

## Abstract

The late Holocene development of oyster reefs can reveal the history of estuary formation through standard stratigraphic and paleontologic analyses. Reefs located at the terminus of the Florida Everglades' Shark River sloughway should record the effects of natural and anthropogenic variability in freshwater delivery. Using the 900-year history recorded in one reef from Broad River, this study determined relative trends in salinity and energy through time. The hypothesis tested was that the reef originated under higher energy and salinity conditions, becoming less energetic and progressively more brackish through history. A core was obtained from the mouth of Broad River according to standard vibracoring procedures. The 210 cm core was divided into 21 – 10 cm horizons and its stratigraphy was described. Oyster shells and fragments greater than 2 cm in length from each horizon were examined to evaluate taphonomic grade, percent encrustation, and *Ciona* sp. boring occurrence. Sedimentology was described using a Malvern laser particle grain size analyzer. T-tests were applied to the sedimentologic and taphonomic data. *Ciona* sp., a bioeroder requiring marine salinities, and mean grain size decrease up section; these trends were statistically significant. Although statistically insignificant, taphonomic grade showed a weak trend of improved preservation up section while encrustation exhibited a decrease. Results indicate salinity has decreased throughout history in Broad River. Commensurate with these changes is a transition from a subtidal origin of the reef 900 years ago to its current intertidal position. The subtidal interpretation is based upon the reef's deep position relative to the sea-level curve we have compiled for Southwest Florida. The increased volume of mud in the upper section could indicate a lowering of energy or reflect greater fluvial sedimentation associated with greater freshwater input. Alternatively, the finer sediments could be due to greater oyster productivity resulting in the trapping of more mud. These results have implications for the management and restoration of hydrologic flow through Everglades National Park. Because freshwater delivery is vital to oyster reef development, significant flow alteration could affect coastal geomorphic change and estuarine ecology.

## Introduction

The late Holocene development of oyster reefs can reveal the history of estuary formation through standard stratigraphic and paleontologic analyses. Reefs located at the terminus of the Florida Everglades' Shark River sloughway should record the effects of natural and anthropogenic variability in freshwater delivery. All of Southwest Florida's modern oyster reefs and virtually all its fossil oyster reefs are intertidal with oyster productivity and survival dropping drastically below the shallow subtidal contours. As sea-level rise rates accelerate, and as humans continue to manipulate the amount of freshwater into the system, these oyster reefs may begin to decline. Determining the developmental history of the reef will allow for a better understanding of how the reef evolved and provide more accurate predictions of future responses to environmental change. Using the 900-year history recorded in one reef from Broad River, this study determined relative trends in salinity and energy

through time by looking at the stratigraphy and taphonomy from the oyster reef. The paleoecology of the reef and the taphonomy of the assemblage can be used as indicators of paleoenvironmental conditions. The hypothesis tested was that the reef originated under higher energy and salinity conditions, becoming less energetic and progressively more brackish through history. The results from this study have implications for oyster reef response to changes in environmental conditions especially in relation to hydrological restoration practices and sea-level rise.

## Study Area

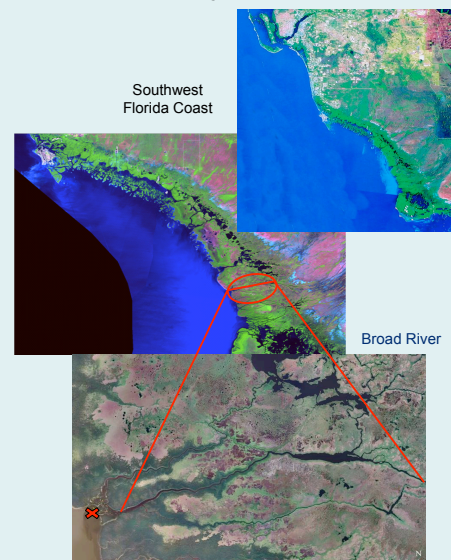


Figure 1. Maps showing location of Broad River core site (indicated by X) within Everglades National Park, Southwest Florida.

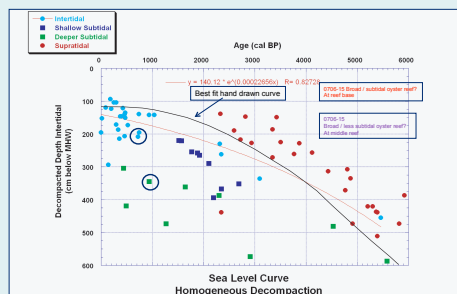


Figure 2. Sea-level curve produced using many radiocarbon dates from all over Southwest Florida. Red and purple circled data points represent dates obtained using oyster shells at 193cm and 96 cm within the Broad River core (Figure 3). These oysters date back 960 yrBP and 750 yrBP respectively and both fall beneath the sea-level curve. This leads to the assumption that the reef must have been subtidal at these points in history.

## Stratigraphic Analysis

A living oyster reef at the mouth of Broad River was vibracored in June of 2007 (Hoye 2009) and revealed through AMS radiocarbon dating a continuous 960 yr history of reef development. On casual inspection there is no visible facies distinctions through the stratigraphic sequence. Any paleoenvironmental differences must be distinguished on more subtle indicators (e.g. patterns in shell preservation and relative abundances of mud).

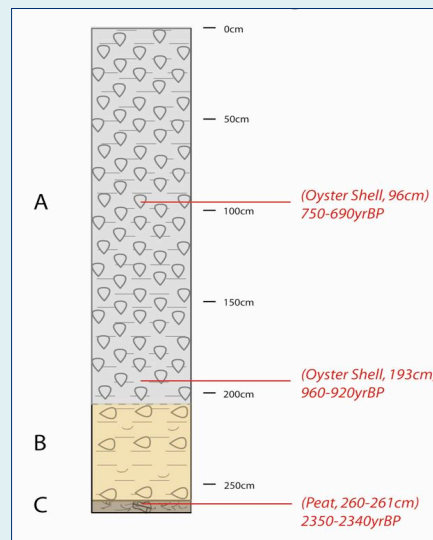


Figure 3. Stratigraphic column for core 0706-15 illustrating the representative facies sequence for this region. Radiocarbon dates (1 sigma calibrated results) derived from oyster shells and peat help define the timing of reef development.

Stratigraphic Column Character Legend	
	Oyster reef / boundstone
	Oyster fragments
	Quartz sand
	Mud
	Bivalves
	Disarticulated bivalves
	Mottling due to bioturbation
	Organics
	Gastropods
	Vermiform-oyster boundstone
	Root mottling
	Shell hash
	Burrow
	Bedrock regolith
	High-spired turritellids
	Vermiform gastropods
	Roots and root casts
	Vertical roots spongy texture
	Peat (fibrous)
	Intertidal oyster reef
	Subtidal oyster reef
	Subtidal vermiform gastropod dominated reef
	Shell rich subtidal sand and mud
	Mottled marginifera sand
	Spongy subtidal
	Organic rich shell poor subtidal sand/mud

Figure 4. Stratigraphic column character legend

## Methods

- The core was divided into 21-10cm horizons.
- Sediment samples were collected from each horizon for grain size analysis using a Malvern Mastersizer 2000.
- All skeletal materials were extracted via washing through 1 and 2mm sieves for subsequent taphonomic analysis.
- A faunal analysis was attempted but the horizon-based assemblages were not diverse and all taxa other than *Crassostrea virginica* were in low abundances.
- Oysters (*Crassostrea virginica*) >= 2cm in length were selected from the harvested material for taphonomic analysis.
- Each shell was assigned an overall taphonomic grade using the method employed by Wohlpart 2007.
- Grades range from one (highest preservation) to four (worst preservation).
- Percent borings (*Ciona* sp.) and encrustation were determined using the point counting method developed by Booth 2008.
- To determine the statistical significance of trends in grain size, taphonomic grade, borings and encrustation between the top and bottom of the core, values for the upper 5 and lower 5 horizons were combined and compared using Student T-tests (p= 0.05).

Characteristic	Grade I	Grade II	Grade III	Grade IV
Articulation	well articulated with ligaments in tact	valves held together in its position with sediments	valves in close association but not in its position	disarticulated
Valve Margin	complete, unaltered	minimal thinning/breakage	moderate thinning/breakage	extensive damage
Interior Boring	absent	minimal microboring and etching	moderate microboring and etching	extensive microboring and etching
Internal Layer	nacreous layer present	some nacreous layer present	internal nacreous layer	nacreous layer absent
Muscle Scar	present with color and texture	present, little to no color or texture	present, little to no color or texture	absent or only outline recognizable
Patella Line	absent	absent	nearly absent	absent
Color	all color retained	significant loss of color	traces of color retained	mostly absent
Encrustation	no encrustation on interior surface	minimal encrustation on interior surface	significant encrustation on interior surface	extensive encrustation on interior surface

Figure 5. Scale used to apply a taphonomic grade to oyster shells. Grades range from one, indicating that shells have undergone few taphonomic processes, to four, indicating extremely poor preservation. Multiple criteria were assessed for each shell. In addition, an overall preservational grade was assigned



Figure 6. Oyster valve with transparent grid. Grids were used in point counting method to determine extent of *Ciona* sp. borings and encrustation

## Taphonomic Analysis

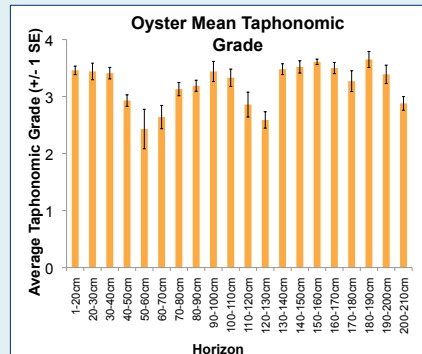


Figure 7. Average taphonomic grade for each horizon plotted with one standard error. T-tests revealed a statistically insignificant trend of improved preservation up section.

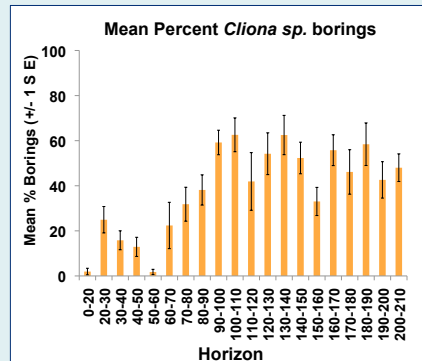


Figure 8. Average percent *Cliona sp.* borings for each horizon plotted with one standard error. T-tests revealed a statistically significant trend of decreased occurrence of borings up section ( $p=0.0002$ ).

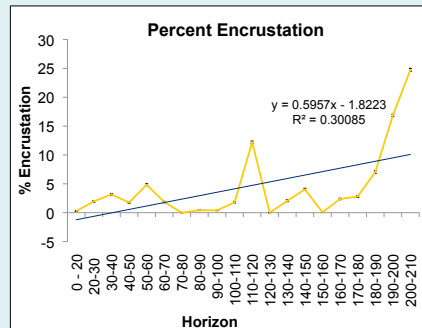


Figure 9. Average percent encrustation for each horizon plotted with one standard error. T-tests revealed a statistically insignificant trend of improved preservation up section.

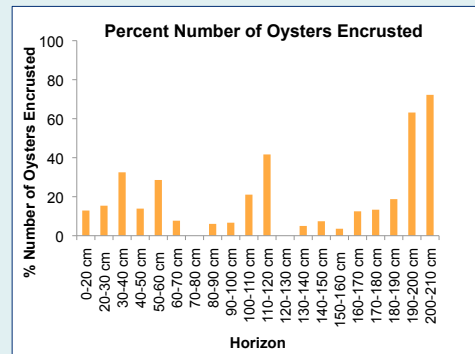


Figure 10. Percent number of oysters encrusted within each horizon. Number of oysters encrusted decreases up-section.

## Sedimentologic Analysis

Horizon (cm)	Graphic Mean (phi)	Mean Grain Size	Graphic Stan Dev (phi)	Sorting
0-10	5.6	medium silt	1.6	poorly sorted
10-20	5.1	medium silt	1.8	poorly sorted
20-30	5.9	medium silt	1.5	poorly sorted
30-40	6.1	fine silt	1.3	poorly sorted
40-50	5.6	medium silt	1.8	poorly sorted
50-60	5.5	medium silt	1.9	poorly sorted
60-70	5.8	medium silt	1.7	poorly sorted
70-80	5.1	medium silt	2.4	very poorly sorted
80-90	5.3	medium silt	2.3	very poorly sorted
90-100	5.4	medium silt	2.3	very poorly sorted
100-110	5.4	medium silt	2.6	very poorly sorted
110-120	4.8	coarse silt	2.5	very poorly sorted
120-130	5.1	medium silt	2.3	very poorly sorted
130-140	4.6	coarse silt	2.3	very poorly sorted
140-150	5.3	medium silt	2.1	very poorly sorted
150-160	3.9	very fine sand	2.9	very poorly sorted
160-170	3.6	very fine sand	2.8	very poorly sorted
170-180	4.2	coarse silt	2.7	very poorly sorted
180-190	4.1	coarse silt	2.8	very poorly sorted
190-200	4.0	very fine sand	2.7	very poorly sorted
200-210	4.0	coarse silt	2.6	very poorly sorted

Figure 11. Summary table of grain size analysis results showing Graphic Mean (phi), Mean Grain Size, Graphic Standard Deviation and Sorting for each horizon.

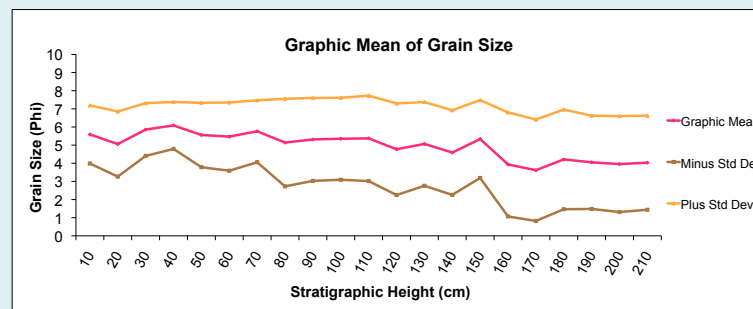


Figure 12. Graph showing  $\pm 1$  standard deviation confidence interval displayed around the mean. Smaller standard deviation is indicative of better sorting. Better sorting is observed as you move up-section.

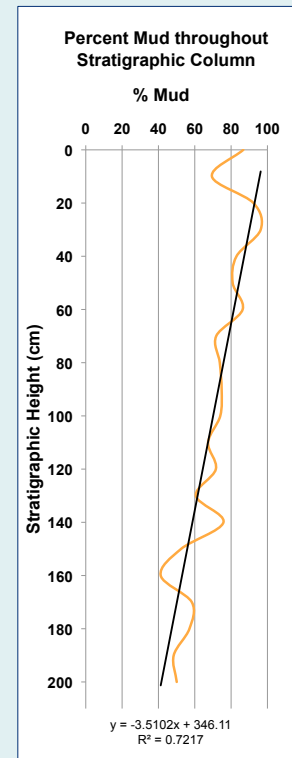


Figure 13. Graph showing percent of mud sized sediment throughout the core. T-tests revealed statistically significant trend of a decrease in mud up-section ( $p=0.0004$ ).

## Discussion

• Results of taphonomic and sedimentologic analyses support the hypothesis that the reef in question originated subtidally under higher energy and salinity conditions, becoming less energetic and progressively more brackish through history.

• The occurrence of *Cliona sp.* borings is used as a proxy for salinity as this genus requires marine salinities. Based on the trend of decreased borings up-section, salinity is inferred to decrease through recent history.

• Trends in taphonomic grade and percent encrustation, although statistically insignificant, mirror the results observed in *Cliona sp.* borings (which is a factor contributing to taphonomic grade). These results suggest that quality of preservation increases up-section.

• The higher percentage of mud up-section may be explained by a number of mechanisms. Lower energy conditions and an increase in oyster productivity (i.e., the trapping of more muds through oyster suspension feeding) up-section are both consistent with the fining-upward sedimentologic trend. Additionally increased freshwater delivery from the Everglades may have caused increased sediment suspension loads.

• Recent shifts in freshwater delivery due to anthropogenic water management and restoration are too recent and the stratigraphic resolution of the reef too coarse to have manifested themselves yet in the reef's taphonomic and sedimentologic response.

• These findings, however, do emphasize the role that altered salinity regimes have on oyster reefs and estuarine systems. Salinity is an important factor influencing the development of oyster reefs and ultimately coastal geomorphology. Restoration managers must consider the role of freshwater input in concert with rising sea-level to adequately assess anthropogenic impacts.

## References

- Booth, A. (2009) Preservational analysis of oyster shells on estuarine reefs: A technique to interpret the history of coastal environmental change. Unpublished masters thesis, Florida Gulf Coast University, Florida, USA
- Davis, S. M. and Ogden, J. C. (Eds.) (1994) *Everglades: The Ecosystem and Its Restoration*. Boca Raton, FL: St. Lucie Press.
- Hoye, B. (2009) Holocene history of the coastal geomorphology of Everglades National Park: The role of reef development, tidal pond formation, and sea-level rise. Unpublished masters thesis, Florida Gulf Coast University, Florida, USA
- Lindland, E. (2002) *Time Accumulation on an Oyster Reef: Implications for the Monitoring of Environmental Change*. Keck Geology Consortium, 15th Annual Undergrad Research Symposium. p. 73-76.
- Wanless, H.R., Parkinson, R.W., and Tedesco, L.P. (1994) *Sea Level Control on Stability of Everglades Wetlands*. In: Everglades, the Ecosystem and Its Restoration. Boca Raton, FL: St. Lucie Press. p. 199-222.
- Wohlpart, S. L. (2007) The development of estuarine systems in Southwest Florida: A perspective from the late Holocene history of oyster reef development. Unpublished masters thesis, Florida Gulf Coast University, Florida, USA