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Investigating The Late Woodland Climate Of Old Tampa Bay, Florida

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INVESTIGATING THE LATE WOODLAND CLIMATE OF OLD TAMPA BAY, FLORIDA

by

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ABSTRACT

Tampa Bay and the broader Central Gulf Coast region of Florida bear evidence of site reduction and population decline during the onset of the Late Woodland period (AD 500-1000). Concomitantly, Weeden Island culture flourished to the north, while climatic instability loomed to the south. It is unclear if the site abandonments in the area between the two are related to social or cultural change, an unstable climate, or a combination thereof. Interdisciplinary research has provided evidence for climate change and sea level regression during the sixth and seventh centuries in Southwest Florida, but these variables have yet to be investigated in Tampa Bay. This study implements a multi-scalar sclerochronological analysis to better understand how the climate of Tampa Bay has changed through time. Analyses of low-resolution stable isotopes (δ13C and δ18O) paired with high-resolution trace elements (Mg, Na, Li, Sr) from 50 eastern oyster (*Crassostrea virginica*) specimens supports climatic instability during the Late Woodland period in Tampa Bay.

Key words: Historical ecology, LA-ICP-MS, climate change, Tampa Bay

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CHAPTER 1: INTRODUCTION

The relationship between humans and the environment is, and likely will always be, an important inquiry in a number of disciplines. In a time when humans contribute equal or greater influence on environmental conditions than many geological forces, understanding this relationship may never be more paramount (Mauser 2006:3). By contextualizing settlement patterns and site formation processes of the past with high-resolution geochemical data, this project contributes to the growing paleoenvironmental discourse along the Gulf Coast of Florida. This literature is relevant not only to archaeologists but climate scientists, policymakers, and ongoing environmental management and restoration efforts.

The spatial focus of this study is Tampa Bay, along the Central Gulf Coast of the low-lying peninsula of Florida (**Figure 1**). Profound consequences of climate change are expected during the next century, including increased frequency and intensity of hurricanes, rising incidences of marine diseases and toxic algae blooms, and of course, coastal flooding (Elsner 2006; Morrison and Yates 2011:31). A recent study by Nerem and colleagues (2018) determined global mean sea level is on pace to rise 65 ± 12 cm by 2100. Glick and Clough (2006:5) conservatively modeled a 15-inch (38.1 cm) rise in Tampa Bay, which indicated severe environmental impacts including a 96% loss of tidal flats, 86% loss of salt marsh and a 10% loss of dry land, not to mention all of the economic consequences.

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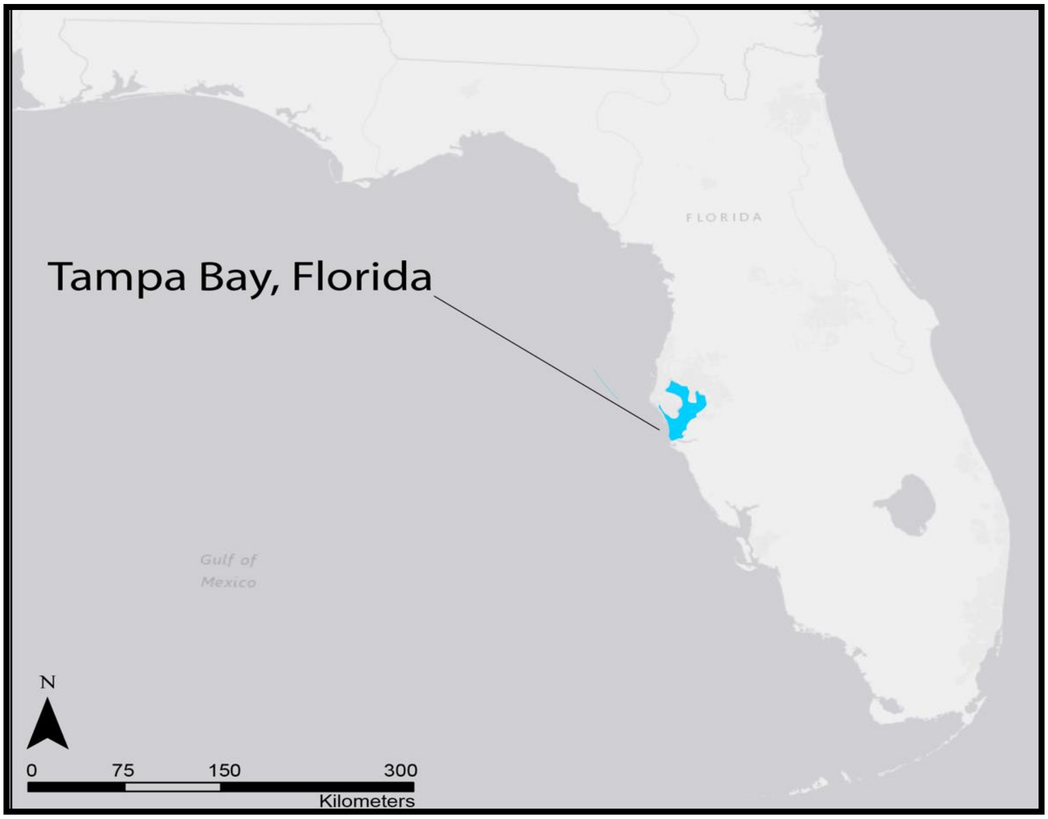

Figure 1. Location of Tampa Bay, Florida.

Of course, we are not the only humans to have faced changing environments and their subsequent challenges. The geologic and archaeological records provide countless examples of climate change in the past and how humans navigated their new surroundings. Archaeologists are particularly skilled at understanding the human-environmental relationship. Indeed, a common human-environmental occurrence discussed by Florida archaeologists is the human response to changing landscapes due to fluctuations in climate and sea levels. Minor changes in sea level can have lasting ecological effects that require social response. By understanding the climate and sea levels of the past, we can better contextualize changes to settlement patterns, subsistence practices, and resource exploitation strategies in the archaeological record. These factors ultimately aid in the overall

interpretation of change within sites and regions. Geochemical techniques are becoming virtually ubiquitous in paleoenvironmental inquiries. Here high-resolution trace element data and low-resolution stable isotopes are paired to analyze the intensity and timing of environmental change in an attempt to contextualize changes to site formation and occupational variability within the Tampa Bay region.

Focus of this Study

Archaeological evidence indicates occupational variability and site reduction in the Tampa Bay region during the sixth and seventh centuries. Some sites, like Bayshore Homes (8PI41), appear to have been abandoned entirely while others, like Yat Kitischee (8PI1753), provide evidence of a small-scale abandonment and changes to site formation. Austin and colleagues (2014:Figure 5.2) present the frequency distribution of radiocarbon dates from Tampa Bay sites (**recreated here in Figure 2**). The bimodal distribution suggests a time of less intensive activity between AD 400 and 900, especially between AD 600 and 799. By broadening the regional focus for a moment, there is also evidence of site reduction elsewhere along the Central Gulf Coast of Florida. Crystal River (8CI1), Shell Mound (8LV42), and Garden Patch (8DI4) (Pluckhahn and Thompson 2017:74; Pluckhahn et al. 2017; Sassaman et al. 2014; Wallis et al. 2015) all appear to go through a similar transition (**Figure 3**).

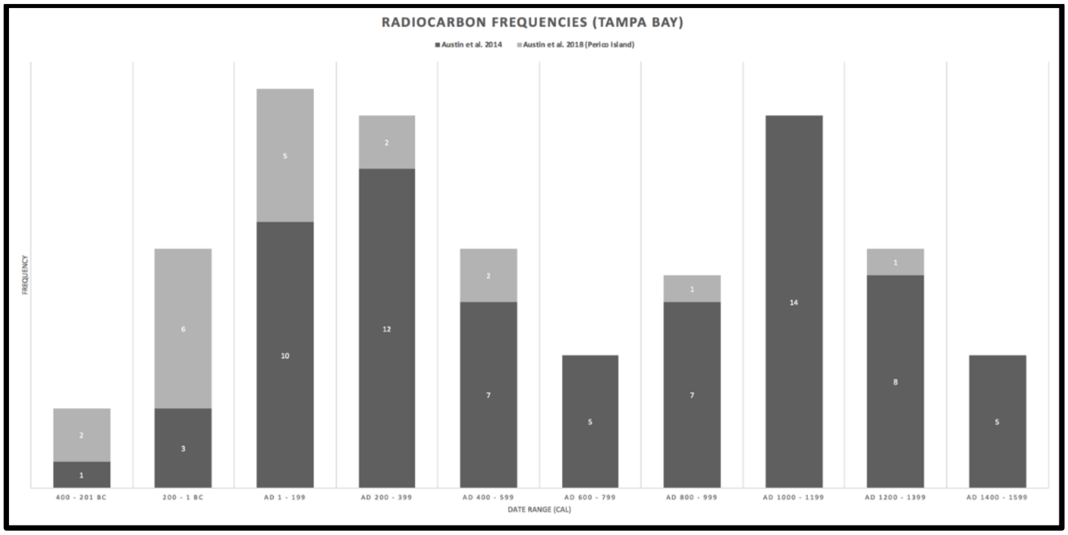

Figure 2. Frequency of radiocarbon dates from Tampa Bay sites.
Dark bars from multiple sites (see Austin et al. 2014:Figure 5.2), lighter bars from Perico Island (Austin et al. 2018).

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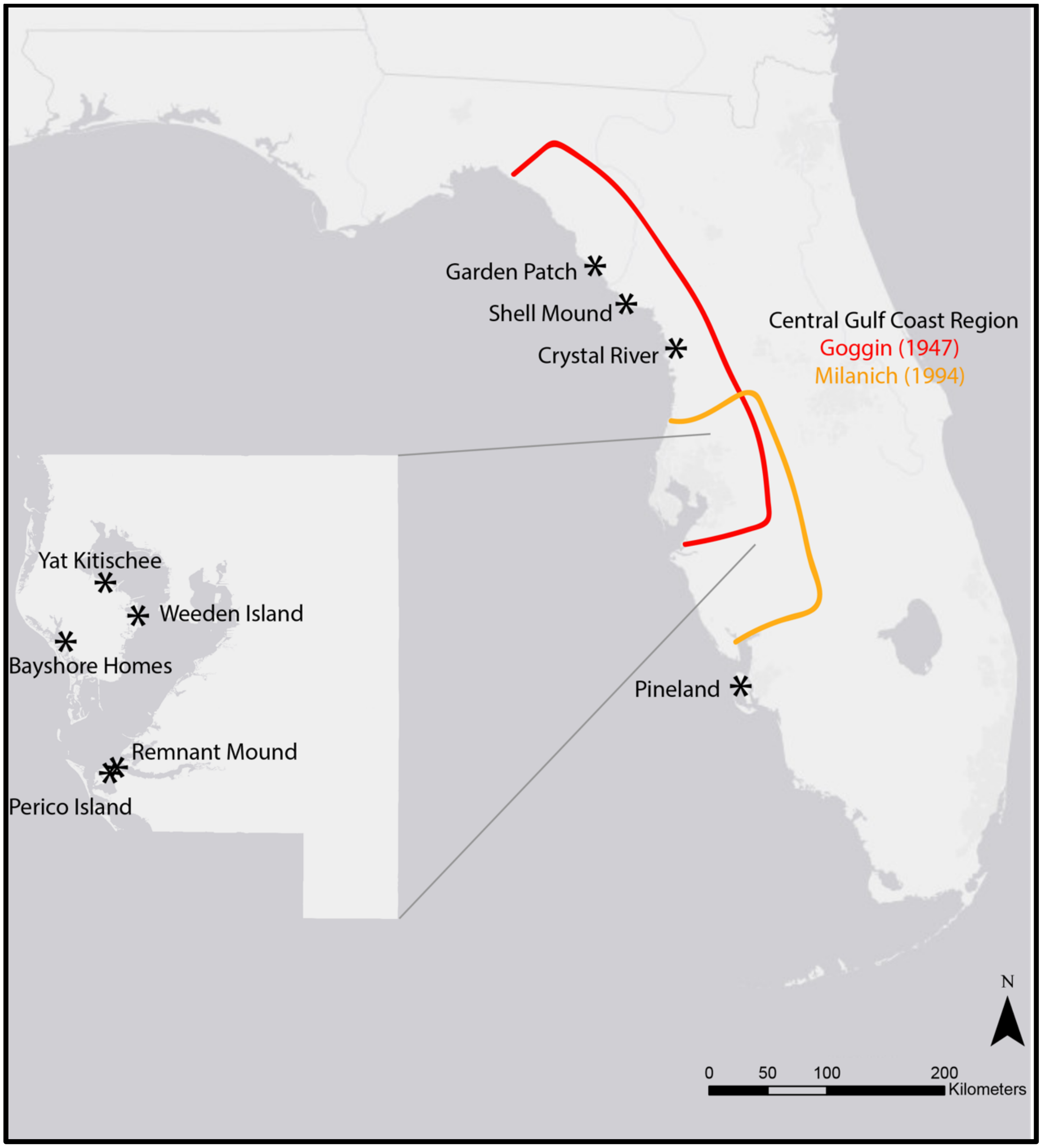

Figure 3. The Central Gulf Coast archaeological region of Florida.

Clearly, something is influencing social change during this time. Perhaps coincidentally, the trough in **Figure 2** aligns almost entirely with the Vandal Minimum (VM) climatic event. The VM (~AD 500 to 850) was a time of unstable climate and appears to have negatively impacted many societies around the globe (Gunn 2000). Southwest Florida generally experienced cooler and drier weather as

well as lower sea levels during this time (Walker 1992, 2013; Walker et al. 1995; Wang et al. 2011). The effects of the VM in Tampa Bay are currently unknown.

This study is targeted at understanding if Tampa Bay experienced similar instability and drought-like conditions to Southwest Florida both in timing and intensity during the VM. This investigation uses two geochemical techniques: laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) and stable isotope analysis on oyster shells (*Crassostrea virginica*) dated to the Middle to Late Woodland Period (~AD 200 to 1000). By incorporating four trace elements (lithium, magnesium, sodium, and strontium) in addition to oxygen and carbon isotopes into this analysis, I hope to overcome particular challenges facing geochemical techniques in estuarine environments.

Research Question and Hypothesis

In order to determine if climatic changes happened in Tampa Bay, the current methods target the occurrences of salinity and water temperature fluctuations to denote times of broader climatic change. Therefore, the main research question is: did salinity and/or water temperature changes take place in Tampa Bay during the Woodland Period (1000 BC – 1000 AD)? If so, how do these climatic and environmental changes relate to the Southwest Florida studies both in timing and intensity?

I hypothesize that, similar to Southwest Florida, the Tampa Bay region experienced a drought during the Vandal Minimum (AD 500-850), which would likely have played a role in the occupational variability of Tampa Bay during the Woodland Period.

Theoretical Perspective

Archaeologists have discussed the role of the environment in social change for quite some time (Childe 1942). Their pursuit during the culture history paradigm, however, was mostly limited to the study of migration and diffusion. Moreover, most seemed engaged in determining the sociocultural

complexity of the artifacts rather than the people that left them behind. Early ecologists interested in humans viewed culture as instinctual. For example, Hawley (1944:404) notes "Human culture is identical in principle with the appetency of the bee for honey, the nest-building activities of birds, and the hunting habits of carnivores." Social ecologists related human behavior to a product of natural selection; in other words, behavior in the present is explained by the success or failure of past actions (Shennan 2002:1). These behaviorally based perspectives are still used today in models like optimal foraging theory.

Dissatisfied with the goals of Culture History and universal ecological principles, Julian Steward's (1955) *The Theory of Culture Change* emphasized the relationship between culture and the environment rather than focusing on just one. Steward (1955) viewed cultural evolution as multilinear and believed local environmental conditions influenced human adaptation and ultimately cultural change. Steward (1955:30, 39) defined the principle meaning of ecology as "adaptation to the environment" and noted that environmental adaptation underlies all of cultural ecology, a theme that would carry into the processualist paradigm. Steward's (1955:34) perspective was distinct from processualist views, however, because he did not advocate universal explanations, he focused on the particulars rather than generalizations that would later dominate processual ecological studies. Binford's (1962; 1967) use of ethnographic analogies and middle-range theory formed the basis for New Archaeology and the roots of a true ecological archaeology later established by Roy Rappaport. These subsequent ecological perspectives were systems centered and synthetic rather than the eclectic perspective of cultural ecology (Rappaport 1968:383). A great example of this approach is Flannery's (1972) simulation of cultural evolution by prime movers. These system centered approaches were viewed as necessary because cultural ecology struggled to interpret different socioeconomic strata, especially "complex societies" (Balée 2006:76). Like any generalization, however, problems arise because human behavior is

often unpredictable. Furthermore, these approaches are environmentally deterministic because humans are viewed as strict adapters to the external environment, a viewpoint in which was heavily criticized by post-processualists in the 80s and 90s. For example, Shanks and Tilley (1987:35) declare, “Human culture is not a part of nature but a transformation of it… they [people] possess the ability to systematically transform it [nature] and create their own world or social construction of reality.”

Processualism was an “ideology of control,” but processes remain an integral part of archaeological analyses in the present (Johnson 2010:83, 86). For example, Pauketat (2001) advocates historical processualism, which emphasizes cultural practice and history rather than behavior and evolution as the impetus of cultural change. While the legacy of processualism provides the foundation for ecological studies, new methodological and theoretical perspectives have changed the way archaeologists conceptualize the human-environmental relationship. These novel approaches embraces holistic concepts of processes, is cognizant of human agency, and strays away from functionalist perspectives (Balée 2006:79; Wallis and Randall 2014:2). As Walker (1992:267) states, “Human agency introduces a complex web of variables that interact with the biotic and physical environments. We can begin to identify this complexity only through familiarity with environmental context.”

Many Florida Gulf Coast archaeologists have turned to historical ecology as a lens through which to view their environmental studies (Duke 2015; Jackson 2016; Jackson et al. 2018; Jenkins 2017; Lulewicz et al. 2017a, b; Marquardt 1992; Savarese et al. 2016; Thompson 2013, 2014; Thompson et al. 2015; Walker 2013; and more). Historical ecology is a framework that views the human-environmental relationship as dialectic, that is, a dialogue rather than a dichotomy (Balée 1998:14; Crumley 1994; Marquardt 1992). In other words, “over the course of reshaping nature, society gradually reshapes itself” (Biersack 1999:9). Or as Thompson (2014:247) states, “The dialectical perspective brings us closer to envisioning the world not as humans and nature but as continuous flows of relationships that emerge

and dissolve." This continuum can be viewed as the landscape or the arena shared by all humans, plants, animals, and other natural resources. Ingold (1993:162) defines landscape as "the physical incorporation of social life, with all of its complexities of temporality and movement." In Florida, past physical manifestations along the landscape are often in the form of shell middens and mounds along the coast. The intentional remnants of past people's relationships with their world transformed the landscape into cultural places and imbued them with values associated with genealogy, history, and myth (Kidder 2013:182; Wallis and Randall 2014:5). In addition to shell middens and mounds, canals were dug, controlled fire was used, and oyster mariculture is likely (Fowler and Konopik 2007; Jenkins 2017). These few examples accentuate that despite being defined as a "small-scale economy," ancient coastal fisher-hunter-gatherer societies actively managed and manipulated their surroundings for various purposes and were not simply adapters (Thompson 2014:249).

To paraphrase Balée's (1998) four postulates of historical ecology: (1) most, if not all of the world has been affected by humans and arguably for a very long time, (2) humans sometimes have a positive relationship with the environment and sometimes have a negative one, it should not be assumed either way, (3) different sociopolitical and economic systems tend to have different relationships with the environment, and (4) communities, cultures, regions, and landscapes should be understood in totality, rather than separating them.

Acknowledging that human beings are a keystone species contradicts views of strict environmental adaptation. In more recent environmental archaeology studies, *adaptation* is a "buzzword" and tends to be avoided, largely due to the stigma of early Processualism (Wallis and Randall 2014:2). I do not avoid using the word adaptation here, but I am mindful that it was not the only option for precolumbian Floridians.

Environmental studies benefit from the incorporation of multiple temporal scales (Dincauze 2000). Thompson (2013:249-250) describes a "pitfall" of using only one temporal scale of analysis, essentially by focusing on one scale, history is neglected, and proximate rather than ultimate explanations become the product. Historical ecologists conceive time in three stages: (1) the event, (2) the cycle, (3) and the Longue durée (Balée 2006:80). The earlier ecological concepts mentioned above lack a historical component. Integrating history provides further context on human actions, as Crumley (1994:11) notes, "Human choices that seem undeniably efficacious and correct in one context or period may prove disastrous in another." Gilmore and O'Donoghue (2015:2-3) argue that analyzing historical events, or, "punctuated and contingent moments of transformation" in the archaeological record provides more beneficial, localized context-specific interpretations, rather than an ultimate explanation for human behavior. Gilmore (2015:119-120) reasons that if practice is socially negotiated, "then every act has at least the potential to incite eventful structural change." This study follows the lead of the aforementioned authors.

Here, the aim is to historicize the occupation at Yat Kitischee by using oysters from five contexts in order to better understand the paleoclimate of Old Tampa Bay and how it may have influenced site formation. A site that shares temporal and spatial proximity along the Old Tampa Bay shoreline with two notable type-sites: Weeden Island (8PI1) and Safety Harbor (8PI2). Understanding how Old Tampa Bay differed from today bolsters our interpretations of these important sites and ultimately helps contextualize changes in settlement patterns, subsistence practices, and resource exploitation strategies throughout Tampa Bay. In addition, by applying this historical ecological perspective, a goal of this project is to provide current policymakers a baseline for what Tampa Bay was like before the many major developments that severely altered the bay, which is valuable for the current habitat restoration efforts (discussed in next chapter).

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Outline of Thesis

The outline of this thesis is as follows. Chapter 2 provides background information on Pinellas County and Tampa Bay, the cultural periods of the Central Gulf Coast, Yat Kitischee, climate and sea level variability, sclerochronology, and oyster ecology. Chapter 3 discusses the material and methods used in this analysis along with an overview of the four trace elements examined. Chapter 4 provides the results of the LA-ICP-MS and stable isotope methods. Chapter 5 discusses the results in relation to the broader climatic and sea level episodes, and how they vary through time, finally Chapter 6 includes the conclusion, limitations, and directions for future work.

CHAPTER 2: BACKGROUND

This chapter provides the relevant background information on the geographic area of investigation, the archaeological periods of the region, what is currently known about the climate and sea level of the last 3,000 years, lastly an overview of *C. virginica* and the methodological approaches implemented upon it here.

Pinellas County

Pinellas County, the most densely populated county in Florida (census.gov), has always been a popular place to live. Over 400 identified archaeological sites in the county bear witness to its persistent attraction (FMSF database updated January 2018). The county enjoys an average of 361 days of sunny weather a year and boasts 580 miles of coastline in which many of the beaches are awarded "America's Best Beach" (pinellascounty.org/facts). It is no wonder why people continue to choose to live in the area. In 1528, the Narváez led Spanish were the first Europeans to land their ships on the shores of the county, possibly in Boca Ciega Bay. Pinellas County's name is derived from the Spanish *Punta Pinal* or point of pines (pinellascounty.org/facts).

Due to the rapid urbanization in the late 19th and 20th centuries, pine trees are not as prevalent as they once were, and are usually restricted to the lower lying areas of the county. The higher elevated areas with better-drained soils support upland forests dominated by oaks, while the coastline is comprised primarily of hardwood hammocks and coastal scrub (Vanatta et al. 1972). The vegetation patterns of the county are ultimately controlled by the drainage characteristics of the soil in which plants live. Lewis et al. (2006:76) characterize the county as being composed primarily of sandy and clayey deposits from the Pleistocene and more recent sands and clays. These soils are highly resilient to weathering; therefore, soils today are similar to when they were first deposited (Vanatta et al. 1972:58-

59). This resiliency provides insights into past vegetation patterns and the subsequent outcome of these patterns, like wildlife populations. These factors ultimately played an important role in what parts of the county past peoples chose to inhabit. Another factor that may have contributed in settlement patterns are the numerous outcrops of limestone and silicified limestone (chert) that scatter the coastline of the county. Many of these chert deposits were exploited for lithic manufacture during precolumbian times. For example, Yat Kitischee residents took advantage of the local Caladesi and Lower Hillsborough River Quarry clusters to manufacture tools (Austin 1995).

Tampa Bay, Florida

Pinellas County forms the western border of the body of water known as Tampa Bay. Tampa Bay was created by the dissolution of the Miocene Arcadia Formation, a Late Oligocene (~30 mya) geologic formation, and subsequent deposition of Quaternary sediments into sinkholes and karst depressions during multiple sea level oscillations (Cronin et al. 2007:117). The dissolution may have been influenced by a fracture of the Ocala Platform causing tensional stress throughout the region (Vernon 1951; Morrison and Yates 2011:52). The formation of the Ocala Uplift, an early Miocene (~20 mya) swell located to the northeast of Tampa Bay, defined the bay's current watershed and runoff characteristics, which extend approximately 2,200 square miles and includes four rivers (the Hillsborough, Alafia, Manatee, and Little Manatee) and about a hundred smaller tributaries and bayous (Lewis III and Estevez 1988:7; Morrison and Yates 2011:25, 52). Stratigraphic evidence indicates Tampa Bay went through multiple transitions from estuarine-marine and non-marine sediments throughout the Quaternary (Cronin et al. 2017:117). Once a freshwater lake, it is now Florida's largest open water estuary (Lewis III and Estevez 1988:25). Despite its area, it is relatively shallow, averaging only about 4 meters today (Morrison and Yates 2011:17).

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The bay is typically split into seven subdivisions for management purposes, listed largest to smallest in terms of area they are: Middle Tampa Bay, Lower Tampa Bay, Old Tampa Bay, Hillsborough Bay, Boca Ciega Bay, Manatee River, and Terra Ceia Bay (**Figure 4**) (Lewis III and Estevez 1988:Table 2). In addition to the general size and shape differences, the variable formation processes of each subdivision play a distinct role in their present salinity and sedimentology differences. These, in turn, influence many different types of shorelines including estuarine sandy beaches, salt barrens, mangrove-dominated embayments, low river marshes and bluffs, pine flatwoods, and rocky shorelines (Lewis III and Estevez 1988:25).

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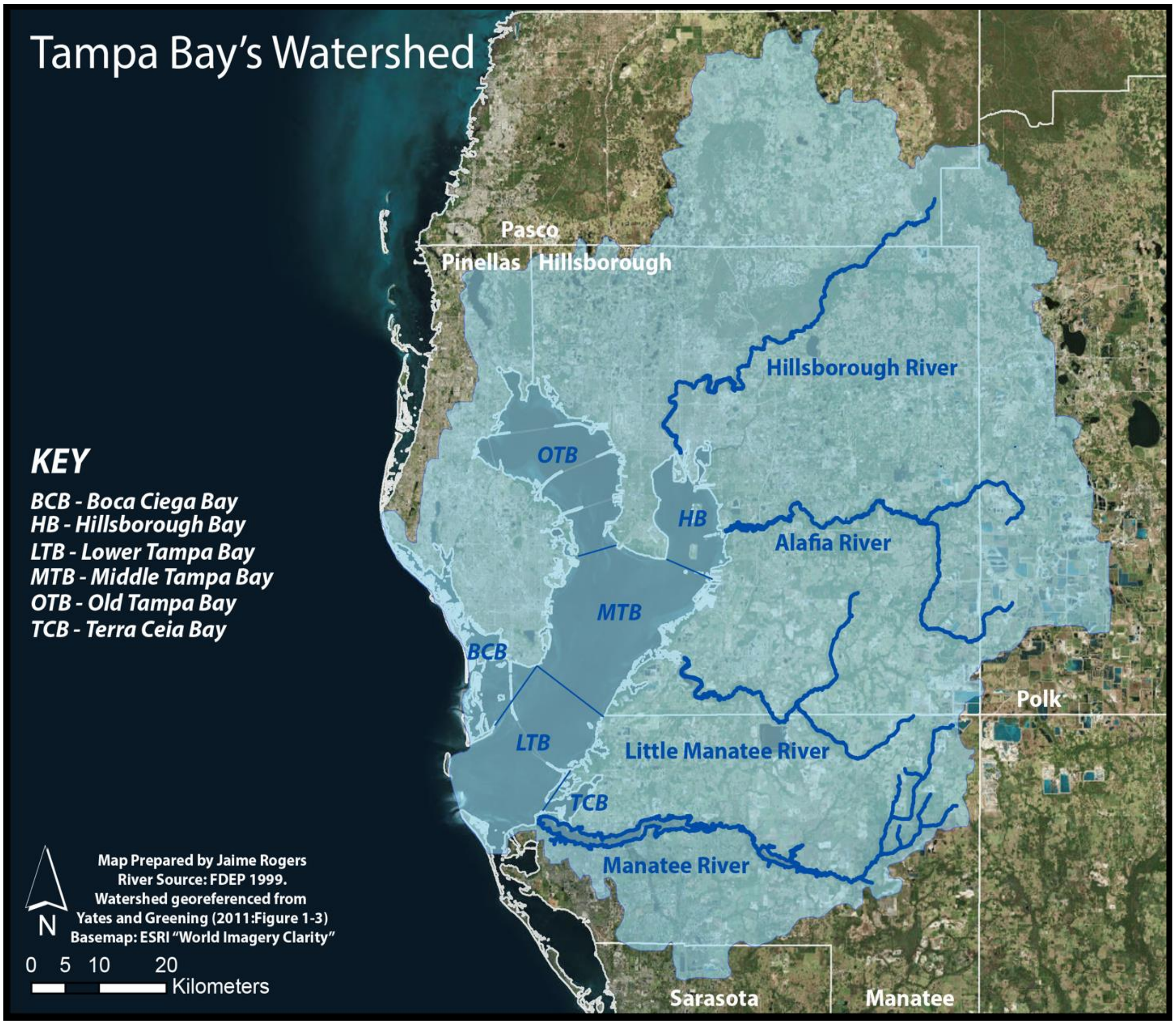

Figure 4. Map of Tampa Bay's watershed.

Old Tampa Bay

Here the focus is Old Tampa Bay, the northwestern segment of the greater Tampa Bay, which although third in total area (80.5 mi^2/208.7km^2) among the subdivisions, has the longest shoreline (211.1 mi^2/339.8km^2) (Lewis III and Estevez 1988:Table 2). Only 2% of Old Tampa Bay is deeper than 6m, the majority (60%) has a depth between 2 and 6m (Brooks and Doyle 1998:392). Although the four rivers mentioned above do not flow directly into Old Tampa Bay, there are many human-made tributaries in

the area, the closest to the project area are Cross Bayou Canal, Allen Creek, and Alligator Creek, which are low-flowing tidal streams with freshwater supplied by surface-water runoff (Morrison and Greening 2011:164).

Currently, red and black mangroves dominate the shoreline near the project area (personal observation), although white mangroves and buttonwood may be present as well. It is unlikely mangrove forests were the dominant vegetation during precolumbian times. Mangroves currently occupy approximately 75% of intertidal wetlands in Tampa Bay, but this is likely a recent phenomenon. A recent United States Geological Survey (USGS) study indicated an average of 72% of Tampa Bay has converted to mangrove wetlands since 1870 (Raabe et al. 2012). Raabe and colleagues (2012:1147) describe Tampa Bay's nineteenth-century shoreline as "a complex mosaic of freshwater habitat, scrub, hammock, and prairie coexisting alongside tidal wetlands" (Raabe et al. 2012:1147).

No Longer its Natural State

While natural causes have certainly contributed to the alteration of the bay, it is more likely the rapidity of urbanization in the area that has influenced these drastic changes to shoreline vegetation. Tampa Bay's population has quadrupled in the last 50 years, with an estimated two and a half million people currently residing in Pinellas and Hillsborough Counties alone (census.gov).

The bathymetry of the bay has been altered since 1880 to allow for commercial vessels to utilize ports in Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay, which is essential to the current economy. This vast network of shipping channels throughout the bay reaches 13m deep and has led to Port Tampa being one of the largest and most productive ports in Florida (Raabe et al. 2012; Yates et al. 2011:5). In other areas, like Boca Ciega Bay, the placement of fill for waterfront housing occurred during

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the early to mid-twentieth century. In addition to these impacts, four major bridges spanning Tampa Bay were erected, and mosquito ditches were excavated in the 1950s.

The mosquito ditches connected freshwater ponds to the bay resulting in changes to salinity regimes. Although the ensuing salinity changes converted salt marsh habitat into mangrove forest and the spoil mounds alongside the ditches created favorable habitat for the invasive Brazilian Pepper, they now provide beneficial habitat for young fishes. Current research is directed at determining the best course of action for restoration (Morrison et al. 2011:246-247). Mosquito ditches are prevalent in the area surrounding Yat Kitischee. All of the modern disturbances discussed above are easily identifiable using satellite imagery (**Figure 5**).

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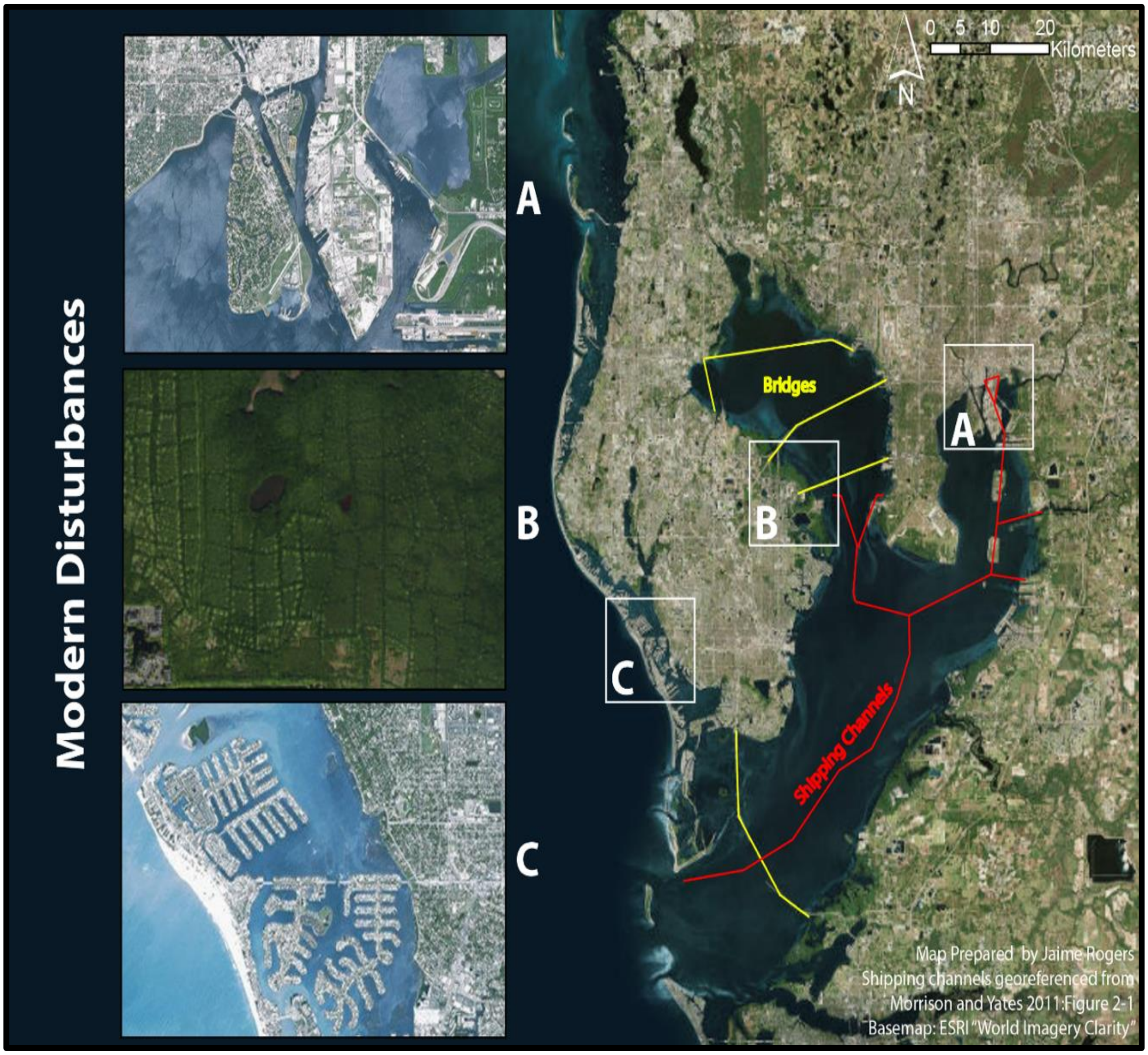

Figure 5. Modern (post-1880) disturbances of Tampa Bay.

Lewis and Estevez III (1988:26, 59) estimate a loss of 44% in total mangrove acreage and an 81% decline in seagrass meadows along the bottom of the bay due to the above projects. The seagrasses of Tampa Bay are incredibly important, providing habitat for smaller aquatic species, helping cycle nutrients, improving the stability of sediment, and as food for manatees and sea turtles (Morrison and Greening 2011:63). Devastating ecological effects were apparent after the projects listed above. In fact, environmental degradation was so severe in areas of the bay it was pronounced "dead" in the late

1970s (Yates et al. 2011:iii). However, Tampa Bay is now considered a success story. Legislation and management practices enacted by numerous agencies since then have helped dramatically increase the water clarity and quality of Tampa Bay. Today water clarity is back to what it was in the 1950s, and current estimates have the original seagrass coverage (>15,000 hectares) back to its natural state by 2045 (Yates and Greening 2011:8).

What is Tampa Bay's "natural state"? Heerschap (1980:1) compiles historic accounts from early visitors to Tampa Bay which describe its now, almost unbelievable conditions before major developments, a time when waters were "so full of fish that they would impede boats." These historical accounts are likely representative of the ecological productivity in Tampa Bay during precolumbian times as well.

Archaeological evidence at the Harney Flats site (8HI507) in Hillsborough County indicates people have lived in the Tampa Bay Area for at least 10,000 years. However, when Harney Flats was occupied, sea levels were much lower than today, and the site would have been 100 miles further inland from the Gulf of Mexico. Moreover, during the occupation of Harney Flats, Tampa Bay was most likely a freshwater swamp (Daniel and Wisenbaker 1983:71: Morrison and Yates 2011:42). The Paleoindians of Harney Flats did not have the ecologically productive Gulf of Mexico and Tampa Bay in their backyard like later people would. Over the next 10,000 years, Tampa Bay underwent many ecological changes, but the earliest occupants of the region likely played a role in shaping some of these alterations.

Florida Archaeological Cultures

Tampa Bay has been occupied throughout all of the archaeological periods of Florida and the greater Southeastern United States, which are divided into the Paleoindian (13000 BC – 8000 BC), Archaic (8000 BC – 1000 BC), Woodland (1000 BC – AD 1000), and Mississippian (1000 AD – European

Contact). The distinctions between each are based on technological and economic innovations, albeit their boundaries are becoming increasingly blurred (Russo 1994; Wallis 2008). For example, earthen mound building, long-distance exchange, and the widespread adoption of pottery, the defining signatures of the Woodland Period, are all represented in the Archaic, but to a slightly lesser degree (Wallis 2008:239). In addition, the worldviews of people from different regions are influenced by the local negotiations of power, identity, and meaning (Wallis 2008:237). Therefore, the smaller regional cultures are more beneficial for archaeologists to investigate, given the smaller spatial scale and more refined chronologies that support interpretations of cultural change. These broader cultural periods form a general template for more regionalized cultures to be studied, here, the focus is the Central Gulf Coast of Florida.

Central Gulf Coast Archaeological Cultures

Three cultural periods are defined within the Tampa Bay area: Manasota (500 BC – AD 700), Manasota-Weeden Island (AD 700 – 1000), and Safety Harbor (AD 1000 – 1500) periods. Their occurrence in time and space continues to be reinforced by archaeological excavations and analyses, albeit with a few exceptions. For example, Weeden Island ceramic types persist longer than initially thought, and Pinellas Plain, a Safety Harbor type, occurs a bit earlier in midden contexts (Austin et al. 2014). Moreover, the exact timing of Weeden Island is a bit unclear in Tampa Bay because few burial mounds representing this time period have been dated.

Archaeological discussions and observations have taken place in Pinellas County since the 19th century. S.T Walker (1880), C.B. Moore (1900) R.D. Wainright (1916), and M.W. Stirling (1930) all provide detailed descriptions of Tampa Bay sites. Indeed, the first professional excavations to take place in Florida were at the Weeden Island site (8PI1) in Pinellas County by Fewkes and Stirling in 1923 (Milanich 1994:8). Goggin (1947:114) viewed Florida’s peripheral location as unique relative to other

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regions, noting the isolation led Floridians, "to be able to participate in the Southeastern cultural picture and at the same time develop characteristic local features." Florida's uniqueness in the Southeast is a theme that continues today (Weisman 2003; Wallis and Randall 2014). Goggin (1947) used existing typologies and physiographic features to divide the state into eight archaeological regions. Although this ecological division was somewhat arbitrary, Goggin viewed the relationship between culture and environment as "permissive rather than restrictive" (Weisman 2003:213). One such area was the Central Gulf Coast.

The material culture excavated from the Tampa Bay region early on helped Gordon Willey (1949) construct a post-Archaic ceramic typology for the Central Gulf Coast of Florida. For the most part, his work has stood the test of time with one exception being the Perico culture, which was later replaced with the Manasota culture (Austin et al. 2014:94-95). Luer and Almy's (1982) definition of the Manasota culture is now the accepted post-Archaic (early to middle Woodland) culture of the Tampa Bay region from ca. 500 BC – AD 700. Surveys and excavations in the region continue to support Luer and Almy's Manasota hypothesis (Austin 1992, 1995; Austin et al. 2018; Schwadron 2002; to name a few). In addition, archaeological evidence supports the notion that Manasota local traditions persisted in the Tampa Bay area for over two thousand years, accentuating the continuity of the coastal lifeways from the Late Archaic until the Mississippian-influenced Safety Harbor period in Tampa Bay (Luer 2014:80; Milanich 1994:222). As a multicomponent site, Yat Kitischee is a prime example of this continuity because it was occupied throughout the Manasota, Weeden Island, and early Safety Harbor periods but held steady to many local traditions, such as the addition of quartz sand temper in ceramics.

Luer and Almy (1982:37) present four defining characteristics of Manasota culture: (1) A small-scale economy of fishing, hunting, and shellfish gathering. Subsistence was primarily fish, although other forms of food were supplemented by hunting and gathering which required mobility within territories

(Luer 2014:82). Although most Manasota sites are linear and parallel to the shoreline (Luer and Almy 1982:39), the interior of Florida was also easily accessible and exploited by Manasota people, especially during winters. (2) Primary, flexed burials in shell middens and/or cemeteries. (3) Sand-tempered plain utilitarian ceramics, mainly flattened globular bowls. One of the most distinctive traits of Manasota culture is the manufacture of thick (>1cm) quartz Sand-Tempered Plain ceramics, known colloquially as STP. These ceramics are undecorated and usually globular in shape with a converged orifice with an inward curving rim and chamfered or rounded lip (Luer and Almy 1982:44). Later STP vessels have straight rims, a rounded lip, and straight walls that gradually thin through time. (4) A heavy utilization of shell tools and less of a reliance on stone and bone tools. As estuarine specialists, the technological toolkit implemented by the Manasota was one mostly manufactured from shell and bone. Virtually every tool (hammer, anvil, scraper, pounder, celts, net sinkers, spoons, cups, etc.) exploited a dedicated species. *Strombus* shell hammers were used intensively between 300 BC and AD 700 until virtually disappearing from archaeological assemblages (Luer and Almy 1982:44).

Around ca. AD 300 there is an adoption of new mortuary customs in the Manasota way of life with influences from northern Florida permeating south down the coast into the Tampa Bay region. These customs, known as Weeden Island culture, were a social-political-ceremonial complex that influenced the Manasota people's treatment of the dead (Luer 2014; Luer and Almy 1982:52; Milanich 1994:222; Willey 1949:403-406). Willey (1949:403) describes the Weeden Island culture as having "a strong orientation toward the dead… and a close relationship between the mundane and sacred powers." During this time, people switched to secondary burials in continuous use sand burial mounds with few grave goods. If ceramics were present, they were undecorated (Luer and Almy 1982:47). During the later phases of the Weeden-Island Manasota period (ca. AD 700), bundle burials became the

most common form of internment often accompanied by exogenous ceramic types and grave goods (Luer and Almy 1982:47).

Burial treatments provide insights into the social stratification of these cultural periods. The Early Manasota Period is believed to have been mostly egalitarian given that the vast majority of burials were interred in shell middens or cemeteries with few to no grave goods. Weeden Island influenced the construction of off-midden, sand burial mounds, which later would increasingly contain exogenous grave goods. Moreover, decorated ceramics are very rare in middens and are generally only found in burial mounds (Luer 2014:86). This is believed to reflect the beginning of social stratification in the Tampa Bay area. That is, it is likely that only the elites or important people were bestowed burials in a mound, while the general populous continued to be interred in cemeteries (Austin 1995:227). People obtained power by acquiring highly valued exotic goods through participation in regional exchange networks (Austin 1995:227). Through time the societies living in Tampa Bay would become increasingly stratified, but it likely began near the onset of the Weeden Island Period.

By AD 900, political and religious ideas emanating from the Mississippi Bottom and spreading across the Southeast influenced the local Weeden Island-Manasota culture enough to now be recognized as archaeologically distinct, the Safety Harbor culture. Mitchem (1989) divides the Safety Harbor period into four phases: Englewood (AD 900-1100) and Pinellas (AD 1100-1500), the two precolumbian phases; and Tathum (AD 1500-1567) and Bayview (AD 1567-1725), two colonial periods.

Increased interaction with Mississippian cultures to the north lead to the integration of Mississippian iconography in local Tampa Bay peoples' ceramic styles (Austin and Mitchem 2014:68). Willey (1949:479) discussed the two apparent influences among Safety Harbor ceramic types, the first of Weeden Island and the second "an offshoot of a Fort Walton style with the Mississippian impetus

behind them." Safety Harbor ceramics, jars, and bottles, with depictions of human hands and maces on pottery are evident of this influence (Austin et al. 2018:50).

Another main difference of Safety Harbor is the site layout, which Bullen (1978:54) describes as consisting of a rectangular temple mound with a ramp leading toward the main part of the midden, the midden, which runs parallel to the shoreline, a burial mound to one side of the midden, and a plaza encompassing the area between these features. Moreover, small midden sites are often present in outlying areas, which likely represent small household clusters within a given polity (Austin et al. 2018:50). Luer and Almy (1981:141) discuss the size, orientation, and geographic distribution of the 15 temple mounds once found in Tampa Bay. They note that the mounds' orientation with the cardinal directions suggests purposeful site planning. It is currently unclear what structures rested atop of platform mounds, but it is likely where the chiefs or caciques lived or perhaps housed elaborate structures where ceremonies took place (Luer and Almy 1981:144).

Milanich (1994:398-399) adds that it is unclear if this settlement system reflects a chiefdom political system. A reliance on agriculture is often associated with increased social and political stratification. Indeed, elsewhere in the Southeast, there is evidence for maize cultivation during the Mississippian. For example, at Fort Walton sites, a northern Gulf Coast Mississippian culture, sites appear larger and tend to migrate inland during the Early Mississippian. Willey (1949:455) interpreted this as a change in the political and social organization towards a trend of political and religious cohesion. This, along with the presence of temple mounds and diminishing amounts of shell led Willey (1949:455, 477) to conclude that the powers of leaders would have increased during the Fort Walton Period, and, to a lesser degree, Safety Harbor. Tampa Bay still lacks evidence for intensive agriculture. Milanich (1994:398) estimates the population of Tampa Bay as far less than in the Fort Walton heartland, noting Safety Harbor's political integration was less complex and most likely not organized

into Mississippian chiefdoms. Nonetheless, relative to the earlier Manasota period the Safety Harbor period is undoubtedly characterized by a high degree of social stratification.

Like Yat Kitischee, many Tampa Bay sites are multicomponent and occupied throughout two or all three of the periods mentioned above. A notable exception would be the Safety Harbor (8PI2) site, which was only inhabited during the Safety Harbor period (Mitchem 1989:57).

Yat Kitischee (8PI1753)

Yat Kitischee (8PI1753), formerly known as Moog Midden, encompasses approximately 3 hectares in a live oak and cabbage palm hammock adjacent to the St. Petersburg-Clearwater International Airport in Pinellas County, Florida (**Figure 5**). The site is located approximately 610 meters south of the current shoreline of Old Tampa Bay. Austin (1995) describes Yat Kitischee as a coastal hamlet, that is, a small, permanent or semi-permanent settlement consisting of several family groups. Janus Research, a Tampa based CRM firm, has conducted the sole excavations at Yat Kitischee in 1992 and 1994, and briefly in 2004.

Janus's site assessment focused on determining the subsistence economy and technology of Yat Kitischee (Austin 1995:11). Along with surface collection, Janus archaeologists excavated 140 shovel tests, 58 50x50 centimeter test units, and three 1x2 meter test units in 1992 and 11 2x2 meter test units in 1994 (Austin 1995:3) (**Figures 6A and B**). Fourteen radiocarbon dates, six from shell and eight from charred wood indicate the site was occupied continually from at least 100 BC to AD 1200 (**Table A1**). It remains unclear if the site was occupied on a seasonal or perennial basis (Austin 1995:220).

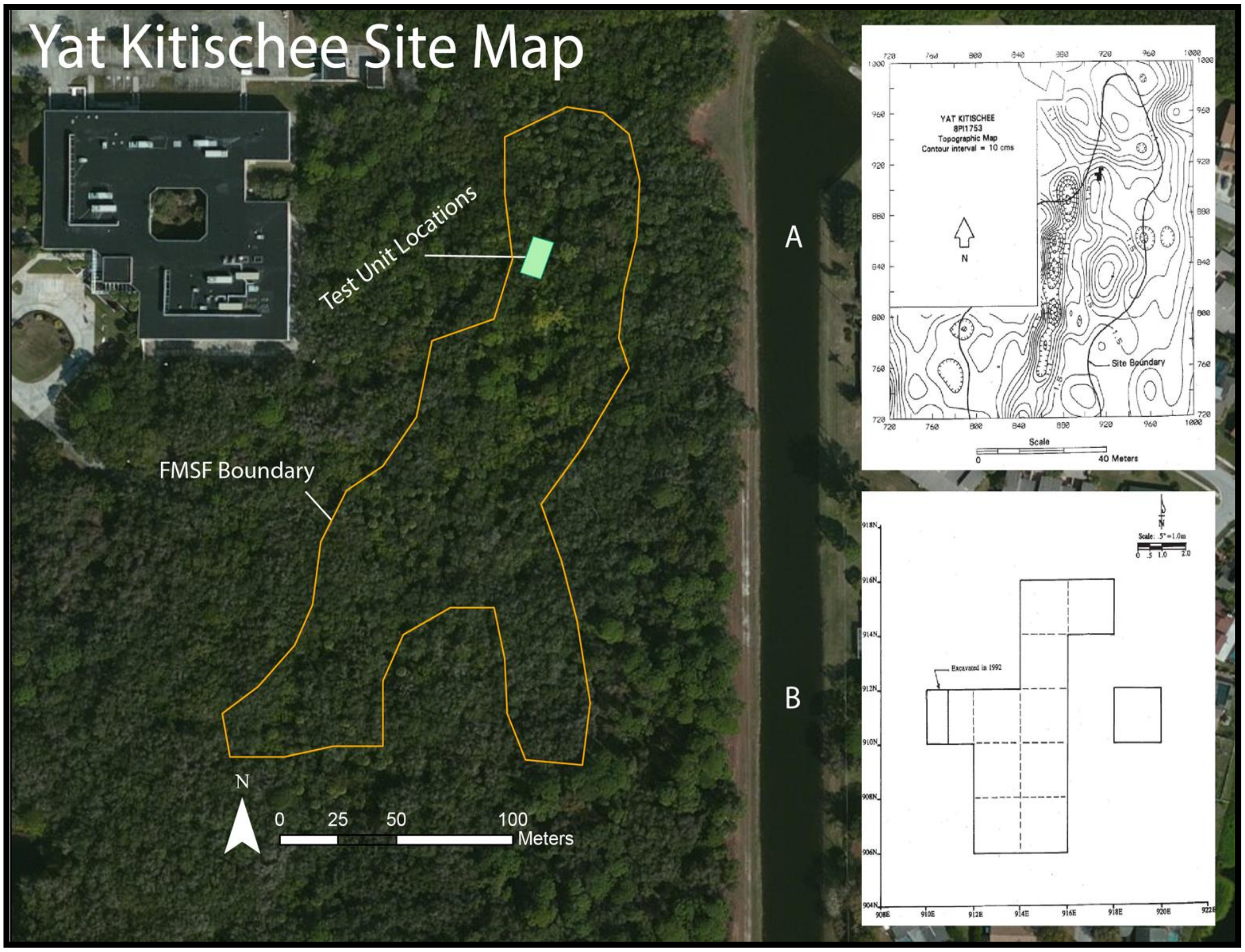

Figure 6. Yat Kitischee's site boundary per the Florida Master Site File.
A – Topographic map prepared by Janus Research (1992)
B – Units excavated by Janus Research at Yat Kitischee.

Stratigraphy and Site Formation Interpretations

Janus observed three stratigraphic zones (A, B, and C – latest to earliest). Defined generally, Zones A, B, and C represent the shell mound, shell midden, and natural ground surface respectively (See Janus Research 1995:22-29 for a complete overview) (**Figure 7**).

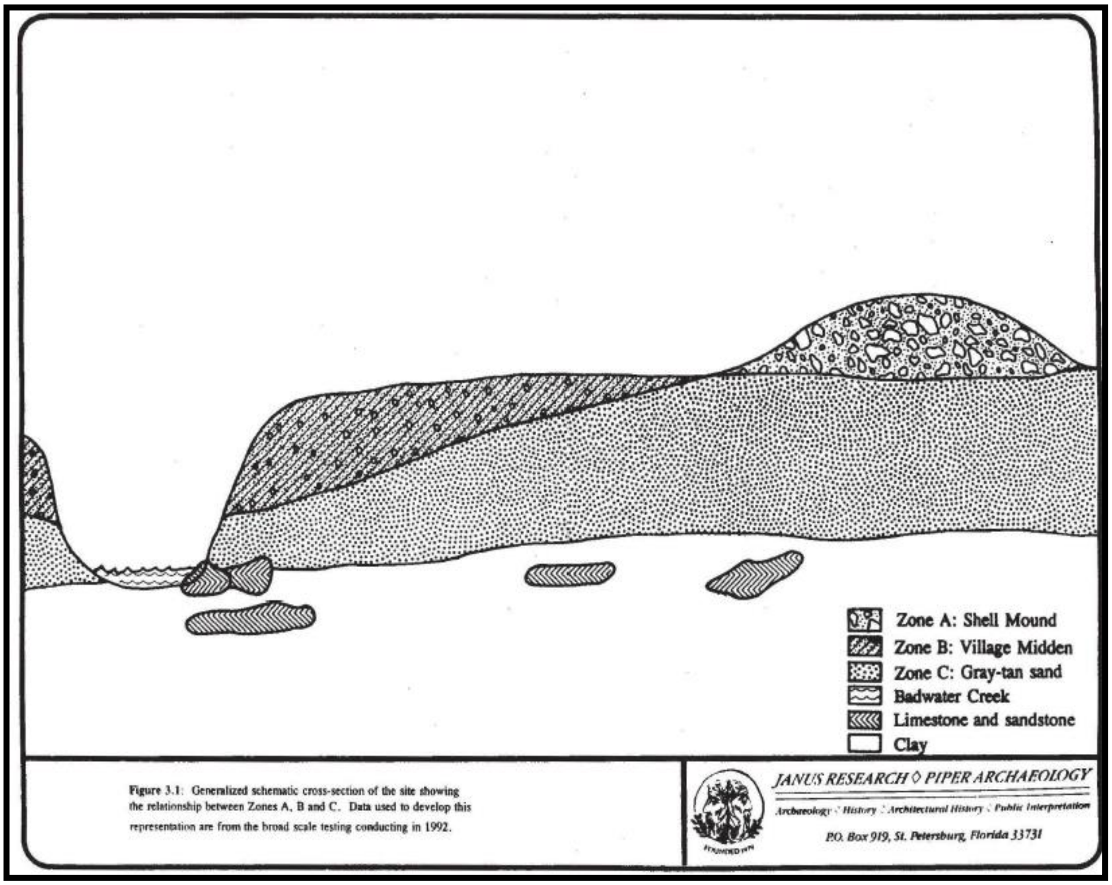

Figure 7. Generalized cross-section of Yat Kitischee showing the three zones (Austin 1995:Figure 3.1).

Zone C is categorized as an Elred fine sand with minimal crushed shell inclusions. This zone underlies the midden layer of Zone B3 and basal portion of the shell mound (Zone A) (Janus Research 1995:22, 26). A radiocarbon date from Feature 1 within Zone C places the earliest site occupation between ca. 180 BC and AD 120. During this time cultural material is sparse. When artifacts were present, they were primarily lithic flakes and broken bifaces, suggesting the earliest inhabitants of Yat Kitischee were most likely living in short-term encampments (Austin 1995:33).

Zone B, further divided into B1, B2, and B3 (latest to earliest), is characterized by a dark gray or black organic sand with moderate to abundant shell, bone, and ceramics (Janus Research 1995:22-24). Overlying Zone C, B3 is represented by a relatively thin (5 – 20 cm) dark gray fine sand with sparse amounts of shell. The shell within B3 is described as homogenous and began accumulating around AD 100 until about AD 400, the beginning of B2 (Janus Research 1995:33). Zone B2 ranged from 20 – 50 cm thick and consists of very dense shell. The shell deposits are distinctly different from the preceding B3 in both sheer abundance and heterogeneity (Janus Research 1995:33). Although predominately oyster, crown conch are also abundant within B2. Janus (1995:26, 33) relates the difference to shell in Zone B2 as individual dumping episodes and a transition from a living space to that of an area of secondary refuse from AD 600 until AD 800. Between Zone B2 and the ground surface, Zone B1 is a 30 – 40 cm thick layer of very dark gray sand with moderately dense amounts of shell, noted as being primarily composed of whole crown conch and broken oysters (Janus Research 1995:24). Zone B1 also had the highest concentration of artifacts relative to all other zones, the number of artifacts increased in depth reaching a peak near the interface of B2 (Janus Research 1995:24). Zone B1 is thought to have been converted back to a living area during this time (AD 800) until AD 900 – 1000 when it appears to have been abandoned (Janus Research 1995:34).

Zone A represents the sole shell mound present at Yat Kitischee. The strata within Zone A are significantly more variable than those in Zone B leading to the interpretation of multiple discarding events taking place over time. Additionally, the lack of features in Zone A further supports the difference in nomenclature as mound versus midden (Janus Research 1995:24). Zone A rests approximately 2 meters above the natural ground surface (Zone C) rather than Zone B and is subdivided into four discrete strata. The basal Zone A4 was a light gray sand with sparse amounts of shell. Zone A3 was a light grayish brown sand dominated with large whole shells. Zone A2, although sharing the same color as

A3 differs significantly. Zone A2 is unique in that the shell represented within the zone are variable in size, species content, and taphonomy compared to the rest of Zone A. Interestingly, a 5cm lens of exclusively crushed shell and small crown conch beginning at 39 cmbd (1.59 m AMSL) sat between the bigger and whole shell present within the rest of Zone A2 (Janus Research 1995:24). The crushed shell present in A2 was absent of organic soil which suggests the likelihood of the shell being crushed elsewhere and purposefully discarded in the mound (Janus 1995:35). The phenomenon observed in A2 was not apparent in any other portion of the site. Lastly, immediately beneath the ground surface, A1 was relatively similar to Zone B in that it is a dark gray organic sand with shell, bone, and ceramics (Janus Research 1995:24). Zone A dates from AD 1050 until 1200, which is the terminal date at Yat Kitischee (Janus Research 1995:32).

Occupational Variability in the Central Gulf Coast

Yat Kitischee's site formation yields interesting questions. Particularly, why are areas at the site being repurposed around AD 600? Interestingly, other Tampa Bay sites also appear to go through changes during this time. Most notably, Bayshore Homes (8PI41), a mound and midden complex was abandoned from AD 565 to 890 (Austin and Mitchem 2014). Further north, there is a decline in settlement activity at the Crystal River site (8CI1), Shell Mound (8LV42), and Garden Patch (8DI4) (Pluckhahn and Thompson 2017:74; Pluckhahn et al. 2017; Sassaman et al. 2014; Wallis et al. 2015) (**Figure 8**). While down south the Calusa began to reinhabit the coast after a period of storminess and sea level rise (Walker 2000:124). The bimodal distribution discussed earlier in **Figure 2** indicates an apparent reduction in site activity in Tampa Bay during the sixth and seventh centuries. What caused these changes?

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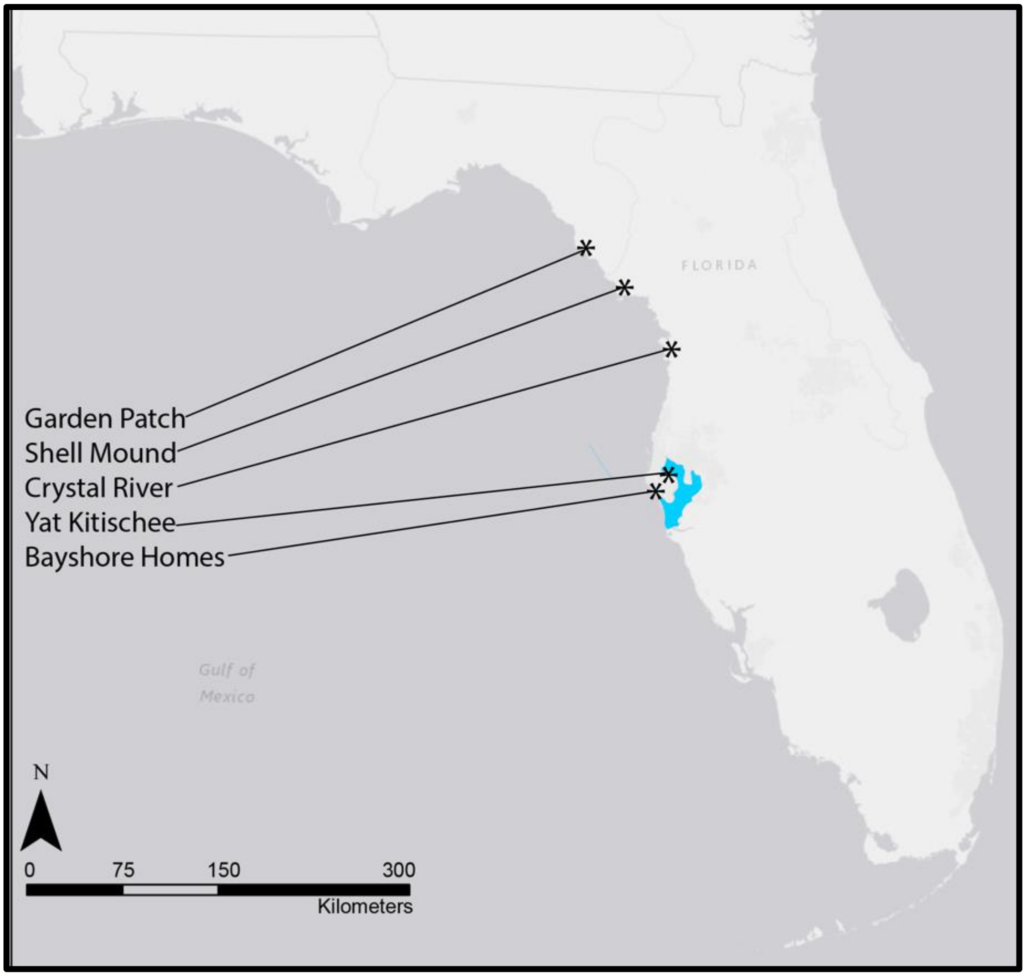

Figure 8. Central Gulf Coast sites participating in "Weeden Islandization" (?).

Using Bayesian modeling, Pluckhahn et al. (2017) make a convincing argument for a migration north and into the interior of the state during this time. This migration is most evident in the decline in southern/central sites and the prosperity of northern sites in the panhandle and interior. Some of the northern sites show evidence of dual organization, more permanent settlement, and differences in material culture, further suggesting visitors from the south. Pluckhahn et al. (2017) describe this period as an "upheaval… facilitated by the development or elaboration of ritual practices." They deem this period a "Weeden Islandization," resulting in an exchange of ideas that the people of the Central Gulf

Coast returned with after migrating back to the coast. Pluckhahn and colleagues (2017) note that the migration may have been broadly related to climate but acknowledge that the lack of uniformity in the dates of the site abandonments suggests social change, rather than climatic.

If climate change or sea level rise was the initial impetus for this migration, however, it could explain why some sites were abandoned while others were not. Sea level fluctuations would most likely have not affected Tampa Bay uniformly. Austin and colleagues (2014:95) attribute this heterogeneity to Tampa Bay's shallow bottom, sedimentation, and "multi-lobed" nature of the bay, which ultimately leads to highly variable tidal fluctuations in the different components of the bay. The diversity of shorelines discussed earlier would also significantly create variance during times of sea level rise or decline. In other words, Boca Ciega Bay, where Bayshore Homes is located may have been more negatively affected by sea level oscillations than Old Tampa Bay, near Yat Kitischee. However, there are other possible explanations for the occupational variability within Tampa Bay. Perhaps a smaller population at Yat Kitischee was more manageable than the larger one at Bayshore or the people at Yat Kitischee actively managed their estuarine resources better. Perhaps the lack of radiocarbon dates around AD 600 in Tampa Bay is simply the result of sampling bias at sites that were established after this period. Maybe people never actually left the Tampa Bay region.

At present, it is unclear what the gap in radiocarbon dates in Tampa Bay actually means. That is, if they are related to climatic or social change, or a combination thereof. With that being said, climatic evidence elsewhere in Florida during this time suggests the climate was unstable and influenced rapid changes to sea level (Walker et al. 1995; Wang et al. 2011, 2013).

Sea Level and Climatic Variability of Southwest Florida

Gulf of Mexico Sea Level During the Holocene

The Gulf of Mexico sea level curve for the last 3,000 years remains somewhat contentious. That is, some studies indicate multiple sea-level oscillations have taken place while others show a (relative) gradual rise to present levels with few to no major fluctuations. Walker (1992:278) defines these two schools of thought as “curvers” and “smoothers” respectively. Detailed discussions of the differences can be found elsewhere (Kuehn 1980:4-22; Thompson and Worth 2011:53-57; Walker 1992:278-279), therefore this will be a very brief overview.

‘Curvers’ tend to analyze the geochronology, geomorphology, and elevational distinctiveness of beach ridges. Most of these studies show major sea level oscillations have taken place in the Gulf of Mexico and that sea level has been higher-than-present during the Holocene (Missimer 1973; Stapor et al. 1991; Tanner 1992, 1993). Notably, Tanner’s (1993) analysis of beach ridges in Denmark aligned with those in Florida (Tanner 1992), providing substantial evidence that these Holocene fluctuations were eustatic (global). The name ‘smoothers’ is derived from the statistical techniques used to achieve the gradual, continuous sea level curve, which essentially compresses the curve and treats oscillations as data errors (Kuehn 1980:4). ‘Smoothers’ tend to analyze the pedological processes of wetlands through coring and the reconstruction of paleo-shorelines (Davies and Cohen 1989; Enos and Perkins 1979; Goodbred et al. 1998; Wright et al. 2005). Analyzing how the wetland ecosystem transitioned through time (e.g. to or from a coastal marsh) provides additional insights given that the formation of coastal marshes takes time and requires relative sea-level stability (Jackson 2016:27; Wright et al. 2005). These studies tend to support the deceleration of sea level transgressions during the last 3,000 years. Albeit, some, like Goodbred et al. (1998), still support the transgressions noted by the ‘curvers’ via shoreline retreat.

Here, I follow Jackson's (2016:25-26) lead by referring to 'smoothers' as the 'alternative' reconstructions because the Florida Gulf Coast archaeological literature is dominated by the beach ridge sea level curves. The differences in field methodologies, sampling strategies, and post-hoc statistical techniques are likely the biggest contributors in the discrepancies between 'smoothers' and 'curvers'.

Although 'curvers' tend to dominate the Florida Gulf Coast archaeological discourse, they are not without criticism in the geological community. For example, Otvos (1992, 1999, 2000) criticizes the use of beach ridges in higher-than-present sea level interpretations. The 'curvers' rely on an assumption that high and low stands can be identified in beach ridges through the differences in morphology, elevation, and texture, an idea that is also contentious. A beach ridge is a landform that is parallel or semi-parallel to the shoreline, it has wave or wind origins developed on prograded coasts with beach shorelines but is now isolated from active shoreline processes (Stapor 1975; Otvos 2000:84). They are formed by high and low wave-energy swash or through a combination of wave and wind deposition (Taylor and Stone 1996:619). By analyzing the size of sediment present in beach ridges, Tanner (1995) asserts that sea level oscillations form beach ridges. Otvos (1992, 1999) demonstrated that grain sizes from beach ridges and foredunes significantly overlap and that many of the beach ridge sets used by 'curvers' are likely relict foredunes. Additionally, Otvos (2000:103) contests the origin or formation of beach ridges themselves noting that many ridges/foredunes were formed by higher-than-average, storm-associated wind tide stages rather than true sea level fluctuations. He goes on to say, "Wave-built, high beach ridges provide little convincing indication for the alleged Late Holocene high stands" (Otvos 2000:105). Tanner (2000:92), however, asserts, "Beach ridges were not built by, or during, a storm, despite the wide popularity of this poorly grounded hypothesis." Donoghue and Tanner (1992:239) dispute Otvos' accusations of beach ridges being relic foredunes, noting that foredunes would be homogenous throughout the landform indicating they were not created by aeolian factors.

Later studies, however, have shown that an aeolian boundary is not always noticeable in coring studies and can sometimes only be deciphered in ground-penetrating radar (GPR) profiles (Rodriguez and Meyer 2006). If beach ridges do indeed act as an indicator of past sea levels, they are likely predisposed to record more local extremes given their location on the coast and vulnerability to strong depositional events (Jackson 2016:29). Despite some of the disputes in the geological discourse, Gulf Coast archaeologists tend to refer to the sea level curves created by the 'curvers', specifically, the southwest Florida sea level curve.

Southwest Florida Sea Level Curve

Relating the timing and presence of archaeological faunal assemblages to existing sea level curves in the area (Missimer 1973; Stapor et al. 1991; Tanner 1991, 1992) allowed Walker et al. (1995) to refine the timing and intensity of four sea level fluctuations over the last 3,000 years in southwest Florida. Briefly, Sanibel I (ca. 1050 BC – 50 BC) was a regression of about 40-60 cm below MSL. Wulfert (ca. 50 BC – AD 550) was a high stand between 0.6 and 1.2 meters above MSL. Buck Key (ca. AD 550 – AD 850) was a regression of 50-60 cm below MSL. Finally, La Costa (ca. AD 850 – AD 1450) was a rise of about half a meter above MSL.

However, regional variation plays a vital role in the response of an ecosystem to changing climate, and the people's response to these changing landscapes as well. Therefore, this curve is not appropriate for inferring change outside of southwest Florida, at least concerning the exact timing and magnitude of the four sea level oscillations discussed above. Although Charlotte Harbor and Tampa Bay are geologically similar (Lewis III and Estevez 1988:53; Morrison and Yates 2011:37), there were likely significant differences in the ecological effects taking place in each locale. Similarly, averaged eustatic sea level curves (Balsillie and Donoghue 2004; Donoghue 2011) support major oscillations but their applicability to archaeological studies is negligible due to the smaller spatial scale used by

archaeologists. There is currently no sea level curve dedicated to Tampa Bay during this time frame. Therefore, the southwest Florida sea level curve is used here as a rough template for the timing and intensity of sea level change.

Climatic Episodes of the Middle to Late Woodland

The temporality of these sea level episodes aligns with three broader climatic episodes known as the Roman Warm Period (RMP) (AD 1 – 550), Vandal Minimum (VM) (AD 550 – 850), and Medieval Warm Period (MWP) (AD 850 – 1200) (Gunn 2000; Walker 2013; Wang et al. 2011, 2013). These climatic episodes were widespread, occurring throughout the greater North Atlantic region (Walker 2013:43). Climatic episodes are flexible, meaning they are less bounded temporally and spatially; they have "fuzzy" beginnings and endings (Gunn 1994:18). The duration and effects of each episode vary by region and are currently unknown in Tampa Bay.

Southwest Florida studies characterize the RWP as having summers that are similar to, or slightly drier than, present and winter conditions that were mostly similar to present but with some colder and some warmer intervals in between (Walker and Surge 2006; Wang et al. 2013). Although there is apparently much variability during the VM, it is generally characterized by coolness with punctuated short-term warming events (Walker 2013:41). Wang and colleagues (2011) provide isotopic evidence for particularly dry summers between A.D. 500-600 and 650-750 in Southwest Florida. Many summers without rainfall may have induced a drought and subsequent lowering of the sea level (Wang et al. 2011:9). A.D. 600-650, however, appears to have been a time of rainy summers indicating that the VM was not constant through time. Further evidence of instability is provided by Jackson's (2016) archaeopalynological analysis at the Crystal River site, which shows a reduction in plant diversity with only the plants capable of tolerating wide swings in temperature and precipitation surviving around cal. AD 500 and Tanner's (2000:95) "zig-zag" sea level curve during this period.

While precursor conditions to the cooling event were undoubtedly present, the origin of the VM is possibly related to a dry fog that lingered for 18 months, blocking sunlight and creating an unstable global climate with a three-hundred-year aftermath (Gunn 2000:12). This is referred to by Gunn (2000) as the "A.D. 536 Event" and is noted historically from many different societies. For example, Procopius (1916), a Byzantine historian writes, "For the sun gave forth its light without brightness, like the moon, during the whole year." The cause of the fog is unknown, but there are three competing hypotheses: a super-volcanic eruption or a series of volcanic eruptions, perhaps from multiple areas around the world (Bryson 1994), a hit or near miss by a meteor or comet (Baillie 1995), or windblown terrigenous dust (Tanner 2000). The similarities between the three are an excess of dust in the atmosphere, which blocked solar radiation. The decreased solar radiation likely modified atmospheric circulation patterns within the subtropical North Atlantic region (Wang et al. 2013:240). Whatever its origin, it is clear that it was a difficult time for many people worldwide.

Finally, the MWP is characterized by an overall warm climate punctuated with short cooler events and increased storminess (Walker 2013:42). This time period was the last time Earth was 1°C warmer than present (Gunn 1994:14). Geological (Stapor et al. 1991; Tanner 1992, 1993), archaeological (Walker 1992), and isotopic (Walker and Surge 2006; Wang et al. 2011, 2013) evidence further corroborates the timing and intensity of these climatic episodes and their relationship between the sea level fluctuations in Southwest Florida.

Salinity Gradient Model

The salinity gradient model is an ecological principle that lies within the presence or absence of species. This model can be applied to archaeological deposits to determine the relationship with the ever-changing estuarine salinity gradient. Walker (1992) demonstrated that changes in faunal states and conditions, that is the number and occurrence and/or disappearance of salinity sensitive species along

the estuarine salinity gradient, aligned with Stapor and colleagues' (1991) sea level curve near Charlotte Harbor. For example, the presence of crested oyster (*Ostrea equestris*) in an archaeological assemblage denotes a time of higher salinity because the optimum salinity for this species is relatively high (≥32 ppt) (Walker 1992:109). In addition, species that are capable of tolerating wider fluctuations in salinity, like the *C. virginica* and *M. corona* can also provide insights. For example, Walker (1992) examined the ratio of oysters to crown conch through time and demonstrated spikes in crown conch populations during sea level regressions.

An increase in populations generally suggests a time when prey items are plentiful. Stressed oysters that had succumbed to exposure would make easy prey for conch and whelk. Other environmental stressors that could weaken oysters include heavy rainfall and storms (Walker 1992:121-122). Essentially, any environmental phenomenon that could increase or decrease salinity to either end of the oysters tolerance could explain an archaeological assemblage with a higher ratio of crown conch than oysters. A number of variables can determine the salinity gradient of a given estuary. A drought would influence the salinity gradient landward, while a time of prolonged rain would shift the gradient towards the sea (Walker 2013:37). Sea level oscillations would also impact the salinity gradient. A lower sea level would shift the freshwater wedge seaward while a higher sea level would shift the gradient landward (Walker 2013:37). Further support of changes to salinity regimes comes from isotopic evidence from *Mercenaria spp.* and *Arius Felis* otoliths that support the broader climatic episodes and timing of sea level oscillations in Southwest Florida (Walker and Surge 2006; Wang et al. 2011, 2013).

Oyster Ecology

Understanding the environmental preferences of oysters is paramount to interpreting the paleoenvironment, but oysters are animals that have served an important ecological and cultural function for millennia. This section discusses the importance of oysters in the ecological community of

Tampa Bay, today and prehistorically.

The eastern oyster, sometimes referred to as the American oyster, is both a keystone species and an ecosystem engineer because of the formative role it plays in subtidal and intertidal estuarine environments. These roles include, but are not limited, to improving water quality and clarity by filter feeding, providing shelter for many smaller animals like shrimp and clams within the oyster bars or reefs, and also stabilizing and protecting the shoreline from wind, boat wake, and storm erosion (Garvis et al. 2015).

In addition to these environmental examples, oysters are also of economic importance. During precolumbian times, oysters, and other shellfish were used during public ritual events such as mound building. In the late 1800's an estimated 500,000 pounds of oyster meat was collected in Tampa Bay, although this number declined significantly over the following century, for example only 100,000 pounds were harvested in 1960 (Finucane and Campbell II 1968:37). Once a booming industry in the area, there are no longer commercial oyster harvests in Tampa Bay for a few reasons. First, many of the dredging projects discussed earlier reduced water clarity and oyster populations. Another primary reason was that unmonitored sewage contaminated oysters in many areas of the bay. Environmental regulations have led to better water quality and higher oyster populations, but oyster harvesting is still prohibited in Tampa Bay.

Pollution, overharvesting, and habitat destruction have led to an estimated 85% loss of the total global population of oysters over the last 130 years (Beck et al. 2011). Frederick and colleagues (2016) note a decline of about 88% in offshore oyster reefs during the last 30 years in the Big Bend Coast of Florida, during which time the height of the average oyster reef fell approximately 8 centimeters per year. To negate the effects of population and habitat decline, much effort has concentrated on oyster reef restoration worldwide. A local example is the work of Dr. Linda Walters and colleagues in multiple

areas of Florida (see Barber et al. 2010 for an example). Walter's projects and similar restoration undertakings are an example of oyster mariculture. Oyster mariculture is a recognition that oysters are beneficial to the environment and must be conserved, a belief that has a very long history. Ancient Floridians likely used similar shelling or clutching techniques in which dead oysters are returned to their origin in order to enhance the substrate for future oyster larvae (Jenkins 2017). Jenkins (2017:76) proposes that the flatter right valve was placed back on the reef and the bigger left valve was used as monumental construction material. The flatter right valve would make a more desirable substrate for young oysters. This could be determined by analyzing the ratios in a given sample. Another mariculture technique called culling, in which people break apart oyster clumps and discard some back to the water is also likely. This action would be evident on oyster shells in the form of attachment scars. Although further work needs to be done to test this hypothesis, Jenkins (2017) makes a convincing argument for oyster mariculture taking place at the Shell Mound site.

The eastern oyster is common in estuaries because of its tolerance to wide ranges of salinity and temperature, although its preference is 10-30 ppt and 8-26 C° respectively (Galtsoff 1964:404-407). Oysters are gregarious, that is, a preference for living near (or on) their own species, forming a living community (Galtsoff 1964:373-374). Oysters reproduce annually, and the timing is controlled primarily by water temperature and plankton abundance (Thompson et al. 1996:335). Gametogenesis is synchronized between sexes, so that sperm and eggs are released simultaneously, the presence of gametes in the water stimulates nearby oysters to do the same, thus maximizing the number of zygotes in a given area (Thompson et al. 1996:335). Once fertilized, the initial life stage of an oyster is a larvae. The larvae floats through the water at the whim of the currents, preying on phytoplankton, detritus, and bacteria for two to three weeks (Thompson et al. 1996:371). Larvae are incredibly vulnerable to predation at this stage. If the larvae survive the challenging three weeks, it begins crawling on hard

surfaces, seeking a place to cement for the rest of its life. This is probably no easy task given the intense spatial competition in many areas (Boudreaux et al. 2009). However, oysters sense chemical cues indicating where to cement themselves (Thompson et al. 1996:371-372). If the larvae senses the stimuli, it cements its left-valve to the substrate, defining its next life stage as a spat (Thompson et al. 1996:372).

Oysters choose to cement in many unique places and can be found attached to wood pilings, mangrove roots, seawalls, and of course other oysters (McNulty et al. 1972:83). In Tampa Bay, it appears the majority of oysters are associated with mangrove habitats and seawalls rather than natural oyster reefs (Drexler 2011). Physical and chemical cues continue to influence the development of the spat and ultimately trigger metamorphosis from spat to oyster (Thompson et al. 1996:373). Ideally, the oyster chose a location with suitable temperature, salinity, substrate, and position in the water column, which all have varying degrees of effect on oyster growth (Jenkins 2017:75).

Environmental or Cultural?

Relating salinity changes to sea level oscillations of the past is difficult. For one, estuaries by definition have seasonal fluctuations in salinity. Moreover, many social, cultural, economic, and environmental factors play a role in shell midden formation, limiting definitive answers on all of the above. From a strictly environmental perspective, salinity changes could be related to variable rainfall patterns, the breaching of a barrier island, or a shift in wind patterns rather than a sea level transgression/regression (Johns and Lee 2012:72; Quitmyer 2002:196).

Agents introduce a number of variables to consider such as changing food preferences, shifting economies, or a combination thereof (Schwardron 2002:215). At Yat Kitischee, Austin (1995:226-227) discusses the possibility of the increase in species richness through time being related to a developing political economy rather than environmental phenomena. These factors undoubtedly concomitantly

influenced the midden deposits examined in the three studies mentioned above, slightly weakening the paleoenvironmental interpretation. A relatively new method called sclerochronology may help bolster these types of analyses by incorporating the geochemical analysis of faunal remains, which is somewhat less influenced by these factors. Albeit, it faces challenges of its own.

Sclerochronology

Sclerochronology is the study of the physical and chemical variations between the accretionary growths of skeletal material (Andrus 2011:2893; Jones 1983:384). In the present study, oyster shell is used. Jones and Quitmyer (1996:341) call molluscan sclerochronology the "marine equivalent of dendrochronology" because similar to trees, shells grow incrementally and provide a record of ambient environmental conditions. Each time a shell grows, it records and retains the ambient water conditions throughout its life (Wingard and Surge 2017:357), depending on the species this can occur at daily, tidal, seasonal, or annual intervals (Andrus 2011:2894; Jones and Quitmyer 1996:340). Mouchi et al. (2013:66) describe shells as an "archive of pertinent paleoclimatic conditions" because sampling a shell for isotopes or trace elements along these incremental growths provides insights into environmental occurrences throughout the organism's life. Many studies have incorporated sclerochronological methods on *C. virginica*, they are discussed below.

Sclerochronology of C. Virginca

Eastern oysters are bivalves composed of two asymmetrical valves joined at the hinge by a ligament. The left valve is larger, more concave or "cuplike," and has a larger hinge than the flat right valve (Galtsoff 1964:16). The growth of *C. virginica* is atypical; many shellfish grow gnomonically, meaning the shell increases in size but not shape thus remaining in perfect proportion throughout its life. This is not the case for the eastern oyster whose shape cannot be determined geometrically (Galtsoff 1964:23, 27). The eastern oyster's plasticity can mostly be attributed to the substratum it

chooses to cement to, but other local environmental factors can also influence the shape of the shell (Galtsoff 1964:23). Similar to other bivalve species, the calcification process takes place in incremental growths, although the incremental growths of *C. virginica* sometimes exhibit a correlation to lunar, seasonal, or annual periodicities, the synchronization of growth bands to environmental occurrences in this species remains convoluted. That is, some studies note a relationship between morphological features like growth bands and seasonality (Kirby et al. 1998), while others cannot replicate these findings (Andrus and Crowe 2000; Durham et al. 2017; Surge et al. 2001). The discrepancies between the aforementioned studies have demonstrated that the only accurate way to determine growth rate, lifespan, and season of collection for these species is likely the use of geochemical techniques, rather than the visual analysis of shell morphology, such as that for species like *Mercenaria spp*. As one of the most common species recovered in shell middens (Thompson and Worth 2011:62), insights into the relationship between *C. virginica* and environmental phenomena are valuable in paleoenvironmental reconstructions.

Many studies have demonstrated the success of using *C. virginica* for a number of sclerochronological inquiries. For example, Kirby et al. (1998) analyzed the relationship between growth rate (and cessation) of oysters and stable isotopes to extrapolate paleotemperatures. Later, Kirby (2001) compared his findings with specimens from the Cretaceous to demonstrate how and possibly why shell size has decreased through time. Andrus and Crowe (2000) refined isotopic methods to determine season of collection to infer the seasonality of archaeological sites in the southeastern United States. This method is now utilized to determine the different types of habitat exploited by ancient peoples, as well as season of occupation (Andrus and Thompson 2012; Lulewicz et al. 2017; Thompson and Andrus 2011, 2013; Thompson et al. 2015). Surge et al. (2001) determined the relationship between *C. virginica* and modern environmental parameters and further demonstrated the usefulness of the species in

paleoenvironmental interpretations. Surge et al. (2003) used geochemistry from modern and archaeological specimens to explore how the channelization of watersheds near the Blackwater River has impacted water chemistry over time. Surge and Lohmann (2008) established a weak but significant relationship between Mg/Ca ratios and water temperature in *C. virginica*. Using oxygen isotopes, Harding et al. (2010) supported historical records of a significant drought taking place at the Jamestown settlement in Virginia during the year 1611. Lastly, Durham et al. (2017) established a rapid way to determine season of collection and growth rate in *C. virginica* using LA-ICP-MS.

Together, the aforementioned studies demonstrate the array of possibilities for implementing geochemical techniques on *C. virginica*. They each provide unique insights into the paleoenvironment or the people that lived in it. *C. virginica* is an ideal candidate for this type of analysis. In addition to their sheer quantity at Florida archaeological sites, they are immobile, essentially forced to tolerate (and record) fluctuating environmental parameters in one locale. Mineralogically, oyster shells are composed primarily of calcite, which is resilient to alteration over time (Bougeois et al. 2014:201). The resiliency of oysters, both in terms of environmental conditions and diagenesis, is beneficial because the organism is capable of surviving changing environments while providing an unaltered record of them, which can be interpreted through elements and isotopes. Most importantly, the organism remains in isotopic equilibrium with the water in which it lives, subsequently creating an accurate reflection of past $^{18}O_{water}$ (Kirby et al. 1998; Surge et al. 2001). Nonetheless, there are some difficulties and limitations to consider when doing this type of analysis, which are discussed in the following section.

Limitations and Assumptions in Sclerochronology

Mollusks are a diverse group of invertebrate animals, those that live in an estuarine environment, like oysters, are capable of tolerating wide swings of temperature and salinity (Wingard and Surge 2017:363). However, the dynamic nature of estuarine environments introduces certain

challenges to sclerochronologists and paleoenvironmental inquires in general (Surge and Lohmann 2008:1) although new techniques are being implemented to overcome these complications (Weckström et al. 2017). These challenges are mostly related to the simultaneous fluctuations of salinity, water temperature, and $^{18}O_{water}$, which are difficult to differentiate with isotopes alone (Wingard and Surge 2017:359). One way to overcome this obstacle is the use of trace elements, specifically those that only correlate with one environmental phenomenon. For example, sodium has been used as a salinity proxy (Wit et al. 2013), and magnesium has had some success as a temperature proxy (Surge and Lohmann 2008).

In addition to the challenges faced by sclerochronologists analyzing modern specimens, shells from archaeological deposits pose even more uncertainties. Andrus (2011:2893) notes, "Samples excavated from shell middens pass through a complex network of discriminatory factors including the environmental availability to site occupants, human resource choice, cultural practices, taphonomy, diagenesis, and archaeological excavation techniques." The present study added additional filters by sampling only the left valve of specimens with a straight or minimally curved chondrophore (**Figure 9**).

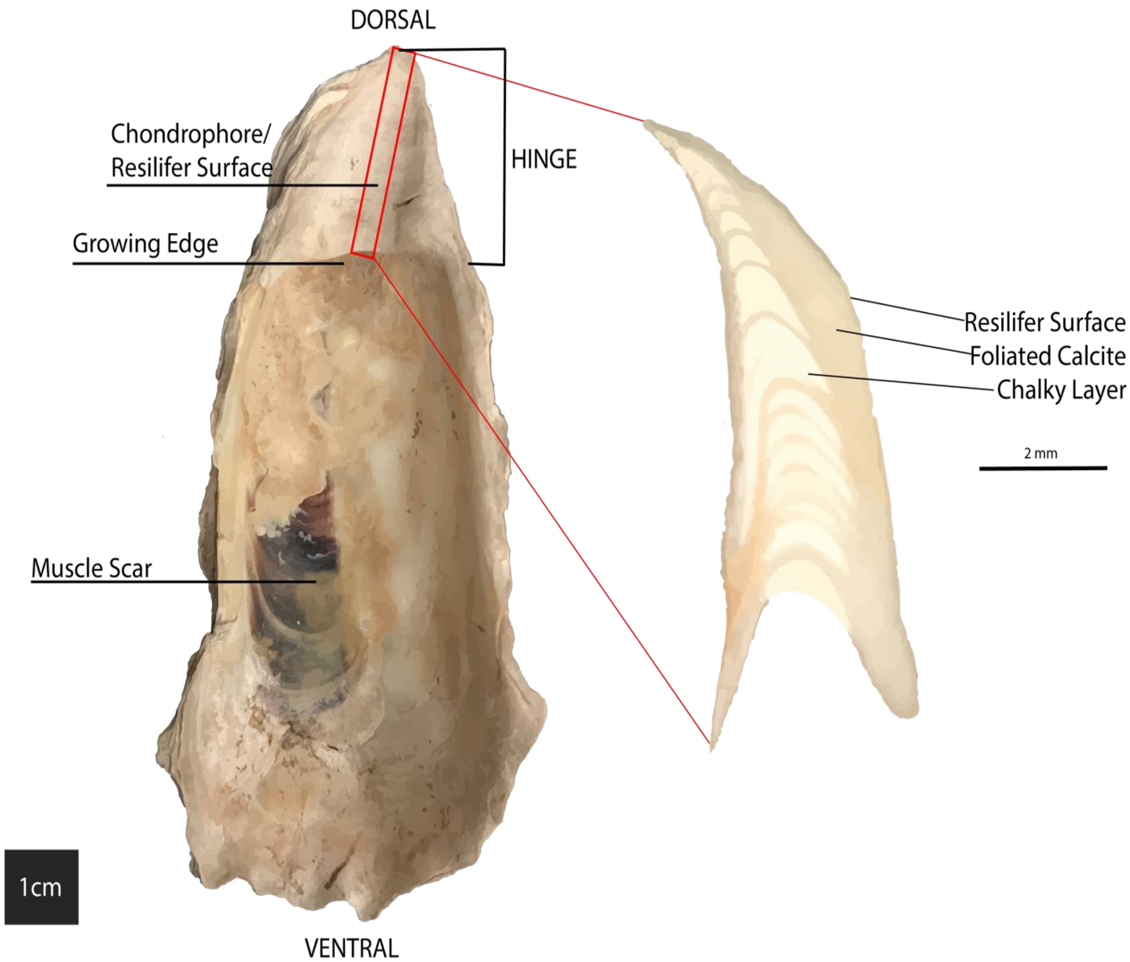

Figure 9. Sampling area.

Although oysters are present in every stratum at Yat Kitischee and were likely readily available during the entirety of site occupation, it is an assumption that all oysters in this study were collected nearby and a reflection of the immediate area. People likely made subsistence choices based on a number of reasons rather than availability and proximity alone, like optimal foraging theory would predict. Cultural practices like cooking can also impact the geochemical signature of shell. Although Müller et al. (2017) demonstrated cooking processes could cause recrystallization of aragonite, its effect on the more stable calcitic shell is unknown.

A few assumptions were made in the present study. First, an assumption that underlies all of sclerochronology is that of temporality, the timing of growth increments must be known and must remain constant through time and space to make accurate inferences into the past (Andrus 2011:2894). For example, it has been demonstrated that the timing of shell growth in *Mercenaria spp.* varies based on latitude (Jones and Quitmyer 1996). Using modern specimens from the same area in the current study helps understand not only the ambient environmental conditions but the average growth rate of animals living in them. Second, the ancient oysters in the current study were collected near Yat Kitischee, therefore, they reflect the past environmental conditions of Old Tampa Bay. Third, cultural practices did not in any way alter the geochemical signature of the shell. There is no evidence on any of the shells that indicate any sort of cooking processes or other taphonomic alterations took place. Lastly, the archaeological techniques used to excavate the samples did not introduce bias. Although the use of column samples is biased against larger species, the zooarchaeological analysis at Yat Kitischee incorporated species from the general levels so that faunal were represented in both contexts. Additionally, another archaeological assumption is that the stratigraphic samples are in chronological sequence, which is currently supported by the radiocarbon dates.

Sea level rise affects oyster abundance, growth rate, size, and ultimately survival (Solomon et al. 2014). An increase in storm activity, as shown during the MWP (Walker 2013), alters sediment and sediment transport, which would have impacted the oyster community (Solomon et al. 2014). If sea level fluctuations and climate change were taking place in Tampa Bay similar to those in southwest Florida, then the isotopes and trace elements in the oysters should reflect these changes. Getting back to the main research question: Did salinity and temperature changes take place in Tampa Bay during the Woodland Period? If so, how do these climatic and environmental changes relate to the Southwest Florida studies both in timing and intensity? Sclerochronological methods are capable of answering

these questions based on the variation of $\delta^{18}O$, Mg/Ca, and Na/Ca present both inter- and intra-shell. The background of each method used here will be discussed in the following section.

Methodology Background

There are many different methodological approaches to sclerochronology inquiries. Here, two methods are utilized: Stable isotope analysis and LA-ICP-MS. Each provides a unique way to contextualize the past environment.

Sampling Location

All stable isotope and trace element samples were derived from the foliated calcite layer of the left valve. This location was chosen for consistency because all modern isotopic studies of *C. virginica* sample from this locale. The left valve is chosen for two main reasons. First, although aragonite is limited to a few areas of the oyster shell (muscle attachments and ligostracum), there are higher concentrations of aragonite present in the right valve (Carriker and Palmer 1979). Aragonite and calcite have different fractionation factors to account for and mixing them would complicate isotopic interpretations (Surge et al. 2001:287). Lastly, a simplistic reason is that the left valve is larger than the right and provides more space for sampling isotopes. The hinge of an oyster is chosen because it is one of the best-preserved portions of the shell. In addition, this area is not altered during times of anaerobic respiration, when the oyster resorbs other parts of the shell to account for lower pH levels (Kent 1992; Surge et al. 2001:287).

Cross-sectioning the shell along the growth direction ventrally to dorsally (through the hinge) exposes three layers: the resilifer surface, the foliated calcite layer, and the chalky layer (Surge et al. 2001:287-288) (see **Figure 8**). The resilifer is the “central gully” of the hinge, sometimes referred to as the chondrophore (Andrus and Crowe 2000; Surge et al. 2001:287). This area is near the aragonitic

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ligostracum and tends to be avoided in most isotopic studies. The foliated calcite layer, beneath the resilifer surface, is densely packed with calcite and is where most researchers derive their samples. Lastly, the chalky layer is porous and textured like a sponge, this area is where the alternating growth bands are located (Surge et al. 2001:287). Although Surge and colleagues (2001:289) determined no statistical difference between the isotopic compositions of the three layers in modern specimens, the process of diagenesis in ancient oysters introduces a complication within the chalky layer. That is, pores can accumulate in this layer over time and affect isotopic and elemental interpretations. Although the chalky layer provides the maximum extension of growth, thus more area to sample, it is avoided in more recent studies. Therefore, the foliated calcite layer is the most appropriate of the three for isotopic sampling, and multiple studies have demonstrated the efficacy of this area for paleoclimate interpretations (Andrus and Crowe 2000; Durham et al. 2017; Kirby et al. 1998; Surge et al. 2001; Surge and Lohmann 2008).

Stable Isotopes

The study of stable isotopes is used in a number of archaeological investigations, including ancient diets, trade, material sourcing, and zooarchaeological analyses. Oxygen and carbon isotopes provide unique insights into paleoenvironmental inquiries and their relationship to water parameters has long been studied (see Epstein et al. 1953). As demonstrated above, researchers have implemented stable isotopes and trace elements in a number of ways to infer climate change of the past. Sclerochronology is one such method, and the focus of this discussion.

Oxygen

Evaporation and condensation are the most important factors influencing the relationship between ^{16}O and the heavier ^{18}O molecules in water. Because oysters remain (mostly) in isotopic equilibrium with the ambient water (Surge et al. 2001), isotopes from the shell reflect the fluctuations of

past $^{18}O_{water}$. The oxygen content of water varies with evaporation, condensation, and other types of seasonal changes that would influence temperature and salinity. During times of warmer temperatures (summer), the salinity of water is usually lower in the Gulf of Mexico because of an increase in rainfall (Surge et al. 2001:288). Conversely, the cooler temperatures of fall and winter are usually associated with higher salinities and a lack of rainfall. These changes are noticeable in the relationship between heavy (^{18}O) and light (^{16}O) oxygen molecules. High or positive ^{18}O values occur with an increase in salinity during drier and colder months while low or negative ^{18}O values coincide with a decrease in salinity during wet and warmer months, this is because the lighter ^{16}O becomes increasingly prevalent as water becomes more diluted (Kirby et al. 1998:563; Surge et al. 2001:293). Because the oyster shell mostly remains in isotopic equilibrium with the ambient water, the alternating high and low oxygen values can denote seasons and the intensity between them.

Carbon

Carbon isotopes are used less frequently by archaeologists but provide additional insights into the paleoenvironment. In mollusks, dissolved inorganic carbon (DIC) is the primary source of carbon that is incorporated into the shell. Changes in $\delta 13C$ in estuarine shells often reflect transformations of vegetation structures and freshwater inputs, which are the leading contributors to evolving $\delta 13C_{DIC}$ (see Surge et al. 2003).

LA-ICP-MS

Laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) is a method used to sample trace elements from solid materials at high resolutions using a UV laser beam (Limbeck et al. 2015). Although this method does not have as long of a history as stable isotopes, since its origin in 1985, LA-ICP-MS has pervaded many fields, most notably forensic science but it is also becoming increasingly common in sclerochronology. The LA-ICP-MS process begins when a sample is put into the

ablation chamber, next, a controlled laser pulse of high-energy photons is converted into thermal energy which vaporize a portion of the sample. The vapor, which is composed of traces of the sample, is then transferred to plasma within the ICP-MS through a carrier gas stream. The ICP-MS detects the mass/charge (m/z) ratio of the particles within the plasma and separates them into individual elemental concentrations (Orellana et al. 2013:2). There are different types of laser pulses used in LA-ICP-MS, here a line scanning method was implemented where a continuous line is vaporized forming a trench along a specified transect.

Limbeck et al. (2015:6953-6594) discussed two fundamental aspects of this technique that constrain its universal applicability. First, the mass/charge ratio is not always a complete representation of the entirety of the sample. That is, a number of variables influence what is being read by the ICP-MS and elemental fractionation may occur during the transport or ablation process. Second, each matrix varies, and subsequently the geometry of the ablated particles may also contribute to the efficiency of transport. That is, the size and shape of the ablated particles may affect their transport from the time it is ablated to the time in which it reaches the ICP-MS. There are ways to avoid or minimize these contributions, however. First, the wavelength of the laser can introduce heterogeneity among ablated material. For example, Hathorne et al. (2008) demonstrated that a 193 nanometer wavelength is ideal for calcitic matrixes. Due to availability, a laser with a wavelength of 266 nm was used here. The higher wavelength may contribute to more heterogeneity within the ablated sample being transported to the ICP-MS. It is unclear to what affect, if any, the laser wavelength had in the present study, but it must be considered when interpreting the data. Another way to avoid these issues is by using a matrix-matched calibration. Here, a matrix-matched calibration is created to minimize the effect of mass/charge ratio.

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Trace Elements of Interest

As previously discussed, estuarine environments pose challenges for isotopic analyses because water temperature, salinity, and $^{18}O_{water}$ fluctuate simultaneously (Wingard and Surge 2017:359). Temperature fluctuations make salinity extremely difficult or impossible to accurately determine. Water temperature and salinity are the two most significant variables in estuarine molluscan studies, not only in determining the locale in which species are capable of living but also the physiological and biological constraints of shell growth and ultimately the survival of the organism (Wingard and Surge 2017:365). Therefore, temperature and salinity changes are essential (but again, difficult) to distinguish. Sclerochronologists have turned to trace elements to provide additional insights where oxygen and carbon isotopes lack.

Numerous studies have been aimed at creating independent temperature and salinity proxies with varying degrees of success. Incorporating trace elements like magnesium and sodium into paleoenvironmental studies can help decipher these sorts of environmental changes because they have been shown to correlate with temperature and salinity respectively. Here I use four trace elements to investigate salinity and temperature proxies for oysters from Tampa Bay. Below a very brief background of each element of interest is presented.

Magnesium (Mg)

Magnesium is one of the most common elements used in sclerochronological studies. Oysters, and other calcitic shells incorporate magnesium easily because of the similar crystalline structures of $MgCO_3$ and $CaCO_3$, the chemical composition of shell (Oomori et al. 1987:327). Although some studies have shown correlations between Mg and salinity (Cronin et al. 2012:251-252 – in Ostracods), it is generally believed that Mg/Ca ratios have a low sensitivity to fluctuations in salinity until the water reaches below 8-10 ppt (Dodd and Crisp 1982:51-52; Durham et al. 2017:207). More often, because of

this low sensitivity to salinity, magnesium is investigated as a temperature proxy. However, there are somewhat conflicting results as to whether Mg/Ca elemental ratios act as a "paleothermometer" (Bougeois et al. 2014; Mouchi et al. 2013; Surge and Lohmann 2008; Tynan et al. 2017).

Surge and Lohmann (2008) evaluated the usefulness of Mg/Ca ratios as a temperature proxy in *C. virginica* specimens living in southwest Florida. When the entire lifespan of the oyster was analyzed a weak but statistically significant correlation was observed ($r^2 = 0.05$; $p < 0.01$). Interestingly, when only the last year of growth was analyzed a higher correlation between Mg/Ca and water temperature was apparent ($r^2 = 0.30$; $p < 0.001$). Surge and Lohmann (2008:5) suggest the increased correlation is related to ontogenetic effects, thus the oyster incorporates different amounts of Mg/Ca throughout its lifetime. However, the increase may also be attributed to an uncertainty of date assignments in their study (i.e. the more recent date assignments are most likely more accurately aligned to the oyster's growth than older ones / the last shell precipitation). Contrarily, Mouchi et al. (2013) determined a significantly strong correlation between juvenile oysters (*C. gigas*) and water temperate rather than adult specimens.

Using an LA-ICP-MS line scan method, Durham et al. (2017) investigated seasonality and growth rates in *C. virginica*. This study is encouraging because although the 16 *C. virginica* specimens were collected from numerous spatial and temporal contexts (Connecticut, South Carolina [modern and Pleistocene], North Carolina [hatchery] and Louisiana), 97% of the shells showed a sinusoidal pattern in Mg/Ca ratios following the peaks and troughs of oxygen isotopes. Durham and colleagues (2017) argue this sinusoidal pattern provides evidence that Mg/Ca ratios are a reliable indicator of seasonality and growth rate in *C. virginica*, but other studies have not replicated this sinusoidal pattern in Mg/Ca data (Surge and Lohmann 2008:4).

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Lithium (Li)

In northwestern France, Thebault and Chauvaud (2011) investigated Li/Ca ratios in the Great Scallop (*Pecten maximus*) and its relationship between daily growth rates (DSGR), salinity, temperature, and chlorophyll α concentrations. In the three-year study, two years showed distinct peaks in Li/Ca ratios, which they classify as "excess." Using simple and linear regressions, Thebault and Chauvaud (2011) determine only DSGR was statistically significant each year and accounted for up to 49% of the average Li/Ca variability ($r^2 = 0.490$; $p < 0.001$), however, during the year with no peaks or excess Li/Ca, the coefficient of determination increased to 73.5% ($r^2 = 0.735$; $p < 0.001$). Similar to DSGR, with peaks present, temperature accounted for only 6.2% of the Li/Ca variability ($r^2 = 0.062$; $p < 0.004$) but without the peaks the coefficient increased ($r^2 = 0.552$; $p < 0.001$). The relationship between salinity and Li/Ca was shown not to be statistically significant in this study ($r^2 = -0.001$; p 0.347).

Thebault and Chauvaud (2011:115) propose phytoplankton blooms as the cause of the excess Li/Ca because the timing of the excess Li/Ca mirrors the temporal variations in the abundance of diatoms with a lag of about three weeks. Many of the diatoms analyzed in this study are known prey to the Great Scallop, therefore, an increase in lithium would occur if the scallop were consuming more Li rich particles in the water. A potential source of excess lithium may be caused by the dissolution of diatom frustules, essentially the silica cell walls of diatoms, which are thought to be a major source of Li in diatomaceous sediments (Thebault and Chauvaud 2011:120; Zurzolo and Bowler 2001:1339). Thebault and Chauvaud's (2011) study provides an interesting avenue of exploration for this study because Tampa Bay is known to have algae blooms and subsequent increase in diatoms as well.

Contrary to Thebault and Chauvaud (2011), Füllenbach et al. (2015) determined a stronger correlation between Li/Ca ratios and water temperature (weakest $r^2 = 0.56$; $p < 0.01$; strongest $r^2 = 0.73$; $p < 0.01$) in the aragonitic bivalve *Cerastoderma edule* from Germany.

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Sodium (Na)

Sodium is one of the primary constituents of sea salt and should therefore reflect changes in salinity, but there are somewhat conflicting results in this regard. Wit et al. (2013) indicate a significant correlation between salinity, Na, and foraminiferal growth in cultured *Ammonia tepida* specimens (r^2=0.96; p <0.01). This strong and significant correlation is encouraging that sodium may be used as a salinity proxy, however, it is worth noting these specimens were cultured in a lab setting and were exposed to rather high salinities, the lowest being 30 ppt. According to the EPC data, salinity has not been higher than 30 ppt in Old Tampa Bay during the last ten years. Unfortunately, Marali et al. (2017:117, 122) observed a low reproducibility of Na/Ca ratios in *A. islandica* and concluded Na/Ca ratios were likely not related to environmental phenomenon such as salinity. To my knowledge, the only study that has analyzed sodium trace elements in oysters is Rucker and Valentine (1961), who found a correlation (r=0.356; p value not specified) between salinity and Na concentrations in a study of 71 oysters throughout the Gulf of Mexico and Atlantic Coast.

Strontium (Sr)

Strontium is relatively common in sclerochronological studies, but it is still somewhat of a mystery what the direct control (if there is one) of Sr/Ca ratios in calcite is. Dodd and Crisp (1982:52) determined salinity plays a negligible role in Sr/Ca ratios until below 8 ppt, which is considerably lower than the salinity in Old Tampa Bay. This has been supported elsewhere (Freitas et al. 2006; Füllenbach et al. 2015; Lea et al. 1999). Others have posed the shell's precipitation rate as the primary driver of Sr/Ca ratios (Lorens 1981; Mucci and Morse 1983). Although a direct comparison between Sr/Ca ratios and temperature data was not made, Surge and Walker (2006:189) show a covariant relationship between $\delta^{18}O_{SHELL}$ and Sr/Ca ratios in *Mercenaria campechiensis* suggesting the potential of Sr/Ca as a temperature proxy.

Freitas and colleagues' (2006) analysis of *Pecten maximus* showed a significant correlation between Sr/Ca and calcification temperature ($r^2 = 0.55$; $p < 0.001$) and Sr/Ca and Mg/Ca ratios ($r^2 = 0.41$; $p < 0.001$) but not Sr/Ca and salinity ($r^2 = <0.01$; p 0.742). When using a multiple linear regression for Sr/Ca ratios (temperature as the independent variable) the relationship between Mg/Ca increased ($r^2 = 0.64$; $p < 0.001$). Despite the correlation between Sr/Ca, calcification temperature, and Mg/Ca, Freitas et al. (2006:5127-5128) note that the amount of shell deposited in a given period may be the best explanation for varying Sr/Ca ratios. They ultimately conclude that several factors related to kinetic effects, like shell precipitation, are probably influencing the Sr/Ca ratios in their study. Similarly, Lea et al. (1999:2369) note that increases in temperature, salinity, and pH all appear to increase the Sr/Ca ratios in their study, "most likely through the kinetic influences of calcification." Mucci and Morse (1983) suggest the process of adsorption on the calcitic surface plays the largest role in Sr/Ca ratios. Ultimately, it appears that Sr/Ca ratios are most likely related to kinetic effects and unfortunately, many variables contribute to the overall effect of strontium intake.

Interestingly, Füllenbach et al. (2015) determined Sr/Li values were strongly and inversely correlated to water temperature in the bivalve *Cerastoderma edule* (weakest $r^2 = 0.64$; $p < 0.01$; strongest $r^2 = 0.77$; $p < 0.01$). To my knowledge, this novel approach has not been attempted on other species outside of cockles, whose growth is apparently not controlled by the incorporation of Sr.

Trace Element Conclusions

This was not meant to be an exhaustive review, but rather a brief overview of some of the complications surrounding the trace elements in this study. Like archaeology, it appears the study of trace elements is subject to equifinality. However, with LA-ICP-MS becoming increasingly popular there will undoubtedly be more research in this field and that will hopefully further our understanding into these elements and their relationship with the environment and the organisms. This is beneficial

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because LA-ICP-MS is a more timely and cost-effective method compared to traditional isotope studies. The current study provides additional insights into the complicated relationship between stable isotopes, trace elements, and oysters within the already dynamic estuarine environment.

Stable isotopes and trace elements provide unique insights into the paleoenvironment that are impossible with zooarchaeological analysis alone. Sclerochronology is the best possible method to determine if salinity and/or water temperature changes have taken place prehistorically because multiple studies have demonstrated that δ18O and Mg/Ca ratios are able to identify such fluctuations in paleoenvironments.

CHAPTER 3: MATERIALS AND METHODS

As the previous chapter demonstrates, sclerochronology is a useful method for investigating climate change of the past. Previous geochemical analyses of oysters validate the application of LA-ICP-MS and stable isotope analyses in such a pursuit. In order to successfully implement sclerochronological methods within a historical ecology framework, multiple spatial and temporal contexts were used. This dataset is comprised of the left valve of 50 oysters (*C. virginica*) from five contexts. Two groups of modern oysters (BCB and OTB) were analyzed and used as a baseline for modern parameters. Three groups of ancient oysters were designated (B1, B2, and B3) based on their stratigraphic provenience within Zone B at Yat Kitischee. Group size ranges from seven to thirteen based on availability. This is a particularly robust sample size for a sclerochronological analysis. Contexts are discussed below.

Oyster Provenience

Ancient Oysters

Thirty ancient oysters were collected from various contexts within the shell midden (Zone B) at Yat Kitischee (**Table 1**). The oysters were then divided into three groups (B1, B2, and B3) based on their provenience within Zone B at Yat Kitischee. B2 and B3 samples were derived from 25 cm x 25 cm column samples and B1, a pit feature (Feature 12). All excavated material was curated at the Alliance for Weeden Island Archaeological Research and Education (AWIARE) lab in St. Petersburg, Florida. The oysters chosen for this study were subject to selection biases: first, a preference for oysters with a complete, unbroken left valve. Second, there was a preference for a straight or minimally curved chondrophore. Lastly, no evidence of epibiont activity along the valve interior, which would indicate the shell was dead before collection.

Table 1. Oyster provenience.

Name	Number	Location	Provenience	Est. Date Range
OTB	10 oysters	Bunker Hill Island	Intertidal Zone	Modern
BCB	10 oysters	Boca Ciega Bay	Intertidal Zone	Modern
B1	10 oysters	Yat Kitischee	B1; Feature 12	AD 865 – 960
	B1_A-J		1.2 - 0.68 amsl	
B2	2 oysters	Yat Kitischee	B2; Level 108	AD 254 – 670
	B2_A-B		1.3 – 1.2 amsl	
	6 oysters	Yat Kitischee	B2; Level 109	
	B2_C-H		1.2 – 1.1 amsl	
	5 oysters	Yat Kitischee	B2; Level 110	
	B2_I-M		1.1 – 1.05 amsl	
B3	5 oysters	Yat Kitischee	B3; Level 110	AD 57 – 254
	B3_C-G		1.05 – 1.00 amsl	
	2 oysters	Yat Kitischee	B3; Level 111	
	B3_A-B		1.00 – 0.90 amsl	

The designation of levels at Yat Kitischee was maintained site-wide through vertical control based on topography. For example, 2.00 – 1.90 meters amsl would be level 101 and 1.90 – 1.80 meters amsl would be level 102 across the entirety of the site. Additionally, the excavation units were in close proximity to one another, extending only 10 meters at the widest. Therefore, each level was comparable to each other based on elevation rather than using a specific level for each unit (Austin 1995:16). Although the ancient oysters are not always derived from the same column sample, it is not viewed as a

limitation here because the variation between spatial and vertical distances was minimal. The original radiocarbon dates from Janus Research are listed in **Table A1**. These dates are not AMS. Using CALIB 14C Calibration Program 7.10, Austin grouped the dates to form an average and provide better stratigraphic context for the oyster cohorts. These dates are presented in **Table 1**.

Oysters in B3, the earliest group, are derived from two levels from two column samples. Two shells were obtained from Level 111 (1.00 – 0.90 amsl) within column sample 4 and five shells from a portion of Level 110 (1.05 – 1.00 amsl) within column sample 1. Together the seven shells represent the oldest specimens in the study. Four features (10, 11, 32, and 38) with charcoal were dated in B3. All features have elevational overlap with Levels 110 and 111. Three of the four dates cluster around a cal. mean date of AD 255, while the fourth is earlier at AD 65. Extending the four dates to two standard deviations and recalibrating them creates a date range of AD 57 – 254. Excluding the fourth date (AD 65), adjusts the date to a later period around AD 123 – 394 (Austin, personal communication 2018). Using either date range places the oysters squarely within the Wulfert High stand and Roman Warm Period. I chose the earlier date range (AD 57 – 254) because it is the most inclusive of the four dates given the provenience of each date (see **Table A1**).

Oysters in B2 are derived from three levels from three column samples. Five oysters were collected from the remaining portion of Level 110 (1.1 – 1.05 amsl) from column sample 1, six from Level 109 (1.2 – 1.1 amsl) from column sample 2, and two from Level 108 (1.3 – 1.2 amsl) from column sample 3. Two radiocarbon dates from Level 109 and 110 in Zone B2 provide a date range of AD 245 – 640 (1σ). The earlier date, AD 245 – 415 (Beta 76967), was from charcoal derived from a post mold originating at 1.18 amsl and extending to 0.88 amsl. The later date, AD 495 – 640 (Beta 53536), was obtained from a shell between 1.13 and 1.07 amsl. There is some elevational overlap between dates, and the earlier date extends into multiple levels and Zone B3 but originates above the later date (see **Table A1**).

Because one date is from shell and the other charcoal, the calibrated dates cannot be averaged. However, when both are extended to two standard deviations the date range is AD 122 – 670 (Austin, personal communication 2018). Although this date range encompasses that of B3 (AD 57 – 254), there is no question that B3 is older than B2, given the stratigraphy of the site (Austin, personal communication 2018). Therefore, group B2 is placed somewhere between AD 254 and 670. This temporal designation places it within the transitionary time between the Wulfert High and the Buck Key Low and the broader Roman Warm Period and Vandal Minimum climatic episodes. Worth noting, within Level 108 there was a date obtained from a shell tool that ranges from AD 1050 – 1200 (Beta 81074) but was viewed as being too late to be representative of Zone B2 (Austin and Woods 1995:32).

Oysters in B1, the most recent group, were collected from Feature 12 within Zone B1. Feature 12 was a large, circular, basin-shaped pit feature encountered at 1.2m amsl (Base of Level 108) in units 912N/914E and 914N/914E (Woods and Austin 1995:44). The pit feature dated to cal. AD 865 – 960 (1σ). A second date within Zone B1 in Level 106 yielded a similar date (cal. AD 810 – 970 (1σ)). Therefore, this group is likely representative of the onset of the La Costa High and the Medieval Warm Period. Feature 12 consisted of very dark gray sand, shell, bone, ceramics, lithics, and charcoal. It appeared to be a single deposit feature (Austin, personal communication 2018). Therefore, the two dates that cluster around this pit are likely a representation of a single event. Although pit features sometimes denote extraordinary events, rather than a direct reflection of the domestic sphere (Gilmore 2015), the provenience of Group B1 is not viewed as a hindrance here. The shells from B1 do not look or feel any different from those in other groups, further suggesting that different treatment was unlikely.

Based on the temporality of associated strata and/or features, I believe the three oyster groups are a good representative sample for comparison with the southwest Florida sea level oscillations and the broader climatic episodes.

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Modern Oysters

In addition to the 30 ancient oysters discussed above, 20 modern oysters were collected alive from Old Tampa Bay and Boca Ciega Bay in November of 2017 under the conditions of Special Activity License #17-1962-SR issued to Jaime Rogers by the Florida Fish and Wildlife Conservation Commission. Specimens from Old Tampa Bay were intertidal and collected near Bunker Hill Island, approximately 1500 meters east of Yat Kitischee and 3000 meters southwest of EPC monitoring station 66 (**Figure 10**). This area was selected based on the proximity to both Yat Kitischee and the EPC monitoring station. The second collection area was in Boca Ciega Bay near the intersection of Cross Bayou Canal and Long Bayou between the Pinellas Trail and Bay Pines Boulevard. The specimens in this locale were also intertidal.

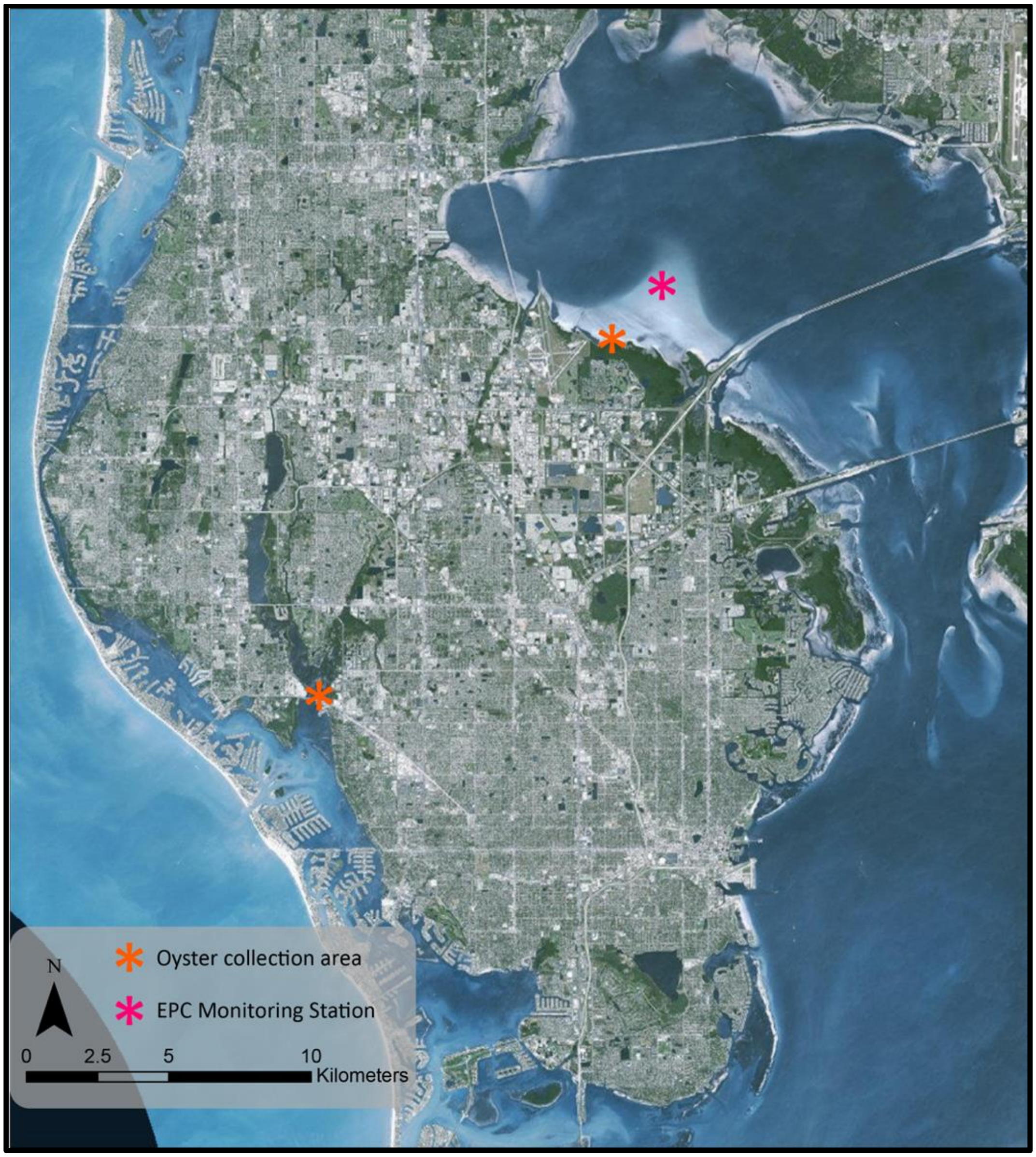

Figure 10. Modern oyster collection sites.

Modern Environment

The Environmental Protection Commission (EPC) monitoring station 66 located in Old Tampa Bay (Latitude 27.9278, Longitude -82.6397) was used to gather monthly salinity and temperature data. No modern data was used for Boca Ciega Bay in the present study because the majority of stations are

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outdated or show highly variable results that may be inaccurate. The Tampa Bay Water Atlas was used to collect monthly precipitation data. Mean monthly and yearly data from 2010 – 2017 are presented in **Table 2** and **Figures 11 and 12** respectively. Based on an analysis of the mean monthly data, June through September have the highest average monthly precipitation in Old Tampa Bay while October through May averages about 2 inches. The data does not indicate any extreme variations in monthly salinity. Generally, salinity is lowest from September to December and the highest from April to July. There are more considerable variations present in water temperature. December through March have comparatively low temperatures while May through October have higher overall temperatures. At the annual level, there is much more variation present.

Table 2. Salinity and temperature data for the last 18 years in Old Tampa Bay.

Month	N = 18	Salinity (ppt)	Temperature (C)	Month		Salinity (ppt)	Temperature (C)
January	Mean	23.77	17.06	**July**	Mean	25.21	29.73
	SD	3.17	3.01		SD	3.87	1.61
	Min	17.00	11.48		Min	17.00	25.00
	Max	30.20	21.11		Max	30.90	31.65
February	Mean	24.31	17.05	**August**	Mean	22.95	30.05
	SD	3.16	1.59		SD	4.65	1.16
	Min	18.00	14.00		Min	13.60	28.01
	Max	30.50	20.02		Max	29.70	31.92
March	Mean	24.24	19.40	**September**	Mean	20.62	29.63
	SD	4.13	2.97		SD	5.25	1.02
	Min	13.79	14.06		Min	12.60	27.77
	Max	31.20	25.68		Max	30.22	31.78
April	Mean	25.32	22.13	**October**	Mean	19.40	27.10
	SD	3.13	2.60		SD	4.37	2.31
	Min	19.30	16.19		Min	13.10	20.00
	Max	30.30	25.70		Max	26.00	29.94
May	Mean	26.16	25.29	**November**	Mean	20.76	23.72
	SD	3.34	2.41		SD	3.38	2.53
	Min	20.00	19.33		Min	16.00	18.89
	Max	32.00	29.10		Max	27.29	27.60
June	Mean	26.95	28.50	**December**	Mean	22.48	19.30
	SD	3.60	1.43		SD	3.26	3.22
	Min	21.70	25.18		Min	18.22	10.48
	Max	32.50	30.43		Max	29.20	22.78

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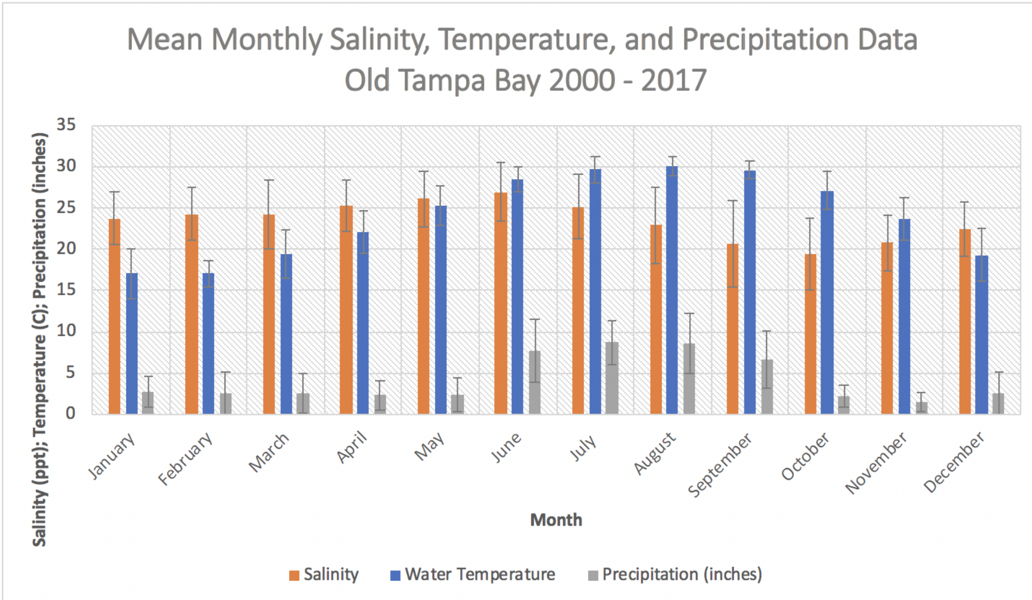

Figure 11. Mean monthly salinity and water temperature measurements for Old Tampa Bay.

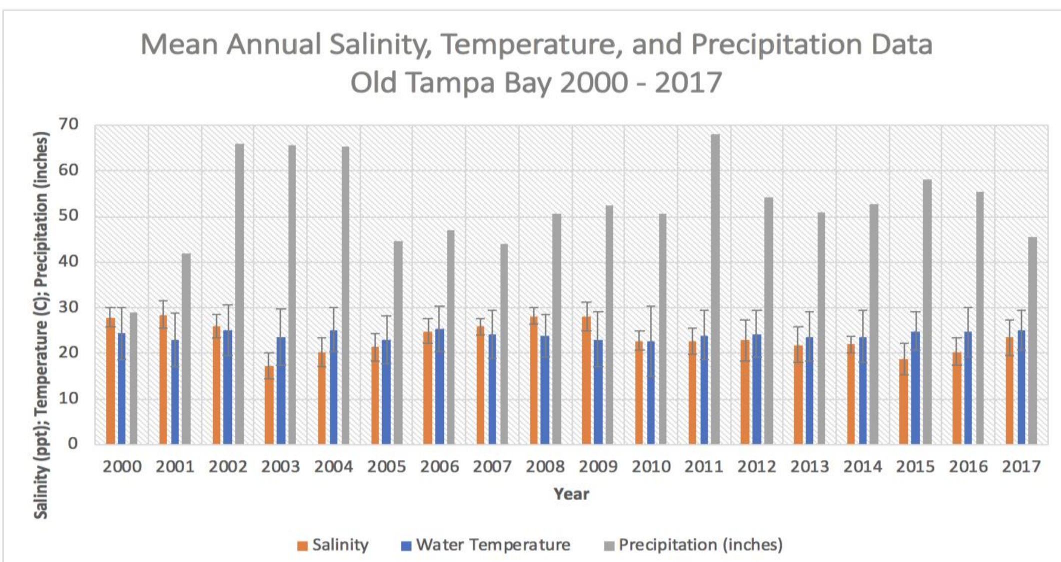

Figure 12. Mean annual salinity and water temperature measurements for Old Tampa Bay.

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Precipitation varies considerably from 2000 - 2017. For example, in 2000 there were only 29.1 inches of annual rainfall, the lowest of any year in the time frame analyzed. From 2002 – 2004 and again in 2011 annual rainfall surpassed 60 inches. The total mean in precipitation for all years is 52.3 inches. Salinity also varies, interestingly the years marked by high precipitation do not have a considerably lower salinity, with perhaps an exception in 2003 when salinity averaged only 17.26 ppt, the lowest in the time frame analyzed. Salinity is highest during the years 2008 and 2009 averaging over 28 ppt. The total mean of salinity was 23.5 ppt. Water temperature remained relatively consistent. The lowest temperatures were during 2001 and 2005 at 22.94°C and 22.92°C respectively. The highest mean temperatures were during 2004, 2006, and 2017 at 25.21°C, 25.35°C, and 25.10°C respectively. The mean water temperature for all years analyzed was 24°C.

Calendar Date Assignments

Modern specimens are required in sclerochronology studies and are used mainly as a control. In other words, because current environmental variables like salinity, water temperature, precipitation, etc. are known, a relationship can be made between them and the stable isotopes and trace elements present in the oyster. This is done by aligning the expected $\delta^{18}O_{shell}$ and the actual $\delta^{18}O_{shell}$ to assign a given date. The ability to assign a calendar date (day or month) depends on how accurate and frequent modern environmental data (salinity and temperature) are recorded.

Epstein et al. (1953) determined the relationship between water temperature (T) and $\delta^{18}O_{shell}$ as:

$$\mathbf{T = 16.5 - 4.30\,(\delta^{18}O_{shell} - \delta^{18}O_{water}) + 0.14(\delta^{18}O_{shell} - \delta^{18}O_{water})^{2}} \qquad (1)$$

Equation 1 predicts water temperature (T) using known $\delta^{18}O_{shell}$ and $\delta^{18}O_{water}$, which would later form the basis of most isotopic analyses. Harding et al. (2010) inversed the above relationship and accounted for Vienna Pee Dee Belemnite (VPDB) and Vienna Standard Mean Ocean Water (VSMOW) differences in order to predict $\delta^{18}O_{shell}$ of *C. virginica*:

$$\textbf{Expected } \delta^{18}O_{shell} = \delta^{18}O_{water} - 0.20 + (4.30 - (18.49 - 0.56 * (16.5-T))^{0.5}) / (0.28) \qquad (2)$$

Equation 2 is used here to create the expected calendar date of last shell growth. When $\delta^{18}O_{shell}$ is known it can be compared with the expected $\delta^{18}O_{shell}$ value on a given date and then relationships between other environmental parameters, such as salinity and water temperature, are established. Again, the accuracy and precision of the prediction is completely dependent on the precision of the modern environmental data.

Paleoenvironmental Inferences

While the previous section addresses the concerns related to exact calendar assignments and the subsequent robusticity of the relationship between measured variables, I would be remiss without at least attempting to infer salinity and temperatures in the past. Surge and Lohmann (2008) formed a linear regression formula that assessed the relationship between water temperature and Mg/Ca ratios in *C. virginica* living in Blackwater River. This equation was derived by analyzing only the last year of growth ($r^2 = 0.30$; $p < 0.01$), where T is water temperature:

$$\mathbf{Mg/Ca = 0.72T - 0.23} \qquad (3)$$

Although designed specifically for the South Florida locale, here the equation is inversed and used as a rough estimate for predicted paleo-water temperature (PWT):

$$\mathbf{PWT = (Mg/Ca - 0.23) / 0.72} \quad (4)$$

The weak or nonexistent relationship between salinity and temperature prevented statistically significant linear regressions in order to predict paleosalinity. More robust modern environmental data are needed to investigate the relationship between salinity and temperature in Tampa Bay.

Shell Preperation

To conduct geochemical analysis, modern and ancient oysters were prepared following the below steps. Modern oysters had their soft tissue removed as soon as possible. Modern and ancient shells were brushed thoroughly with deionized water and left to air dry for a minimum of 24 hours. Using a Dremel, oysters were cut laterally just below the hinge. This removal of excess shell below the hinge was done so that the remainder of the shell would fit within resin molds. The specimens were brushed again and then put into an Ultrasonicator with deionized water for a minimum of ten minutes or until clean. The shells were air dried for at least 36 hours prior to embedding in resin. The epoxy resin and hardener were prepared following a ratio of 25:3 respectively and then placed in a depressurizer between 20 and 25 psi for a minimum of 36 hours. Once removed from the depressurizer, the shells remained secure in a resin mold. This step was performed so the shell would not waver during the cross-sectioning process. The samples were cross-sectioned through the resilifer surface towards the direction of growth, perpendicular to the anteroposterior axis. They were then thick sectioned (~1.5 mm) using a slow speed diamond wafering saw (approximately 250 rotations per minute). LA-ICP-MS was utilized on

the thick section while isotopes were hand milled on the mirrored side of the remaining oyster cross-section.

LA-ICP-MS

A Q-switched Nd:YAG laser operating at 266 nm was used to induce material ablation. The focal spot of the laser was 100 µm (0.1 mm) at an operating energy of 5% or approximately 0.625 mJ. The laser was set to line scan mode and followed a set transect at a speed of 1.1 mm per second. The ablated material was carried to the ICP-MS by a continuous flow (0.6 L/min) of helium gas where it was then measured by mass and charge. The wavelength of the laser (266 nm) is higher than ideal (193 nm) (see Hathorne et al. 2008) so the operating energy was lowered in an effort to contribute less heterogeneity amongst the ablated material.

Transects were created using MatLab software. Ten shells (25% of samples) from B2 had two transects in each region approximately 0.1 mm apart. This was done in an effort to demonstrate replicability within line scans. The resulting trace element concentrations were then converted to elemental ratios over calcium (the reference element) if possible (issues discussed in following section). Elemental ratios over calcium (e.g. Mg/Ca) are how trace element data is presented in sclerochronological articles.

Calibration

A matrix-matched calibration standard was used in the form of a pure carbonate base spiked with known amounts of the elements of interest (Mg; Li; Na; Sr). This type of standard, called external calibration, is the most widely accepted approach in LA-ICP-MS (Pozebon et al. 2017:892). Five different pellets were created and spiked with increased amounts of the elements of interest. Before each run on

the LA-ICP-MS, ten lines were scanned on the surface of the pellet. These values were averaged in order to create a calibration curve for each element.

Stable Isotopes

Isotopic samples were drilled by hand at low-resolution intervals (approximately 5 mm) using a 0.5 mm carbide burr dental drill, yielding approximately 200 µg of carbonate powder. Isotope samples were sent to the University of Georgia where they were acidified in 100% H_3PO_4 in purged Exetainers to produce CO_2. The samples were analyzed on a Thermo Gas Bench II coupled to a Thermo Delta V isotope ratio mass spectrometer (IRMS). Oxygen isotopes are corrected for ^{17}O contributions and reported in the VPDB correction standard in which enrichments are reported in parts per mil (Craig 1957):

$$\delta^{18}O = [(^{18}O / ^{16}O_{smpl} / ^{18}O / ^{16}O_{std}) - 1] \times 1{,}000 \qquad (5)$$

Only 16 shells were sampled for isotopes. Four from OTB, B1, B2, and B3 were selected randomly for isotopic sampling: OTB_C, D, H, and I; B3_B, C, D, and E; B2_A, F, H, and I; and B1_B, E, H, and I. Each shell had six samples taken from the foliated calcite layer slightly above the interface of the chalky layer.

Statistical Techniques

SPSS software was used to perform all statistical analyses in this project. Normality was assessed using the Kolmogorov-Smirnov test, and non-parametric tests were utilized in instances of non-normality. Outliers were identified using boxplots and removed before statistical analyses.

Replication was assessed using Mann-Whitney U tests and Spearman's Rho correlations for each shell that had multiple line scans (n=10). The Mann-Whitney U test is a non-parametric alternative to the independent t-test, and Spearman's Rho is a non-parametric alternative to the Pearson's correlation. Both statistical techniques were implemented because the trace element data were not normally distributed. Elemental correlations were assessed at 50, 150, and 300 data point levels, which translates to approximately to the first 2 mm, 6 mm, and 12 mm of the line scans respectively. These data point levels were arbitrarily chosen and meant to represent varying periods close to the time of collection. Lastly, a multivariate analysis of variance (MANOVA) followed by post-hoc ANOVAs was performed to determine the effect of independent variables (OTB, BCB, B1, B2, and B3) on multiple dependent variables (trace elements) at the same time. MANOVA's were performed at both the 50 and 300 data point level. The normality assumption was violated for the MANOVA test, but the non-parametric alternative Kruskal Wallis test yielded the same results. Therefore, the MANOVA results are presented. The Games-Howell multiple comparison technique was implemented for post-hoc ANOVA analysis to determine which pairwise comparisons contributed the most to driving significant MANOVA results. This post-hoc test multiple comparison procedure was used because group variances were unequal.

Both the materials and methods used in this study provide an adequate foundation for the determining climatic change in Tampa Bay over time. The following chapter provides the results of the geochemical and statistical analyses.

CHAPTER 4: RESULTS

With the above methods in mind, the following chapter discusses the results of the geochemical analyses in order to determine if the paleoclimate of Tampa Bay changed through time.

Outliers

Outliers were identified using boxplots and removed before statistical analyses. For the stable isotope data, only one outlier was identified by SPSS: Sample E1 from Group B3 (Shell B3_E) for both 18O and 13C. Trace element data from shell B1_D was also deemed an outlier, as each of the four trace elements was extremely high compared to the rest of the shells in the study. Lastly, the majority of oysters (7/10) from OTB had unusually low values for each of the four trace elements. Given that the trace element values were much lower (often zero) than the other four groups, they are likely a result of instrumentation error, rather than environmental phenomena. The seven shells were excluded from statistical analyses. The remaining three shells are included but should be considered with caution.

The Modern Environment

The relationship between salinity, water temperature, and precipitation derived from the EPC monitoring station was assessed using a Pearson's Correlation in SPSS. There is no apparent relationship between salinity and water temperature (r = -0.073; p = 0.287) or precipitation (r = 0.046; p = 0.503). However, there is a moderate positive correlation between precipitation and water temperature (r = 0.497; p = <0.001). Due to the relatively low resolution provided by the EPC monitoring station, however, these results should be interpreted with caution. Only 216 samples were used to investigate the relationship between these three variables over the course of 18 years. Interestingly, when only the mean annual measurements are investigated (n=18) there is a statistically significant relationship

between salinity and precipitation (r = -0.549; p = 0.018) but not precipitation and water temperature (r = 0.216; p = 0.390). The relationship between these modern environmental parameters warrant a cautious interpretation given that the correlation directions remained the same, but the strengths essentially reversed.

Paleotemperature Equation

The relationship between $\delta^{18}O_{shell}$ and water temperature has long been established (Epstein et al. 1953). Using **Equation 2 and 4** yields predictive temperatures for each group (**Table 3**). Although OTB has the highest maximum predicted water temperature value, the average predicted temperature is higher in B1 by approximately 1°C. The minimum, average, and maximum values suggest that water temperature increased through time, with the coldest water temperature reaching 8.87°C in B3. Compared to modern environmental values (**Table 2**), the predicted maximum water temperature values are significantly less than the actual mean summer values recorded over the last 18 years in Old Tampa Bay. Estimated winter water temperature values are close to those experienced today, with the exception of B3, which is approximately 2°C lower than any temperature values recorded by EPC in the last 18 years. Interestingly, Mg/Ca ratios demonstrate some discrepencies. Both the minimum and maximum water temperature values were recorded in B1, per the Mg/Ca ratio equation. This relationship is discussed further in the paleoenvironmental interpretation section.

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Table 3. Comparison of predicted water temperature equations.

Predicted Temperature (°C)						
	Epstein et al. (1953)			Surge and Lohmann (2008)		
Group	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**
OTB	10.13	15.20	23.36	6.72	8.63	16.74
BCB	N/A	N/A	N/A	6.38	12.02	20.97
B1	11.30	16.68	22.00	3.58	11.34	28.14
B2	10.68	14.62	20.07	5.81	14.45	27.26
B3	8.87	12.59	19.18	5.06	10.80	21.87

Stable Isotopes

Oxygen

Overlap exists between all four groups as depicted in **Table 4** and **Figure 13**. However, OTB has the most variation, while B3 has the least variation and is more positive. **Table 5** indicates the results from the one-way ANOVA for oxygen isotopes, which are statistically significant (F = 6.494; df = 3, 91; p = <0.001), the observed power is strong (0.965) while the effect size is low (h^2 = 0.176) suggesting only about 17.6% of the variance in oxygen isotopes are related to the different temporal periods. For completeness, a Kruskal-Wallis test (χ^2 = 17.496, df = 3, p = 0.001) test was conducted, which resulted in the same conclusion. A post-hoc Games-Howell test suggests the mean difference of δ18O values from B1 and B3 (-0.8775; p = 0.001) is contributing to the statistically significant differences between temporal groups (**Table 7**).

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Carbon

Groups B1, B2, and B3 have a similar distribution but group OTB does not overlap (**Table 4**) (**Figure 13**). **Table 5** presents the results from the one-way ANOVA for carbon isotopes, which are statistically significant (F = 118.334; df = 3, 91; p = <0.001), the observed power is strong (1.00) as is the effect size (h^2 = 0.796) suggesting about 79.6% of the variance in carbon isotopes are related to the different temporal periods. For completeness, a Kruskal-Wallis test (χ^2 = 60.573, df = 3, p = < 0.001) test was conducted, which resulted in the same conclusion. A post-hoc Games-Howell test suggests the mean difference of δ13C values from OTB is contributing to the statistically significant differences between temporal groups, although B1 and B3 (0.5908, p = <0.001) are also statistically different (**Table 7**).

Oxygen and carbon isotopes have a weak but statistically significant correlation (*r* = 0.345, p = <0.001) (**Table 6**). The individual isotope data are presented in **Table A2**.

Table 4. Descriptive statistics for oxygen (‰) and carbon isotopes (‰).

Group	18O Mean	18O SD	95% Lower Bound	95% Upper Bound	18O Min	18O Max
OTB	0.340	1.060	-0.105	0.787	-1.520	1.560
B1	-0.027	0.690	-0.318	0.265	-1.230	1.260
B2	0.456	0.617	0.195	0.716	-0.810	1.420
B3	0.950	0.599	0.690	1.210	-0.610	1.890
Group	**13C Mean**	**13C SD**	**95% Lower Bound**	**95% Upper Bound**	**13C Min**	**13C Max**
OTB	-6.426	0.683	-6.714	-6.137	-7.670	-5.480
B1	-3.704	0.579	-3.949	-3.460	-5.000	-2.570
B2	-3.641	0.801	-3.980	-3.302	-5.260	-2.120
B3	-2.998	0.647	-3.277	-2.718	-4.580	-1.950

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Table 5. ANOVA results for oxygen and carbon isotopes.

DV	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
18O	11.409	3; 91	3.803	6.494	<0.001	0.176	0.965
13C	165.491	3; 91	55.164	118.334	<0.001	0.796	1.000

Table 6. Correlation results for oxygen and carbon isotopes.

Spearman's Rho	18O and 13C
Correlation Coefficient	0.345
Sig. (2-tailed)	0.001
N	95

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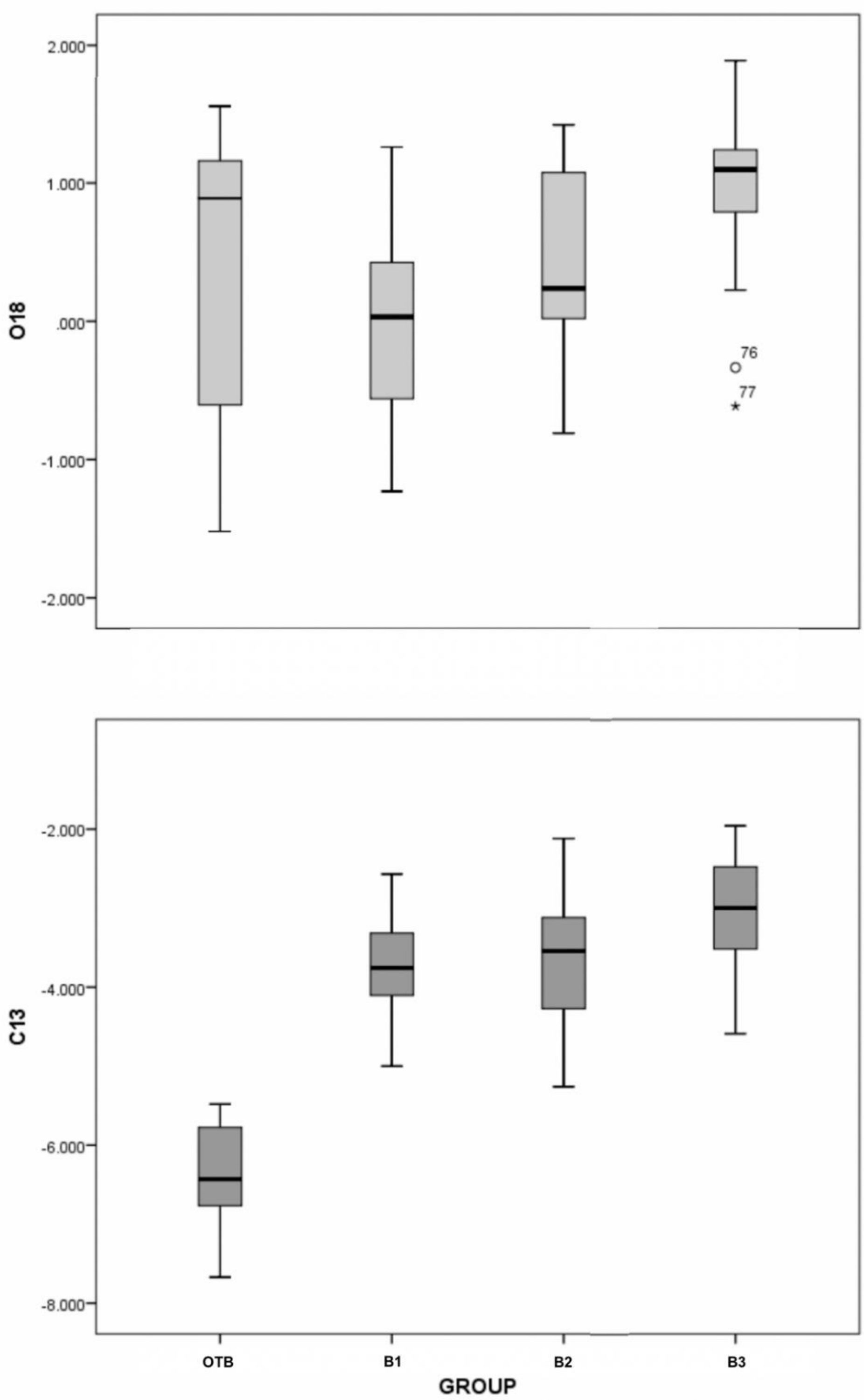

Figure 13. Boxplots for oxygen isotope (‰) (top) and carbon isotope (‰) (bottom) data.

Table 7. Results of Games-Howell Multiple Comparisons Test (Isotope Data).

Games-Howell Multiple Comparisons							
Dependent Variable	**(I) Group**	**(J) Group**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval Lower Bound**	**Upper Bound**
δ18O	OTB	B1	.3254	.27359	.637	-.4099	1.0607
		B2	-.1571	.26625	.934	-.8749	.5607
		B3	-.5521	.28105	.219	-1.3055	.2014
	B1	OTB	-.3254	.27359	.637	-1.0607	.4099
		B2	-.4825	.18892	.065	-.9863	.0213
		B3	-.8775	.20926	**.001***	-1.4355	-.3195
	B2	OTB	.1571	.26625	.934	-.5607	.8749
		B1	.4825	.18892	.065	-.0213	.9863
		B3	-.3950	.19957	.211	-.9278	.1378
	B3	OTB	.5521	.28105	.219	-.2014	1.3055
		B1	.8775	.20926	**.001***	.3195	1.4355
		B2	.3950	.19957	.211	-.1378	.9278
δ13C	OTB	B1	-2.7213	.18280	**<.001***	-3.2090	-2.2335
		B2	-2.7842	.21489	**<.001***	-3.3575	-2.2108
		B3	-3.3121	.22240	**<.001***	-3.9059	-2.7183
	B1	OTB	2.7213	.18280	**<.001***	2.2335	3.2090
		B2	-.0629	.20182	.989	-.6028	.4770
		B3	-.5908	.20979	**.036***	-1.1528	-.0289
	B2	OTB	2.7842	.21489	**<.001***	2.2108	3.3575
		B1	.0629	.20182	.989	-.4770	.6028
		B3	-.5279	.23828	.134	-1.1631	.1073
	B3	OTB	3.3121	.22240	**<.001***	2.7183	3.9059
		B1	.5908	.20979	**.036***	.0289	1.1528
		B2	.5279	.23828	.134	-.1073	1.1631

Based on observed means.
The error term is Mean Square (Error) = 0.541.
*The mean difference is significant at the 0.05 level.

Trace Elements

Calibration

Unfortunately, an unknown issue prevented the calibration of Li, Na, and Sr. Although it is currently unclear what caused the inability to calibrate the three elements, a few educated guesses are made. First, the concentrations of lithium may have simply been too low for the ICP-MS to detect using

the current parameters. Of the few studies that have analyzed lithium, the element is presented as µmol/mol, rather than mmol/mol, suggesting lithium signals are extremely minute and may be difficult to detect. Second, strontium may have migrated upwards during the simmering process, when the powder was hardening into a pellet. Small crystals along the edge were identified shortly after the pellets were made and were likely composed of strontium, sodium, or both. If either or both elemental concentrations were higher near the edges, rather than evenly distributed, this may explain why their levels were variable in the standards. Third, humidity may have also altered the carbonate pellets in some way. Although it should be noted that the pellets were kept in a humidity-controlled box so this explanation is unlikely. The Mg calibration was successful, and is therefore, the only element presented over calcium ratios (mmol/mol). The other elements are not converted over Ca. Instead, their overall signal concentration as measured by the LA-ICP-MS is presented. Signal values still exhibit patterns but are not translatable to other studies in the same way as elemental concentrations.

Line Replication

As previously discussed, the incorporation of trace elements in shell are sometimes influenced by non-environmental factors such as biological effects. Line replication is way to double check the accuracy of the instrumentation used in the present study. Here, line replication was examined using a Mann-Whitney U test for each scan that had multiple lines (n=10).

The results of the Mann-Whitney U test indicate only two (B2_L and M) of the ten shells had Mg/Ca values that demonstrated no mean difference between line scans, five (B2_B, D, G, J, and K) for lithium, four (A, B, D, and K) for sodium, and five (F, G, H, J, and K) for strontium (**Table 8**) (**Figure 14**). The variability in the results of the Mann-Whitney U tests may be attributed to the lines being slightly offset, the uneven number of variables being compared, the energy of the laser contributing to sample size heterogeneity, or a combination thereof. In order to investigate whether the offset nature of the

line scans was the contributing factor to the results of the Mann-Whitney U tests, Spearman's rho correlation tests were implemented on a set arbitrary number of variables (first 50, 150, 300 data points) for each line scan (**Tables A3-A7**). The results are discussed in the following section.

Correlations

The three data point levels translate to approximately 2 mm, 6 mm, and 12 mm of growth respectively. A Spearman's rho correlation test was used rather than a Pearson's correlation test because the assumption of normality was violated for each trace element. Correlations are interpreted as very weak (0-0.19), weak (0.2-0.39), moderate (0.40-0.59), strong (0.60-0.79), and very strong (0.80-1.0). The statistically significant correlations throughout the 50, 150, and 300 data point levels for the line scans of each trace element strengthens the claim of line reproducibility within the current study. Moreover, a visual analysis of each line suggests each have the same number of peaks and troughs, further supporting replication, albeit at a slightly more or less pronounced rate.

Table 8. Mann-Whitney U results for B2 shells with multiple line scans.

ID	Mg	Li	Na	Sr	ID	Mg	Li	Na	Sr
B2_A					**B2_H**				
MWU	18445	73430	96354	77115	MWU	207599	256791	254090	278395
Z	-21.116	-6.892	-0.962	-5.939	Z	-8.527	-2.621	-2.946	-0.028
Sig.	<0.001	<0.001	**0.336**	<0.001	Sig.	<0.001	0.009	0.003	**0.978**
B2_B					**B2_J**				
MWU	31124	36416	36385	30545	MWU	39859	41826	39376	41324
Z	-3.064	-0.160	-0.177	-3.382	Z	-2.549	-1.627	-2.776	-1.863
Sig.	0.002	**0.873**	**0.859**	0.01	Sig.	0.011	**0.104**	0.006	**0.062**
B2_D					**B2_K**				
MWU	45092	66152	68539	48419	MWU	77690	95555	96624	91271
Z	-8.590	-1.519	-0.717	-7.473	Z	-5.327	-0.633	-0.352	-1.758
Sig.	<0.001	**0.129**	**0.473**	<0.001	Sig.	<0.001	**0.527**	**0.725**	**0.079**
B2_F					**B2_L**				
MWU	58203	65871	63842	85052	MWU	46682	41485	41599	41741
Z	-8.620	-6.447	-7.022	-1.011	Z	-0.392	-2.741	-2.689	-2.625
Sig.	<0.001	<0.001	<0.001	**0.312**	Sig.	**0.695**	0.006	0.007	0.009
B2_G					**B2_M**				
MWU	172641	186016	177701	181288	MWU	25703	12813	9203	20105
Z	-2.919	-0.788	-2.113	-1.541	Z	-0.90	-7.990	-10.202	-3.521
Sig.	0.004	**0.431**	0.035	**0.123**	Sig.	**0.928**	<0.001	<0.001	<0.001

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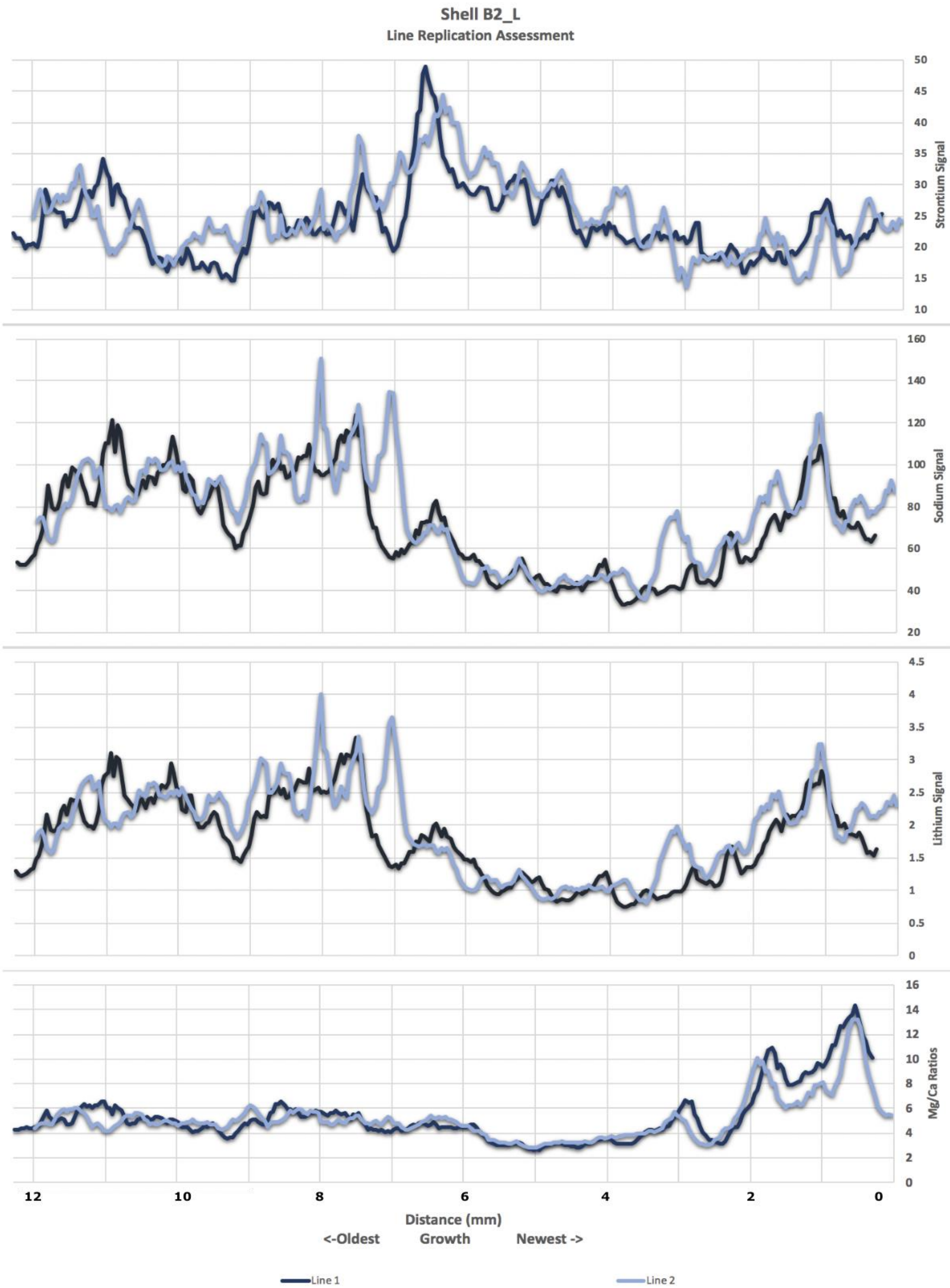

Figure 14. Line Replication Assessment of B2_L.

Statistically significant correlations were observed between the two magnesium (Mg/Ca) line scans for all ten oysters at the 300 data point level (lowest r= 0.315; highest r= 0.942). Of the ten oysters, one had a weak correlation (B2_M), at the 150-data point level (**Table A7**).

Statistically significant correlations were observed between the two lithium line scans for nine oysters at the 300 data point level (lowest r= 0.173; highest r= 0.810). Of the ten oysters, two had a very weak correlation (B2_G and K), three had a weak correlation (B2_A, H, and M), one had a moderate correlation (B2_F), three had a strong correlation (B2_D, J, and L), and one had a very strong correlation (B2_B). Moreover, in comparison to the other number of data points (50 and 150), correlations increased in six oysters (B2_B, F, G, H, J, and L) at the 300-point level. A higher correlation was demonstrated in three oysters (B2_A, K, and M) in the first 50 data points, and B2_D had the highest correlation at the 150-point level. B2_K was the only oyster that did not have a statistically significant correlation between lithium line scans at the 300-point level (**Table A6**).

Statistically significant correlations were observed between the two sodium line scans for nine oysters at the 300 data point level (lowest r= 0.260; highest r= 0.785). Of the ten oysters, one had a very weak correlation (B2_K), two had a weak correlation (B2_G and H), three had a moderate correlation (B2_A, F, and M), and four had a strong correlation (B2_B, D, J, and L). Moreover, in comparison to the other number of data points (50 and 150), correlations increased in six oysters (B2_B, F, G, J, L, and M) at the 300-point level. A higher correlation was demonstrated in three oysters (B2_A, D, and K) at the 150-point level, and B2_H was the sole oyster with the highest correlation at the 50-point level. B2_K was the only oyster that did not have a statistically significant correlation between sodium line scans at the 300-point level (**Table A6**).

Statistically significant correlations were observed between the two strontium line scans for eight oysters at the 300 data point level (lowest r= 0.243; highest r= 0.621). Of the ten oysters, two had

a very weak correlation (B2_A and M), two had a weak correlation (B2_F and K), five had a moderate correlation (B2_B, D, H, J, and L), and one had a strong correlation (B2_G). Moreover, in comparison to the other number of data points (50 and 150), correlations increased in two oysters (B2_G and K) at the 300-point level. A higher correlation was demonstrated in three oysters (B2_F, L, and M) at the 150-point level, and five oysters (B2_A, B, D, H, and J) had the highest correlation at the 50-point level. B2_A and M were the only oysters that did not have a statistically significant correlation between strontium line scans at the 300-point level (**Table A3-7**).

Statistically significant correlations were observed between Mg, Li, Na, and Sr in each shell, with varying degrees of strengths. In order to determine if correlations improved or weakened through time, the strongest correlation was noted for each element per shell at the 50, 150, and 300-point level (**Table 9**). The relationship between Mg and Li, Na, and Sr was consistently stronger within the first 50 points. The relationship between Sr and Li, as well as Sr and Na, was also strongest during the first 50 points. The correlation between Li and Na was evenly split between the 50 and 300-point level, with five shells each. While a number of factors likely influence these results, the stronger correlation in the most recent growth suggest a possible external environment relationship, rather than biological control because younger portions of oysters possibly incorporate (and record) more trace elements during growth (see Surge and Lohmann 2008 for Mg/Ca example).

Trace element values from each group were averaged to compare trends (**Figures A1 – A7**). When the two modern groups are compared, it is clear that OTB (n=3) values are more variable, exhibiting more peaks and troughs relative to BCB (n=10) for each element. Mg may be the only exception, where the averaged values for both BCB and OTB exhibit highs and lows, rather than a flatter line. Although the averaged values are not the best representation of environmental phenomena given that the age and growth rates of each shell are different, Spearman's rho correlation test was used to

examine the relationship between elements in the modern and ancient specimens **(Table 10**). Within the averaged OTB values, only Mg and Sr (-0.565) and Li and Na (0.949) exhibited a statistically significant correlation. Statistically significant correlations within BCB included Mg and Na (-0.535), Mg and Sr (0.538), Li and Na (0.788), and Li and Sr (0.316). Interestingly, B1 is the only group where all trace elements correlate with one another. B2 and B3 share similar relationships with BCB although in B2 and B3 Mg and Li are correlated. The moderate negative correlation (~-0.5) between Mg and Na exists in each group except OTB.

Table 9. B2 shells with strongest correlation at 50, 150, or 300 data point level.

N	Mg – Li	Mg – Na	Mg – Sr
50	6 (B2_D, G, H, J, K, and M)	6 (B2_D, G, H, J, K, and M)	9 (B2_B, D, F, G, H, J, K, L, and M)
150	3 (B2_A, B, and L)	3 (B2_A, B, and L)	1 (B2_A)
300	1 (B2_F)	1 (B2_F)	0
N	**Li – Na**	**Li – Sr**	**Na – Sr**
50	5 (B2_D, F, H, K, and M)	6 (B2_A, D, G, H, J, and L)	7 (A, D, G, H, J, K, and L)
150	0	3 (B2_B, F, and K)	2 (B2_B and F)
300	5 (B2_A, B, G, J, and L)	1 (B2_M)	1 (B2_M)

Table 10. Correlations between averaged trace elements in all groups.

OTB	Mg	Li	Na	Sr
Mg	1			
Li	0.076	1		
Na	0.004	0.949**	1	
Sr	-0.565**	0.052	0.113	1

BCB	Mg	Li	Na	Sr
Mg	1			
Li	-0.092	1		
Na	-0.535**	0.788**	1	
Sr	0.538**	0.316**	-0.005	1

B1	Mg	Li	Na	Sr
Mg	1			
Li	-0.406**	1		
Na	-0.561**	0.953**	1	
Sr	-0.366**	0.386**	0.479**	1

B2	Mg	Li	Na	Sr
Mg	1			
Li	-0.667**	1		
Na	-0.751**	0.978**	1	
Sr	0.025	0.513**	0.452**	1

B3	Mg	Li	Na	Sr
Mg	1			
Li	-0.389**	1		
Na	-0.459**	0.957**	1	
Sr	0.320**	0.104	0.099	1

*Correlation is sig at 0.05 level (2-tailed)
**Correlation is sig at 0.01 level (2-tailed)

A visual analysis of the averaged lines provides further insights. First, the prominent peaks in lithium are also accompanied by peaks in sodium but generally not magnesium or strontium, as suggested by the correlation results. Moreover, the strong relationship between lithium and sodium appears to extend through time. That is, the ancient oysters exhibit very strong correlations between the two elements as well. Lithium spikes often occur before peaks in Mg, which suggests that the environmental phenomenon that is causing higher lithium concentrations may be taking place in the mid-to-late Spring. The high peaks of Mg/Ca recorded in the shell are believed to be the apex of summer, when water temperature is the highest (June - September) and Mg/Ca in water is the highest (see Surge and Lohmann 2008 and Durham et al. 2017).

B2 and B3 were also averaged by level (**Figure A5**). B2 was comprised of three levels (Lvl 108-110). The two shells from Level 108 had a lower than average magnesium value, higher than average sodium and lithium values, and about average strontium values. The six shells from Level 109 had higher than average magnesium values and average lithium, sodium, and strontium values. The five shells from Level 110 had close to average values for each trace element (relative to B2 average). B3 was comprised of two levels (Lvl 110-111). The five shells from Level 110 had close to average values for each trace element (relative to B3 average), while the two shells from Level 111 had higher than average magnesium and strontium values with average lithium and sodium values. B3 exhibited the lowest average trace element line for each element. B1 and B2 demonstrated a more variable pattern.

Trace Element Values

Descriptive statistics for each trace element at the 50 and 300 data point level can be found in **Table 11** and **Table 12**, respectively. Descriptive statistics for the entire line scan can be found in **Tables A8 – A11**. Therefore, each trace element is described succinctly below.

Magnesium

The ranges of Mg/Ca ratios remained similar at both data point levels for each group, with the exception of BCB, where the maximum value increased by 6.165 mmol/mol. However, mean Mg/Ca values slightly decreased in each group (**Figure 15**). OTB has the least amount of variation in Mg/Ca ratios when compared to the precolumbian counterparts. BCB (300) almost encompasses the entire range of each group. When looking at only the precolumbian groups, B3 has the lowest maximum values, while B2 has the lowest minimum value. The highest maximum value was recorded in B1, and the highest minimum value was recorded in B2. B3 has the lowest average Mg/Ca line, followed by B1, B2, OTB, and BCB, the highest. However, **Figure A7** indicates prominent peaks in B2 that exceed the other averaged groups.

Lithium

Each group demonstrates a broader range of lithium values at the 300 data point level, perhaps most significant are the higher lithium values in OTB. Indeed, the minimum lithium signal value of OTB exceeds the mean value for the other groups. Mean lithium values increased in each group at the 300 data point level, except OTB, where the signal declined approximately 0.259 (**Figure 15**). B3 has the lowest average Li signal, followed by BCB, B2, B1, and OTB, the highest.

Sodium

All but B2 demonstrate significant increases to the maximum sodium value at the 300 data point level, although the maximum signal value of B2 did climb by 14. Mean sodium values slightly increased in each group except OTB, where the signal declined by approximately four (**Figure 15**). The averaged lines indicate B3 has the lowest Na signal, followed by BCB, B2, B1, and OTB, the highest.

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Strontium

Each group demonstrates a broader range of strontium values at the 300 data point level. However, strontium values from B2 reveal the largest range. Mean values are very similar between the 50 and 300 data point levels (**Figure 15**). Strontium values remain relatively consistent through time but B2 has the largest variation. The averaged lines demonstrate a similar pattern but similar to sodium, B3 again, has the lowest signal. OTB has the highest average strontium line, although the average line falls beneath other groups occasionally.

Table 11. Descriptive statistics of trace elements at the 50 point interval (~ 2 mm) for each group.

Element	Group	Mean	Std. Deviation	Min	Max	95% CI Lower Bound	95% CI Upper Bound	N
Mg	BCB	8.884	2.390	4.825	15.327	8.655	9.112	500
	OTB	8.640	1.201	6.722	12.284	8.222	9.057	150
	B1	8.396	3.220	2.810	20.490	8.155	8.637	450
	B2	10.631	2.289	4.412	19.854	10.430	10.831	650
	B3	8.006	2.983	2.777	15.973	7.733	8.280	350
Li	BCB	0.829	.239	0.423	2.028	.796	.863	500
	OTB	5.050	.884	3.114	7.616	4.990	5.111	150
	B1	1.292	.299	0.726	2.358	1.257	1.327	450
	B2	1.191	.371	0.654	2.832	1.163	1.221	650
	B3	0.788	.268	0.390	1.669	.749	.828	350
Na	BCB	36.727	8.123	23.828	58.259	35.580	37.875	500
	OTB	94.308	31.820	51.225	185.747	92.213	96.403	150
	B1	48.237	9.696	31.864	81.952	47.027	49.447	450
	B2	45.955	12.847	28.226	109.379	44.948	46.961	650
	B3	35.126	8.571	21.354	59.430	33.755	36.498	350
Sr	BCB	22.069	2.773	16.341	32.335	21.777	22.361	500
	OTB	27.181	5.193	16.145	42.128	26.648	27.714	150
	B1	24.288	3.534	16.226	33.759	23.981	24.596	450
	B2	23.682	3.380	15.780	33.251	23.426	23.938	650
	B3	22.414	2.586	17.651	29.640	22.065	22.763	350

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Table 12. Descriptive statistics of trace elements at the 300 point interval (~ 12 mm) for each group.

Element	Group	Mean	Std. Deviation	Min	Max	95% CI Lower Bound	95% CI Upper Bound	N
Mg	BCB	8.734	2.974	3.816	21.492	8.625	8.843	3000
	OTB	8.432	1.661	4.692	12.917	8.233	8.631	899
	B1	7.469	3.418	2.806	21.173	7.359	7.578	2959
	B2	8.655	3.286	2.627	19.854	8.559	8.751	3875
	B3	5.945	2.476	2.777	15.973	5.807	6.082	1879
Li	BCB	0.968	0.264	0.423	2.028	.951	.986	3000
	OTB	4.791	1.021	3.101	10.593	4.760	4.824	899
	B1	1.491	0.625	0.549	4.118	1.474	1.510	2959
	B2	1.282	0.409	0.612	3.341	1.267	1.298	3875
	B3	0.811	0.281	0.292	2.597	.789	.834	1879
Na	BCB	43.925	10.875	23.828	131.601	43.338	44.512	3000
	OTB	90.990	30.587	51.225	243.571	89.917	92.062	899
	B1	55.618	20.404	26.159	141.526	55.027	56.209	2959
	B2	50.332	14.414	25.428	123.896	49.816	50.849	3875
	B3	37.423	9.279	21.354	92.849	36.681	38.165	1879
Sr	BCB	22.498	3.272	15.084	35.472	22.369	22.627	3000
	OTB	26.453	4.697	16.144	42.128	26.217	26.688	899
	B1	24.966	3.993	15.083	41.456	24.836	25.095	2959
	B2	23.200	3.494	14.070	49.040	23.086	23.313	3875
	B3	22.013	3.051	15.188	34.175	21.850	22.176	1879

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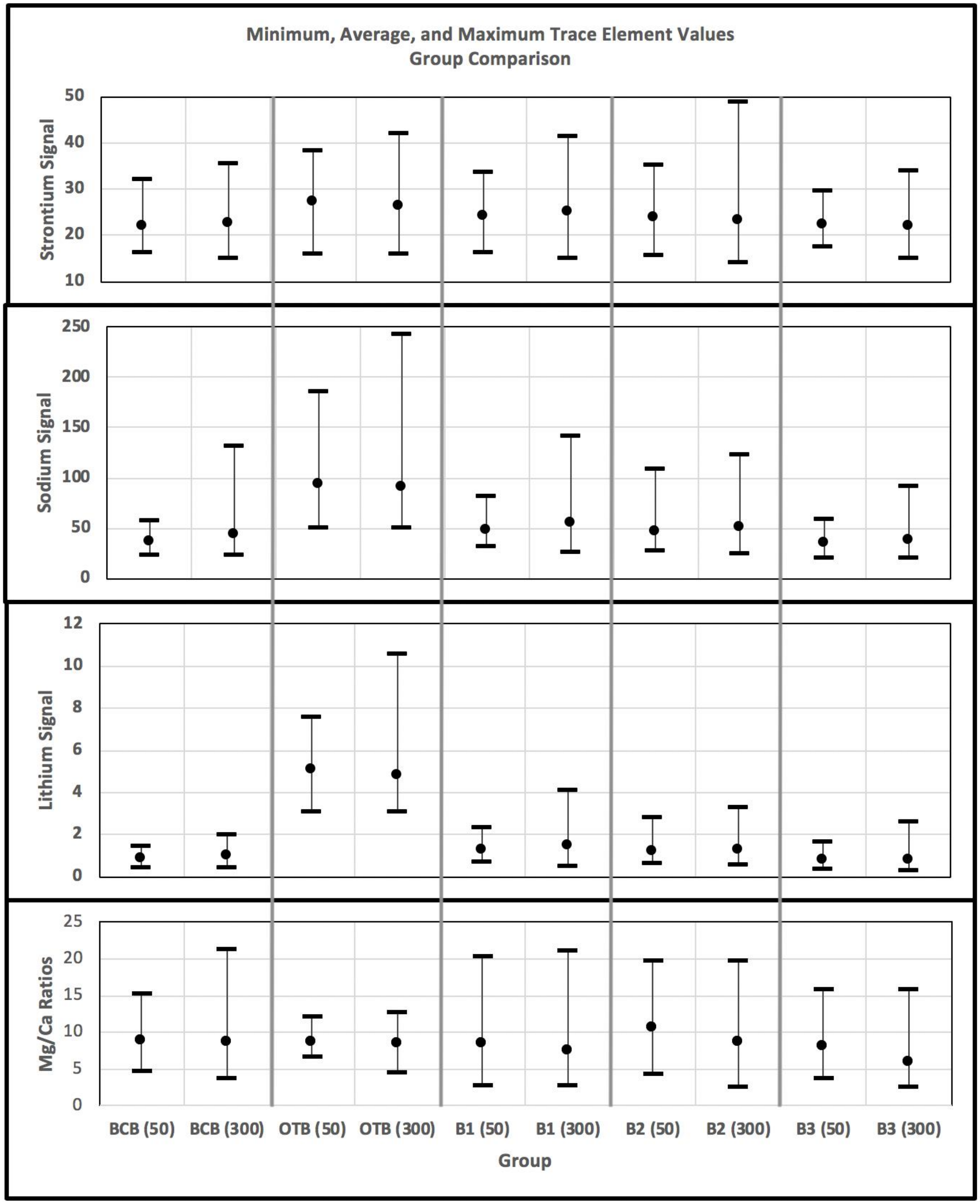

Figure 15. Minimum, average, and maximum trace element values for each group.

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Manova Results

The results from the MANOVA indicate a significant multivariate effect (p = < 0.001) of the group assignment on all of the trace elements for each multivariate test at the 50 data point level (**Table 13**). In other words, the four trace elements are affected by their temporal designation. The results from post-hoc ANOVAs also indicates that group assignment had a significant effect (p = < 0.001) on the four trace elements (**Table 14**). Effect size varies per element. Mg/Ca and Sr demonstrate small effect sizes (0.135; 0.140), while the effect size of Na (0.549), and particularly Li (0.885) is much higher. This suggests about 88% of the variance between lithium values in oyster shells are a result of the temporal designation, while 55% of the variance in Na, and only about 13.5% in both Mg/Ca and Sr account for temporal designation. Observed power is strong (1.00) for each element. Although group assignment had a significant effect on each element, the post-hoc Games-Howell multiple comparison test provides insights into which groups were contribute most to these differences. The results from the MANOVA and post-hoc ANOVAs at the 300 data point level yielded the same statistical conclusions. However, effect size was slightly lower for each element.

Games-Howell multiple comparison tests suggest that the difference in Mg/Ca values between BCB and OTB (0.2445; p = 0.444), BCB and B1 (0.4874; p = 0.067), OTB and B1 (0.2429; p = 0.664), and B1 and B3 (0.3900; p = 0.391) failed to reach statistical significance. B2 was the only group that demonstrated statistically significant differences between the other groups. Interestingly, BCB and B3 are the only groups that are statistically similar for Li (0.0412; p = 0.145), Sr (-3.444; p = 0.343), and Na (1.6009; p = 0.050), barely (**Table A-12**).

Table 13. Results of MANOVA test for trace element data.

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
50 data point level (~2 mm)								
Wilks' Lambda	.058	615.695	16.000	6391.803	<0.001	.509	6639.213	1.000
300 data point level (~12 mm)								
Wilks' Lambda	.102	2672.370	16.000	38506.494	<0.001	.435	29613.242	1.000

Table 14. Results of post-hoc ANOVA tests for trace element data.

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[e]
50 data point level (~ 2 mm)								
MG[a]	2213.452	4	553.363	81.452	<0.001	.135	325.808	1.000
LI[b]	2317.045	4	579.261	4041.458	<0.001	.885	16165.832	1.000
NA[c]	436653.749	4	109163.437	637.424	<0.001	.549	2549.697	1.000
SR[d]	3768.384	4	942.096	85.006	<0.001	.140	340.024	1.000
300 data point level (~ 12 mm)								
MG[a]	12215.306	4	3053.827	329.269	<0.001	.095	1317.075	1.000
LI[b]	11614.371	4	2903.593	11810.64	<0.001	.789	47242.558	1.000
NA[c]	1999012.637	4	499753.159	1856.890	<0.001	.371	7427.561	1.000
SR[d]	21710.617	4	5427.654	417.502	<0.001	.117	1670.006	1.000

a. R Squared = .135 (Adjusted R Squared = .133).		a. R Squared = .095 (Adjusted R Squared = .094)
b. R Squared = .885 (Adjusted R Squared = .885)		b. R Squared = .789 (Adjusted R Squared = .789)
c. R Squared = .549 (Adjusted R Squared = .548)	**<-50 300->**	c. R Squared = .371 (Adjusted R Squared = .371)
d. R Squared = .140 (Adjusted R Squared = .138)		d. R Squared = .117 (Adjusted R Squared = .117)
e. Computed using alpha = .05		e. Computed using alpha = .05

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To sum, the descriptive results reported here provide basic information on the chemical composition of the oysters in this study. Inferential test results indicate significant differences between groups that may indicate environmental change took place in Tampa Bay. The following chapter provides possible interpretations of climate change.

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CHAPTER 5: DISCUSSION

The previous chapter provided evidence that statistical differences in the geochemistry of oysters may be representative of climate change taking place in Tampa Bay. This chapter interprets stable isotope and trace element signatures, discusses what type of environmental change may be influencing the differences in shell geochemistry, as well as what these changing climates may have meant to the Manasota Culture.

Interpretation of δ13C and δ18O Signatures

The mean values for δ13C decrease through time. Indeed, modern specimens exhibit about twice the negative value as group B3. The reduction of δ13C in modern specimens is common in sclerochronology studies and is likely related to many factors. Surge et al. (2003:749) exhibit the same pattern in Southwest Florida and propose three explanations: (1) a change in carbon source from anthropogenic influences, (2) a change in freshwater inputs, and (3) a change in vegetation structure. All three explanations are probable in Tampa Bay as well.

All sclerochronology studies are affected by the global phenomenon known as the Suess Effect. The Suess Effect accounts for the differences between increased amounts of CO_2 in the atmosphere from burning fossil fuels and other post-industrial contributions. It is mostly predictable and generally contributes to a decline of 1.0-1.5‰ between pre- and post-industrial samples (Sonnerup et al. 1999). The decline in δ13C from B1 to OTB is approximately 2.5‰ in the present study. There are indeed changes to the freshwater inputs in Old Tampa Bay given the dredging of canals and mosquito ditches in the vicinity of the study area. Additional freshwater runoff and the introduction of organic nutrients and pollutants would contribute to the reduction of dissolved inorganic carbon ($δ13C_{DIC}$). Changes to freshwater inputs, however, may not be the best explanation for the reduction in δ13C, given that it is

not accompanied by the same shift in δ18O. A switch in the dominant carbon sources, from terrestrial or aquatic C_4 plants to C_3 plants, like mangroves is also a possible explanation (Raabe et al. 2012). The USGS has demonstrated a remarkable transition from coastal marsh to mangroves over the past century in Tampa Bay (Raabe et al. 2012). Moreover, spoil piles created by the dredging of the mosquito ditches near Old Tampa Bay are dominated by mangroves and Brazilian pepper, further influencing the reduction of δ13C over time. Therefore, the lower δ13C values in OTB are likely a combination of more CO_2 in the atmosphere and the environmental alterations that have taken place in Tampa Bay over the last century.

Although statistically different, δ13C values for the precolumbian groups (B1-B3) overlap and are much more similar than those of OTB. However, the results from the Games-Howell test suggest B1 and B3 were statistically different. A distinct negative trend is apparent through time with B3, the oldest, exhibiting the most positive δ13C values (-2.998), followed by B2 (δ13C = -3.641), and B1 (δ13C = -3.704). $\delta 13C_{shell}$ values are partly controlled by the $\delta 13C_{DIC}$ of the ambient estuarine water (Surge et al. 2001). In Southwest Florida $\delta 13C_{DIC}$ is correlated with salinity, although primary productivity and terrestrial output are also contributing factors (Surge et al. 2001). More work needs to be done in Tampa Bay to determine the relationship between salinity and the $\delta 13C_{DIC}$.

A weak, but statistically significant correlation is apparent between δ18O and δ13C values. This correlation is likely the result of the constant fluctuations of temperature and salinity within the estuary. Despite the correlation, modern δ18O values exhibit much greater variability than their δ13C counterparts. OTB has the greatest range of any group (-1.520 - 1.560) and encompasses all of B1 and B2. B1 and B2 are similar, but the latter is slightly more positive. B3 has the most positive δ18O values (-0.610 - 1.890) of any group. Similar to δ13C, δ18O values become more negative through time in the

precolumbian groups. The reduction in δ13C could relate to a number of factors including a shift in plant regimes or an increase in freshwater input.

The mean δ18O values are as follows: 0.340 for OTB, -0.027 for B1, 0.456 for B2, and 0.950 for B3. The results from the Games-Howell test suggests that the mean differences between B1 and B3 are the greatest. It is unclear if the disproportionate representation of positive δ18O values, primarily in B2 and B3 is a function of the climate or sampling bias, given the small (n=6) sampling per shell, it may just be that winter values were randomly milled more often. Because the oysters in B1 were recovered from Feature 12, rather than a column sample, they may be more representative of a shorter or more specific time, rather than a broader range like B2 and B3.

Interpretation of Trace Element Signatures

Using LA-ICP-MS in sclerochronology is a relatively new method. Although trace elements are more difficult to correlate to environmental parameters than stable isotopes, they can provide unique insights in certain situations. As more researchers turn to LA-ICP-MS in paleoenvironmental studies a better understanding of these trace elements will be accomplished.

Magnesium

Many studies have demonstrated weak or moderate correlations between magnesium and water temperature. The values obtained from using Surge and Lohmann's (2008) equation for water temperature in southwest Florida showed some notable discrepancies when compared to the well-established δ18O equation (Epstein et al. 1953)(**Table 3**). For example, the predicted minimum and maximum values for each show conflicting results on what period is warmest or coldest. There are likely many factors that contribute to the discrepancy. Salinity changes may alter the accuracy of the Epstein formula. Also, Surge and Lohmann's equation was designed for southwest Florida, not Tampa Bay.

Ontogenetic effects are known to influence the incorporation of Mg/Ca throughout the lifespan of oysters (Mouchi et al. 2013; Surge and Lohmann 2008), although notoriously difficult to determine the age of oysters, this may be a significant factor. It is also possible that while Mg/Ca ratios are an accurate indicator of seasonality, they may not be a reliable paleothermometer (see Durham et al. 2017).

Most shells in the present study exhibit a sinusoidal pattern, which would be expected if Mg/Ca ratios fluctuate with water temperature. Moreover, the negative correlation exhibited between Mg/Ca and Na suggests that when water temperatures rise, salinity drops, which would also be expected. Given these factors, as well as results from previous studies (Durham et al. 2017; Surge and Lohmann 2008), it is likely that Mg/Ca ratios in the present study reflect changes in water temperature.

Lithium

Lithium is rarely used in paleoenvironmental studies. Here, mean lithium signal values range from 0.811 to 4.791. Li is by far the highest in OTB. Indeed, the minimum lithium signal value exceeds the mean value for the other groups. B3 has the lowest average Li signal, followed by BCB, B2, B1, and OTB, the highest.

Lithium is often strongly correlated with Na in the present study, which may suggest that Li fluctuates with salinity. Thebault and Chauvaud (2011) suggest Li spikes are related to algae blooms. Algae blooms are more common in summer months when water is warm. Interestingly, Li tends to spike before Mg in the present study, suggesting that if an environmental phenomenon is influencing Li values, it may be most prominent in the mid-to-late Spring. Given the high lithium values in OTB and the known occurrences of algae blooms in Old Tampa Bay, the possibility remains that this trace element and environmental occurrence are related. However, perhaps a simpler explanation is that the strong correlations between Li and Mg and Na suggests Li is at least minimally influenced by seasonal

differences in water temperature and salinity, as Füllenbach et al. (2015) suggest, rather than a direct correlation between algae bloom occurrences or a single environmental phenomenon.

Sodium

As one of the primary components of salt, sodium should reflect fluctuations in salinity. However, conflicting studies cloud the relationship between the two. In this study, sodium values are relatively flat with occasional peaks, which sometimes loosely align to peaks of Mg/Ca.

Na is weakly correlated to Mg in most shells but has a moderate negative correlation (-0.535) in the averaged BCB values. The negative correlation is promising, considering that when temperature rises (Mg), presumably during the summer months when rainfall is more prevalent, then salinity (Na) should fall. However, Na tends to have a stronger correlation with Li in most shells in the current study, and it is currently unclear why. Na also does not demonstrate a statistically significant correlation with Sr in averaged modern values. Given the current relationship between salinity and water temperature in Old Tampa Bay and Boca Ciega Bay, it is difficult to determine if these small peaks in the Na signal reflect salinity changes. Modern data do not indicate any extreme variations in salinity throughout the year but it is generally lower from September to December and highest from April to July.

Although the trace element data from OTB are suspect, it is worth noting that OTB has higher Na signal values than BCB, if higher signal values of sodium are related to higher salinity, then BCB should have higher sodium values given that salinity is presently higher in Boca Ciega Bay. Unfortunately, the questionable Na signal data from OTB prevents certainty in their comparison.

Strontium

Strontium values remain relatively consistent through time. B2 has the largest variation, however. The strontium values in the present study have a sinusoidal pattern. However, interpretations

of what strontium represents vary significantly, and it is currently unclear what is influencing this pattern. It is known that salinity plays a negligible role in the uptake of Sr/Ca ratios in water above 8 ppt (Dodd and Crisp 1982). Given the strong correlation between Mg/Ca ratios and Sr signal and the lack thereof between Na and Sr, temperature may be the largest contributor to the oscillations, rather than salinity. A multitude of variables influence the incorporation of strontium in shells, however, including shell precipitation and other kinetic effects (Freitas et al. 2006; Lea et al. 1999; Mucci and Morse 1983; Surge and Walker 2006). The averaged lines indicate B3 has the lowest Sr signal, followed by BCB, B2, B1, and OTB, the highest.

Interpretation of the Paleoenvironment of Old Tampa Bay

Although significant variation within and between groups limits conclusive interpretations of climate change, the isotopes and trace elements in the present study support the notion of climatic instability throughout the Late Woodland period. Interestingly, some of the geochemical data, like those from B3 during the RWP, do not align to previous interpretations made in southwest Florida (Walker and Surge 2006; Wang et al. 2011, 2013). Combining the results of the present study with zooarchaeological assemblages from other Tampa Bay sites shows a trend for changing salinity, but the relationship between salinity and sea level is still unclear. However, as others have suggested, two methodological issues hinder direct inferences from zooarchaeological and isotopic studies to those of sea level models. First, terrestrial and tidal elevations use different datums, and the conversions between each often involve error ranges. Therefore, the relationship between sea level and landforms is not precise (Austin et al. 2018:620; Walker and Marquardt 2013:53-59). Second, the comparison of radiocarbon dates is convoluted given that many dates from geological studies and early archaeological studies are not adjusted for fractionation or calibrated. Moreover, many geologists date shell, which presents challenges of its own (see Cherkinsky et al. 2014). In many of the geological studies that archaeologists

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cite regarding sea level, the dates have no indication of whether or not they were calibrated (Austin et al. 2018:620). These are factors to consider in the present study.

Group B3: AD 50 – 250

Group B3 is squarely within the Wulfert High (ca. 50 BC – AD 550) and Roman Warm Period (AD 1 – 550) as experienced in southwest Florida. Interestingly, the geochemical signatures of B3 suggest cooler temperatures when compared to the other groups. Salinity and its relation to sea level, however, are more indeterminate.

δ18O values for Group B3 are more positive than the other groups suggesting cooler temperatures and/or higher salinities. The predicted temperatures are the lowest of all the groups despite this period being squarely within the Roman Warm Period. B3 exhibited the lowest average trace element line for each element. Similar to the positive δ18O values, the lower mean Mg/Ca values also suggest cooler temperatures. Moreover, the maximum Mg/Ca value of B3 is lower than all of the other groups, except for OTB, although OTB values are suspect. The lower maximum values suggest a cooler temperature in the summer, but the minimum Mg/Ca values suggest winter temperatures were similar through time but not as warm as today, given that they are lower than modern values. When the total lines are averaged, Mg/Ca values for B3 are the lowest, with only a few slight deviations above B1.

Within Zone B3, Level 111 (oldest) exhibits higher peaks of magnesium and strontium values compared to the averaged values from the subsequent Level 110. Lithium and sodium signals are similar within Zone B3. The lower peaks of Mg/Ca and Sr in Level 110 may indicate that although this period was cooler than subsequent times, water temperature was warmer near the dawn of the first millennia and began to cool down shortly thereafter, before rising again. The δ18O values from Level 111 (n=6 from B3_B) are more negative than those from Level 110 (n=17 from B3_C, B3_D, and B3_E). The more

positive δ18O values during Level 110 suggest cooler temperatures and/or an increase in salinity were taking place during the deposition of Zone B3.

Walker and Surge (2006) demonstrate a similar pattern in their isotopic analysis of a single *Mercenaria campechiensis* shell and *Ariopsis felis* otolith from Pineland dated to the same time (AD 100 – 200). The most negative δ18O values (Summer) at Pineland during this time are 1‰ more positive than modern or Little Ice Age specimens. However, Walker and Surge (2006:9) argue the 1‰ offset reflects higher salinity, rather than seasonal temperature changes, given that the interannual water temperature variation would equate to a cooling of 4°C in the summer months, a transformation that is unreasonable for south Florida. Moreover, a higher salinity is also supported by the zooarchaeological assemblage of Pineland. However, winter δ18O values for the RWP specimens were similar in the modern and Little Ice Age shells. Walker and Surge (2006:9) conclude, "The chronological, stratigraphic, and zooarchaeological position of the deposits is such that they may represent a transitional stage toward rising water levels, increasing salinity, and increasing storm activity, all of which seems to have culminated during Caloosahatchee I-Late-B (AD 200 – 400)."

Despite the Wulfert High Stand raising water levels perhaps as much as 1.4 m higher than present levels in southwest Florida, no sedimentological indicators of higher sea levels have been recovered at Yat Kitischee, Remnant Mound, or Perico Island. Perhaps the best explanation is that if sea levels were rising, they were certainly not to the same magnitude as those in southwest Florida (Schwadron 2002:199). If sea levels were on the rise, however, there would likely be an increase in salinities at these estuarine sites because the saltwater wedge would be shifted landward (Walker 2013:37).

The positive δ18O values could also indicate an increase in salinity, rather than cooler temperatures as previously suggested, but a number of factors point to cooler temperatures being the primary driver of the positive oxygen isotopes. Na values are lower in B3 than any other group. If Na is related to salinity, then the present data suggests salinity was lower between AD 50 and 250, rather than higher, as Walker and Surge (2006) propose for southwest Florida. Sr values are also lowest in B3, although it is unclear if this reflects temperature, salinity, or a combination thereof. Notably, BCB and B3 are statistically similar for Li, Na, and Sr, but not Mg, per the Games-Howell Multiple Comparisons post-hoc test. This statistical difference in Mg may point to lower temperatures than today, but other elements suggest salinity may have been within the modern range of BCB, which is higher than modern OTB.

Although there are no preceding periods at Yat Kitischee to compare, the zooarchaeological assemblage of Zone B3 is dominated by eastern oysters with few crown conchs being represented, a ratio of 11:1 (Austin 1995). The disproportionate number of eastern oysters suggests the environment was favorable for the species, that is, salinity, water temperature, and sea level were not too high or low for their survival. Admittedly, the smaller B3 assemblage likely hinders direct comparisons with later zones at Yat Kitischee. However, the zooarchaeological assemblage from Remnant Mound, at the mouth of the Manatee River, supports a time of higher salinity (Schwardron 2002) as Walker and Surge (2006) propose for southwest Florida. If salinity was higher in Tampa Bay, as in southwest Florida, it was not high enough in Old Tampa Bay (≥32 ppt) to sustain crested oysters. Modern data from the EPC station suggests salinity may occasionally reach 32 ppt in OTB but likely does not sustain these levels long enough to support crested oyster populations. The assemblage of species with a preference for high salinity at Remnant Mound may be the best current evidence of sea level rise in Tampa Bay during this period but other variables can also influence salinity changes (see Salinity Gradient Model section).

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There are some discrepancies with the sea level model and the placement of features across the Tampa Bay landscape. For example, at Perico Island, multiple dates from Feature 536 cluster between cal 154 BC and AD 84. Feature 536 had a top elevation of -0.57 m below modern sea level, while the bottom is over two times lower (-1.41 m). If the bottom of the feature was not below the water table than presumably sea levels were much lower as well. Moreover, five other dated contexts at the site with elevations ranging from ~ - 0.50 to 0.50 m are within the Wulfert High stand (ca. 50 BC – AD 550) (see Austin et al. 2018). These elevations suggest that if the sea level were rising at the same intensity as in southwest Florida, then the rise must have happened towards the middle or tail end of the proposed date range, closer to AD 550.

Midden deposition began at Yat Kitischee sometime around AD 100. The lowest excavated level at Yat Kitischee (Level 115) begins at 0.5 m amsl (sterile sand beneath). Given this elevation, the possibility of a sea level transgression of 50 cm in Old Tampa Bay remains. However, Yat Kitischee is ~600 meters from the present shoreline, much further than Perico Island. Therefore, the elevation of midden deposits at the site may not be the best representation of sea level. At Shaw's Point, shell ridges are situated in a chronological sequence with the oldest ridges (365 BC – AD 110) located furthest inland, and the youngest (AD 1050 – 1395) closest to the present shoreline, which also suggests sea level may have been higher (Schwardron 2002).

The shell ridges and zooarchaeological data from Shaw's Point suggest salinity and sea level were higher during this time, but the archaeological evidence from Perico Island and Yat Kitischee contradict the timing and intensity of the Wulfert High. The comparatively drastic changes in salinity at Remnant Mound are expected given the site's proximity to the mouth of the Manatee River, where changes to the salinity gradient due to variable rainfall patterns (or sea level) would have been more pronounced. If sea level rise was the primary driver of these salinity changes, it may have happened

rapidly towards the end of the time frame designated as the Wulfert High in southwest Florida, to accommodate the time difference between southwest Florida and Tampa Bay.

The present data suggest an overall cooler temperature between AD 50 – 250, which may have influenced a drought, or generated less rainfall compared to later periods. In Old Tampa Bay conditions likely remained within the preferred temperature and salinity range of eastern oysters but salinity was likely higher at Shaw's Point, near the mouth of the Manatee River, than it was in Old Tampa Bay.

Group B2: AD 250 – 700

Group B2 is within the transitionary period between the Wulfert High (ca. 50 BC – AD 550) and Buck Key Low (ca. AD 550 – 850), as well as the Roman Warm Period (AD 1 – 550) and Vandal Minimum (AD 550 – 850), as experienced in southwest Florida. The geochemical signatures suggest that after the deposition of Zone B3 water temperature and salinity began to rise, but possibly only during the contexts that were deposited within the RWP (Level 110, and perhaps Level 109). Within Zone B2, the three levels exhibit peaks in Mg/Ca that are similar in intensity, suggesting summers were likely similar through the period, although these are slightly lower in Level 109 (middle level). The most recent context, Level 108, has an average Mg/Ca line that is lower than the other B2 groups, and more similar to Zone B3. Given its stratigraphic positioning, this may be the only group within B2 that is a true reflection of the VM.

The mean Mg/Ca values (8.665) for B2 are slightly lower than BCB (8.734), while the averaged line indicates higher peaks than found in BCB, suggesting warmer summers than present. Winters, however, were likely cooler than present because the B2 line falls beneath the BCB average. The lighter oxygen isotope values also support a general warming trend and/or a higher salinity. Although temperature might be a better explanation for the lower oxygen values because Na values are higher in

B2 relative to B3, and are similar, albeit slightly higher than BCB. Trace element data in the present study suggests climatic variability during this period as well. Indeed, B2 was the only group of oysters that demonstrated statistically significant differences for each trace element when compared to the other groups.

δ18O values for Group B2 exhibit more negative values than the preceding B3, but more positive values than the later B1. The lighter oxygen isotope values support a general warming trend and/or a higher salinity after the deposition of Zone B3. B1 and B3 were the only groups to contribute to the statistically significant differences in oxygen isotopes between temporal groups. Therefore, the climatic conditions during B2 were likely somewhere in between those experienced in B1 and B3. Interestingly, δ18O values for Level 110 (n=6 from B2_I) exhibit more variability than those from Level 109 (n=12 from B2_F and B2_H) and Level 108 (n=6 from B2_A). δ18O values from Level 108 exhibit a more positive mean than earlier levels of Zone B2, suggesting a cooling trend towards the later phase of Zone B2.

The average trace element signals of B2 at the 50 and 300 point value falls within the other four groups, with one exception. B2 has the lowest and highest Sr values in the study. The reason for the slightly broader range of Sr values is unclear. Mean Mg/Ca values (8.665) are slightly lower than modern BCB (8.734), suggesting temperatures during B2 exhibited a similar range as today.

When the average B2 line is compared to the other groups, B2 exhibits the highest peaks in Mg/Ca but is situated near the average of the other groups in the remaining elements. Within Zone B2, the five shells from Level 110 (oldest) remain close to the B2 average. The six shells from Level 109 demonstrate higher than average magnesium values but are close to the average in the remaining three elements. Lastly, the two shells from Level 108 are lowest in magnesium, highest in lithium and sodium, and about average in strontium, albeit with more peaks.

The magnesium values suggest that during the early deposition of Zone B2 water temperature was higher than it was in Zone B3 but would become even warmer during the middle of B2. The most recent Zone of B2 (Level 108) indicates higher peaks of Mg/Ca when compared to the other B2 groups, however, the averaged line of Level 108 is less than the others and more similar to Zone B3 levels (**Figures A4 – A5**). The averaged line from Level 108 may indicate some warmer summers, but perhaps milder winters or a generally cooler climate during the later phase, as the oxygen isotopes suggest.

Mean Na values (50.332) during B2 are higher than BCB (43.925). Salinity is higher in BCB than in OTB. Therefore, salinity during AD 250-700 may have been more similar to BCB rather than OTB prehistorically (higher than today). Sodium values also increased during the phase of B2 (Level 108), suggesting salinity may have also increased during the latter part of this interval.

Although the zooarchaeological assemblage of Zone B2 at Yat Kitischee indicates a reduction of eastern oyster relative to the total MNI compared to the earlier and later strata of Zone B, the ratio of oysters to crown conch increases to 42:1, the highest of Zone B. This indicates that the environment was likely favorable to eastern oysters. The same trend is apparent at Perico Island, where oysters are more prevalent in Strata IIB (AD 231 – 774) than Strata IIA (AD 774 – 967), and during Zones A and B (AD 310 – 895) of Remnant Mound (Austin et al. 2018; Schwardron 2002).

Similar to the previous period, the disproportionate number of eastern oysters suggest the environment was more favorable for the species, that is, temperature, salinity and sea level were not too high or low for their survival. However, given the increase of oysters at each site, the environment was possibly more favorable than before (but more so than later periods).

Given that this period is situated between the Wulfert High (50 BC – AD 550) and Buck Key Low (AD 550 – 850) of southwest Florida, it is unclear what period(s) the oysters in the present study reflect.

When compared to preceding and following climatic episodes, the VM was generally cooler and drier than the RWP and MWP (Walker 2013). The VM also coincides with the lower salinity and sea levels in southwest Florida (Walker et al. 1995; Wang et al. 2011:10). The Buck Key, a sea level regression of 50-60 cm below MSL, would have pushed the salinity gradient seaward near the mouth of the Manatee River. The zooarchaeological assemblage at Remnant Mound between AD 310 – 895 supports a lower salinity. It is uncertain how the salinity gradient would respond to a regression in Old Tampa Bay, relatively far away from the four rivers of Tampa Bay. If salinity increased during a regression, as it likely would away from the influence of a river, then the data from Level 108 of a cooling episode paired with a time of higher salinity may be evidence of the Buck Key low in Tampa Bay.

The VM is difficult to investigate given its climatic instability and the lack of available radiocarbon dates in Tampa Bay. The wide date range of B2 poses challenges, but the geochemical differences in Level 108 relative to the rest of Zone B2 may be evidence of the VM. The trace element data supports the notion that this time period was climatically unstable, but it is unclear if this reflects the VM or a combination of RWP and VM datasets. Additional radiocarbon dates from within B2 would help better determine when the oysters were deposited.

Group B1: AD 850 – 950

Group B1 represents the onset of the Medieval Warm Period (AD 850 – 1200) and La Costa High (ca. AD 850 – AD 1450), as experienced in southwest Florida. Walker (2013:42) characterizes this climatic episode as an overall warm period punctuated with short cooler events and increased storminess. The geochemical signatures of B1 suggest warmer temperatures compared to the other groups. Salinity, and its relation to sea level, however, are difficult to determine with the present data.

δ18O values for Group B1 exhibit variability but are generally more negative than B2 and B3. The negative δ18O values in B1 suggest warmer or wetter periods and/or a decrease in salinity. The Games-Howell multiple comparison test indicated that the mean difference in δ18O between B1 and B3 was the greatest, suggesting significant differences in temperature and/or salinity between B1 and B3.

Table 3 indicates that the minimum and average predicted water temperatures from the oxygen isotopes are higher than any other group, the maximum predicted value is only 1 degree shy of OTB. Interestingly, the predicted values gained from the Mg/Ca ratios indicate the lowest minimum temperature and the highest maximum temperature of any group. This suggests there may have been dramatic temperature swings within this interval. B1 Mg/Ca values are statistically similar to both modern groups. At the 50 data point, level B1 has the highest maximum Mg/Ca value (20.490) suggesting warmer summers. However, when the average line is analyzed, B1 appears to have the second lowest average of Mg/Ca. **Figure A3** indicates that the majority of oysters in B1 recorded high peaks during the first 25 mm of growth, and three of the ten may be skewing the average results with lower values. The peaks of Mg/Ca demonstrated by the seven oysters in **Figure A3** are higher than those in the other groups, suggesting warmer than present summers.

Although temperature rise seems to be an appropriate explanation for the more negative δ18O values, given the higher values of Mg/Ca in B1, a lower salinity is also a possible explanation for the negative oxygen isotopes. B1 has the highest average Na values, as well as the broadest range of Na values out of the precolumbian groups. If Na signal is related to salinity, then the data suggests salinity increased, rather than decreased throughout B1.

At Yat Kitischee, the zooarchaeological assemblage of Zone B1 is less dominated by eastern oyster compared to crown conch (2:1) during this period. Crown conch and moon snail, alongside

oysters, contribute to the vast majority of the molluscan MNI. Crown conch and moon snail share a similar salinity range as eastern oysters, but their populations often spike when oysters are stressed (Walker 1992). Zone A and B at Remnant Mound may slightly overlap with this period (AD 310 – 895). Similarly, lower salinity tolerant species were present in the later contexts of Remnant Mound. At Perico Island, predatory gastropods comprise over double the molluscan MNI compared to the preceding period, further suggesting oysters were stressed and easy prey. Additionally, the representation of eastern oysters drops from about 35% to 15% of the molluscan MNI during this time (AD 774 – 967).

A number of environmental factors could potentially stress oysters. A possible explanation for the zooarchaeological data is a sea level regression. Lower sea levels would expose oysters, weakening them and making them easy prey for gastropods, thus, explaining the increase in gastropods and decrease at oysters at the majority of Tampa Bay sites. The time period for B1 (AD 850 – 950) is squarely within the transition between the Buck Key Low (AD 550 – 850) and La Costa High (AD 850 – 1450) in southwest Florida. Thus, the zooarchaeological assemblages may indicate the effects of the Buck Key Low were still being experienced in Tampa Bay, later than in southwest Florida. The effects of the La Costa High, a rise of about half a meter above MSL, could also have potentially placed stress on oyster populations. However, given the present data, another explanation is that higher summer temperatures were the stressor of oysters, rather than a change to sea levels. *C. virginica* stops depositing shell when water temperature is above 28($\pm$2)°C (Surge et al. 2001). The predicted water temperature using Mg/Ca ratios from B1 equaled 28.14°C, but only 22°C using the isotope equation.

The higher average Na values in B1 may relate to sea level but it is difficult to determine at present. Again, depending on how the salinity gradient of Old Tampa Bay responds during sea level fluctuations, the increase in salinity is possibly indicative of lower sea level, rather than higher sea level, because it is further away from any of the four rivers. If lower sea level creates higher salinities in Old

Tampa Bay, but lower salinities near the Manatee River, this could explain why there are more lower salinity tolerant species in Remnant Mound and more predatory gastropods at other Tampa Bay sites. An increase in salinity during a sea level regression would also explain why the Na signal of B1 is higher when oysters may have succumbed to exposure during sea level regression.

Together the isotope and Mg/Ca ratios data suggests a warming interval, likely the warmest in the present study, and warmer than present. Although Mg/Ca values are statistically similar to the modern groups, B1 exhibits more peaks in Mg/Ca and higher maximum values. Na values are highest during this period, but it is unclear if they actually reflect salinity. Generally, the changes to the zooarchaeological assemblages are believed to be the result of increasing water temperatures but a sea level regression is also possible. Temperatures may have reached above the tolerance of oyster populations, making them easy targets for predatory gastropods. Likewise, a sea level regression would have exposed and weakened the oysters.

Given that this period dates to the transitionary phase between the VM and MWP, and the Buck Key and La Costa, it is difficult to determine the environmental stressor of the oysters. A combination of warmer temperatures and lower sea levels is possible given that a warming period would have likely marked the onset of the MWP and transition to higher sea levels if they took place to the same intensity as southwest Florida.

Implications for Manasota Culture

Although Charlotte Harbor and Tampa Bay are geologically comparable and may have experienced similar effects of climatic and sea level changes, the human response to those changes was likely unique. Luer and Almy (1982:38-39) describe the ecological communities that comprise each region and how these differences would have likely necessitated different technologies and subsistence

practices between Calusa and Manasota groups. They note the Manasota region as primarily composed of pine flatwoods that gradually transition to coastal marsh and hardwood hammocks, with hilly xerophytic oak and longleaf pine forests to the north. While the bays of the central Gulf coast are relatively narrow with well-drained shores, those of the Charlotte Harbor region are broad and shallow with mangrove dominated shorelines.

Walker (2000, 2013) and Marquardt and Walker (2013) argue that southwest Florida is particularly vulnerable to small-scale climate change and that the time during the VM is markedly different from the preceding and subsequent centuries. Walker (2000) uses site stratification, paleosalinity gradient analysis, faunal population dynamics, and cultural change as evidence of the effects of the VM. In regard to cultural change, the Calusa apparently abandoned the coast in favor of South Florida's interior between AD 300-500 during the Roman Warm Period. Walker (2000:124) notes that when the coast was reinhabited, during a time of lower sea level, the Calusa brought with them many changes and innovations associated with Belle Glade culture. However, when sea level began to rise again, during the MWP, instead of leaving for the interior again, the Calusa residents literally built up their landscape with shell and stayed (Walker 2000:124).

Similar to the Calusa, the Manasota culture consisted of a group of peoples highly specialized to coastal living who would have been directly impacted by small-scale climatic changes. The effects of these climatic changes were likely different throughout the Tampa Bay region and would have required different management or adaptive strategies to overcome. Although the Manasota culture is known for its cultural continuity (Luer 2014:80; Luer and Almy 1982:38-39; Milanich 1994:222), modifications take place through the time period known as the Manasota Period (ca. 500 BC – AD 700), especially Late Manasota-Weeden Island. Most notably, their treatment of the dead, but also more mundane

occurrences such as the thinning of STP vessel walls accompanied by different rims and lips, and cessation of *Strombus* shell hammers.

Changes in the Manasota subsistence strategy through time are generally not observed, or readily obvious during the Manasota Period. The advantageous location adjacent to estuaries provided energy-rich fish and plentiful shellfish for consumption. The pine flatwoods would have offered many other plant and animal options as well and may have been exploited more in the winter when fish were less abundant in the estuary (Luer 2014; Luer and Almy 1982:43). Variation in species diversity at any archaeological site may be a product of the environment or cultural phenomena. At Yat Kitischee, species richness increases through time. Austin (1995: 226-227) discusses the possibility that an increase in species richness through time was related to a developing political economy rather than a sole product of the environment. Interestingly, the trend is the opposite further north at the ceremonial center Crystal River. Duke (2015) suggests the decrease in species diversity and increased reliance of shellfish was an employed subsistence strategy for mound building purposes and to ameliorate growing populations at Crystal River. At Perico Island, species diversity is moderately high throughout midden contexts. However, gastropods are six times more common during the Late Manasota period (ca. AD 300 – 700).

Perhaps the most notable implications for changing climate can be found at the site level. The repurposing of areas at Yat Kitischee and the abandonment of Bayshore Homes have both been hypothesized to be related to sea level fluctuations, among other reasons (Austin 1995; Austin and Mitchem 2014; Austin et al. 2014). At Yat Kitischee, an apparent transition from a living area to one of secondary refuse takes place within Zone B2. The transformation of this area is evidenced by the smaller size distribution of ceramics and lithic waste flakes, as well as only one of the thirty-three post molds identified at the site being found within the zone. At the time of excavations, Austin (1995:34) proposed

sea level rise as a possible explanation, given that the rise would have made the area less favorable to live on, or near. However, the reorganization of the site takes place during the Buck Key Low of southwest Florida. The possibility remains that a small transgression may have taken place during the broader regression of the Buck Key Low, given the unstable climate during the VM. In 2014, Austin et al. (2014) revisited the hypothesis and proposed lower sea levels may have been the impetus for the transition of this portion of the site. Moreover, they suggested the people living at Yat Kitischee followed the retreating shoreline of Old Tampa Bay, a hypothesis that is supported by a single radiocarbon date (cal. AD 415 – 590) from the nearby Shoreline Midden (8PI11569) site (Austin et al. 2014:102-103). This may also be the time when mound building began at the nearby Feather Sound Mound (8PI1700), closer to where the retreating shoreline would have been situated. However, the history of Feather Sound Mound has yet to be investigated.

At Bayshore Homes (8PI41), a Manasota-Weeden Island mound and midden complex, there is a hiatus between cal. AD 565 and 890. Interestingly, this abandonment takes place when the Calusa begin to reinhabit the coast. Soon after returning to Bayshore Homes, the residents construct a large linear shell midden adjacent to the shoreline. Austin and Mitchem's (2014) radiocarbon dates help contextualize the unusual ceramic sequence originally identified by Sears (1960). That is, a redepositional event took place that positioned older midden deposits on top of more recent ones. This depositional event may have been related to monumental mound construction, perhaps linked to the memory of sea level rise or storm activity. Building the shell ridge higher would have protected the site from storm surges or higher sea levels, similar to what the Calusa were doing to the south. No evidence of storm or flooding has been found at the site. The hiatus is during the sea level regression in southwest Florida, rather than a time of sea level rise. However, a sea level regression of the magnitude suggested in southwest Florida would have had drastic effects in Boca Ciega Bay, a much shallower

estuary than other components of Tampa Bay. A regression of even a small magnitude would have exposed oyster beds and made life difficult for a number of estuarine species. Even with effective management strategies, the narrow shape and shallowness of Boca Ciega Bay may have been a severe disadvantage to the residents of Bayshore Homes, compared to those of Yat Kitischee. Or, given the size difference of the sites, a larger population at Bayshore Homes may have been more difficult to sustain during difficult times.

Unfortunately, the comparatively large time range of B2, among other factors, prevents direct inferences to sea level during this time, but the present data certainly supports climatic variability. Periodic warming and cooling trends of varying intensities may have been more or less difficult to manage during certain intervals but a higher chronological resolution is needed to test this hypothesis.

Simultaneous with the manifestations at Bayshore Homes and Yat Kitischee during the VM, Central Gulf Coast sites further north also experienced change: Crystal River (8CI1), Shell Mound (8LV42), and Garden Patch (8DI4) were either abandoned or witnessed a significant decline in settlement activity (Austin and Mitchem 2014; Pluckhahn and Thompson 2017:74; Pluckhahn et al. 2017; Sassaman et al. 2014; Wallis et al. 2015). Perhaps coincidentally, Weeden Island culture was adopted more intensively in the Tampa Bay region shortly thereafter. To what effect, if any, climate change contributed to the adoption of new beliefs can certainly be debated. As Sassaman (2012:264) states, "an archaeology that attributes all such action to the invisible hand of the economy or environment fails to understand that such acts were discursive in that the actors were in the dialogue between a lived past and an imagined future." By imagined future Sassaman (2012) means that new ways of practice or planning, whether proactive or reactive, were influenced by past experiences. Moreover, Sassaman (2012) discusses multigenerational patterning and argues oral histories or other forms of media (ceramics, mound building) may last only three or four generations. Thus, the memory of

certain events, like sea level transgressions, may be preserved throughout this time but will be lost thereafter. This way of thinking grants more recognition towards resilience of the mind, memory, and tradition, rather than that of the environment and landscape. Sassaman (2012:264) posits "that the erosion of traditions of ancestor veneration [Weeden Island] after AD 750 had less to do with the nadir in sea level at the end of the Vandal Minimum, but rather a loss of salience in elders to relate their memories of past experiences to futures on the horizon."

Certainly, abandoning one's home is a difficult decision, and surely leaving because of depleted resources due to an unstable climate would be a valid reason. But, at least for an archaeologist, the cause for leaving may not be as important as understanding where people went and the experiences they confronted. Pluckhahn, Wallis, and Thompson (2017) view the adoption of Weeden Island culture as a historical process, one that "involved the movement of people, materials, ideas, and practices across large areas." Bayesian modeling of radiocarbon dates from the four sites above indicates the abandonments may have progressed from south to north. Pluckhahn et al. (2017) note, "as the communities of the central peninsula declined, those to the north in the panhandle and adjacent interior prospered, incorporating ideas, practices, and probably people from the south." This exchange may be most evident in the form of circular villages being incorporated into a number of existing village sites during this time period. For example, divisions, or dual occupations are evident at Kolomoki in Georgia, and the Hare Hammock ring in the Florida Panhandle. Pluckhahn et al. (2017) indicate the timing of such occupations and the changes that take place within them, suggest "a rapid 'Weeden Islandization' of a previously established mortuary program occurred in concert with coalescence in the large villages of the northern Gulf Coast." If people did leave the Central Gulf Coast, their return brought new ideas and beliefs. The Manasota culture incorporated these ideas into their own traditions while still participating in the larger regional beliefs.

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As we confront climate change today, we certainly have one advantage, predictive models. And, if Sassaman's (2012) notions of multigeneration patterning and imagined future are accepted in this context, peoples participating in the Manasota culture were likely confronting an unstable climate (VM) that their recent ancestors had never experienced and a possible migration to the panhandle.

All of the changes taking place to the Manasota way of life during this time, some subtle, others not, may have been ancient people's way to inscribe their memory of this unique time on the landscape.

CHAPTER 6: CONCLUSIONS

Confronting climate change poses unique challenges for people to overcome. The occupational variability of Tampa Bay during the climatic event known as the Vandal Minimum, and the material culture left thereafter are evidence left behind by the Manasota culture. Revisiting my research question: Did salinity and/or temperature changes take place in Tampa Bay during the Woodland Period? If so, how did these climatic and environmental changes relate to the Southwest Florida studies both in timing and intensity?

Yes, both salinity and temperature changes occurred in Tampa Bay over the course of the Woodland Period. However, the timing between these changes and those in southwest Florida is still obscure, especially in regard to sea level. This is primarily due to the date ranges in the present study often falling during transitionary times between climatic episodes. The present data suggest there was a general cooling trend between AD 50 – 250, which may have caused a drought, but conditions remained within the preferred temperature and salinity range of eastern oyster. The following period (AD 250 – 700) was climatically unstable but had intervals of warmer summers and cooler winters than today. Temperatures became cooler and salinity increased towards the latter part of this interval. Lastly, temperatures were likely higher than present between AD 850 – 950, possibly high enough to place stress on oyster populations throughout Tampa Bay.

To what degree, if any, these climatic changes played a role in the occupational variability of Tampa Bay is unknown. Similar to other studies, climatic instability during the VM was observed. Even with the evidence of climatic instability, however, it is hard to believe that the Manasota culture had a difficult time acclimating when populations on the coast both to the north and south appeared to remain, and even grow. If the majority of people did leave the Tampa Bay region, as the current

distribution of radiocarbon dates suggest, they may have pursued the Weeden Island culture in the north. It is clear that at least some people never left the Tampa Bay area, however, remaining committed to the Manasota traditions.

CHAPTER 7: LIMITATIONS AND FUTURE RESEARCH

It has become undoubtedly clear that in order to understand the paleoclimate of Tampa Bay much more work needs to be done in the present. Interdisciplinary research primarily drawing from archaeology and geology is needed in Tampa Bay to determine how climate change affected sea level, and how sea level relates to salinity. Higher resolution modern environmental data, a localized sea level curve, higher resolution isotopic analysis, and a better understanding of trace elements in Tampa Bay will certainly be needed to make claims related to sea level. The current study provides evidence for climate change but should be viewed as complimentary to those that study sea level.

There are two limitations to the current study that need to be addressed. The first is the low sampling resolution of the modern environmental data recorded by the EPC. A single (non-average) monthly reading hardly is representative of a specific month. Some sclerochronological studies average daily temperatures to develop their linear regressions. The differences in recording time significantly limit the ability to determine strong correlations between the environment and isotopes/trace elements because it is extremely unlikely one value is representative of the entire month.

The second is the low sampling resolution of the isotopes from the oyster shells, which were done by hand as opposed to using a micromill are another limitation. The combination of these limitations causes a significant third, the inability to assign calendar dates, and subsequently, distinct correlations between modern environmental parameters such as water temperature and salinity, and trace elements and isotopes. This study relies on previous research that was able to exhibit a correlation between such phenomena. The inability to assign calendar dates also suffers because $^{18}O_{water}$ and Mg/Ca_{water} concentrations of Tampa Bay are unknown. Here, a constant value of 75‰ is used for $^{18}O_{water}$. This number is derived from a database of over 22,000 global $^{18}O_{water}$ measurements and used to

approximate locations without known relationships between salinity and $^{18}O_{water}$ (Schmidt et al. 1999).

Like most archaeological research, this project would have also benefited from better chronological control as well as a larger sample size, primarily in Zone B2 which overlapped the transitionary period of the RWP and VM.

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APPENDIX:A ADDITIONAL FIGURES

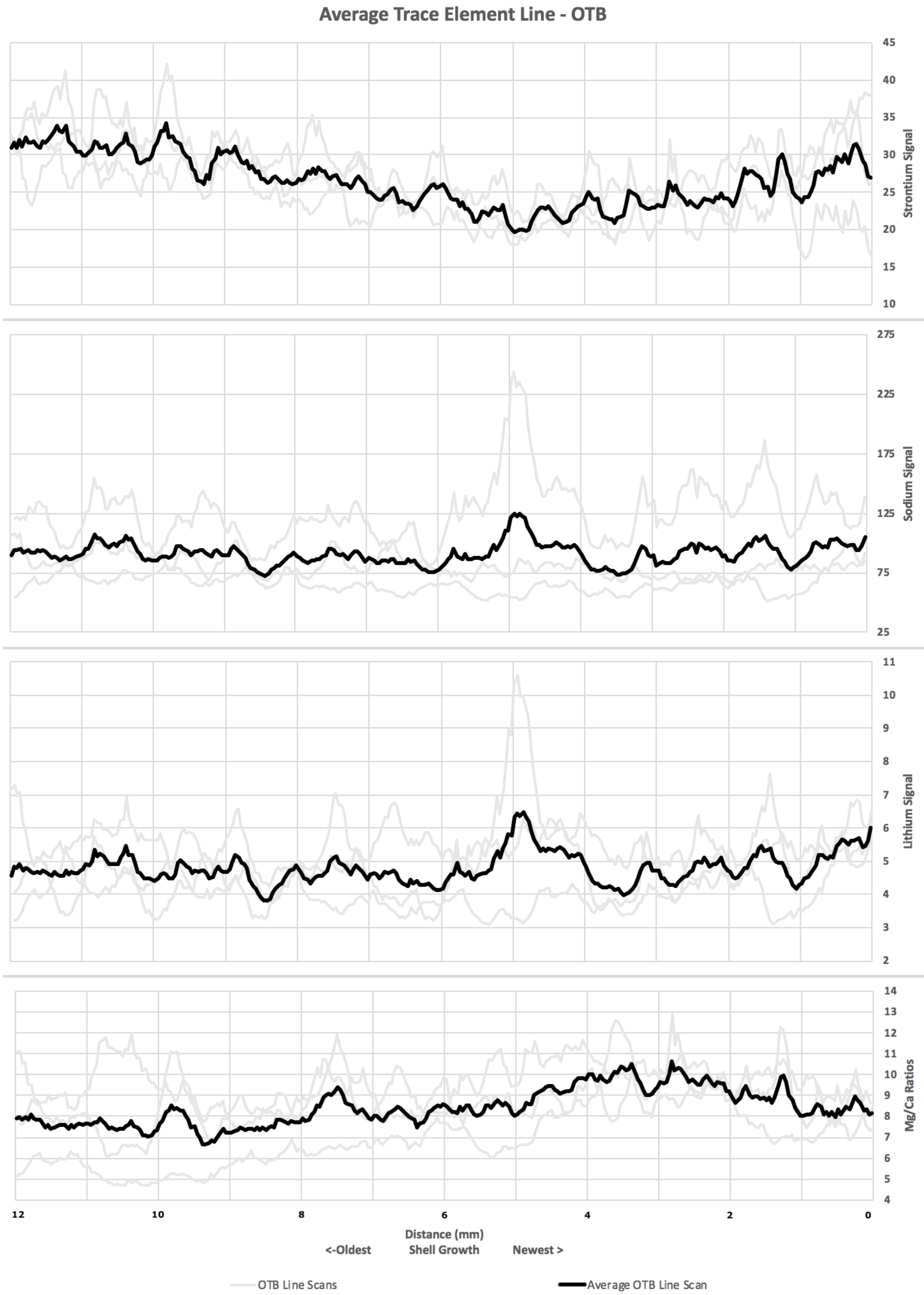

Figure A 1. Averaged trace element line for OTB.

`

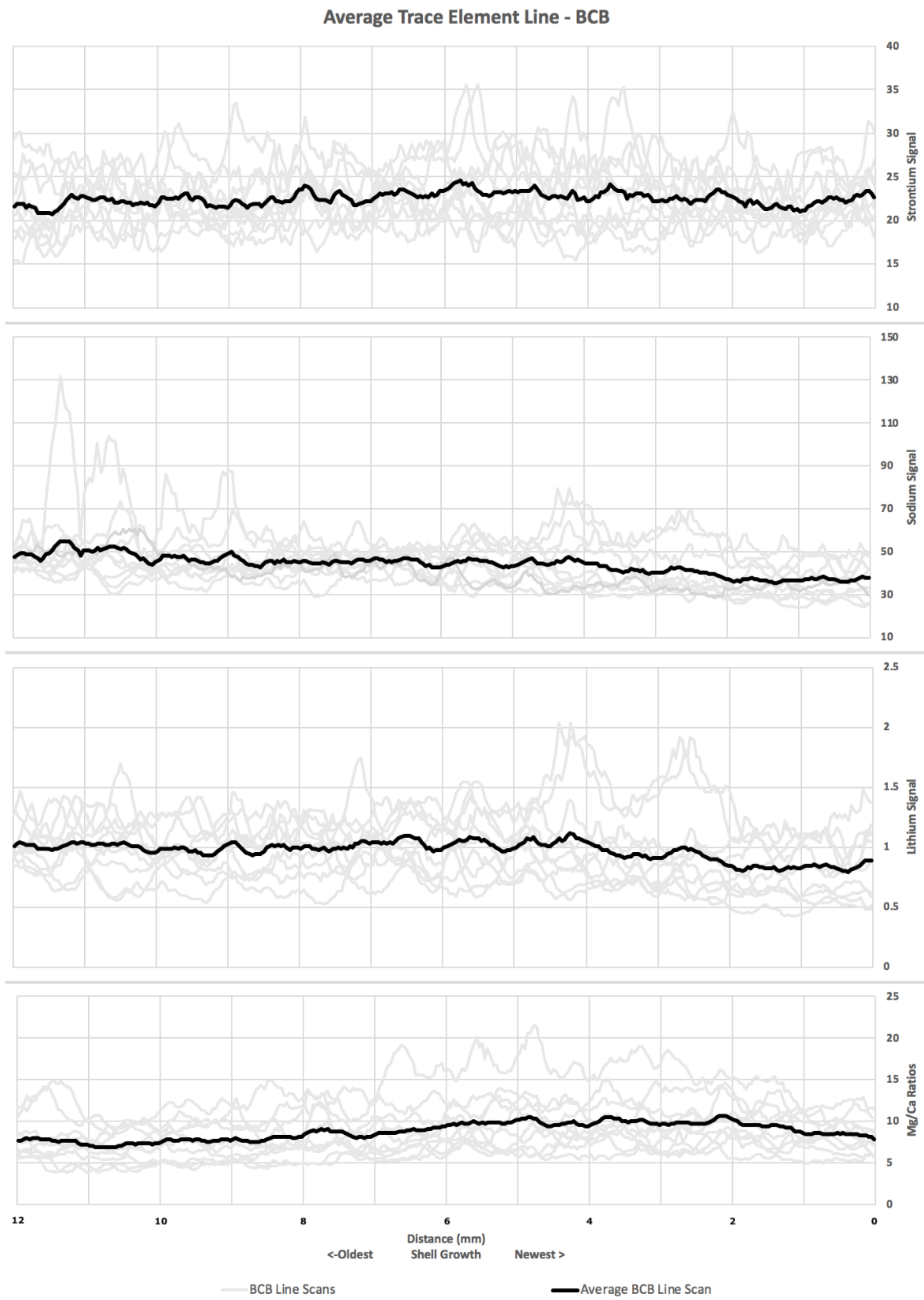

Figure A 2. Averaged trace element line for BCB

`

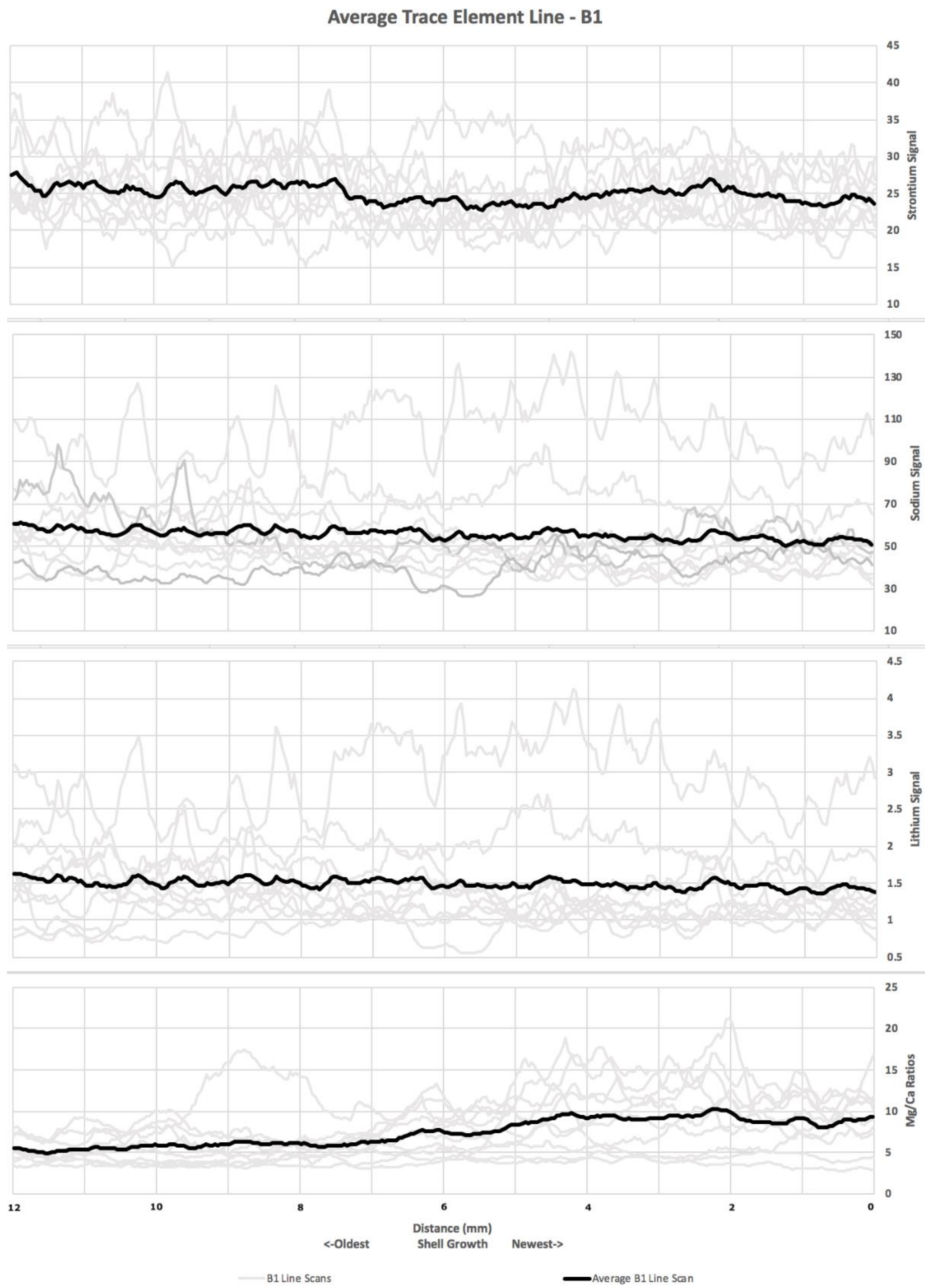

Figure A 3. Averaged trace element line for B1.

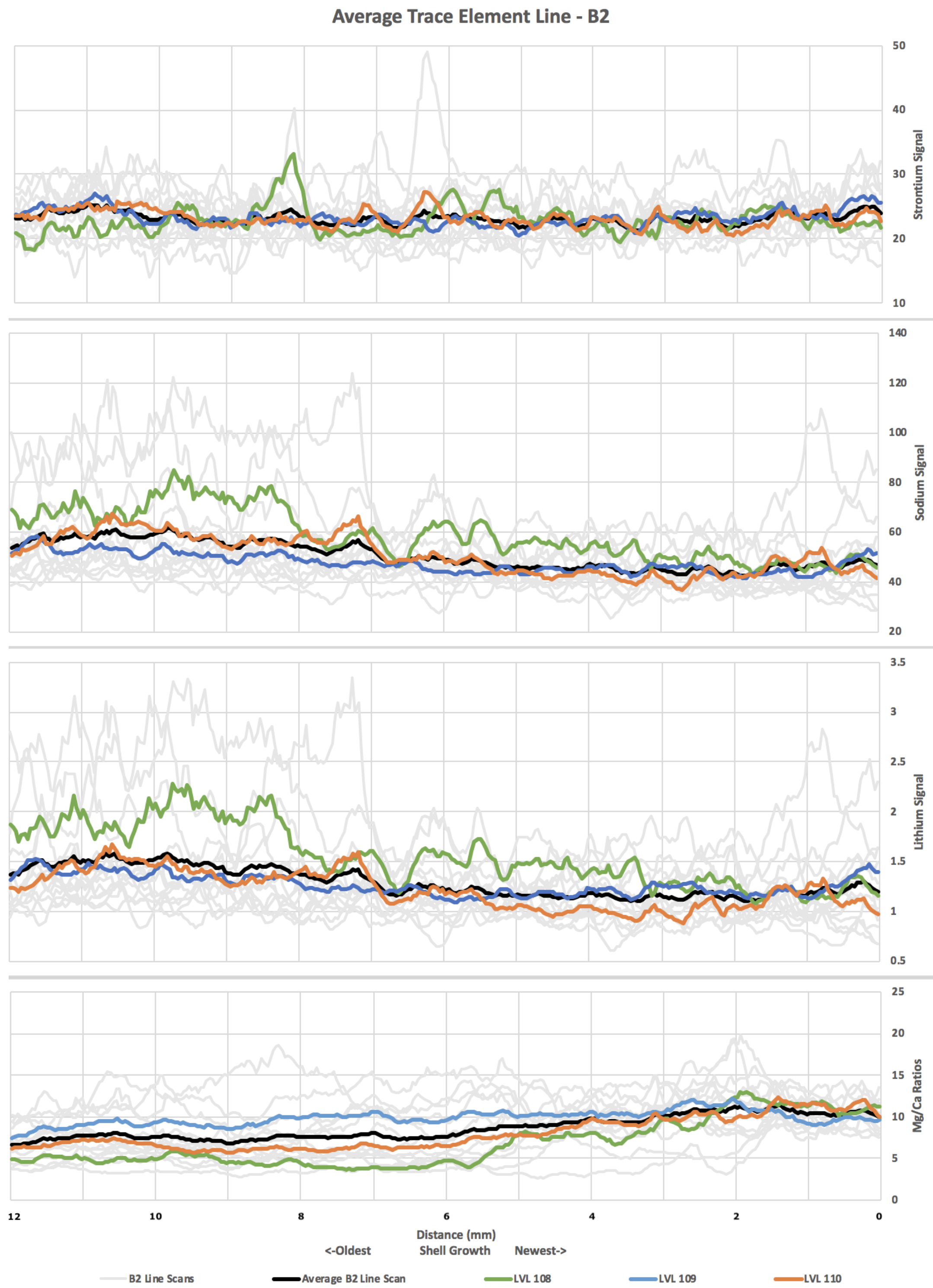

Figure A 4. Averaged trace element line for B2.

`

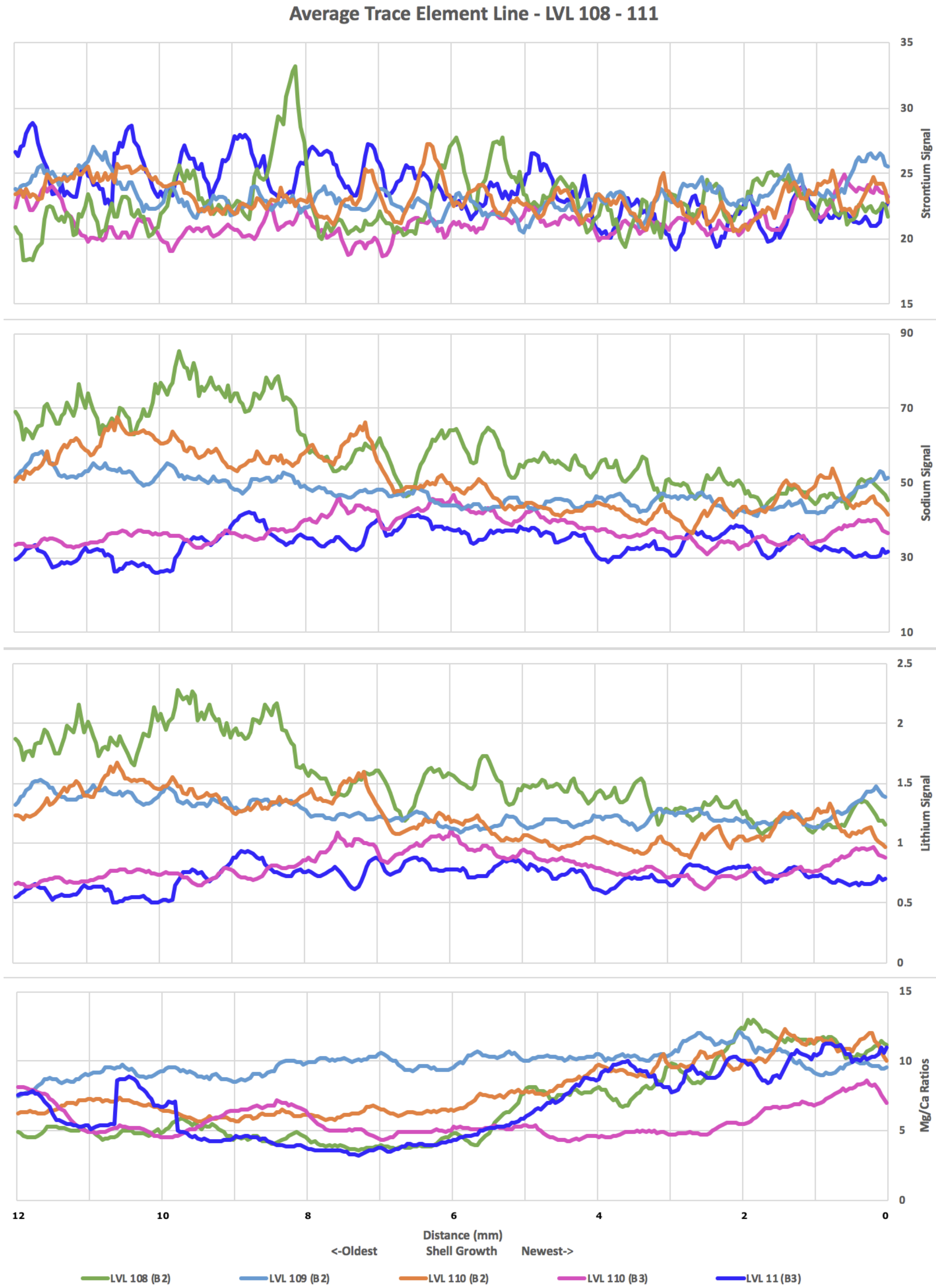

Figure A 5. Averaged trace element line for Levels 108-111.

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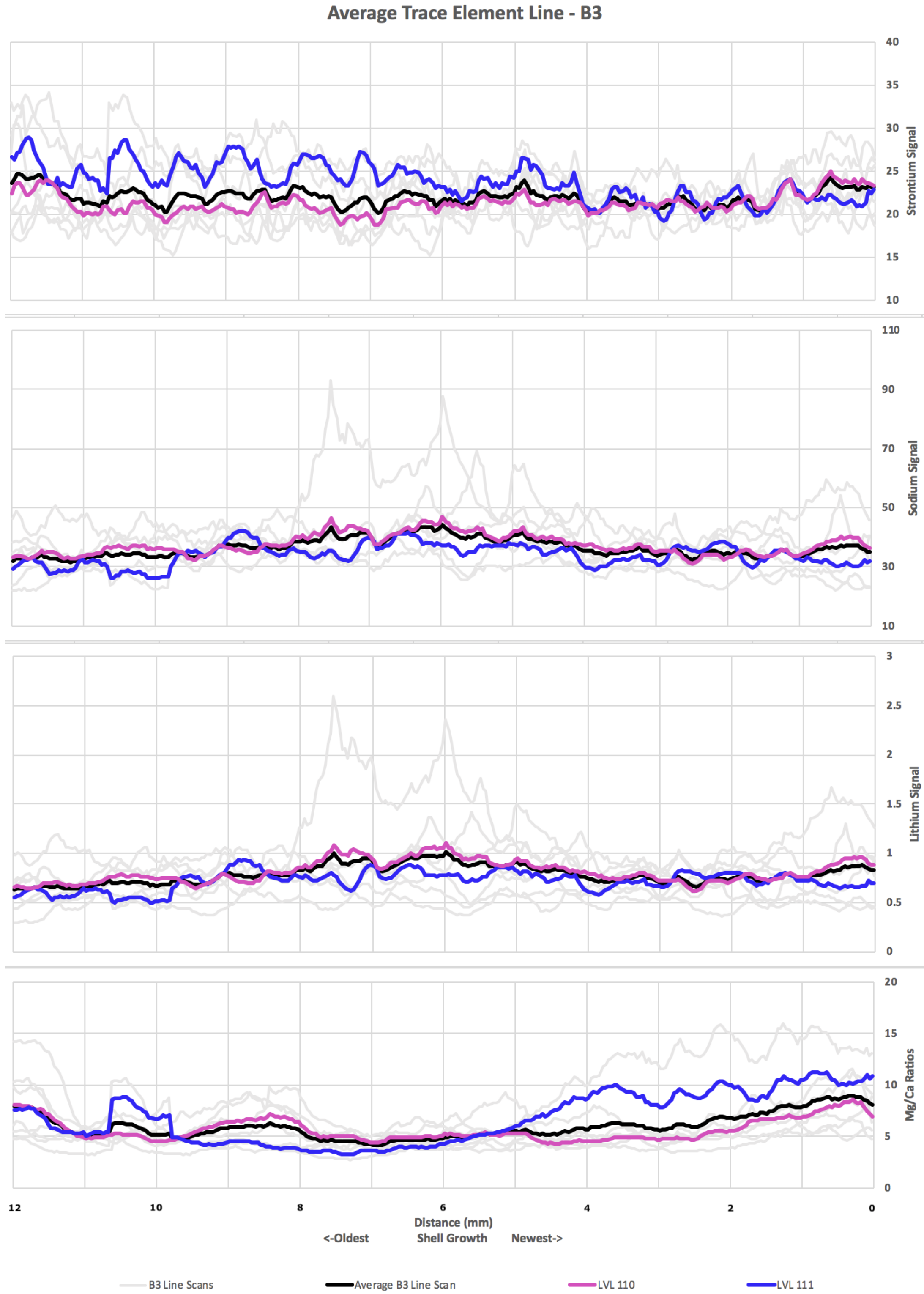

Figure A 6. Averaged trace element line for B3.

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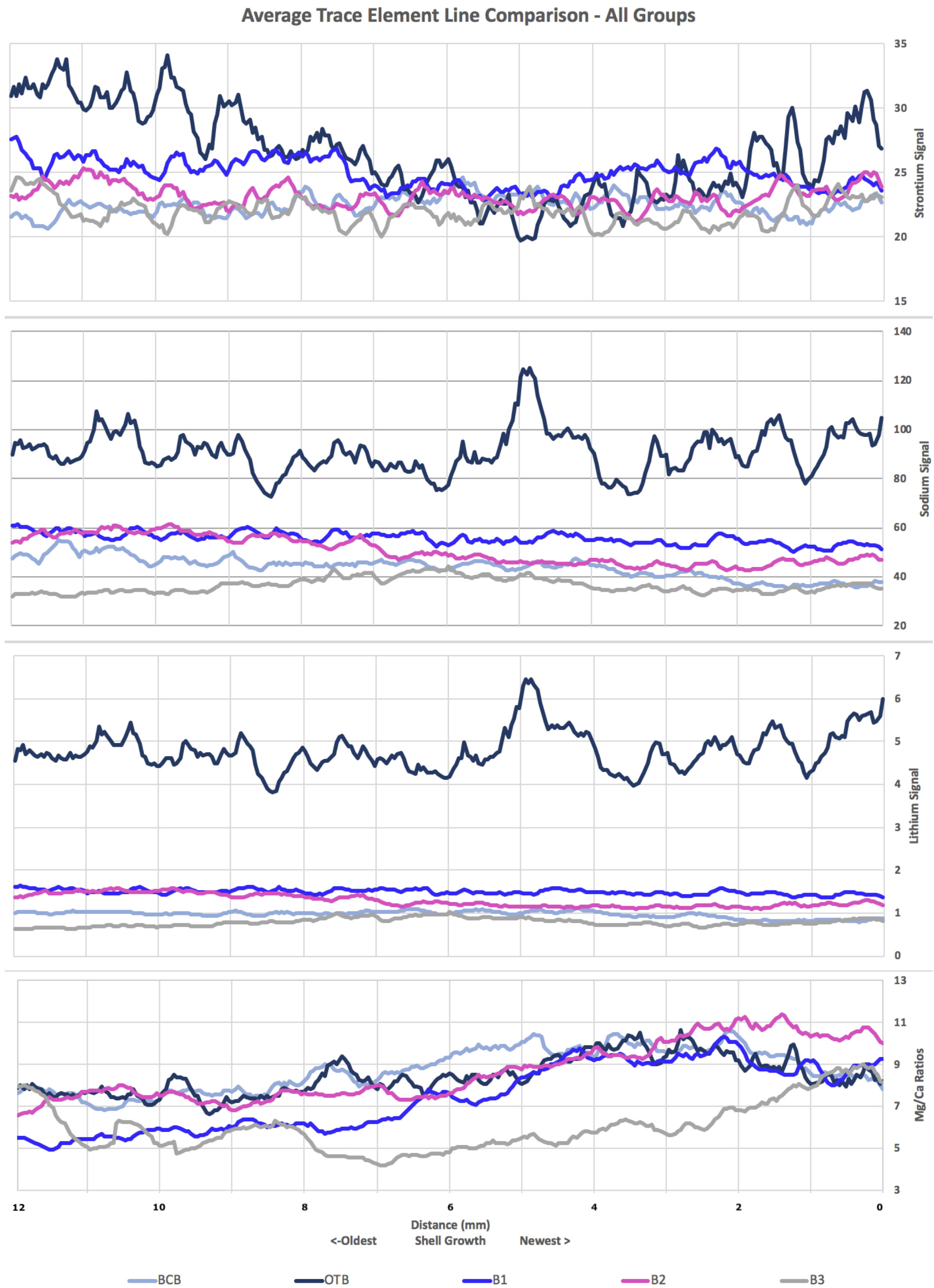

Figure A 7. Averaged trace element line for all groups.

Special Activity License

Florida Fish and Wildlife Conservation Commission
Division of Marine Fisheries Management
620 S. Meridian St., Mail Station 4B3, Tallahassee, Florida 32399-1600
Phone: 850-487-0554 • email: SAL@MyFWC.com
http://myfwc.com/license/saltwater/special-activities/

Issued To: Jaime Rogers
University of Central Florida

License Number: SAL-17-1962-SR
Effective Date: 10/16/2017
Expiration Date: 10/15/2018

Purpose: Collection of marine organisms for scientific research purposes pursuant to 68B-8, F.A.C.

Project Title: Microscale Environmental Change and Occupational Variability of Tampa Bay During the Woodland Period: A High Resolution Analysis of Trace Elements and Stable Isotopes from *Crassostrea virginica*.

Licensee Signature *Jaime Rogers* Date October 16, 2017

Not valid unless signed. By signature, confirms that all information provided to issue the license is accurate and complete, and indicates acceptance and understanding of the provisions and conditions listed below. **Any false statements or misrepresentations when applying for this license may result in felony charges and will result in revocation of this license.**

Authorized by: Pamela Gruver, Biological Scientist IV for: Nick Wiley, Executive Director

Authorizing Signature *Pamela Gruver* Date October 16, 2017

Authorized Activities: Authorized to permanently retain up to thirty (30) eastern oysters (*Crassostrea virginica*), of any size, with waiver of seasonal, fishery and area closures, size and bag limits.

Authorized Locations: State waters of Pinellas County, with the following specifications and exceptions:

1) This license does not authorize any activity in federal waters, unless species-specific state regulations are extended into federal waters.
2) This license does not authorize any activity within any state park, unless a state park permit has been obtained from the Florida Department of Environmental Protection, Division of Recreation and Parks.
3) This license does not authorize any activity within any federal park, unless a federal park permit has been obtained from the National Park Service.

Authorized Personnel: Jaime A. Rogers.

Authorized Gear: Hand collection only.

Figure A 8. Special Activity License.

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APPENDIX:B ADDITIONAL TABLES

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Table A 1. Radiocarbon dates from Yat Kitischee (Austin 1995:Table 3.1).

Sample No. (Beta)	Provenience (cmbd)	Material	Radiocarbon Age[a]	^{13}C Adjusted Age[b]	Cal. Date Range[c]	Cal. Mean Date[d]
53533	829.5N/925E Zone A1; 10-20	Shell	880 ± 60 BP	1250 ± 60 BP	AD 1070-1240	AD 1175
53534	829.5N/925E Zone A2; 39-49	Shell	970 ± 50 BP	1340 ± 50 BP	AD 1020-1125	AD 1050
53535	910N/910E Zone B1; 10-20	Shell	1170 ± 60 BP	1520 ± 60 BP	AD 810-970	AD 890
76969	912N/914E Zone B1; Fea. 12	Charcoal	1180 ± 40 BP	1160 ± 40 BP	AD 865-960	AD 885
81074	912N/914E Zone B2; 1.22 m	Shell	860 ± 50 BP	1290 ± 50 BP	AD 1050-1200	AD 1125
535536	910N/910E Zone B2; 47-53	Shell	1490 ± 60 BP	1850 ± 60 BP	AD 495-640	AD 575
76967	910N/912E Zone B2; Fea. 30	Charcoal	1750 ± 70 BP	1720 ± 70 BP	AD 245-415	AD 350
81073	914N/914E Zone B3; 0.99 m	Shell	820 ± 70 BP	1260 ± 70 BP	AD 1065-1240	AD 1170
76965	908N/914E Zone B3; Fea. 10	Charcoal	1780 ± 110 BP	1750 ± 110 BP	AD 145-420	AD 290
76966	910N/912 E Zone B3; Fea. 32	Charcoal	1810 ± 90 BP	1770 ± 90 BP	AD 145-395	AD 250
76968	906N/912E Zone B3; Fea. 38	Charcoal	1870 ± 120 BP	1820 ± 120 BP	AD 75-380	AD 225
76964	908N/914E Zone B3; Fea. 11	Charcoal	1980 ± 70 BP	1960 ± 70 BP	20 BC – AD 120	AD 65
76963[e]	906N/914E Zone C1; Fea. 6	Charcoal	1070 ± 50 BP[e]	1040 ± 50 BP[e]	AD 980-1025[e]	AD 1005[e]
76962	910N/910E Zone C1; Fea. 1	Charcoal	2040 ± 130 BP	2020 ± 130 BP	180 BC-AD 120	5 BC

a = Uncalibrated ages in years before AD 1950 ± 1 standard deviation

b = Correction for δ13/12C resulting from isotopic fractionation. Ages are in years before AD 1950 ± 1 standard deviation.

c = Dendrocalibrated dates ranges (± 1 standard deviation)

d = Calibrated mean calendrical date as determined by the intercept of the mean radiocarbon age with the calibrated curve

e = Out of place stratigraphically and likely the result of a later root intrusion.

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Table A 2. Raw isotope data (‰) (n=96).

SHELL ID	SAMPLE	O18	C14	SHELL ID	SAMPLE	O18	C14
OTB_C	1	0.98	-5.77	**B2_A**	1	-0.04	-3.59
OTB_C	2	0.84	-6.78	**B2_A**	2	0.03	-3.04
OTB_C	3	-1.40	-7.09	**B2_A**	3	0.92	-2.12
OTB_C	4	-0.93	-6.60	**B2_A**	4	0.73	-2.31
OTB_C	5	0.50	-5.78	**B2_A**	5	1.25	-2.89
OTB_C	6	1.06	-6.44	**B2_A**	6	0.96	-3.41
OTB_D	1	0.31	-6.50	**B2_F**	1	0.26	-3.48
OTB_D	2	0.94	-5.50	**B2_F**	2	0.20	-3.84
OTB_D	3	1.03	-6.11	**B2_F**	3	-0.26	-3.54
OTB_D	4	1.02	-6.39	**B2_F**	4	0.01	-3.21
OTB_D	5	1.47	-6.33	**B2_F**	5	0.32	-3.20
OTB_D	6	1.30	-6.09	**B2_F**	6	-0.22	-3.43
OTB_H	1	-1.11	-7.50	**B2_H**	1	0.10	-4.80
OTB_H	2	-1.17	-7.50	**B2_H**	2	0.60	-4.56
OTB_H	3	-0.28	-6.75	**B2_H**	3	1.23	-3.79
OTB_H	4	1.40	-5.50	**B2_H**	4	1.19	-4.61
OTB_H	5	1.56	-5.48	**B2_H**	5	0.00	-5.26
OTB_H	6	1.19	-5.67	**B2_H**	6	0.13	-3.98
OTB_I	1	-2.52	-7.63	**B2_I**	1	0.22	-3.54
OTB_I	2	-1.42	-7.67	**B2_I**	2	1.42	-2.82
OTB_I	3	0.33	-6.42	**B2_I**	3	1.30	-2.79
OTB_I	4	-0.25	-6.48	**B2_I**	4	-0.81	-4.64
OTB_I	5	1.15	-5.75	**B2_I**	5	0.05	-4.51
OTB_I	6	1.17	-6.48	**B2_I**	6	1.35	-4.03
B1_B	1	-1.10	-3.83	**B3_B**	1	0.39	-3.51
B1_B	2	0.51	-3.49	**B3_B**	2	1.17	-3.22
B1_B	3	-0.27	-3.78	**B3_B**	3	1.22	-3.42
B1_B	4	-0.22	-3.85	**B3_B**	4	-0.33	-3.62
B1_B	5	-0.59	-2.98	**B3_B**	5	-0.61	-4.58
B1_B	6	-0.05	-3.29	**B3_B**	6	0.89	-3.53
B1_E	1	1.26	-3.22	**B3_C**	1	1.08	-2.71
B1_E	2	0.23	-2.57	**B3_C**	2	1.10	-2.46
B1_E	3	0.16	-3.92	**B3_C**	3	1.63	-2.34
B1_E	4	-0.53	-4.11	**B3_C**	4	1.89	-2.55
B1_E	5	-0.68	-5.00	**B3_C**	5	1.16	-1.95
B1_E	6	-1.23	-4.46	**B3_C**	6	1.32	-2.13
B1_G	1	0.89	-3.35	**B3_D**	1	0.90	-2.43
B1_G	2	0.89	-3.34	**B3_D**	2	1.12	-2.06
B1_G	3	0.85	-3.74	**B3_D**	3	1.77	-2.99
B1_G	4	-0.10	-4.10	**B3_D**	4	0.82	-3.51
B1_G	5	0.11	-4.24	**B3_D**	5	1.49	-2.94
B1_G	6	-1.01	-4.55	**B3_D**	6	0.62	-3.16
B1_H	1	0.20	-4.13	**B3_E**	1	-1.41	-5.77
B1_H	2	-0.26	-2.80	**B3_E**	2	0.23	-3.74
B1_H	3	0.76	-3.02	**B3_E**	3	0.77	-2.88
B1_I	1	0.34	-3.88	**B3_E**	4	1.27	-3.58
B1_I	2	0.16	-3.73	**B3_E**	5	0.82	-2.48
B1_I	3	-0.96	-3.52	**B3_E**	6	1.11	-3.16

Table A 3. Correlation results for B2_A and B2_B.

Shell B2_A: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.695**			
Li1	.207	1.000				-.480**		
Na1	-.034	.899**	1.000				-.316*	
Sr1	-.259	.558**	.738**	1.000				-.574**
Mg2					1.000			
Li2					-.080	1.000		
Na2					-.209	.919**	1.000	
Sr2					.235	.535**	.460**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.670**			
Li1	-.354**	1.000				.465**		
Na1	-.342**	.971**	1.000				.565**	
Sr1	.254**	.369**	.432**	1.000				.256**
Mg2					1.000			
Li2					-.119	1.000		
Na2					-.072	.936**	1.000	
Sr2					.084	.389**	.540**	1.000
N = 300	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.896**			
Li1	-.062	1.000				.378**		
Na1	-.014	.960**	1.000				.433**	
Sr1	.023	.423**	.524**	1.000				.043
Mg2					1.000			
Li2					-.020	1.000		
Na2					-.026	.939**	1.000	
Sr2					.006	.376**	.551**	1.000
Shell B2_B: Line 1 and 2 Correlations (50; 150; 276)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.848**			
Li1	-.306*	1.000				.336*		
Na1	-.389**	.931**	1.000				.031	
Sr1	.514**	.142	.172	1.000				.609**
Mg2					1.000			
Li2					-.075	1.000		
Na2					-.039	.962**	1.000	
Sr2					.366**	-.282*	-.254	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.955**			
Li1	-.466**	1.000				.692**		
Na1	-.483**	.942**	1.000				.641**	
Sr1	-.124	.398**	.542**	1.000				.528**
Mg2					1.000			
Li2					-.679**	1.000		
Na2					-.711**	.987**	1.000	
Sr2					-.302**	.543**	.549**	1.000
N = 276	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.942**			
Li1	-.520**	1.000				.810**		
Na1	-.529**	.985**	1.000				.785**	
Sr1	.119	.166**	.218**	1.000				.532**
Mg2					1.000			
Li2					-.522**	1.000		
Na2					-.523**	.989**	1.000	
Sr2					.067	.307**	.359**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

`

Table A 4. Correlation results for B2_D and B2_F.

Shell B2_D: Line 1 and 2 Correlations (50; 150; 299)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.911**			
Li1	.780**	1.000				.840**		
Na1	.772**	.990**	1.000				.775**	
Sr1	.812**	.827**	.856**	1.000				.711**
Mg2					1.000			
Li2					.871**	1.000		
Na2					.868**	.989**	1.000	
Sr2					.851**	.883**	.867**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.692**			
Li1	.113	1.000				.844**		
Na1	.049	.954**	1.000				.792**	
Sr1	.346**	.496**	.560**	1.000				.290**
Mg2					1.000			
Li2					.449**	1.000		
Na2					.355**	.981**	1.000	
Sr2					.610**	.526**	.480**	1.000
N = 299	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.758**			
Li1	-.254**	1.000				.691**		
Na1	-.279**	.959**	1.000				.678**	.
Sr1	-.079	.745**	.764**	1.000				.451**
Mg2					1.000			
Li2					-.159**	1.000		
Na2					-.202**	.955**	1.000	
Sr2					.107	.708**	.688**	1.000
Shell B2_F: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.151			
Li1	.166	1.000				.066		
Na1	.403**	.887**	1.000				.263	
Sr1	.782**	-.287*	.020	1.000				.219
Mg2					1.000			
Li2					.318*	1.000		
Na2					.417**	.986**	1.000	
Sr2					.486**	.594**	.614**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.300**			
Li1	-.344**	1.000				.333**		
Na1	-.194*	.940**	1.000				.201*	
Sr1	-.403**	.523**	.625**	1.000				.256**
Mg2					1.000			
Li2					-.259**	1.000		
Na2					-.047	.948**	1.000	
Sr2					-.058	.751**	.770**	1.000
N = 300	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.683**			
Li1	-.640**	1.000				.507**		
Na1	-.578**	.962**	1.000				.475**	
Sr1	-.277**	.547**	.555**	1.000				.243**
Mg2					1.000			
Li2					-.446**	1.000		
Na2					-.325**	.960**	1.000	
Sr2					-.189**	.667**	.652**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

Table A 5. Correlation results for B2_G and B2_H.

Shell B2_G: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				-.122			
Li1	.458**	1.000				.083		
Na1	.511**	.949**	1.000				.244	
Sr1	.667**	.731**	.821**	1.000				.405**
Mg2					1.000			
Li2					.684**	1.000		
Na2					.740**	.944**	1.000	
Sr2					.817**	.818**	.841**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.831**			
Li1	.365**	1.000				.137		
Na1	.297**	.971**	1.000				.113	
Sr1	-.076	.584**	.661**	1.000				.363**
Mg2					1.000			
Li2					.405**	1.000		
Na2					.519**	.943**	1.000	
Sr2					.403**	.534**	.569**	1.000
N = 300	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.712**			
Li1	.399**	1.000				.173**		
Na1	.326**	.946**	1.000				.260**	
Sr1	.079	.009	.021	1.000				.621**
Mg2					1.000			
Li2					-.017	1.000		
Na2					-.010	.974**	1.000	
Sr2					.534**	-.104	-.162**	1.000
Shell B2_H: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.325*			
Li1	.584**	1.000				.075		
Na1	.582**	.893**	1.000				-.383**	
Sr1	.432**	.432**	.695**	1.000				-.801**
Mg2					1.000			
Li2					.708**	1.000		
Na2					.622**	.973**	1.000	
Sr2					.605**	.891**	.919**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.457**			
Li1	.367**	1.000				.083		
Na1	.299**	.935**	1.000				.111	
Sr1	.233**	.350**	.375**	1.000				-.216**
Mg2					1.000			
Li2					.172*	1.000		
Na2					.157	.955**	1.000	
Sr2					.207*	.644**	.624**	1.000
N = 300	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.607**			
Li1	.328**	1.000				.224**		
Na1	.271**	.937**	1.000				.284**	
Sr1	.369**	.527**	.579**	1.000				.432**
Mg2					1.000			
Li2					-.017	1.000		
Na2					.031	.941**	1.000	
Sr2					.282**	.555**	.613**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

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Table A 6. Correlation results for B2_J and B2_K.

Shell B2_J: Line 1 and 2 Correlations (50; 150; 299)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.839**			
Li1	.913**	1.000				.444**		
Na1	.902**	.969**	1.000				.583**	
Sr1	.925**	.913**	.870**	1.000				.676**
Mg2					1.000			
Li2					.323*	1.000		
Na2					.436**	.916**	1.000	
Sr2					.835**	.663**	.808**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.434**			
Li1	.461**	1.000				.422**		
Na1	.487**	.974**	1.000				.446**	
Sr1	.636**	.298**	.356**	1.000				.312**
Mg2					1.000			
Li2					.173*	1.000		
Na2					.164*	.933**	1.000	
Sr2					.749**	.268**	.315**	1.000
N = 299	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.882**			
Li1	-.532**	1.000				.697**		
Na1	-.537**	.980**	1.000				.699**	
Sr1	-.256**	.658**	.651**	1.000				.516**
Mg2					1.000			
Li2					-.609**	1.000		
Na2					-.639**	.974**	1.000	
Sr2					-.186**	.618**	.630**	1.000
Shell B2_K: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.019			
Li1	.740**	1.000				-.321*		
Na1	.859**	.932**	1.000				-.082	
Sr1	.745**	.530**	.684**	1.000				-.180
Mg2					1.000			
Li2					.125	1.000		
Na2					.226	.952**	1.000	
Sr2					.532**	.487**	.586**	1.000
N = 150	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				-.492**			
Li1	.079	1.000				-.193*		
Na1	.019	.896**	1.000				-.233**	
Sr1	.586**	-.088	.008	1.000				.143
Mg2					1.000			
Li2					.081	1.000		
Na2					.005	.928**	1.000	
Sr2					-.121	.544**	.676**	1.000
N = 300	**Mg1**	**Li1**	**Na1**	**Sr1**	**Mg2**	**Li2**	**Na2**	**Sr2**
Mg1	1.000				.708**			
Li1	-.542**	1.000				-.027		
Na1	-.556**	.925**	1.000				.004	
Sr1	.580**	-.108	-.047	1.000				.252**
Mg2					1.000			
Li2					-.015	1.000		
Na2					-.071	.919**	1.000	
Sr2					.618**	.360**	.412**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

Table A 7. Correlation results for B2_L and B2_M.

Shell B2_L: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				-.173			
Li1	.177	1.000				-.224		
Na1	.243	.984**	1.000				-.227	
Sr1	.465**	.618**	.678**	1.000				.155
Mg2					1.000			
Li2					-.038	1.000		
Na2					-.146	.951**	1.000	
Sr2					.420**	.495**	.349*	1.000
N = 150	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				.704**			
Li1	.743**	1.000				.622**		
Na1	.715**	.988**	1.000				.599**	
Sr1	-.315**	-.089	-.037	1.000				.639**
Mg2					1.000			
Li2					.806**	1.000		
Na2					.808**	.991**	1.000	
Sr2					-.421**	-.455**	-.437**	1.000
N = 300	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				.640**			
Li1	.680**	1.000				.729**		
Na1	.658**	.994**	1.000				.743**	
Sr1	-.023	.090	.117*	1.000				.525**
Mg2					1.000			
Li2					.616**	1.000		
Na2					.608**	.992**	1.000	
Sr2					-.215**	-.141*	-.127*	1.000
Shell B2_M: Line 1 and 2 Correlations (50; 150; 300)								
N = 50	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				.335*			
Li1	.670**	1.000				.379**		
Na1	.328*	.888**	1.000				.252	
Sr1	.699**	.462**	.294*	1.000				-.006
Mg2					1.000			
Li2					.786**	1.000		
Na2					.880**	.936**	1.000	
Sr2					.531**	.198	.385**	1.000
N = 150	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				.552**			
Li1	-.009	1.000				-.130		
Na1	-.191*	.924**	1.000				-.008	
Sr1	.572**	.126	.065	1.000				.304**
Mg2					1.000			
Li2					.522**	1.000		
Na2					.434**	.913**	1.000	
Sr2					.666**	.118	.117	1.000
N = 300	Mg1	Li1	Na1	Sr1	Mg2	Li2	Na2	Sr2
Mg1	1.000				.315**			
Li1	.033	1.000				.341**		
Na1	-.190**	.926**	1.000				.597**	
Sr1	.563**	.506**	.404**	1.000				.043
Mg2					1.000			
Li2					-.377**	1.000		
Na2					-.560**	.931**	1.000	
Sr2					.628**	-.013	-.113	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

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Table A 8. Descriptive statistics for each line (Mg/Ca).

ID	N	Mean	SD	95% Lower Bound	95% Upper Bound	Min	Max
OTB_A	748	8.348	2.233	8.188	8.508	3.88	12.80
OTB_B	552	6.167	1.583	6.034	6.299	3.91	12.59
OTB_C	728	7.342	1.311	7.246	7.437	5.00	10.89
OTB_D	434	6.274	1.619	6.121	6.427	4.37	11.44
OTB_E	768	7.158	2.021	7.014	7.301	3.95	11.87
OTB_F	351	4.269	0.740	4.191	4.347	3.33	6.19
OTB_G	258	4.678	1.468	4.498	4.858	3.53	12.17
OTB_H	459	10.566	4.371	10.165	10.967	3.68	18.87
OTB_I	762	10.789	4.129	10.494	11.081	3.39	21.17
OTB_J	940	8.285	1.235	8.206	8.364	5.36	12.92
B1_A	779	6.835	2.216	6.679	6.991	3.453	12.778
B1_B	671	6.581	3.481	6.317	6.844	3.222	18.807
B1_C	259	4.277	0.606	4.203	4.351	3.218	5.678
B1_D	701	12.147	5.678	11.798	12.824	3.340	46.552
B1_E	611	8.033	3.851	7.727	8.339	3.150	17.514
B1_F	361	4.194	0.643	4.128	4.261	2.807	6.520
B1_G	501	12.096	6.657	11.512	12.681	4.844	28.019
B1_H	391	7.604	3.154	7.291	7.917	2.857	16.797
B1_I	496	9.038	2.547	8.814	9.264	5.207	16.823
B1_J	441	5.346	2.110	5.148	5.543	3.051	12.087
B2_A	458	5.225	2.054	5.036	5.413	2.729	12.035
B2_B	276	8.341	3.968	7.869	8.814	3.316	19.854
B2_C	501	6.952	3.430	6.651	7.524	3.073	19.444
B2_D	371	7.830	2.187	7.606	8.053	3.924	14.343
B2_E	648	8.574	2.924	8.348	8.800	3.848	15.414
B2_F	421	9.362	1.830	9.186	9.537	5.520	14.288
B2_G	615	9.436	2.087	9.191	9.680	4.350	17.032
B2_H	743	9.381	2.727	9.815	9.578	4.614	18.523
B2_I	849	7.877	2.642	7.699	8.055	3.852	13.852
B2_J	299	9.471	2.923	9.138	9.803	3.404	14.715
B2_K	425	8.212	2.756	7.949	8.474	4.126	14.873
B2_L	300	5.330	2.284	5.070	5.589	2.627	14.356
B2_M	517	8.463	2.602	8.239	8.688	3.746	15.193
B3_A	245	8.327	4.625	7.745	8.909	2.777	15.974
B3_B	266	5.471	1.495	5.291	5.615	3.700	10.671
B3_C	296	4.815	1.109	4.688	4.942	3.429	8.021
B3_D	536	5.321	0.895	5.246	5.398	3.660	9.414
B3_E	295	6.162	2.333	5.895	6.429	3.482	14.349
B3_F	211	6.301	1.496	6.098	6.504	4.169	9.812
B3_G	266	5.342	1.938	5.107	5.576	3.249	11.257

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Table A 9. Descriptive statistics for each line (Li).

ID	N	Mean	SD	95% Lower Bound	95% Upper Bound	Min	Max
OTB_A	748	5.242	0.726	5.189	5.293	3.131	7.729
OTB_B	552	4.011	1.702	3.869	4.153	2.196	16.206
OTB_C	728	0.00008	0.001	0.00007	0.00008	0	0.0005
OTB_D	434	0.00005	0.00006	0.00004	0.00005	0	0.0002
OTB_E	768	0.001	0.001	0.00009	0.0001	0	0.0006
OTB_F	351	0.0003	0.0004	0.00002	0.0003	0	0.0002
OTB_G	258	0.0002	0.0003	0.00001	0.00002	0	0.0001
OTB_H	459	0.001	0.0026	0.0002	0.002	0	0.0011
OTB_I	762	0.0002	0.0025	0.0001	0.0001	0	0.0018
OTB_J	940	4.110	2.848	3.928	4.292	1.867	18.350
B1_A	779	1.894	0.245	1.876	1.911	1.393	2.702
B1_B	671	1.058	0.386	1.029	1.087	0.514	2.110
B1_C	259	1.327	0.244	1.297	1.357	0.766	1.913
B1_D	701	10.240	29.474	8.055	12.426	0.543	377.915
B1_E	611	1.350	0.373	1.321	1.380	0.749	2.791
B1_F	361	1.324	0.301	1.293	1.355	0.830	1.982
B1_G	501	1.728	0.466	1.687	1.769	0.985	3.084
B1_H	391	1.204	0.174	1.186	1.221	0.959	2.279
B1_I	496	1.127	0.156	1.113	1.140	0.790	1.547
B1_J	441	0.957	0.184	0.940	0.975	0.550	1.450
B2_A	458	1.104	0.161	1.089	1.118	0.698	1.564
B2_B	276	1.898	0.579	1.829	1.966	1.130	3.331
B2_C	501	1.834	0.424	1.797	1.871	1.075	3.209
B2_D	371	1.141	0.168	1.124	1.158	0.756	1.591
B2_E	648	1.429	0.159	1.413	1.438	0.972	1.981
B2_F	421	1.123	0.203	1.103	1.142	0.640	1.670
B2_G	615	1.394	0.167	1.380	1.407	0.945	1.971
B2_H	743	1.067	0.119	1.058	1.075	0.820	1.453
B2_I	849	1.079	0.135	1.070	1.089	0.671	1.441
B2_J	299	1.148	0.208	1.124	1.172	0.674	1.679
B2_K	425	1.097	0.208	1.077	1.118	0.457	1.787
B2_L	300	1.785	0.638	1.172	1.857	0.754	3.341
B2_M	517	1.021	0.139	1.009	1.034	0.612	1.377
B3_A	245	0.879	0.105	0.865	0.892	0.649	1.146
B3_B	266	0.616	0.108	0.603	0.629	0.426	0.913
B3_C	296	1.146	0.426	1.097	1.195	0.552	2.597
B3_D	536	0.837	0.154	0.824	0.850	0.505	1.297
B3_E	295	0.820	0.197	0.797	0.843	0.292	1.420
B3_F	211	0.587	0.140	0.568	0.606	0.370	1.062
B3_G	266	0.631	0.120	0.616	0.645	0.363	0.938

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Table A 10. Descriptive statistics for each line (Na).

ID	N	Mean	SD	95% Lower Bound	95% Upper Bound	Min	Max
OTB_A	748	78.641	10.391	77.895	79.387	51.013	115.313
OTB_B	552	66.498	24.666	64.436	68.560	38.524	248.533
OTB_C	728	1.976	0.399	1.946	2.005	1.019	3.152
OTB_D	434	1.644	0.556	1.592	1.697	0.950	3.386
OTB_E	768	1.936	1.103	1.858	2.014	0.772	8.920
OTB_F	351	0.888	0.232	0.863	0.912	0.551	1.464
OTB_G	258	0.679	0.198	0.654	0.703	0.473	1.541
OTB_H	459	2.967	1.360	2.842	3.092	0.682	5.474
OTB_I	762	2.923	1.290	2.831	3.014	0.549	6.227
OTB_J	940	93.858	54.404	90.376	97.341	50.964	357.019
B1_A	779	69.946	7.747	69.401	70.491	54.166	98.043
B1_B	671	43.889	11.599	43.009	44.768	26.400	76.236
B1_C	259	50.826	8.902	49.737	51.916	31.591	73.072
B1_D	701	341.066	956.904	270.107	412.026	30.619	12085.164
B1_E	611	49.341	11.322	48.441	50.240	31.464	90.030
B1_F	361	47.903	8.372	47.037	48.770	33.531	65.134
B1_G	501	62.416	14.948	61.104	63.728	38.232	105.067
B1_H	391	44.706	6.690	44.041	45.371	34.190	82.216
B1_I	496	47.503	4.835	47.076	47.926	36.279	61.600
B1_J	441	40.233	5.713	39.698	40.768	26.159	55.953
B2_A	458	44.200	5.215	43.721	44.679	32.352	60.385
B2_B	276	70.445	19.410	68.145	72.745	42.848	122.102
B2_C	501	67.725	14.646	66.439	69.010	42.957	114.340
B2_D	371	45.789	6.598	45.115	46.462	30.699	63.688
B2_E	648	47.746	5.506	47.321	48.171	33.474	64.063
B2_F	421	42.365	6.830	41.711	43.020	27.617	59.961
B2_G	615	54.390	5.858	53.926	54.854	36.633	73.170
B2_H	743	43.930	5.138	43.559	44.300	32.710	59.024
B2_I	849	46.605	5.163	46.257	46.953	31.917	62.010
B2_J	299	49.666	8.767	48.669	50.664	29.161	71.558
B2_K	425	46.255	7.671	45.523	46.986	26.094	72.237
B2_L	300	71.134	23.198	68.498	73.770	33.428	123.896
B2_M	517	44.084	6.207	43.548	44.621	25.429	60.381
B3_A	245	37.815	4.122	37.297	38.334	30.239	47.502
B3_B	266	32.027	4.575	31.474	32.579	22.449	45.098
B3_C	296	48.058	12.987	46.573	49.544	30.652	92.849
B3_D	536	39.284	5.362	38.829	39.739	27.389	54.269
B3_E	295	37.452	7.210	36.626	38.278	21.995	59.952
B3_F	211	28.978	5.628	28.214	29.742	21.354	45.266
B3_G	266	32.315	5.157	31.692	32.938	22.193	43.933

Table A 11. Descriptive statistics for each line (Sr).

ID	N	Mean	SD	95% Lower Bound	95% Upper Bound	Min	Max
OTB_A	748	25.123	3.995	24.836	25.410	17.959	38.910
OTB_B	552	29.563	4.580	29.180	29.946	18.431	43.749
OTB_C	728	0.350	0.086	0.343	0.356	0.133	0.575
OTB_D	434	0.281	0.081	0.273	0.289	0.162	0.480
OTB_E	768	0.257	0.085	0.251	0.263	0.114	0.465
OTB_F	351	0.186	0.035	0.182	0.190	0.122	0.266
OTB_G	258	0.139	0.019	0.137	0.141	0.104	0.211
OTB_H	459	0.443	0.164	0.428	0.458	0.145	0.906
OTB_I	762	0.247	0.095	0.240	0.254	0.108	0.562
OTB_J	940	28.832	4.350	28.554	29.111	16.145	42.128
B1_A	779	24.738	2.303	24.576	24.900	18.376	30.939
B1_B	671	23.176	1.852	23.035	23.316	18.454	28.949
B1_C	259	27.037	3.163	26.649	27.424	21.284	39.146
B1_D	701	23.011	6.445	22.533	23.488	1.628	94.328
B1_E	611	24.816	2.592	24.610	25.022	18.827	33.925
B1_F	361	24.708	3.103	24.386	25.029	17.652	32.318
B1_G	501	26.859	4.504	26.464	27.255	17.871	43.429
B1_H	391	21.755	2.119	21.545	21.966	16.226	27.580
B1_I	496	30.909	3.509	30.600	31.219	22.994	41.585
B1_J	441	28.426	4.634	27.992	28.860	17.098	38.631
B2_A	458	24.543	3.122	24.256	24.830	18.107	33.796
B2_B	276	22.010	3.585	21.585	22.434	14.070	40.181
B2_C	501	21.862	3.772	21.531	22.194	13.326	33.170
B2_D	371	25.699	2.944	25.399	26.000	20.236	36.633
B2_E	648	22.103	2.215	21.932	22.273	17.383	30.232
B2_F	421	22.332	2.426	22.099	22.564	17.373	28.803
B2_G	615	27.317	3.164	27.066	27.567	19.208	38.371
B2_H	743	24.021	3.599	23.761	24.280	16.956	37.258
B2_I	849	24.714	3.039	24.509	24.919	18.593	36.092
B2_J	299	20.961	2.821	20.640	21.282	15.435	28.323
B2_K	425	22.651	2.462	22.416	22.886	18.075	31.550
B2_L	300	23.980	5.627	23.341	24.619	14.686	49.040
B2_M	517	25.405	3.248	25.125	25.686	18.429	36.258
B3_A	245	23.345	2.204	23.068	23.623	18.102	27.414
B3_B	266	23.934	3.392	23.525	24.344	18.251	33.800
B3_C	296	20.806	1.850	20.595	21.018	16.851	27.389
B3_D	536	20.881	2.195	20.695	21.067	16.313	30.569
B3_E	295	24.308	3.091	23.953	24.662	17.813	34.175
B3_F	211	20.325	2.625	19.969	20.681	15.188	27.045
B3_G	266	20.270	1.925	20.038	20.503	16.393	27.015

Table A 12. Results of post-hoc Games-Howell Multiple Comparisons tests.

Games-Howell Multiple Comparisons							
Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Mg	BCB	OTB	0.2445	0.1451	0.444	-0.1527	0.6417
		B1	0.4874	0.1857	0.067	-0.0203	0.9951
		B2	-1.7472	0.13963	<0.001*	-2.1287	-1.3656
		B3	0.8774	0.19199	<0.001*	0.3522	1.4026
	OTB	BCB	-0.2445	0.1451	0.444	-0.6417	0.1527
		B1	0.2429	0.18076	0.664	-0.2517	0.7375
		B2	-1.9917	0.13299	<0.001*	-2.356	-1.6274
		B3	0.6329	0.18722	0.007	0.1204	1.1455
	B1	BCB	-0.4874	0.1857	0.067	-0.9951	0.0203
		OTB	-0.2429	0.18076	0.664	-0.7375	0.2517
		B2	-2.2346	0.1764	<0.001*	-2.7169	-1.7522
		B3	0.39	0.22018	0.391	-0.212	0.9921
	B2	BCB	1.7472	0.13963	<0.001*	1.3656	2.1287
		OTB	1.9917	0.13299	<0.001*	1.6274	2.356
		B1	2.2346	0.1764	<0.001*	1.7522	2.7169
		B3	2.6246	0.18301	<0.001*	2.1238	3.1254
	B3	BCB	-0.8774	0.19199	<0.001*	-1.4026	-0.3522
		OTB	-0.6329	0.18722	0.007	-1.1455	-0.1204
		B1	-0.39	0.22018	0.391	-0.9921	0.212
		B2	-2.6246	0.18301	<0.001*	-3.1254	-2.1238
Li	BCB	OTB	-4.2208	0.07304	<0.001*	-4.4224	-4.0192
		B1	-0.4626	0.0177	<0.001*	-0.511	-0.4142
		B2	-0.3623	0.01808	<0.001*	-0.4117	-0.3129
		B3	0.0412	0.0179	0.145	-0.0077	0.0902
	OTB	BCB	4.2208	0.07304	<0.001*	4.0192	4.4224
		B1	3.7582	0.07362	<0.001*	3.5551	3.9613
		B2	3.8585	0.07371	<0.001*	3.6551	4.0619
		B3	4.262	0.07367	<0.001*	4.0588	4.4653
	B1	BCB	0.4626	0.0177	<0.001*	0.4142	0.511
		OTB	-3.7582	0.07362	<0.001*	-3.9613	-3.5551
		B2	0.1003	0.02029	<0.001*	0.0449	0.1557
		B3	0.5038	0.02013	<0.001*	0.4488	0.5588
	B2	BCB	0.3623	0.01808	<0.001*	0.3129	0.4117
		OTB	-3.8585	0.07371	<0.001*	-4.0619	-3.6551
		B1	-0.1003	0.02029	<0.001*	-0.1557	-0.0449
		B3	0.4035	0.02047	<0.001*	0.3476	0.4594
	B3	BCB	-0.0412	0.0179	0.145	-0.0902	0.0077
		OTB	-4.262	0.07367	<0.001*	-4.4653	-4.0588
		B1	-0.5038	0.02013	<0.001*	-0.5588	-0.4488
		B2	-0.4035	0.02047	<0.001*	-0.4594	-0.3476

Games-Howell Multiple Comparisons							
Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Na	BCB	OTB	-57.5807	2.62343	<0.001*	-64.8219	-50.3396
		B1	-11.5097	0.5839	<0.001*	-13.1058	-9.9136
		B2	-9.2274	0.62122	<0.001*	-10.9248	-7.5301
		B3	1.6009	0.58474	0.05	0.0018	3.1999
	OTB	BCB	57.5807	2.62343	<0.001*	50.3396	64.8219
		B1	46.071	2.63805	<0.001*	38.7914	53.3507
		B2	48.3533	2.64657	<0.001*	41.0512	55.6553
		B3	59.1816	2.63824	<0.001*	51.9015	66.4617
	B1	BCB	11.5097	0.5839	<0.001*	9.9136	13.1058
		OTB	-46.071	2.63805	<0.001*	-53.3507	-38.7914
		B2	2.2822	0.68036	0.007	0.4233	4.1412
		B3	13.1106	0.64722	<0.001*	11.341	14.8801
	B2	BCB	9.2274	0.62122	<0.001*	7.5301	10.9248
		OTB	-48.3533	2.64657	<0.001*	-55.6553	-41.0512
		B1	-2.2822	0.68036	0.007	-4.1412	-0.4233
		B3	10.8283	0.68108	<0.001*	8.9669	12.6897
	B3	BCB	-1.6009	0.58474	0.05	-3.1999	-0.0018
		OTB	-59.1816	2.63824	<0.001*	-66.4617	-51.9015
		B1	-13.1106	0.64722	<0.001*	-14.8801	-11.341
		B2	-10.8283	0.68108	<0.001*	-12.6897	-8.9669
Sr	BCB	OTB	-5.1121	0.44181	<0.001*	-6.3299	-3.8943
		B1	-2.2192	0.20772	<0.001*	-2.787	-1.6514
		B2	-1.6128	0.18157	<0.001*	-2.1089	-1.1167
		B3	-0.3444	0.18571	0.343	-0.8521	0.1634
	OTB	BCB	5.1121	0.44181	<0.001*	3.8943	6.3299
		B1	2.8929	0.45561	<0.001*	1.6385	4.1473
		B2	3.4993	0.4443	<0.001*	2.2749	4.7237
		B3	4.7677	0.44601	<0.001*	3.5388	5.9967
	B1	BCB	2.2192	0.20772	<0.001*	1.6514	2.787
		OTB	-2.8929	0.45561	<0.001*	-4.1473	-1.6385
		B2	0.6064	0.21295	0.036	0.0244	1.1884
		B3	1.8748	0.2165	<0.001*	1.2829	2.4668
	B2	BCB	1.6128	0.18157	<0.001*	1.1167	2.1089
		OTB	-3.4993	0.4443	<0.001*	-4.7237	-2.2749
		B1	-0.6064	0.21295	0.036	-1.1884	-0.0244
		B3	1.2684	0.19155	<0.001*	0.7448	1.792
	B3	BCB	0.3444	0.18571	0.343	-0.1634	0.8521
		OTB	-4.7677	0.44601	<0.001*	-5.9967	-3.5388
		B1	-1.8748	0.2165	<0.001*	-2.4668	-1.2829
		B2	-1.2684	0.19155	<0.001*	-1.792	-0.7448

Based on observed means.

The error term is Mean Square (Error) = 11.083.

*. The mean difference is significant at the .05 level.

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