5-15-2023

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Maria Gabriella Saraiva de Almeida
Lynn University

Recommended Citation

de Almeida, M. S. (2023). *Assessing paleoenvironmental change of a Boca Raton inlet through midden shell artifact snalysis* [Masters thesis, Lynn University]. SPIRAL. https://spiral.lynn.edu/etds/393

ASSESSING PALEOENVIROMENTAL CHANGE OF A BOCA RATON INLET THROUGH MIDDEN SHELL ARTIFACT ANALYSIS

by

Maria Gabriella Saraiva de Almeida

A THESIS

submitted to Lynn University in partial fulfillment

of the requirements for the degree of

M. S. in Biological Science

2023

College of Arts and Sciences

Lynn University

Abstract

In this archeological study of a barrier island shell midden in Boca Raton, FL, we evaluate possible environmental and cultural changes that occurred through time by performing a quantitative analysis of shell artifacts of Giant False Donax (*Iphigenia brasiliana*) and Common Atlantic Oyster (*Crassostrea virginica*) collected from the shell midden. Middens are archeological trash sites used by researchers to identify artifacts used by past populations to understand their behaviors. The artifacts collected in shallow portion of the midden are younger (therein representing more recent time periods) and the artifacts collected at the deeper portion are older artifacts (therein representing older time periods).

Generally, changes across the metrics measured (oyster size, diversity analysis, height length ratios, and sponge borehole patterns) indicate either salinity changes in the local environment or harvesting strategies. Results could also indicate that there was harvesting pressure during periods of times where shell sizes were smaller. The evidence of reef oysters can also be linked with evidence of attachment in samples. The findings in this research provide insights for evidence of human and environmental influence occurring in South Inlet Park in Florida. Through, cohesive analysis of the oyster, effects of environmental changes and harvesting techniques are clearly present.

Acknowledgments

I would like to express my deepest gratitude to Dr. Lecher who guided me through this study and inspired me to be a better researcher. I am also grateful for all the guidance that my committee Dr. Law, Dr. Doctor, and Dr. Korte has given me throughout, as well as Dr. Watson for all the valuable advice. I would also like to tank my lab group throughout my years at Lynn. My friends that from afar gave me the strength to keep going. Lastly, I would like to thank my family; without them none of this would be possible.

Dedication

I would like to dedicate this to my parents Zacarias and Shirley and my siblings João and Fernanda for the constant love and support. This is also specially dedicated to the memory of Flavia Viera who will forever inspire me to pursue my dreams.

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Assessing Paleoenvironmental Change of a Boca Raton Inlet Through Midden Shell Artifact Analysis

In this study we apply a heritage science approach to an archeological shell midden to evaluate possible environmental and cultural changes that occurred throughout time, which involves applying methods from natural science disciplines to learn about cultural resources (resources in the environment and changes in the environment that impact those resources) of the Tequesta and Jeaga tribes that lived in the region of the study. More specifically, we will be utilizing quantitative analysis of shell artifacts excavated from a coastal Florida site within the area known to be inhabited by the Tequesta and Jeaga tribes. Shell artifacts have been used previously to ascertain environmental change, such as changes in salinity, water velocity, aquatic substrate, and organismal changes over time (Silva et al., 2017, Hesterberg et al., 2020, Georgopoulos, 2014). This study analyzes two common species of shell found in South Florida middens: *Crassostrea virginica* (Eastern or Common Atlantic Oyster) and *Iphigenia brasiliana* (Giant False Donax or Giant Coquina).

The *Crassostrea virginica* belong to the family Ostreidae, which are found in oceanic waters of eastern North America. Their natural habitat is in brackish to saline water and in warmer places (20-36 °C) in intertidal zones from 8 to 35 feet deep. Their shell is in oval shape and has smooth edges, with the inside of the shell having a white color. Common Atlantic Oyster shell sizes reach up to 8 inches at maturity, and their lifespan can last up to 20 years. *Crassostrea virginica* has fast growth rates (6 to 8 months to reach maturity) and high reproduction rates (females produce about 100 million eggs per season) (NOAA Fisheries, 2023, Harding, 2020).

Archaeological research on the Common Atlantic Oyster in Florida has found this species to be common in shell middens throughout Florida (Jenkins, 2017, Hesterberg et al., 2020).

Additionally, the shape and features of the shell can indicate changes in temperature, salinity, and mariculture practices. As changes in temperature and salinity also affect oyster growth and reproductive success, these features can give an overview of the entire oyster population that comprised the middens (Jenkins, 2017). A study of oyster middens on the Gulf Coast of Florida additionally found a decrease in modern oyster size (maximum = 121.7 mm), compared to archaeological oyster (maximum = 188.1 mm), and a complete lack of colossal size oysters in modern samples, attributed to changes in seasonal salinity patterns, sediment load, and other environmental factors (Hesterberg et al., 2020). Another study in the same area found that lack of change in oyster size with depth is indicative of rapid midden accumulation, as oyster sizes change with depth as the oyster population fluctuates over longer time periods (Sampson, 2015).

The *Iphigenia brasiliana* (Giant False Donax) belong to the family Donacidae, and it is found from the Gulf of Mexico to Brazil. Giant False Donax are found mostly in sandy or muddy beaches and are usually in regions under freshwater influence or in estuaries. Individuals of this species have a smooth outer shell surface with irregular growth lines. The average size for adults in this species is 70 mm of length and have an elongated, moderately inflated sub trigonal shell shape. For younger shells it is less inflated (Silva, et sl., 2016). The outer surface of the shell is a tan cream color with purple umbonal region and brown periostracum (Barros et al., 2021).

This species has been extensively studied in Brazil. This is the only Donacidae of the genus that is found in Brazilian waters. This species has a strong cultural link to local riverine populations in Brazil because they are used in cooking and are commonly sold in local markets especially in the states of Pernambuco, Bahia, and Rio de Janeiro (Barros et al., 2021). In a modern survey of 120 samples of the Giant False Donax the average size was found to be from 4 to 7 centimeters in length and 1.3 to 4.6 centimeters in width. The sex ratio (M: F) was 40:69 with most wild specimens being female. Most of the samples were recovered from beaches and estuaries (Mesquita et. al., 2001). Unfortunately, there is not much information published about this species in the United States.

In terms of archaeological research Giant False Donax has been identified in coastal archaeological sites throughout Brazil. The Giant False Donax has been used to date archeological sites (Sambaquis in Portuguese) in Rio das Ostras, Brazil where shells of the species are found near estuaries, however raw data for most archeological studies are lacking (Coe et al., 2017). Its presence has also been used to elucidate the impacts of middens on coastal dynamics in northeast Brazil however the studies did not explain any further details (Klokler et al., 2021).

Shell middens are an important factor in archeological studies. They can preserve records of thousands of years of past occupation (The University of Maine, 2019). Middens are an archeological term for trash or garbage heap; they are indicative of food and tools utilized by the cultures that built the middens. The study of shell middens serves many purposes such as identifying food processing methods the living areas, and the period in which those people have lived (Hirst, 2019). In this case of this study, the people studies are the Jeaga and Tequesta Tribes.

The Jeaga indigenous tribe occupied the present-day regions from Boca Raton Inlet to North of Jupiter Inlet. From archeological sites it can be suggested that they arrived in those areas 5,000 years ago. They lived in homes with wooden poles stuck in the ground with palmetto leaves on the top. They were hunter-gatherers and their main type of foods were oysters, conch, fish, deer, alligator, and shark. (Castello, 2021).

The Tequesta were a powerful tribe that were second in command to other small tribes around Florida. The Tequesta were also hunter-gathers, and they lived in villages. These villages usually had kitchen middens where there were shells, broken pottery, bones, and ash accumulation. The middens were usually located near the water. The Tequesta consumed similar food to the Jeaga; deer, fish, alligators, shellfish, and plants. The Tequesta and Jega people are vastly understudied since they had little contact with the Spanish colonizers (Palm Beach County History Online, 2009). Additionally, it is unclear how much the tribes overlapped or even if they were subgroups of the same tribe. This study is valuable to those tribes in that it provides additional information about a tribe for which less in known that the other larger tribes in Florida at that time.

The goals of this study are threefold: 1) We will characterize the *Iphigenia brasiliana* in the South Florida Midden as previous studies were only performed in Brazil. 2) We will evaluate shell size and morphology change in Common Atlantic Oyster and Giant False Donax with depth through time, and 3) we will analyze shell assemblage data and the abundance of parasitic sponges on the Common Atlantic Oyster as indicators of environmental change. Combining these three points together will provide a cohesive story of how the environment changed through time and potentially impacted Oyster and Donax shell morphology.

Materials and Methods

Excavation

Artifacts for this study were recovered from a shell midden at South Inlet Park in Southern Florida. South Inlet Park in Southern Palm Beach County, South Inlet Park is located on a barrier island in the low-lying coastal area in Boca Raton, Florida. The park is located on the border of Palm Beach and Broward Counties. South Inlet Park is east of the Atlantic Ocean, west of A1A road system, and south of the Boca Raton Inlet. This study site is located on a barrier island directly behind the natural dune system (Lecher & Watson, 2021).

A specific characteristic of the land of this park is that it lies up to 10 m above sea level. There are three middens in South Inlet Park, South Inlet Middens 1, 2 and 3. However, in this research the shells were collected from an excavation on Midden 1, called Unit 3. The South Inlet Midden 1 is considered a typical shell midden. The mound indicates that this site is connected to the East Okeechobee, Glades, or Belle Glades cultural periods (Lecher & Watson, 2021).

In the past researchers collected shell, bone, and pottery artifacts. The most common shell in the midden was Common Atlantic Oyster, the second most common being the Giant False Donax. Other common shells included whelks and conchs. The midden was excavated in 2018 as a 1 m^3 unit (Unit 3) that was excavated in 10 cm thick layers. Artifacts were not discovered in every level but were present in the top 20 cm and below 40 cm where the bulk of the shell midden structure occurred (Lecher & Watson, 2021). Assemblage data was utilized from the artifact catalog produced as part of the post-excavation report (Watson & Lecher, 2022). Artifact assemblage was evaluated by total weight in each level.

Laboratory Analysis

For analysis of the Common Atlantic Oyster, only right (top) valves were used in the analysis to avoid double counting of individuals. Furthermore, only complete valves were used for this analysis. There were five measurements taken for the Common Atlantic Oyster, valve height, valve length, scar height, weight, and bore hole pattern type using established methods (Kent, 1989). The valve height was taken by the dorsal to ventral points of the shell, the valve length was taken from the anterior to posterior points of the shell, they were measured using a measurement app called “Ruler 2.0”, which has been shown to be an effective and fast alternative to calipers for archaeological shells (Kent, 1989 & Lagor, et, al., 2022). The scar height was measured using a caliper and it was taken from the dorsal point to the adductor muscle scar. The weight of the shell was taken with a digital balance and recorded in grams to the tenths place. The sponge bore hole pattern type, which helps identify the salinity regime of the water, was taken based on a scale from the book “Making Dead Oysters Talk” with the scale shown in Table 1 (Kent, 1989).

Table 1:

Salinity regimes from sponge boreholes as per (Kent, 1989)

Regime	Salinity	Description
A	Salinity below 10 ppt for about half of year and rarely above 20 ppt	Oyster with no bore holes
B	Salinity below 10 ppt for about one-fourth of year below 15 ppt for about half of year, and occasionally above 20 ppt	Oyster with small bore holes
C	Salinity occasionally below 15 ppt above 20 ppt for one-fourth to half of year	Oyster with small bore holes, more common than large holes
D	Salinity rarely below 15 ppt and above 20 ppt for most of year.	Oysters with more large bore holes than small

There were three measurements taken for the Giant False Donax, length, weight and width. The width of the shell was taken from the dorsal point of the shell to the ventral point of the shell. The length was taken from the posterior to the anterior point of the shell using a caliper as well. The weight was taken using a digital balance and was recorded in grams to the tenth place.

Statistical Analysis

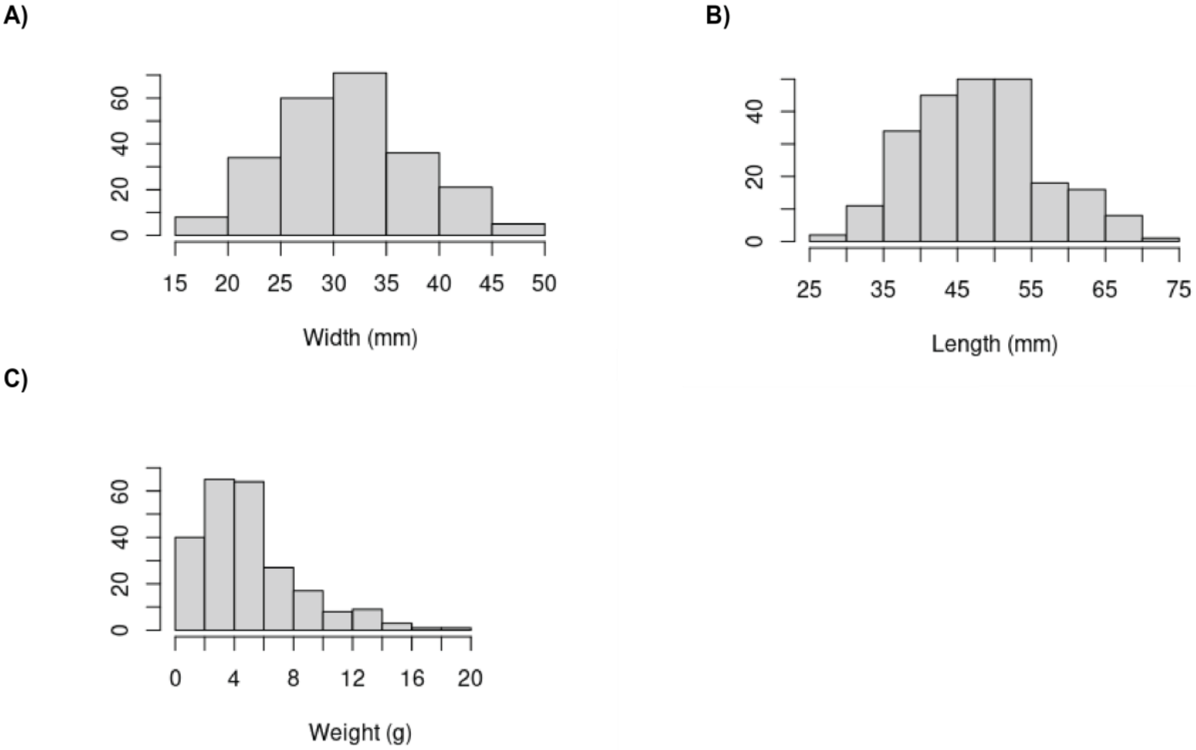
Analyses of shell shape trends with depth was conducted via a t-test of slope; null hypothesis: slope is not significantly different from 0, alternative hypothesis: slope is significantly different from 0. This would indicate if there were a continual change in depth in any of the shell morphology measurements (Navarro, 2013). A chi-squared goodness of fit test was applied to the Giant False Donax data to determine how the measurements were distributed (Navarro, 2013). Additionally, the ecology metrics of richness, diversity, and evenness were calculated for each level based on the assemblage data (Gotelli & Colwell, 2001, Keylock, 2005, Bulla, 1994).

Results

Histogram measurements of Donax data (all levels combined) are shown in Figure 1. There were 235 shells analyzed for width, length, and weight. The values for width (Figure 1A) were 15-47.9 mm, and the average was 31.3 ± 0.4 mm. The values for the length (Figure 1B) were 28.2-70.6 mm, and the average was 47.9 ± 0.5 mm. The weight values (Figure 1C) were 0.78- 19.21 g, and the average 5.05 ± 0.2 g. All data were normally distributed according to a chi-squared goodness of fit with a Monte-Carlo simulation to account for low count bins ($p > 0.1$).

Figure 1:

Histograms of Giant False Donax data

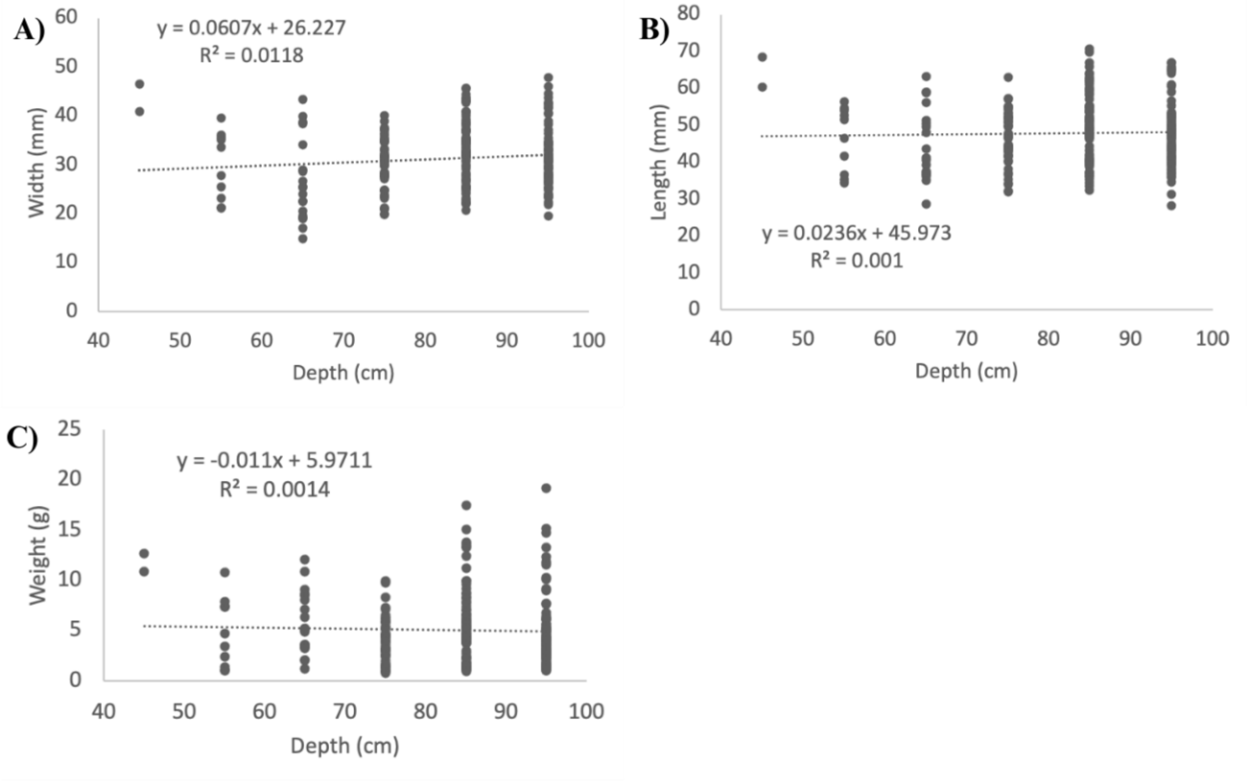


Note. A) width (mm) B) length (mm) C) weight (g).

Donax measurements by depth are shown in Figure 2. There was not a consistent change with depth from any of the measurements as shown by the slope (<0.07), R^2 (< 0.02) and the p-values (<0.05). The only measurement that may be considered to have a borderline significant change with depth is the width (p = 0.09). However, the largest measurements are consistently found in the deepest two levels. For example, level 6 (55 cm depth) shows lower maximum values for width (39.6 mm), length (56.3 mm) and weight (10.8 g). There is an increase in the maximum values with level 7 (65 cm depth) for width (43.4 mm), length (63.3 mm) and weight (12.06 g). In level 8 the maximum values decrease again before increasing in the deepest levels. Measurements for level 9 (85 cm depth) and level 10 (95 cm depth) contained the largest measurements for the shells in width (44.4 mm for level 9 and 47 mm for level 10) this trend is consistent for length (70.6 mm for level 9 and 67 mm for level 10) and weight (17.4 g for level 9 and 19.2 g for level 10).

Figure 2:

Regression scatter plot of Giant False Donax with depth

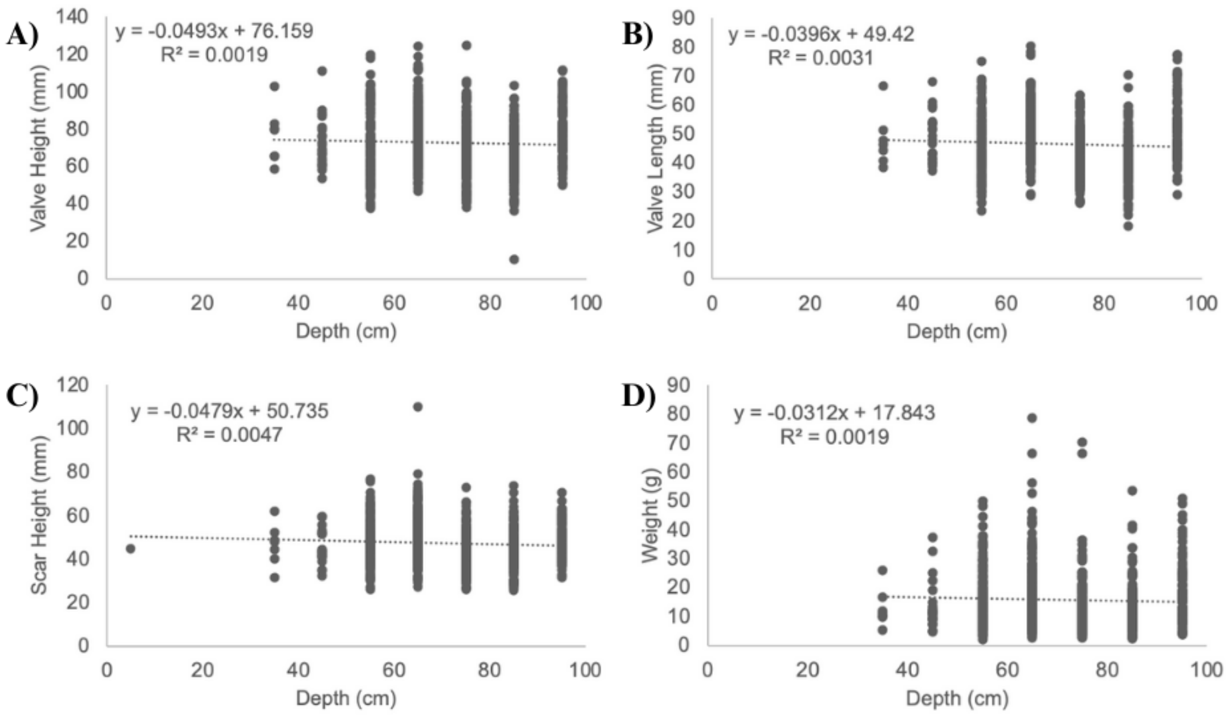


Note. A) width by depth (p-value = 0.09), B) length by depth (p-value = 0.63), C) weight by depth (p-value = 0.56).

Common Atlantic Oysters measurements by depth are shown in Figure 3. There were 772 samples of oyster shells analyzed. Only whole right valves were analyzed to prevent double counting individuals. The values for valve height (Figure 3A) were 10.3- 124.8 mm, and the average 72.6 ± 0.5 mm. The values for valve length (Figure 3B) were 18.4- 80.4 mm and the average 46.5mm ± 0.3 mm. The values of all for scar height (Figure 3C) were 25.6-110 mm and the average 47.29 ± 0.3 mm. The values for the weight (Figure 3D) were 2.07-78.5 g and the average 15.6 ± 0.3 g. There was a significant change with valve length (p-value = 0.02), scar height (p-value = 0.02), weight (p-value = 0.02) and a borderline significance value for the valve height (p-value = 0.09). Additionally, there is the same pattern in valve height and length as the Donax in that measurements in level 10 are generally larger than levels 9 and 8, before increasing again in the shallower levels. In comparison for scare height and weight, the maximum values at first increase with depth up to level 7 (61.9 mm in level 4 up to 110 in level 7 mm) and then decrease again until level 10 (70.6 mm).

Figure 3:

Regression scatter plot for Common Atlantic Oyster with depth

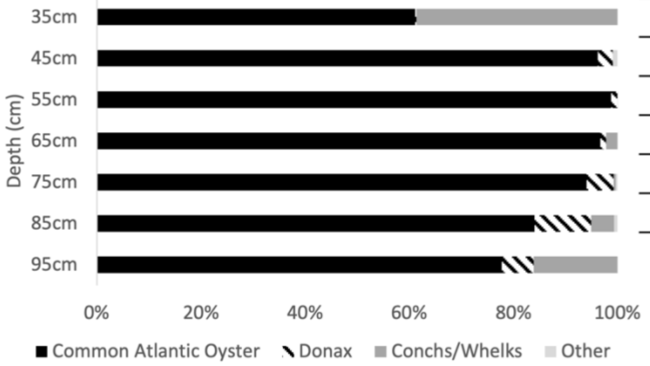


Note. A) valve height (p-value = 0.09), B) valve length (p-value = 0.02), C) scar height (p-value = 0.02) D), weight (p-value ≥ 0.05).

Assemblage and diversity data are shown in Figure 4. Level 4 (35 cm depth) does not seem to be part of the midden as it is distinctly different from the other levels. Level 6 (55 cm depth) has the most oyster dominance, however as depth increases there is a shift and the oyster dominance is reduced as Donax, Conchs and Whelks increase. Diversity and evenness increase by depth along with this shift away from total oyster dominance. However, diversity and richness decrease in level 10 (95 cm depth) because jingle shell and blood ark are not present in level 10.

Figure 4:

Assemblage data stacked bar graph with diversity information.

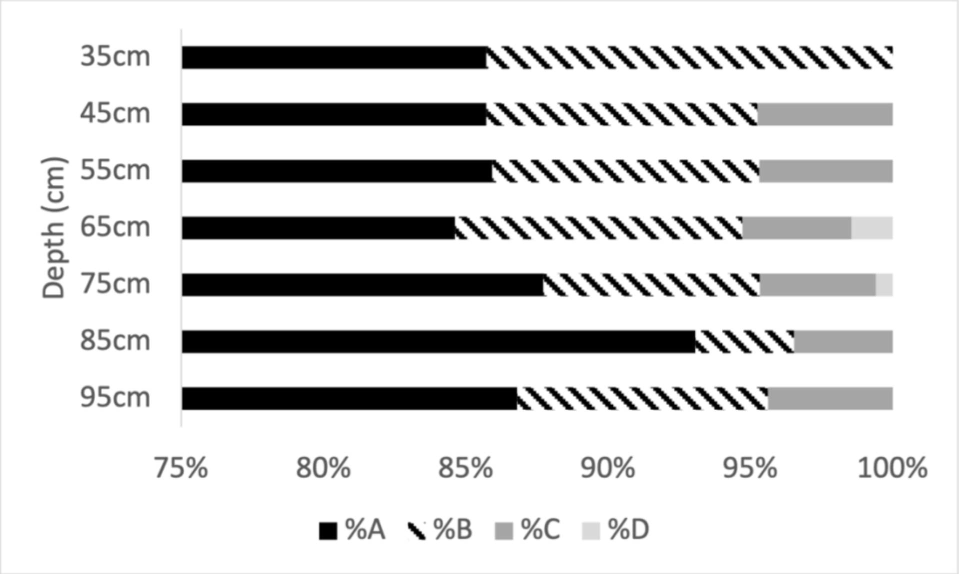


Abundance	Richness	Diversity	Evenness
94	4	0.26	0.19
136	4	0.24	0.18
880	5	0.05	0.03
1979	6	0.15	0.08
1468	9	0.51	0.23
1413	9	0.65	0.30
1178	6	0.56	0.31

Sponge bore hole data is shown in Figure 5. In this graph, level 4 (35 cm depth) also seems to not be a part of the midden as it is distinctly different from the other levels. Level 5 (45 cm depth) and level 6 (55 cm depth) have similar proportions for the different regime types, ~85% for type A, ~9% for type B, and ~4% for type C. In level 7 (65 cm depth) there is a change in the percentage of the regimes where type B pattern percentages increased compared to the previous two levels and type D pattern appear as well. However, in level 8 (75 cm depth) there is a systematic decrease in regime D pattern percentages with a corresponding increase in regime A pattern percentages until in level 9 (85 cm depth) and level 10 (95 cm depth) where regime D disappears once again. Regime corresponding A increases until level 10, when it decreases again as regime B increases.

Figure 5:

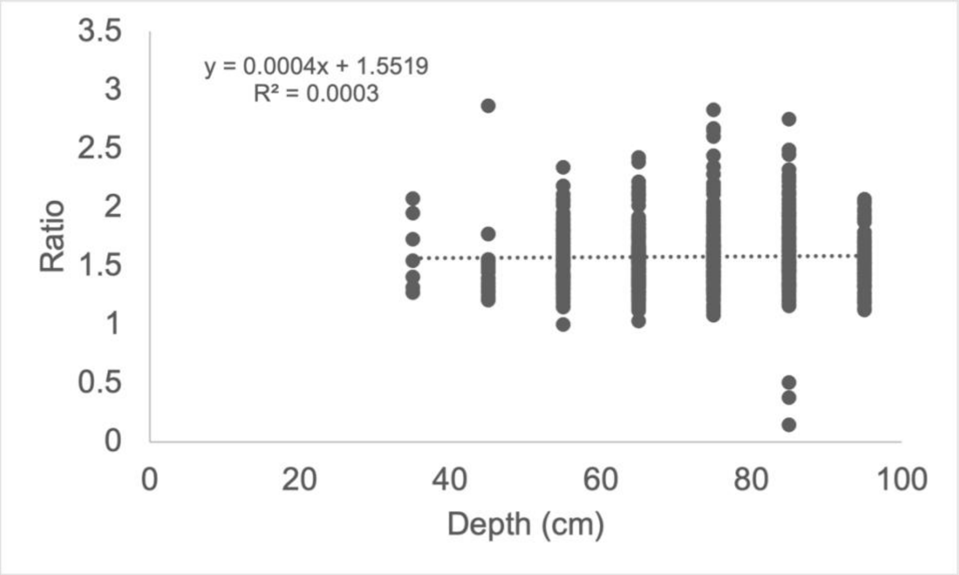
Sponge bore hole pattern type percentages (A, B, C, D) of each level by depth (cm).



Ratio of oyster valve height and length (HLR) with depth are show in in Figure 6. In level 5 (45 cm depth) much of the HLR is under 1.3 mm which shows that many of them were sand oysters located on intertidal or in shallow water. There is an increase of the values for level 6 (55 cm depth, 1.0- 2.3) and level 7 (65 cm depth, 1.0- 2.4) as there is an increase in the number of shells that have a HLR above 2.0, indicating they are reef oysters and located in intertidal waters. Level 8 (75 cm depth, 1.1-2.8) and level 9 (85 cm depth, 0.1-2.8) show an increase in the maximum values when compared to level 7. Both levels contain reef oysters and sand oysters as well as bed oysters with an HLR between 1.3 and 2.0. When looking at level 10 (95 cm depth, 1.1-2.1) there is a decrease on the ratio when compared to level 8 and level 9.

Figure 6:

Regression of the ratio of the valve height and length (HLR) by depth



Note. p-value < 0.01

Discussion

Giant False Donax

From the results gathered we can characterize the Giant False Donax in this Floridian midden. Based on the chi-squared test, the Donax data was normally distributed which shows that we have a large enough sample size to analyze our findings without bias for selection. As reported in the introduction, archeological raw data for the Donax are lacking. However, prior studies with modern samples of the Donax in Brazil indicate that they were 40-70 mm in length and 13-46 mm in width, with no weight was reported for this study (Mesquita et. al., 2001). The results for the current study in Florida indicate that their considerable overlap in size with 28.2-

70.6 mm in length, 15.0-47.9 mm in width, and 0.78-19.21 g in weight as reported in *Figure 1*. Since there is this overlap, it seems that the Giant False Donax is similar in size across these Florida and Brazil sites when comparing to the measurements from past (Florida archeological) and present (modern samples from Brazil).

In terms of changes through time with the Donax, even though there is not a significant change shown in the measurements for the Donax there are still some interesting findings. There is a trend in Figure 2 where in level 6 (55 cm depth) the maximum measurements are smaller for width, length and weight when compared to level 7 (65 cm depth), the maximum values decrease again in level 8 (75 cm depth), and then the maximum values increase in level 9 (85 cm depth) and level 10 (95 cm depth), These trends are similar to trends in oyster size in another Florida midden documented by Sampson (2015) which can indicate that the human activity of that area during those periods of times could have influenced the shell sizes. The indigenous people at that time could be selecting the size of the Donax due to their personal preferences. The other implication would be that the opening and closing of the inlet during that time could be affecting Donax growth in that area. When the inlet is closed the salinity of the inlet would be lower due to less water exchange with the open ocean. If salinity fluctuated throughout time due to the inlet opening and closing, then the Donax may increase in size during time periods when the salinity is more favorable for their growth. Donax will reduce weight when they experience stress and generally prefer brackish conditions. The reduction of weight could indicate a switch to more oceanic conditions and an opening of the inlet (Silva, 2017). Thirdly, it is possible that there is some loss of the largest Donax size if that size was overharvested in the region. A similar effect was seen on oyster in Crystal River, FL where the largest size classes of oysters were found only in archaeological shell and not in modern shell. The causes of that large oyster loss were unknown but could have been due to overharvesting or environmental changes (Hesterberg et al., 2020).

This finding provides a baseline of morphology of the Giant False Donax in archaeological sites in the United States. However, since this study only targeted one excavation site it would be beneficial for future research to investigate other archeological sites with the presence of the Donax to see if the size and morphology differs by site or time period.

Changes Through Time

This study set out with the aim of assessing shell size and morphology of the Common Atlantic Oyster to see if there are changes could indicate environmental changes or harvesting changes with time. For this analysis it is useful to look cohesively at the data starting with the oldest (i.e. deepest) moving forward in time (i.e. moving upward through the midden). Starting with level 10 (95 cm depth) the mean for valve height, reported as average (minimum-maximum), was 72.7 mm (40.8-117.4 mm), valve length was 51.8 mm (43.7-77.5 mm), scar height was 48.6 mm (44.8-70.6 mm) and weight was 17.3 g (3.61-50.9 g). This level shows a mean for the HLR of 1.53 (1.13-2.07). These measurements indicate that most of the oysters were sand oysters and are generally in intertidal or shallow water. However, there is some indications of reef oysters present as well as bed oysters. Looking at the sponge bore hole pattern percentage for this level; the results indicate that ~84% of oysters were type A which shows that the environment brackish but was on the fresher side of most of the levels. This level had a dominance of Common Atlantic Oysters as they represented ~77% of the species present, followed by Conchs and Whelks (~16%), then Giant False Donax (~6%) and other species were ~0.02%.

Moving forward in time to the next shallower level, (level 9, 85cm) there was a slight decrease in oyster measurements where valve height was 71 mm (49.8- 103.4 mm), valve length was 41.4 mm (37- 70.5 mm), scar height was 45.3 mm (44.8- 70.6 mm), and weight was 13.3 g (3.6- 50.9 g). This change could indicate that if the indigenous people were collecting the biggest oysters and that there was a dwarfing of the organism size. However, there are alternative explanations for this change. The HLR is slightly longer at this level with a mean of 1.6 (0.1- 2.7) when compared to level 10 (95 cm depth). The main difference is that there was an increase on the maximum values, which could indicate a larger proportion of reef oysters. When compared to level 10 (95 cm depth) there seems to be evidence of the water getting fresher with sponge borehole type A pattern representing more (~93.1%, Figure 3) of the oysters. This is supported by the lower on the number of conchs and whelks present at this level (~4.4% of species, Figure 4) since they generally prefer environments with higher salinity (Garland & Kimbro, 2015). Another interesting finding was that the presence of Common Atlantic Oyster (~84%) and Donax (~10.8%, Figure 4) increased when compared to the other levels. This finding may suggest that the indigenous people were finding more Donax and Atlantic Oyster, it could also mean that they were harvesting for these bivalves in a different location such as an oyster reef, which is supported by the change in HLR.

Moving forward again in time to the next shallower level, level 8 (75 cm depth) measurements increase again in most maximum oyster measurements when comparing to level 9 (85 cm depth). Level 8 (75 cm depth) shows a mean for valve height 67.8 mm (38.3-124.8 mm), valve length 43.3 mm (35.6- 63.5 mm), scar height 44.1 mm (40.4- 72.9 mm) and weight 12.9 g (45.1-73.5 g). The valve length was smaller when compared to both level 9 (85 cm depth) and level 10 (95 cm depth). HLR also maintained a similar value with a mean of 1.6 (1.1- 2.8) with an increase in the maximum when compared to level 9 (85 cm depth), which again could indicate a shift towards reef oyster presence during that time. Sponge bore hole pattern data for this level show a decrease in type A pattern (~87%) with an increase of type B (~7.6%) and C (~3.5%). This is also the first level with evidence of pattern D (~0.6%), cohesively indicating the water increased in salinity when compared to other levels. In this level there is also an increase on the amount of Common Atlantic Oysters (~94%), and consequently there is a decrease on the Donax (~5.1%), Conchs/Whelks (~0.38%) and other species (~0.4%). Since the oyster HLR is the same, that indicates the collection location was still predominantly sand oysters and oyster reef, but increasing salinity could indicate an opening of the inlet or sea level rise that would bring more higher salinity ocean water into the area. While one might expect a reduction in the presence of oyster compared to conchs and whelks, a large buildup of oyster reefs in the previous time period may have had enough of an effect to outcompete the other species as food sources, i.e. oysters were more present due to an already established oyster reef system that made them easier to harvest than conchs and whelks. Additionally, as Donax struggle with abrupt changes in the environment (Silva, 2017), the reduction in Donax in this level is in line with this hypothesis of increasing salinity. However, this change could be related to a change in harvesting area where the indigenous people ware collecting them in areas with more oceanic salinity, but still in sand and oyster reef areas or a change in dietary preference.

Moving forward again in time to the next shallower level, level 7 (65 cm depth) there is a shift again where oyster size increases compared to level 9 (85 cm depth) and level 8 (75 cm depth). Oysters in level 7 (65 cm depth) had a mean of valve height 82.7 mm (68.7- 124.1 mm), valve length 50.8 mm (44.5-80.2 mm), scar height 50.5 mm (44.7- 110 mm) and weight 17.9 g (2.5- 78.6 g). The HLLR is lower when compared to level 8 (75 cm depth); the mean for level 7 is 1.5 (1.1- 2.4). There is also decrease on the Donax (~1%) and other (~0.02%) species in this level. However, there is another increase in Common Atlantic Oyster (~96%) in level 7 (65 cm depth), with an increase in Conchs/Whelks (~2.2%) which corresponds with higher salinity as indicated by the sponge bore hole pattern data. Sponge borehole pattern A (~84.6%) and C (~3.8%) decreased compared to the previous level, and pattern D increased (~1.4%). There was also an increase of regime B (~10.1%) when comparing to level 8 (75 cm depth). Overall, the shift in borehole patterns and reduction in Donax presence indicate a shift towards saltier water, possibly due to inlet changes (opening) or sea level rise.

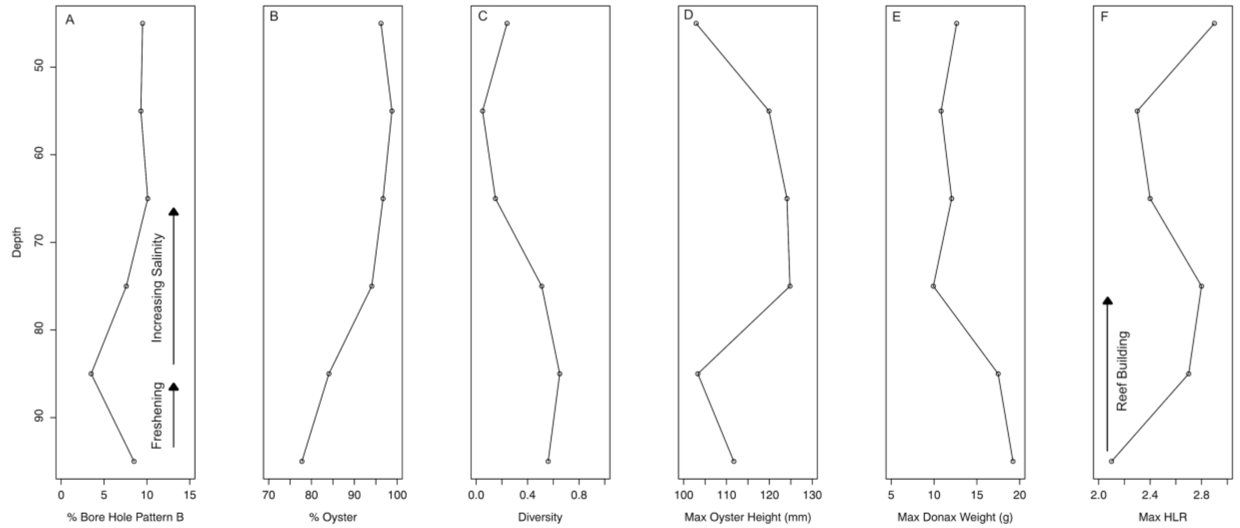
Moving up another level and onto the next time period in level 6 (55 cm depth) the measurements for the oysters suffer a change and decreased when compared to level 7 (65 cm depth). The mean of valve height was 71.2 mm (49.4- 119.9 mm), valve length was 45.6 mm (40-75.2 mm), scar height was 48.1 mm (40.5- 76.8 mm) and weight was 16.5 g (2.1- 49.9 g). The HLR also showed a similar mean 1.6 (1- 2.3) however there is a slightly smaller maximum number, but this ratio indicates the same type of harvesting environment as level 7 (65 cm depth). The dominance of oysters (~98%) and Donax (~2.2%) increased when comparing to level 7 (65 cm depth). One interesting finding is that there's no evidence of Conchs/Whelks in this level and only about 0.01% of other species. This could be related to the fact that there is also a shift in the salinity regime as indicated by sponge borehole patterns. There is an increase in type A (~85%) and type C patterns (~4.8%) and just a slight reduction in regime type B pattern (~9.3%). Level 6 does not show any evidence of regime type D which indicates a reduction in salinity, further supported by the lack of conchs and whelks as if the water is fresher this limits the number of Conchs/Whelks.

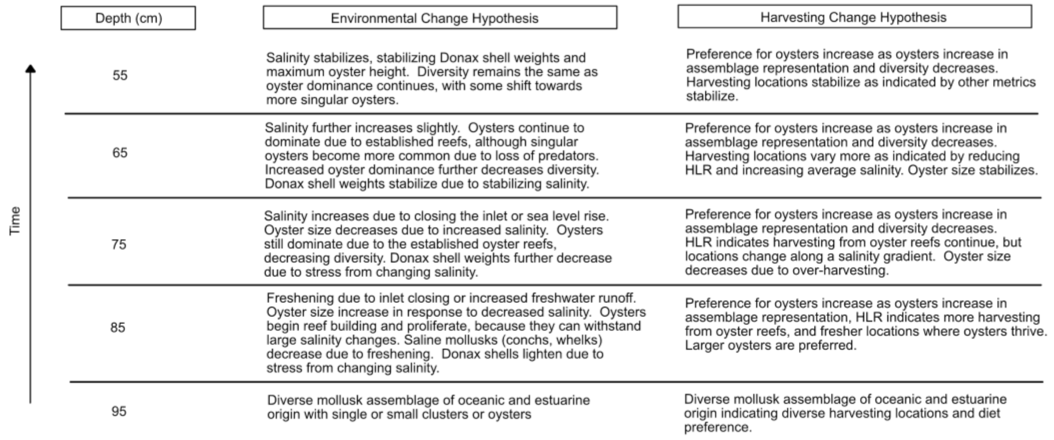
Moving on to level 5 (45 cm depth) oyster measurements reduce again when comparing to the other levels. The mean for valve height was 72.6 mm (60.9- 111.2 mm), valve length was 48.8 mm (39.7- 68 mm), scar height was 45.2 mm (40.7- 59.5 mm). As for the HLR, the mean was 1.5 (1.2- 2.9) and therein smaller compared to level 6 (55 cm depth) as can be seen in *Figure 6.* This can indicate a change on the environment where the shells were located since it seems to have more sand oysters on that level with fewer evidence of reef oysters. There was a small increase of Donax (~2.8%) and other species (~0.9%) with a slight decrease in the number of Common Atlantic Oyster (~96%) present when compared to the previous level. Still there is no evidence of Conchs/Welks in this level as well. This level also seems to exhibit shells from an area very similar in salinity to the previous level as there is a majority of type A (~86%) and type B (~9.5%) patterns. Type C (~4.6%) stayed the same and again no evidence of regime D was shown. Cohesively all the data together indicate very little environmental change or change in harvesting location compared to the previous level.

In this research we came to the conclusion that these results can be caused due to two different hypotheses. First is the environmental change hypothesis, which could be attributed to changes in salinity patterns. Second is the changes in harvesting hypothesis, which are mainly attributed by the different harvesting patterns of the indigenous population at that time. To observe these changes, we must look at the bore hole patterns, the oyster abundance and maximum oyster height together since they can sustain larger changes in the environment and react by changing their size (Hesterberg, 2020), diversity patterns, maximum Donax weight because they react to stress caused by abrupt environmental change by getting lighter (Silva et. al., 2017) and max HLR., The two hypothesis are illustrated in the conceptual model (Figure 7)

Figure 7:

Conceptual model of changes in artifact assemblage if driven by salinity changes or changes in harvesting activities





Depth (cm)	Environmental Change Hypothesis	Harvesting Change Hypothesis
55	Salinity stabilizes, stabilizing Donax shell weights and maximum oyster height. Diversity remains the same as oyster dominance continues, with some shift towards more singular oysters.	Preference for oysters increase as oysters increase in assemblage representation and diversity decreases. Harvesting locations stabilize as indicated by other metrics stabilize.
65	Salinity further increases slightly. Oysters continue to dominate due to established reefs, although singular oysters become more common due to loss of predators. Increased oyster dominance further decreases diversity. Donax shell weights stabilize due to stabilizing salinity.	Preference for oysters increase as oysters increase in assemblage representation and diversity decreases. Harvesting locations vary more as indicated by reducing HLR and increasing average salinity. Oyster size stabilizes.
75	Salinity increases due to closing the inlet or sea level rise. Oyster size decreases due to increased salinity. Oysters still dominate due to the established oyster reefs, decreasing diversity. Donax shell weights further decrease due to stress from changing salinity.	Preference for oysters increase as oysters increase in assemblage representation and diversity decreases. HLR indicates harvesting from oyster reefs continue, but locations change along a salinity gradient. Oyster size decreases due to over-harvesting.
85	Freshening due to inlet closing or increased freshwater runoff. Oyster size increase in response to decreased salinity. Oysters begin reef building and proliferate, because they can withstand large salinity changes. Saline mollusks (conchs, whelks) decrease due to freshening. Donax shells lighten due to stress from changing salinity.	Preference for oysters increase as oysters increase in assemblage representation, HLR indicates more harvesting from oyster reefs, and fresher locations where oysters thrive. Larger oysters are preferred.
95	Diverse mollusk assemblage of oceanic and estuarine origin with single or small clusters or oysters	Diverse mollusk assemblage of oceanic and estuarine origin indicating diverse harvesting locations and diet preference.

Note: Artifact metrics that indicated changes in artifact assemblages and characteristics that indicate either changes in salinity or harvesting practices. The conceptual model should be read moving forward with time, i.e. from the bottom up.

In general, if environmental changes were responsible for the level-to-level changes in shell artifacts it could be due to changes in the development of the barrier island system combined with sea level rise. This can be shown because the environment started with evidence of brackish water as indicated by the bore hole pattern data in level 10 (95 cm depth) and level 9 (85 cm depth) and changed to more oceanic water through levels 8 (75 cm depth) and level 7 (65cm depth), before reducing again to more estuarine conditions in the shallowest levels. Cohesively, this could mean the barrier island was in the very early stages of development in the deepest levels, and as it developed (potentially even in the inlet closing) it entrained freshwater behind it decreasing the salinity. This is further supported by the shift towards oyster dominance. Then in levels 7 and 8 the change in bore hole pattern data indicates a shift back towards more saline condition, possibly due to sea level rise or opening of the inlet. The oyster dominance does not decrease however with this shift, probably due to the established oyster reef systems during this time as indicated by the HLR. There is one caveat to consider with the sponge borehole pattern data. The low percentages for salinity regime pattern D could be because only the right valve of the oyster was analyzed for this study to avoid double counting individuals. It may be that the burrowing sponges prefer the lower valve (left valve), although there is no indication in the literature that this is the case. Further research with left valve of the oyster may be beneficial to take this variable into account.

Change in oyster size showed similar trends as reported by Thompson et al., (2020) where oyster sizes were larger in shallower levels, then decreased in middle levels, and increased to their largest size in deeper levels. These results could indicate that there was a harvesting pressure during periods of times where shell sizes were smaller. It is also possible that when there is an increase in these values the environment could be going through increases in the ecosystem's productivity, as is reported in Thompson, et. al. (2020). When analyzing the archeological values for oyster height in our study (10.3-124.8 mm) we see similar results to the modern Florida shells in Hesterberg et al., 2020 (~30-121 mm) not the archeology shells (~30-188 mm). Our data also indicates that the population was not selecting just the larger oysters since we have wide range of measurements and no signs of dwarfism which is also reported in a previous study in Virginia (Rick, et. al., 2016). It is unlikely that we have a size bias a chi-squared test of Oyster length measurements showed a normal distribution indicating that it was a large enough sample size.

The results for this research could also support the idea that there was human influence in the environment. Even though the HRL results generally show that most of the Common Atlantic Oysters were sand oysters in intertidal beaches of coarse sand (Kent, 1988) there is evidence of reef oysters. These results could be linked to the fact that there is evidence of attachments in some oysters. A similar result can be seen in Quitmyer, (1998) with the assumption that the oysters were collected from a cluster, however they were connected to solid substrates. Overall, this could be showing that the indigenous people started harvesting from shallow water near the inlet as indicated by the evidence in level 10 (95 cm depth) and then they switched to intertidal and deeper channels as indicated by evidence in level 9 (85 cm depth) and level 8 (75 cm depth), after they went back again to shallow waters as shown in level 7 (65 cm depth), level 6 (55 cm depth) and level 5 (45 cm depth). This alternative explanation could also explain the changes in borehole pattern data as the salinity of the locations would differ. Another hypothesis is that the indigenous people could be doing some form of crop rotation in order to avoid overharvesting of the species, this was also evidenced in a previous study (Lepofsky et, al,, 2015).

Conclusion

The findings in this research provide insights for evidence of human and environmental influence occurring in South Inlet Park in Florida as well as helping characterize a species (Giant

False Donax) that was not previously studied in Florida. Through cohesive analysis of the oyster (bore hole patterns, valve length, width, and weight, scar height, and HLR) effects of environmental changes and harvesting techniques are clearly present. Finally, it is important to address the limitations of this study. Since this study is limited to only one archeological site it is encouraged to conduct further investigation specially with the Donax in Florida to have a better understanding of this species in the United States. It would be interesting to do further research with the left valve of the Common Atlantic Oysters to examine the possible differences between them and the right valve of this shell which was addressed in this study.

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