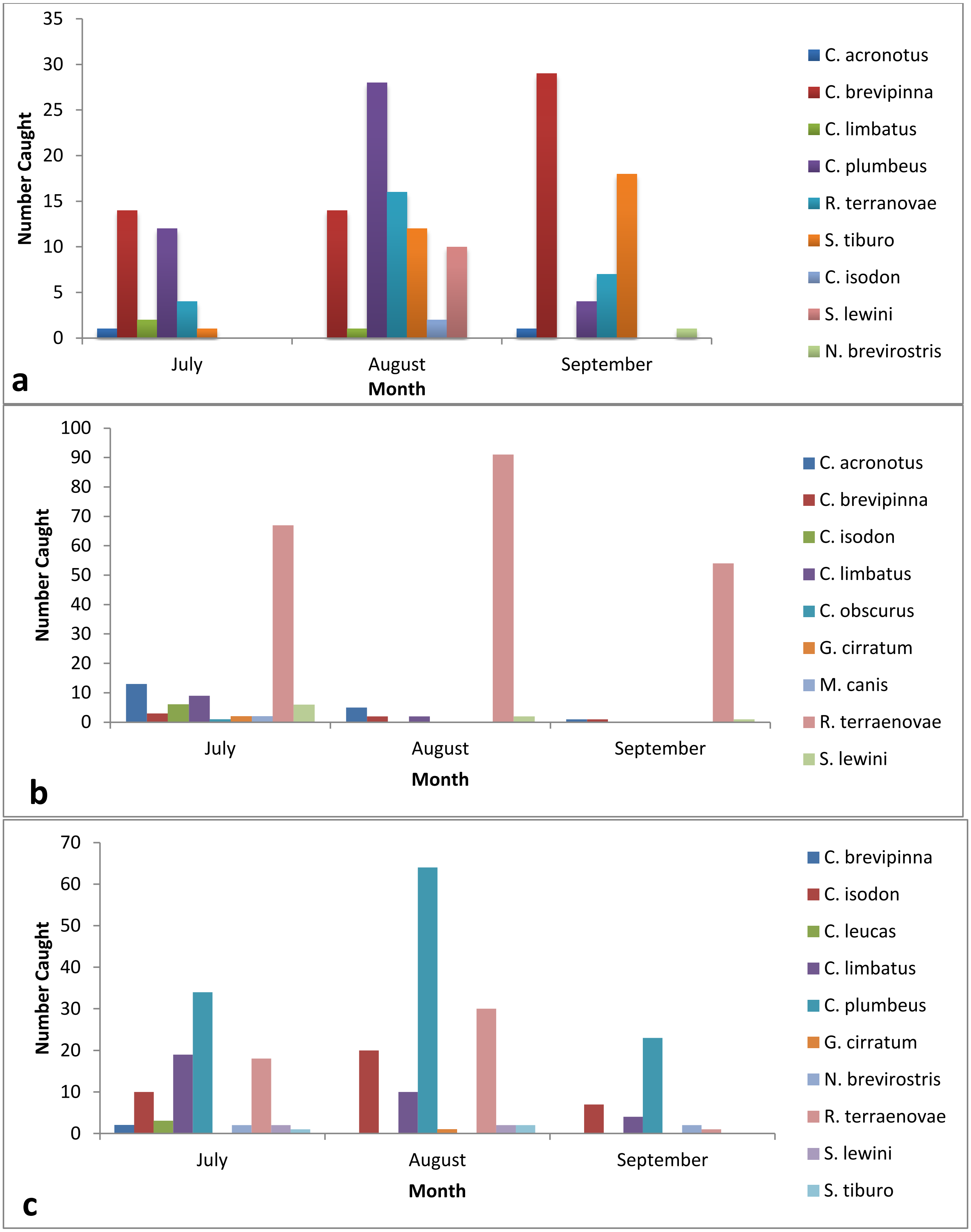

Figure 7: Number caught of each species per month for this study (a), UNC (b), and Gary (2009) (c).