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Article

Observing how the distance from the mouth of a Bahamian mangrove affects biodiversity

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SUMMARY

Mangroves are salt-tolerant shrubs that have elaborate root structures and are found on tropical coastlines. Their complex root structure, along with other characteristics, allow mangroves to filter out salt from saltwater. This filtration results in varying salinity levels throughout mangroves and can affect what type of organisms can live in mangroves. Looking at the biodiversity of different sections of a mangrove can give insight into what certain species are attracted to in their habitat. Our experiment focused on determining how the distance from the mouth of a mangrove affects biodiversity. We determined this biodiversity by selecting three sites located at different distances from the mouth of the mangrove. By using the assumption that salinity decreases as you move farther away from the mouth of the mangrove, we were able to compare each site's relative salinity with its biodiversity. At each location, we recorded all marine species and their abundance for a total of twenty minutes. From the data collected, we used a Simpson's diversity index to calculate the biodiversity of each of the sites. We predicted that the site closest to the mouth would have the highest diversity since more animals are adapted to living in saltwater than freshwater. Once we collected the data, it was clear that the site 260 meters away from the mouth had the lowest diversity, and the sites that were 90 and 135 meters away were similar in biodiversity. We also observed that almost all of the fish found were either juvenile or under five inches, which supported our prediction that the majority of fish would be smaller because they use the compact roots as protection from predators. Overall, our hypothesis that biodiversity would be highest near the mouth was partially supported because although the 135-meter site was the most diverse, it was very similar to the 90-meter site. They were both significantly denser in biodiversity than the 240-meter site.

INTRODUCTION

Salinity levels are a crucial component of water ecosystems because they keep more than 75% of the world's organisms alive and biodiversity high (1). Mangroves are unique in the fact that they have varying salinity at different locations (2). The combination of salinity's vital role in the life of aquatic species and mangrove's ability to alter salinity levels offered the opportunity to explore the true effects of varying salinity in a localized habitat. The objective of this study was to determine whether biodiversity changes as a result of a changing salinity gradient based on the assumption that salinity decreases the further away the site is from the mouth of the mangroves.

Mangroves' prop roots, which are exposed, give extra support and an excellent place for other species to claim as home, including species that live specifically around mangroves. Although the ecosystems of mangroves are diverse, many of the fish and shellfish that place themselves there are temporary due to the need to breed or place eggs. The roots of the mangrove trees consist of hard and durable wood that helps to stop large waves and winds from pushing further inland of a coastal region (3). They can also filter out pollutants and trap sediments from the land (4). Apart from their ecosystems, mangroves include a wide variety of species, including the common, red mangroves, black mangroves, and the nipa palm, which are members of the Arecaceae family (4).

A study done in 2001 investigated the correlation between a variety of juvenile fish and mangroves (5). It found that areas with structures similar to mangroves attracted more fish than areas with little structure. They also tested whether juvenile fish were attracted to places with more or fewer algae. Their data showed that structures left to form algae attracted four times the total number of fish than areas with a clean structure or lack of structure (5). The report concluded that the most important characteristic of a mangrove environment for small juvenile fish was the complex structure of roots that provide an abundance of food and protection from predators. As the fish grow, they tend to shift their habitat to mudflats due to a change in diet and reduced vulnerability to predators (5). Biodiversity is the variety in life on earth on all levels, from physical traits down to the genes of the organisms. Biodiversity is what allows ecosystems to function properly since each species has a unique function to play. (6). In the Bahamas, there is a vast amount of biodiversity. The surrounding water contains many different types of fish and marine life.

A biodiversity index shows how diverse groups of organisms are. It uses the number of species in an environment, as well as the abundance of each of those species. A biodiversity index will show that as the richness and evenness of species increase, so does the diversity. Evenness is defined as how close in numbers each species in the recorded data set are

A biodiversity index will generate a number between one and zero, with one being extremely diverse and zero, no diversity (8).

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

The diversity formula above (previous page) is known as Simpson's Diversity index. The D in the equation is the diversity value on a scale of zero to one. The value n is representative of the total number of organisms of a particular species, and N is representative of the total number of all species in the data set. By dividing the sum of each species "n(n-1)" value by the "N(N-1)," one obtains the root value, which is then subtracted from 1 to obtain the diversity (D) value (8).

A group of organisms with only one or two species would be considered less diverse than one with the same abundance but multiple species. Simpson's index uses the richness and relative abundance to give the sample set a rating from zero to one (8). One primary assumption we used during calculation is that we accurately identified the species across their different life stages. This diversity value is also limiting because it is hard to compare data from one experiment to another since they could have two drastically different ways of recording the species and their number. For instance, one study may record only adult organisms or record flora and fauna instead of just fauna (8).

The Bray Curtis Index uses the values of two different sites (in this case, the abundance of each species) and the lowest number of shared values to give a value to how different the sites are from one another. This value is then subtracted from one and multiplied by one hundred to find the similarity. This test is limited because the accuracy depends on how many values there are at each site: the more values, the more accurate the index number. The one major assumption that has to be used in calculations is that both site areas are the same size. The formula does not include a space variable and is only working with species count. In this experiment, all sites were equal in area, so we were able to calculate the index without adjustments to the formula (9).

$$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$$

We used the above formula, where BC_{ij} is the Dissimilarity value that was subtracted from one and multiplied by a hundred to obtain the similarity value in a percentage form. In the formula, S_i represents the total number of species recorded at one site, and S_j represents the total number of species recorded at the other site. C_{ij} is the sum of only the lesser counts for each species found in both sites. For example, in **Table 2**, Blue Crabs were spotted at both site one and site two, so during the calculation of similarity for the sites, C_{ij} was calculated using the lesser value of each of the shared species, which was the one blue crab at site 2 (9).

We used these formulas to determine whether salinity affects biodiversity in mangroves. Salinity in the oceans is almost always consistent at around 35 PSU but can vary along coastlines where seawater is mixed with freshwater rivers resulting in brackish water. Brackish water presents a unique challenge for wildlife since it requires them to adapt quickly to changing salinity levels. (10).

Salinity levels are a crucial aspect of the distribution of marine and estuary species. Salinity can shape an entire ecosystem and provide specific adaptations for different species. The effects of changing salinity on the ecology of an ecosystem are based mainly on the tolerance of the underlying organism to that change. Salinity levels can vary on both short

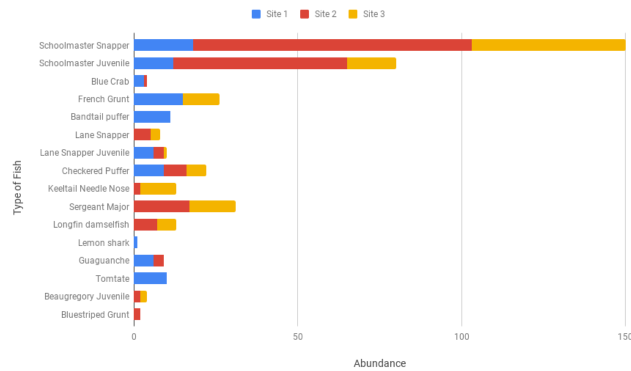

Figure 1: Stacked bar graph of the abundance of each species of fish. Site 2 (in red) had the highest number of different types of fish. For each type of fish recorded throughout the experiment, its total abundance is represented by the multi-colored bar next to its name. Schoolmaster snappers were the most common fish found across our sites. Each bar is separated into different colors representing the abundance for each site. Site 1 is represented in blue, site 2 in red, and site 3 in yellow. The data on the abundance of each fish was acquired by counting the number of its kind that passed through a 225 m^2 perimeter set up at the different sites within two 10 minute windows.

term and long term scales. Because of this, many organisms have adapted a tolerance to varying salinity levels. Most of the time, estuarine species are euryhaline, meaning that they can tolerate and live in a wide range of salinity. Unlike estuarine species, many other marine species are stenohaline and extremely limited in the salinity level they can tolerate. Lower salinity levels can provide a subsidy for estuarine species by reducing competition in the environment. Salinity levels outside of an organism's tolerance can change their behavior, limit their chance of reproduction and germination, and can reduce their fitness for survival in the environment. Salinity can work synergistically or antagonistically with other environmental factors in making a constantly changing habitat. Salinity levels are also influenced by Anthropogenic activities or human factors such as the ice caps melting and the rapid heating and evaporation in the tropics (11).

Using the assumption that the salinity gradient decreases further into a mangrove (**Table 1**), it is predicted that the biodiversity will be greater in saltier water or closer to the mouth because fewer organisms have adapted to live in

	Site 1	Site 2	Site 3
Distance from the mouth of Mangrove	260 meters	135 meters	90 meters
Assumed salinity	Lowest	Median	Highest
Depth	40 cm	60 cm	85 cm
Substrate	The sand was much finer than other sites	Coarse sand with many small rocks in the channel	Coarse sand with rocks
Current	Little current	Strong current	Strongest currents
Mangroves density	Less dense than other sites	Densest mangroves	Similar to site 2
Sampling dates and times	April 30, 2019 Trial 1: 10:30am - 10:40am Trial 2: 2:35pm - 2:45pm	April 30 and May 2, 2019 Trial 1: 10:45am - 10:55am Trial 2: 11:10am - 11:20am	April 30 and May 2, 2019 Trial 1: 2:20pm - 2:30pm Trial 2: 2:25pm - 2:35pm
Characteristics	Consistently windier than all other sites	Located at the curve in the creek of mangrove (Fig. 2) Sheltered from the wind	The narrowest part of the mangrove creek Fish hide in the mangroves, few to no fish in open areas

Table 1: Description of Each Site in The Page Creek Mangrove System shown in Figure 2.

Figure 2: Location of Each Site in The Page Creek Mangrove System and Distance from the Mouth of Mangrove in Meters.

fresher water, so there is less competition (11). In addition, it is predicted that the majority of the fish in the mangroves will be either juvenile or small types of fish due to the mangrove's compact and safe environment (6).

RESULTS

A large number of species had been observed at all of the sites (**Table 2**, **Figure 1**). To find the biodiversity of each site, a Simpson's biodiversity index was used to give each site a biodiversity rating from 0 to 1, with one being the most diverse. Site 1, which was located farthest from the mouth of the mangrove (**Figure 2**), was given the lowest rating at 0.12. Site 1 was located 240 meters from the mouth of the mangroves, and it was also much less dense of a mangrove than sites 2 and 3. Site 3 was the second most diverse., with a biodiversity index of 0.21 and the most diverse site was site 2, with an index reading of 0.34. The Simpson index is calculated using both the number of species and richness of the species. We can, therefore, see that it is no surprise that site 2 was the most diverse because it had 12 of the 15 species recorded in the entire mangrove. One can also see in **Figure 1** that site 2 had the highest abundance of each species found at the site. The adult and juvenile Schoolmaster Snapper were the most abundant at all sites (**Table 2**, **Figure 1**).

Common Name	Species Name (Author, Year)	Site 1	Site 2	Site 3
Schoolmaster snapper	*Lutjanus apodus* (Walbaum,1792)	18	85	47
Schoolmaster juvenile	*Lutjanus apodus* (Walbaum,1792)	12	53	15
Blue crab	*Cardisoma guanhumi* (Latreille,1828)	3	1	0
French grunt	*Haemulon flavolineatum* (Desmarest,1823)	15	0	11
Bandtail puffer	*Sphoeroides spenglerpia* (Bloch, 1785)	11	0	0
Lane snapper	*Lutjanus synagris* (Linnaeus, 1758)	0	5	3
Lane snapper juvenile	*Lutjanus synagris* (Linnaeus, 1758)	6	3	1
Checkered puffer	*Sphoeroides testudineus* (Linnaeus, 1758)	9	7	6
Keeltail needle nose	*Platybelone argalus* (Lesueur, 1821)	0	2	11
Sergeant major	*Abudefduf saxatilis* (Linnaeus, 1758)	0	17	14
Longfin damselfish	Stegastes diencaeus (Jordan & Rutter, 1897)	0	7	6
Lemon shark	*Negaprion brevirostris* (Poey, 1868)	1	0	0
Guaguanche	*Sphyraena guachancho* (Cuvier, 1829)	6	3	0
Tomtate	*Haemulon aurolineatum* (Cuvier, 1829)	10	0	0
Beaugregory juvenile	*Stegastes leucostictus* (Castelnau, 1855)	0	2	2
Bluestriped grunt	*Haemulon sciurus* (George Shaw, 1803)	0	2	0
Simpson's Diversity Index		**0.1204**	**0.3413**	**0.213**

Table 2: Total Number of Fish and Species Recorded at sites 1,2, and 3 and each Sites Simpson's Index.

	Site 1	Site 2
Site 2	31.7	
Site 3	46.4	63.4

Table 3: Percentage of Similarity Between Each Site Using The Bray Curtis Index.

In order to compare the similarity between the sites, we used the Bray Curtis Index. The index used the abundance of each species at each site to establish a percentage number to represent their similarity. **Table 3** shows that site 1 was least similar when compared to both site 2 and site 3 with a similarity rating of 31% and 46%, respectively. This low similarity percentage supports and mirrors the diversity test because site 1's index was 0.22 away from site 2's index and 0.09 away from site 3's index. **Table 3** also shows that sites 2 and 3 are 63% similar. The similarity between sites 2 and 3 and the lack of similarity compared to site 1 is due to the site's distance from each other, as shown in **Figure 2**. Site 2 was only 45 meters away from site 3 compared to 125 meters away from site 1 (**Table 1**).

The main outliers observed from the data were the extreme number of both schoolmaster and schoolmaster juveniles observed in site 2 and the extremely low number of lemon sharks observed. The high number of schoolmaster snappers was caused by the second recording of fish at site 2. During that ten minute recording period, the tide was extremely low. In addition to the tide being very low, site 2's mangrove density was also much higher than the other two sites. These two factors caused the high tide number of schoolmasters to hide deeper into the mangroves where we could not see them, while the low tide forced all the fish to come into full view where we were recording. Another small outlier was the lemon shark. During the two days of recording, the only lemon shark that was recorded was at site 1. This outlier was most likely a random and an unusual coincidence.

DISCUSSION

Our hypothesis that the regions closer to the mouth of the mangrove would be more diverse was partly supported by the data. Sites 2 and 3 had higher biodiversity index values than site 1, which was 260 meters away from the mouth of the mangrove and had a lower assumed salinity level. Site 2, however, had the highest biodiversity index instead of the predicted site 3, which was closest to the mouth of the mangrove. Although site 2 had higher biodiversity than site 3, it still supports the idea that the closer to the mouth a site is, the more diversity it will have. It supports this idea because sites 2 and 3 were only 45 meters apart and had the most similar recordings, which means the data was probably just impacted by a small sampling error. Our hypothesis about

Figure 3: Location of Mangrove System in Relation to The Island School on The Island of Eleuthera in The Bahamas.

the majority of fish being small was also supported. Through our observations of the fish, it was clear that the majority of the fish were either small adults or juveniles. In addition, the majority of fish were recorded inside the compact mangroves, which further proved the predicted fact that juvenile and small fish choose mangroves as a habitat because they can use the structure as shelter.

One of the downsides of testing in the field is that several unwanted factors can affect the experiment. One such factor was that site 1 was shallower and contained a much less dense mangrove than the other sites. This difference in mangrove density could have affected our data because it was clear that fish in the mangroves liked to swim in the denser roots while they would tend to stay away from the thinner rooted mangroves. Another factor that could have affected the data was the weather. During the two testing days, there was about half an inch of rain that could have affected the salinity in the mangrove. The current of the mangrove system also could have affected the results. At all testing periods, site 3 had a very strong current compared to the other sites. The increased current most likely resulted in fish taking shelter deeper in the mangrove, where we were not able to record their abundance. A source of error that most likely occurred during the experiment was a miscount of the abundance of fish. There was a significant amount of fish that had to be recorded one by one, and since they were constantly moving around, the same fish may have been recorded more than once. Each team member did their best to record as accurately as possible, but errors always occur when using observation-based data. These errors most likely did not have a huge effect on the data because the miss counts were low enough that it would not have affected the biodiversity index value. One final source of error was the fact that there were multiple people in the mangrove. There were a total of eight individuals in a very small region of the mangrove, many of them not paying attention to where they were walking and how they were disrupting their environment. These disturbances in the testing area most likely caused fish to swim away from our testing site or swim deeper into the mangrove, where we were not able to observe them. Overall, these errors and factors undoubtedly affected the data. However, the effect was not large enough to make a quantifiable difference in the data that would lead to any significance.

Assuming that these results are mainly accurate, there are still limitations that have to be kept in mind when applying the data. One of them is the assumption that as one goes further into the mangrove, the salinity will decrease. We have no evidence of how drastic or slight the change may be. We are just using the assumption that salinity decreases. This limitation only applies when one is looking at the biodiversity at varying salinities. If, however, one is only looking at how biodiversity changes at different distances from the mouth, this assumption does not have to be used, although it can be if wanted. Overall the data collected in this experiment would be most helpful comparing locations with different diversity at different distances from the mouth, not the diversity at different salinities. Using the distance from the mouth value to compare the data, it is clear that the locations closer to the mouth and with more dense mangroves will have more biodiversity.

In future experiments, we recommend that a salinity probe be used to get an accurate reading on the salt levels of each of the sites. It would also be advised that the team be extremely cautious of their footsteps and how they can easily scare the fish away. In the future, it would also be recommended that each site be recorded for longer than twenty minutes in total. The accuracy of the biodiversity index would be significantly more accurate if each site was recorded for more than twenty minutes. Lastly, in the future, it would be highly suggested that a different system of recording the fish be adopted rather than the error-prone manual method.

MATERIALS & METHOD

The mouth of the mangrove system was determined and marked with a stake. Then, a transect line was run from the mouth to points that were 90, 135, and 260 meters away. Each of the points was marked with a stake. A 15 meter by 15-meter perimeter was created around each stake. Then each of the four-team members was placed in the corners of the perimeter with waterproof cameras. A timer was set for 10 minutes. During the 10 minutes, if a team member saw a fish, he would yell out a short description and the quantity he had seen. He would also record the fish with the camera so it could later be identified if not known. The data recorder

Figure 4: Images of each of the sampling sites looking upstream. Site 1 was furthest from the mouth of the mangrove, and site 3 was nearest.

for the team wrote down the description and the quantity of fish into a waterproof notebook. This process was repeated every time a team member spotted a new fish or another number of a previously recorded fish. The number of fish was recorded with a tally system to ensure an accurate number. To ensure that no fish were counted more than once, each team member would track where the fish were going and announce it to the other members so they would not count them again. Once ten minutes had expired, the team moved to the next location and repeated the method of recording fish and their quantity. Each site was recorded for a total of twenty minutes. Once all the data had been collected, the fish were identified. Using the camera footage, the short description, and each person's memory of the fishes, the species name of each fish was found using *Reef fish identification of Florida, The Caribbean, and The Bahamas* by Paul Humann and Ned Deloach. Then using the richness and abundance of fish at each site, a Simpson's diversity index was calculated using Google Sheets.

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