ARCHAEOLOGICAL EVIDENCE OF OYSTER MARICULTURE IN THE LOWER SUWANNEE REGION OF GULF COASTAL FLORIDA

By

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To Naomi Marrow, whose never ending support and encouragement has inspired me in this and every endeavor I have undertaken

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Archaeological evidence from oyster shells recovered from Shell Mound (8LV42), located in the Lower Suwannee region of Florida's Gulf Coast, indicates that maricultural practices were used by coastal inhabitants when the scale and intensity of oyster procurement increased during a time of ritual economy and mound-building activity from A.D. 550–650. Shell Mound was transformed from a quotient village site to a coastal civic-ceremonial center, likely related to the burial complex on Palmetto Mound (8LV2), during a time of environmental and sea-level uncertainty. The mound was constructed in less than two centuries, accumulating as many as 1.2 billion oysters. Mariculture, which has been in practice since at least 2,000 years ago, was likely practiced at Shell Mound as a mechanism to prevent over-exploitation of the resource and to sustain the local oyster reefs for daily subsistence, feasting, and mound construction. Analysis of 3,252 oyster shells from a single test unit that encompasses three phases of occupation shows that culling and shelling were practices used when the scale and intensity of oyster harvesting increased.

CHAPTER 1
INTRODUCTION

People began harvesting oysters on the Gulf Coast of Florida 7,200 years ago, and at about 2,000 years ago, the region was teeming with aboriginal communities that harvested oysters and collected the inedible remains in huge mounds and middens. The importance of oysters to ancient communities in the Lower Suwannee region of Florida is evidenced by the monumental architecture constructed from shell, numerous subsistence refuse middens, and the potential role of this resource in the regional political and ritual economy during feasting or pilgrimage events related to burial complexes such as Palmetto Mound (8LV2). Given the intensity of harvesting at this time, oyster populations may have declined or become depleted in certain areas, forcing communities unwilling or unable to relocate to find ways to sustain production, potentially through the use of maricultural practices.

In the broadest sense, mariculture can be defined as the manipulation of a marine resource for economic gain by humans. Mariculture incorporates management of marine resources or making any conscious decisions that could influence the resource, including choices about location, timing, catch limits, habitat enhancement, or transplantation the resource (Lepofsky and Caldwell 2013:2; Lepofsky et al. 2015:237). Maricultural practices can be as simple as shelling the bottom, or returning dead shell to known reefs to encourage recruitment of larval oyster, or spat, or as complex as creating a massive industry outfitted with specialized technology for the successful reproduction of marine resources.

Based on archaeological evidence, maritime management techniques are known to have been in place at least 2,000 years ago on the Northwest coast of North

America, supporting ethnographic accounts that management has long been practiced (Brown and Brown 2009; Lepofsky et al. 2015). Marine culturing and management techniques have also been described and documented in other parts of the world; such global archaeological evidence, combined with historical and ethnographic accounts, indicate that some sort of management of aquatic and marine resources was practiced in the past by coastal communities where resources were heavily exploited. Despite this, investigation into shellfish management, culturing, and cultivating practices has not been previously investigated on the eastern and Gulf coasts of North America, where numerous massive oyster shell mounds and middens populate the coast.

In the past few decades, archaeological shell of the oyster *Crassostrea virginica* has been analyzed for various other purposes including as an indicator of seasonality of site use (Custer and Doms 1990; Russo 1991), environmental changes such as drought (Harding et al. 2010), subsistence economies, including caloric and protein considerations (Erlandson 1988), harvesting strategies (Bird et al. 2004; Crook 1992), harvesting location (Schmidt and Haven 2004), and to further the goal of ecological reconstruction (Kirby 2004; Rick and Lockwood 2013). Some general conclusions reached are that oysters are not necessarily a seasonal food, but can be harvested and eaten year round (Russo 1991), and that oysters have a greater protein and caloric value in coastal subsistence economies than previously assumed (Erlandson 1988). While these findings further support the idea that oysters were an important subsistence resource, it is unclear how oyster populations, which are vulnerable to overharvesting due to their ease of accessibility, were maintained during times of intensive and sustained harvest.

There have been multiple studies in the archaeological literature that have dealt with the reality of overharvesting and declining oyster populations in estuarine settings (e.g. Erlandson et al. 2008; Lightfoot et al. 1993). Given the abandonment of coastal sites at various points in the past, some researchers have hypothesized that over-exploitation of natural oyster populations caused widespread economic collapse (e.g. Dame 2009; Mannino and Thomas 2002). Despite the evidence of resource decline in many estuarine settings, research has shown, though the analysis of archaeological oyster shell, that over-exploitation may not necessarily be the motivating factor of relocation (Doucet 2012). Furthermore, this hypothesis ignores the agency and resiliency of coastal communities in the face of challenging circumstances, especially as shellfish are ideal candidates for mariculture.

Oysters are easy to manipulate by humans as they are resilient, hardy, sessile, suspension feeding organisms that consume food low on the food chain (Castagna et al. 1996:676). For example, one culturing technique called relaying can be used to move oysters from intertidal to subtidal conditions, so that oysters grow faster and have a better meat quality. A similar culturing technique is to transplant oysters from areas of high salinity, where they are vulnerable to parasitic and predatory attack, to areas of lower salinity where many oyster predators and parasites cannot survive.

Possible reasoning for the lack of research into oyster culturing practices of coastal peoples who heavily harvested oysters is that signs of oyster maricultural practices in the archaeological record may be ephemeral. Whereas in other parts of the world there is tangible archaeological evidence of culturing practices (such as the clam gardens on the Northwest coast and the fishponds of the Native Hawaiian agriculturalists), no research has endeavored to establish if similar management processes are archaeologically evident on the eastern and Gulf coasts of North America.

Archaeological oyster shell offers a unique avenue of assessment into pre-Columbian subsistence practices, as they represent almost perfect indicators of the environment in which the harvested oysters grew. This is important because, in order to successfully cultivate the resource, ideal conditions must be known for the organism's productivity and success during different life stages. By careful analysis, archaeologists are able to infer ecological conditions under which oysters grew, such as salinity levels, tidal conditions (intertidal versus subtidal), and substrate. Other attributes of oyster shells allow assessment of the relative health of the oyster when harvested or whether the oyster was alive or dead upon collection. With the use of maricultural techniques, these ecological variables can be manipulated by humans not only to sustain oyster populations in times of intensive harvesting, but also to produce the "ideal oyster" in terms of nutrition and taste.

The hypothesis of this thesis is that if coastal populations in the Lower Suwannee regularly and intensively harvested oysters during times of increased sedentism 2,000 years ago, maricultural practices were employed to sustain the resource. To test this hypothesis, archaeological shell from Shell Mound (8LV42) in the Lower Suwannee region of Florida was evaluated for indications of oyster harvesting and culturing practices.

The area of focus for this study is the Lower Suwannee region of the northern Gulf Coast of Florida (Figure 1-1). The study location encompasses a 47 kilometer

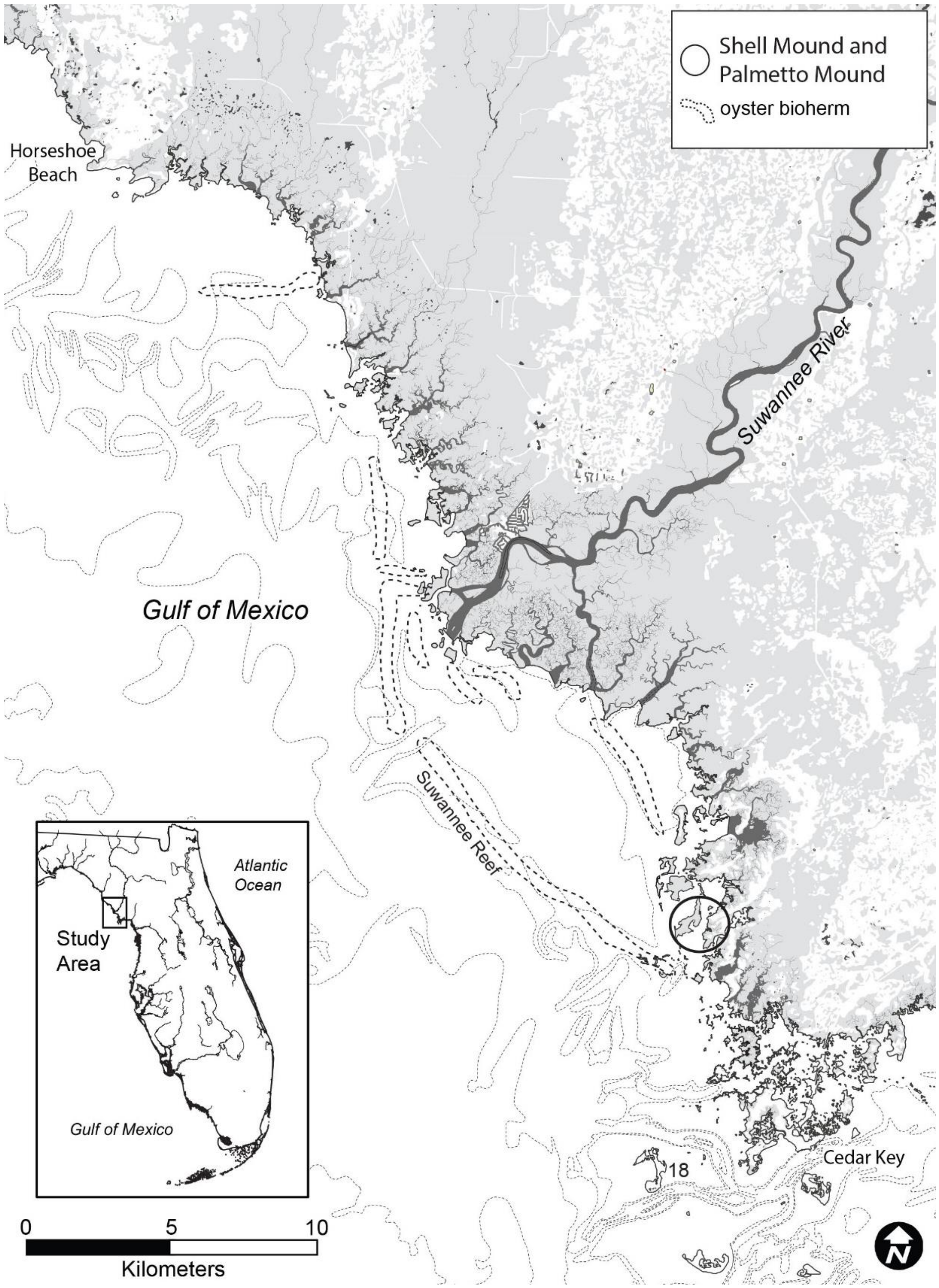

Figure 1-1. Map of the Lower Suwannee Archaeological Survey study area (image adapted from Sassaman et al. 2016).

stretch of Gulf coastal lands and surrounding islands of Dixie and Levy counties, and was designed as part of a research endeavor known as the Lower Suwannee Archaeological Survey conducted by the Laboratory of Southeastern Archaeology at the University of Florida. The research area is bounded by Horseshoe Beach to the north and Cedar Key to the south, with the Suwannee River in the middle of the coast. This coastline is particularly attractive for sustained settlement because of the plethora of exploitable resources produced by a rich estuarine and intertidal environment. Notable among the resources of economic value to humans is the Eastern Oyster (*Crassostrea virginica*).

Although the specifics of environmental change are debated, the Gulf Coast has been subject to periods of sea-level rise and transgression along with periods of drier conditions during the late Pleistocene and wetter conditions during the Holocene (Wright et al. 2005:621). Sea levels have risen ~100 meters since the end of the Ice Age, which has resulted in the flooding of about half of the original Florida peninsula (Sassaman et al. 2011:1). Environmental changes such as this have affected the type and availability of marine resources, including oysters. Sea-level rise decelerated during the middle to late Holocene, with an average rise of ~0.16 cm/year between 7500 and 5500 cal yr B.P., to ~0.07 cm/year between 5500 and 2500 cal yr B.P., and slowing to ~0.05 cm/year between 2500 and 750 cal yr B.P. (Wright et al. 2005:631). Hine et al. (1988) propose that this sea-level rise deceleration established the modern coastline of the Lower Suwannee and allowed for the establishment of oyster reefs, or bioherms.

From what can be understood archaeologically about the region from sites that are not submerged due to rising sea level, the Lower Suwannee has been a region of occupation for people, perhaps in greater numbers than that of today, starting at least 4,500 years ago (Sassaman et al. 2011). The study area once consisted of at least 20 earthen mounds, two large shell mounds, smaller mounds, linear ridges, and large U-shaped middens, many of which are now destroyed because of sea level transgression (Sassaman et al. 2011:12).

Of particular importance to this study is the Woodland period site of Shell Mound (8LV42), 10 kilometers north of Cedar Key. Shell Mound is the largest and most formalized above-ground mound in the research area, being 190 x 180 meters in plan and about 7 meters tall. The mound is comprised primarily of oyster shell, with an estimate of between 420 million and 1.2 billion oysters being deposited in the mound in less than two centuries (manuscript on file at LSA). This mound is one of about two-dozen archaeological sites in the vicinity, many of which are arcuate and linear shell ridges. Oyster shell from bulk samples recovered from a deeply stratified test unit at the apex of Shell Mound provide the samples used in this research.

In terms of the structure of this thesis, Chapter 2 describes aspects of mariculture from the present to archaeological evidence of past aquatic management practices from various places around the world. In this chapter, the importance of “farming the sea” is emphasized, especially among ancient non-agricultural societies, in order to propagate the regular harvesting of important marine resources. In this chapter, relevant biological and ecological factors affecting oyster populations and mariculture are described. An intimate understanding of these variables is crucial for the successful management of oyster populations as well as a nuanced interpretation of archaeological data. Furthermore, due to the dynamic nature of estuarine settings, the ecology of the Lower

Suwannee estuary is described. Chapter 3 outlines the archaeological and cultural history of the study area as well as the recent excavations in the Lower Suwannee, focusing primarily on Shell Mound and Palmetto Mound. Within this chapter, the chronology of the Shell Mound is established by century (A.D. 200-700) based on radiocarbon dates and excavation results. Chapter 4 explains the sampling strategy and methodology employed to collect relevant data pertaining to oyster harvesting and possible management practices. Chapter 5 reveals the results of the research as well as discusses the results in a broader context. Chapter 6 concludes the thesis with recommendations for future research based data that can be extrapolated from archaeological oyster shell.

CHAPTER 2
OYSTER ECOLOGY AND MARICULTURE PAST AND PRESENT

Introduction

Aquaculture is the "husbandry of aquatic animals and plants," and mariculture specifies the husbandry or culturing of marine animals and plants, such as shellfish and finfish (National Resource Council 1992:9). According to the National Research Council on Marine Aquaculture, there is evidence of aquaculture from the earliest records of human history, and it is a rapidly growing industry in many parts of the world today (1992:9). Mariculture, also called "farming the sea," specifically refers to human intervention in naturally existing conditions, and therefore requires, "understanding and controlling the environment in order to obtain a greater yield of a desirable product from a given area" (McKee 1969:4). It is also argued that oyster culturing is the oldest form of mariculture practiced in the United States, where, "virtually all oyster production…involves some human intervention and manipulation, however primitive, and therefore a form of aquaculture" (National Resource Council 1992:29).

Mariculture is being used today in many parts of the world as important natural marine populations have been rapidly declining. For example, oyster reefs have declined 85 percent from historic levels worldwide, and the oyster industry has been in steady decline for over 70 years (National Research Council 1992; Seavey et al. 2011). Among the reasons for such decline are disease epidemics, pollution, and blooms of toxic algae, but the primary reasons are overfishing and habitat loss (National Research Council 1992:29). To respond to these issues, especially those concerning public health, many oyster beds have been closed to harvesting, although people are now taking advantage of the opportunity to use mariculture in order to revitalize oyster production. Management efforts to restore oyster reefs include conservation of available shell stock for replanting as cultch, protection of spat through cull laws, seasonal closures or the protection of productive areas, and restrictions on harvesting gear (Castagna et al. 1996:675). Despite these efforts, oyster populations have not fully rebounded, and as of a 1992 report, the U.S. marine aquaculture industry had not sufficiently demonstrated long-term economic viability (National Research Council 1992:9).

Historically important locations of oyster production on Florida's Gulf Coast are not immune to the overall global decline and collapse of oyster reefs. For example, Apalachicola Bay, the Suwannee Sound, and Tampa Bay have all been suffering from natural and anthropogenic effects on local reefs, hindering large-scale commercial production of oysters in these areas (Seavey et al. 2011). Recently, local community mariculture endeavors as well as harvesting laws have been enacted to protect and sustain what is left natural reefs for hopeful future proliferation (Castangna et al. 1996).

Although reasons for the declining oyster production in the past may be different from that of today, maricultural practices may have been very similar. For example, although oysters did not suffer from the same pollution that is destroying reefs today, reefs of the ancient past were affected by ecologically stressful events and large-scale exploitation. Since at least 4,500 years ago, Florida's Gulf Coast experienced impactful environmental change, including periods of drought and flooding, climate change, and sea level rise and regression (McFadden 2015; Sassaman and Wallis 2015; Wright et al. 2005). All of these changes affect the type and availability of marine resources and create differentiated access for humans to economically viable oyster reefs through time. Unstable conditions in the Gulf create stressful conditions for oysters to live in; the stress on their populations is exacerbated by regular, heavy, and at times intensified, exploitation, further weakening oyster reefs, making them susceptible to collapse.

Cultivating oysters is not only important in order to sustain exploitation by coastal peoples, but also because oysters are a keystone species, meaning that they provide many essential ecological services such as maintaining food webs, regulating water quality, creating habitat for numerous fish, crustacean, bivalve, mollusk, and gastropod species to survive, and protection coastal lands (Beck 2011; Kennedy 1996; Kilgen and Dugas 1989). Oyster shells were also used by pre-Columbian people as building material, in mortuary practices, and as tools and ornamentation. Because of their significance in many aspects of life, the maintenance of oyster populations is a priority for long-term coastal occupation by ancient and modern coastal peoples alike.

Archaeological evidence of mariculture is apparent in many parts of the world, where coastal communities of the past implemented management practices to sustain marine exploitation (Nash 2011; Lepofsky et al. 2015). Both shellfish and fish were cultivated, and the cultivation practices not only affected the resource, but also had important cultural and political implications for non-agricultural communities, making research into possible culturing practices valuable to broader archaeological interpretation (i.e., Grier 2014).

Several points are discussed in this chapter that are critical for interpreting oyster mariculture in the Lower Suwannee. First, I will discuss the relevant biological and ecological attributes of the Eastern oyster, *Crassostrea virginica,* which must be understood in order for people successfully to cultivate the resource. Next, I describe oyster mariculture, and review the various types of practices that are used to manipulate ecological conditions so that oysters prosper. Then I outline the specifics of those ecological conditions along Florida's Gulf Coast, with a discussion about present-day ecological conditions and maricultural practices. I then use those same basic ecological variables to structure a discussion of changing environmental conditions in the Lower Suwannee region of Florida's Gulf Coast starting about 4,500 years ago, and the implication of the shifting environment on natural oyster populations. Finally, I use global archaeological examples of mariculture to lead to a concluding discussion of the hypothesis that mariculture was possibly practiced by people 2,000 years ago in the Lower Suwannee region.

General Oyster Biology and Ecology

The study of oysters from an archaeological perspective first requires knowledge of basic biology and ecology. Understanding the natural aspects of oysters allows for a nuanced interpretation of how oyster populations of the past were affected by dynamic estuarine conditions and long-term environmental change, how human predation impacts oysters' natural productivity, and how people can intervene to sustain oyster populations during times of intensive harvest.

Biology

Oysters are bivalves, meaning that they have two calcareous valves, or shells, that protect the soft body of the organism. The two valves are joined at the dorsal edge by a resilient hinge ligament and interlocking hinge teeth (Eble and Scro 1996:19). In order to filter-feed, oysters open and close their shells by contracting and relaxing the pair of abductor muscles running between the valves (Kent 1988:3). The adductor muscle scar is visible in the form of a dark purple half-moon shape on the inside of the valves. Oyster valves are asymmetrical, with the left valve being larger and more deeply cupped than the right, which tends to be flat. Oysters usually attach on the left valve, meaning that the right is generally uppermost. The shape and quality of oysters are influenced by four main ecological variables discussed below: temperature, salinity, substrate, and location in the water column (Supan 2002).

Temperature and Salinity

While some argue that temperature is the most important ecological variable affecting the success of oysters (e.g., Gunter 1957), others argue that salinity is the most important variable (e.g., Butler 1949). In reality, the synergistic effect of these two variables likely has the most profound effect on the success of oyster populations (Shumway 1996). Together, these variables affect feeding, respiration, utilization of food reserves, gonadal development and time of spawning, parasite-disease interactions, predation rates, growth, and distribution (Shumway 1996:467). These factors are variable during an oyster's life-cycle. For example, an oyster's tolerance to temperature and salinity are more sensitive during the mobile larval stage or reproductive period than at any other stage in their lives (Dame 2012:44).

Temperature is important as a determinant of oyster distribution and growth rates; as temperatures increase, growth rates generally increase and then gradually decrease towards the fringe of their tolerance (Dame 2012:45). Oysters are found in waters where the annual range is from -2°C to 36°C, and can often stand extremes for short amounts of time (Shumway 1996:468). The general rule is that warmer waters, such as in the Gulf of Mexico, facilitate the rapid growth of oysters, not only in height, but in volume of meat produced (Shumway 1996:484). Temperature not only affects oyster growth rates, but also respiration, feeding, excretion, and spawning, all of which are crucial for the success of oyster populations. In most of these aspects, oysters are the most successful in the intermediate range of their temperature tolerance (~15°C), with factors such as spawning being negatively affected by extremes (Shumway 1996:474–475).

Much like temperature, salinity levels impact multiple aspects of the ability for oyster populations to survive and thrive, with the primary effect being population distribution. Salinity is also a highly dynamic variable, with variations in estuaries being diurnal, seasonal, or spatial with gradual or abrupt changes (Shumway 1996:467). Salinity in estuarine and coastal environments varies along a gradient, generally in accordance with distance from freshwater inputs. Oysters are able to survive in estuarine environments where salinity ranges from oceanic levels of 35 ppt to areas where the influence of freshwater brings salinity to as low as 1–2 ppt.

Despite the ability of *C. virginica* to survive in a wide range of salinity levels, there are conditions under which success is more likely. For example, there are optimal salinity conditions that ensure the organisms success in different life stages: 10–15 ppt for larval development, 10–29 ppt for larval growth, 16–22 ppt for spat settling, and 10–30 ppt for juveniles and adults (Patillo et al. 1997). Generally, the optimum salinity level for oyster populations is 14–28 ppt, although the upper levels of this “optimum” range make the oyster vulnerable to parasites that can only live in high salinity waters (Shumway 1996:468).

Substrate

While temperature and salinity are instrumental to the success of oyster populations, the type and availability of suitable substrate and bottom conditions are also important factors. Oysters are gregarious, meaning that, while they are larvae, their settlement preference for attachment is their own species, forming aggregations of conspecifics in the form of oyster beds or reefs (Kennedy 1996:396). Oyster reefs, composed of both live and dead oysters, tend to form in estuarine environments where oysters have already settled on muddy sand bottoms with a scattering of hard substrates, and where ecological conditions are favorable. Excessive siltation slows the development of extensive oyster beds, and on clean, well-sorted sand, wave-action regularly dislodges oysters and removes newly settled larvae and young spat (Kent 1988:8).

Location in the Water Column: Subtidal Versus Intertidal

The final ecological aspect of oysters that is relevant to this study is the depth of the water that oysters grow in and where they fall in the water column. Because of the generally shallow nature of their habitat, oysters grow both subtidally and intertidally. This difference greatly affects how oysters grow, their success rates, and their economic value to human populations. Subtidal oysters often have ovate to subovate shell outlines and have regular refuge from the elements, as well as longer feeding times, increasing their growth rate to about 1.5 times that of intertidal oysters. Subtidal oysters in high salinity areas also often are affected by predators and parasites such as boring sponges, worms, and boring clams. The shells of subtidal oysters are usually thicker with increased valve cupping (Lawrence 1988:267). In contrast, intertidal oysters grow in tight clumps or burrs, causing their shells to be relatively small, thin, and elongate. Intertidal oysters benefit by having refuge from marine predators as well as freedom from competition.

Optimal Ecological Conditions

Oysters have specific conditions under which they are naturally most prosperous. The optimal natural conditions for oysters to survive and thrive are subtidal environments with salinities between 14–28 ppt, temperatures close to 15° C and in areas with muddy sand bottoms. The four ecological variables discussed above can be manipulated by humans to affect oyster production as well as encourage desirable qualities such as taste and nutrition. In order for humans to manage the resource successfully, optimal conditions are slightly different than what they would be naturally; for example, although oysters naturally grow faster in high salinity waters, the most favorable conditions for oysters to be grown in are areas that allow seed beds to be bathed in water of reduced salinity, to control for the negative effects of parasites and predators in higher salinity waters (Korringa 1976; Shumway 1996). For oyster farmers today, it is also important to know how to grow oysters under conditions where they will have the fastest growth, the firmest meats, the best flavor and the deepest shells. Balancing these specifications often makes the best places for growing oysters in the Gulf today to be near the shore, especially in the cooler months (Korringa 1976:64).

Oyster Mariculture

Oyster farming includes enhancing substrate for larval settlement, transferring oysters to sites where they do not settle naturally, and protecting the crop against predators, parasites, and competitors (Korringa 1976). Maricultural practices can be as simple as tending to known reefs, shelling the bottom and creating habitat, or as complex as creating an industry with technology specifically geared toward the specialized production of oysters.

Mariculture is necessary to sustain oyster populations if natural stocks become depleted and need to be enhanced by reseeding of the bottom. The modern process of culturing oysters usually has three phases: “captage” (seed production), “ėlevage” (the growing phase), and “affinage” (fattening to marketable quality). Seeding of oyster beds can be accomplished today by buying seed from hatcheries, which is often costly, or the collection of natural seed. The collected seed is then placed in the water by oyster farmers at strategic times and locations (Korringa 1976:2; National Research Council 1992:212). The six types of oyster mariculture being investigated for this study are relaying, culling, shelling, size/age selection, selective harvest location, and off-bottom techniques. These maricultural practices were chosen because of their likelihood of being practiced in the Gulf Coast 2,000 years ago, based on archaeologically identified practices of shellfish management in the past, and also the feasibility of being able to determine these practices from the archaeological record in the Lower Suwannee.

Relaying

Relaying is the term used for moving live oysters from areas of an estuary that are suboptimal and transplanting them to areas of optimal conditions. For example, intertidal oysters can be relayed to subtidal locations in order to increase their growth rates. Also, oysters in high salinity areas can be moved to areas of lower salinity to decrease the number of predators and parasites. Although this method is effective, suddenly altering the conditions under which oysters are living could increase the mortality rate. In culturing methods today, once oyster spat are about 2.5–3.8 cm in shell height, they are considered large enough to be transplanted. Oysters are transplanted to areas where they grow more rapidly and are intentionally planted at lower densities to allow for regularity in their growth patterns. After the oysters are moved to new locations, it generally takes 13 months to five years before the oysters reach legal harvest size based on local environmental conditions (Castagna et al.:675–676).

Culling

Separating individual oysters from larger aggregations (i.e., clumps or burrs) is called culling. Culling includes separating oysters from one another, as well as removing biofouling organisms and dead shell from healthy oysters. Oysters are often culled while oystermen are still on the water; the removed spat, dead shells, and oysters that are less than legal harvest size (3 inches in the US) are returned to the water. Oysters that are not yet large enough to be harvested are returned to the water as “singles” so that they can grow without hindrance of other organisms; this allows oysters to grow without stress of competition, making their shells more deeply cupped and rounded, which is considered ideal for the health, growth, and reproductive capabilities of oysters.

Shelling

Shelling is the process of returning dead shell to existing oyster reefs or in areas of ideal ecological conditions that could support an oyster reef. Returning dead shell to the water is one step towards ameliorating habitat depletion. Without suitable habitat for oysters to settle on, populations would collapse. Because oyster larvae have a natural tendency to settle on other oysters for attachment as spat, studies have shown that the best artificial substrate, or cultch, for culturing oysters is clean, seasoned (i.e., air dried for about 12 months) whole or partially crushed oyster shells (Crisp 1967; Castagna et al. 1992:684). The process of laying down cultch in areas where reefs are depleted or nonexistent is to encourage spat settlement and growth in the most suitable environmental conditions. Today cultch is usually obtained from stockpiled shells from shucking houses or dredged from fossil beds, and is put back into the water over reefs and estuary bottoms in areas where larval settlement is generally high due to hydrography and other suitable environmental conditions (Castagna et al. 1992:675). The cultch is then left relatively undisturbed.

Size/Age Selection

The selective harvesting of oysters of a certain size or age is a maricultural practice that allows for populations to be sustained in a certain area. For example, by harvesting large numbers of oysters that have not lived through reproductive cycles, the population size will eventually diminish. Today this is practiced with the enactment of fishing laws dictating “legal harvest size” for marketable oysters, therefore all oysters under the legal limit (3 inches) must be returned to the water to continue growing before they can be harvested.

Selective Harvest Location

By selectively harvesting oysters from certain locations, others are left undisturbed so that populations can naturally rebound. If all reefs in an area are harvested regularly and at the same rate, it is likely that, should collapse happen, all of the reefs would collapse at the same time. Due to resource depression in many estuaries today, oyster reefs have been subject, by law, to closures in hopes that populations will naturally replenish themselves without human predation pressures slowing the process.

Off-Bottom Techniques

Oysters can be grown directly on estuary bottoms or using hanging culture techniques on ropes, rafts, nets, or in cages. Growing oysters in this three-dimensional mode allows them greater access to food and protection from sedimentation and benthic predators. Also, more oysters can be grown per unit area in this way than by bottom culture methods (National Research Council 1992:212).

Why Mariculture?

In 2009 the Nature Conservancy released a report that there have been oyster losses worldwide of up to 85 percent, and both anthropogenic as well as ecological factors have been blamed for such a loss. Researchers have cited various forces for this loss including erosion and storm damage (Goodbred and Hine 1995; Seavey et al. 2011), pollution and disease (Beck et al. 2011), sea-level rise (Wright et al. 2005), and overharvesting (Jackson et al. 2001; National Research Council 1992). Also, unstable salinity regimes, dredging, hurricanes, channelization, watershed projects, activities of the petroleum industry, and predators can all adversely impact oyster-reef communities (Kilgen and Dugas 1989). Although there are many stresses that can devastate oyster communities, Jackson et al. (2001) argue that overharvesting is the primary contributor, explaining that such unsustainable large-scale harvesting is responsible for the majority of the 52-fold decline of oyster populations they studied in the Chesapeake Bay, with decline in water quality and disease as secondary contributing factors. Each of the six techniques described above help sustain oyster populations during times of resource decline and depression, and are especially impactful when used in conjunction with one another.

Present-Day Ecology and Mariculture in Florida Gulf Coast Estuaries

Gulf Coast Ecology

Florida’s Gulf Coast is generally characterized by low-lying terrain interspersed with swamps and marshes, and extensive offshore oyster reefs. The climate is generally mild to warm, with hot wet summers and drier winters. Along the coast are numerous areas of freshwater inflow from small and large rivers and springs. Estuaries are produced in areas where freshwater inflow meets the higher salinity water of the Gulf of Mexico, and are highly productive environments for a variety of fauna to survive. Shumway (1996:468) describes Gulf estuarine environments to be prime locations for high oyster growth rates and reproductive capability because of generally optimal salinity and temperature conditions.

Oysters are abundant in the shallow, brackish water of estuarine environments such as those on Florida's Gulf Coast. Estuarine environments are dynamic, with daily and seasonal variation of influential ecological factors that may have different ranges of water quality in different geographic locations. While there are some forty estuarine areas along Florida's 1,240 km Gulf coastline, ecological factors are inequitably distributed within and between estuaries, creating areas with differential capabilities of natural oyster productivity (McNulty et al. 1972).

The Suwannee Sound

The Lower Suwannee has been characterized as the one of the largest low-gradient open-marine marsh shorelines in North America (Wright et al. 2005:621, 623). The Suwannee River, the main source of freshwater inflow to the estuary, is located in the middle of the estuary and is the second largest river system in Florida (Mattson 2002). Salinity levels in the Suwannee Sound are less than 0.01 ppt in the Suwannee River, and reach near 35 ppt at sampling stations that were the farthest offshore, approximately 31.5 kilometers from the coast (Bledsoe and Phlips 2000:461). The average salinity has been gaged in parts of the estuary as between 21 and 28 ppt, fluctuating with storm and drought events (Baker, personal communication). The Suwannee estuary is unique in that the brackish transitional zone between freshwater and seawater is much more extensive than in any other Florida Gulf Coast estuary (Mattson 2002:1337). Oyster habitats are the main structural habitat feature in the Suwannee Sound, with the best reef development in areas of reduced salinity (Mattson 2002:1338).

Present-Day Mariculture on Florida's Gulf Coast

In Florida's Apalachicola Bay today, culling, shelling and age selection are practiced in conjunction, allowing for enhancement of substrate as well as letting less mature oysters to grow to harvestable size. Oystermen in Apalachicola Bay harvest oysters using oyster tongs or oyster rakes. These tools allow the oystermen to stand on their boats and harvest oysters at the bottom of the Bay without diving for them. The tongs are nonselective, and a single tong lick will pick up anything from large live oysters, to spat, jelly fish, crabs, mud, dead shells or substrate, or anything else in the general area. Once the tongs are filled, they are raised out of the water and placed onto a board on the boat where they can be sorted and culled. According to law, oystermen are allowed to only harvest oysters that are of legal size, which in this case is three inches. The smaller oysters and all dead shell are returned to the water to continue to develop and act as substrate to attract spat settlement, thereby encouraging population rebounding, or at least maintain the current population.

As well as oyster tongs, other important tools that were used included a boat of proper size and proportion, a small rake to be able to sort oysters, a sharp shooter shovel to easily return unwanted materials back into the water, a tool used for feeling the estuary bottom in order to find oyster reefs, buckets or bags for collection, and a tool that was used to break up clusters of oysters, or burrs, removing dead shell and separating single oysters. This tool also has another purpose: at the opposite end is a measuring tool that is three inches, so that an oyster is easily measured to see if it is of legal harvest size before it is collected for distribution or consumption. All steps of this process can be done alone, but are much faster when done with at least one other person.

Because the Suwannee Sound is not a protected area like Apalachicola Bay, culturing practices are different. Instead of shelling the bottom for encouraging spat growth, spat are produced and harvested from protected areas, or grow houses, and when they are large enough they are transferred to leases in the water where they are grown in bags. Every few months, depending on growth rates, the oysters are put into new bags until they reach harvestable size. Based on the location of the leases, oysters are exposed to different environmental conditions, some of which are better for oysters' growth than others. The oyster bags are regularly checked and flipped to avoid sedimentation and to discourage fouling. Here, the maricultural techniques being used include a mix of transplantation, size selection, and off-bottom cultivation.

The two examples discussed above exemplify how different culturing techniques can be used in conjunction, and that different culturing techniques are appropriate for different locations based on environmental factors. Not only do we as researchers need to have an understanding of the environment and ecology of oysters to be able to discern mariculture in the archaeological record, but people in the past who were manipulating oyster resources would too in order for their efforts to be successful.

Past Environmental and Ecological Variation of the Lower Suwannee

From at least 4,500 years ago, the coastal dwellers of the Lower Suwannee have been subject to periods of dramatic environmental change which likely impacted important marine resources to a great extent. Aside from a steady supply of food regulated by water flow and tidal action, the success of oyster populations is dependent on four main ecological factors (discussed above): water temperature, salinity, substrate, and location in the water column (Supan 2002). Although oysters can withstand wide ranges of ecological conditions, sudden, drastic, or prolonged changes in these conditions, such as those that occurred throughout pre-Columbian history in the Lower Suwannee, can cause reefs to collapse and subsistence practices to change.

Below is a projection of major shifts in sea-level and climate in the Lower Suwannee region. Because of the lack of fine-grained detail on the exact aspects of how global or regional climatic events and sea level fluctuations were manifested in the Lower Suwannee, the following is the best interpretation based on the limited data to date. While acknowledging the short-comings of some of the data, I believe this is a useful exercise in discussing the unstable nature of estuarine environments, the risk involved in coastal living, how oyster populations respond to major climate events and change, and how variable natural conditions coupled with social and cultural change through time may have instigated human intervention into marine resources.

4500–4300 BP

From what is understood from sites not submerged due to today's rising sea level, during the time of occupation from about 4500–4300 years ago, conditions on Florida's Gulf Coast were likely drier and salinity levels were higher. Such observations of environmental conditions dating to this time (~4300 cal. yr. BP) are drawn from proxies from the Ehrbar site (8LV282) near Cedar Key. Excavations from two test units at the site show high proportions of high-salinity species, such as scallop, to oyster in shell middens (McFadden and Palmiotto 2013). If the contents of the midden were collected from local resource patches, it would follow that the salinity of the surrounding waters was high. This is important as salinity is arguably the most important variable for the success of oysters, and salinity levels consistently on the higher end of oysters' tolerance produce larger and denser oyster populations. Hopkins (1957:416) argues that oysters are more prolific, larger, and more prosperous in areas of high salinity, although high-salinity predators and parasites, such as oyster drills, barnacles, and bioeroding sponges, can be a limiting factor, increasing mortality rates. Also, salinity and species diversity are positively correlated; therefore, if salinity levels were high during this early phase of occupation in the Lower Suwannee, there was likely a plethora of exploitable resources, distributing predation pressure on multiple species (Wells 1961:262). Shellfish ratios from Ehrbar show that salinity levels were higher during the earliest phase of occupation, and lessened during later occupations, indicating observable environmental change within this period (McFadden and Palmiotto 2013:35).

Using a single component site as the sole indicator of environmental conditions in a larger region is inherently problematic, especially in the absence of independent data on environmental change (Sassaman et al. 2010:139). As salinity is the main controlling factor of the distribution of marine species, it follows that the species within a midden could be used as a proxy for local conditions. This, though, disregards human agency and preference; perhaps high-salinity species were preferred, and thus inhabitants of the Ehrbar site travelled to high-salinity waters to acquire resources which were later disposed of in the middens. More samples from midden sites within this time period need to be taken throughout the Lower Suwannee to see if the trend is replicable, and independent paleoclimatic data should be established as a further means of verification.

3200–2500 BP

The next notable time period of change in the region is from ca. 3200–2500 BP; this period is marked by structural change in the Southeast, and, in the Lower Suwannee, the absence of coastal sites (Thomas and Sanger 2011). This period is accompanied by a global climatic event called the Neoglacial, where precipitation increased, temperatures dropped, sea-level rose, and instances of river flooding increased (Kidder 2006). If these global events also shifted the environmental conditions in the Lower Suwannee, salinity and temperature would have changed significantly, likely impacting oyster populations.

Increased precipitation and instances of river flooding during this time would have significantly lowered the salinity of the Lower Suwannee estuary, although sea-level rise may have offset this to an extent. During times of ecological stress, oysters have the ability to tightly close their shells to protect them from sudden changes in ecological conditions. Oysters are able to adjust to salinity ranges from 3–35 ppt in only a few hours, but only have the ability to survive for up to two weeks when salinity levels drop below their normal threshold (Pearse and Gunter 1957:135, 139–140). Therefore, where it has been shown that salinity levels were likely high in the preceding period, such a dramatic drop in salinity levels would have possibly killed off, depleted, or significantly altered oyster reefs in the area. If populations did rebound or stabilize, salinity levels consistently on the lower end of oysters' tolerance would produce small populations of small, roundish oysters, which are less desirable or economically beneficial to humans.

The other significant environmental change that would affect oyster populations is the drop in temperatures, specifically when combined with the regression of sea levels during this period. Low temperatures decrease growth rates, and if temperatures are regularly outside of the organisms' tolerance, the populations may die out and be replaced with more tolerant forms (Dame 2012:45). Furthermore, the effects of temperature tolerance are differentially experienced by oyster populations depending on the depth of water they are in; oysters in very shallow water will experience a wider range of temperatures following seasonal and daily climatic variations (Dame 2012:45). Therefore, as sea level was lower during this time, subtidal oyster populations, that flourished in the preceding period of high salinity and warmer temperatures, likely became intertidal and highly vulnerable to decreased temperature and salinity.

2500 BP

At about 2500 BP, human populations returned to the coast in dispersed settlements. By this time, the modern coastline was more or less established, and there was a period of oyster bioherm growth and marsh aggradation (Wright et al. 2005). At about this time, environmental conditions became more favorable for estuarine resources such as oysters as it became warmer, sea level rose, and conditions reached relative stability, albeit with occasional "pulses" of change (Sassaman and Wallis 2015).

A.D. 200-650

An important change affecting people living along the coast of the Suwannee Estuary was an increase in sea level at about A.D. 200–300, when large sites such as Crystal River and Garden Patch became the loci of occupation in the region as people dispersed from vulnerable coastal locations in the Lower Suwannee, abandoning previous sites, leaving them to be inundated by the rising sea (Goodbred et al. 1998;

McFadden 2015; Sassaman and Wallis 2015). Large aggregations of populations at these civic-ceremonial centers may have threatened their long-term sustainability, as both were eventually abandoned (Sassaman and Wallis 2015). The abandonment of Crystal River and Garden Patch at about A.D. 600 occurs around the same time as a 200-year period of cooling in the Lower Suwannee, which, as discussed above, could negatively impact estuarine resources, especially if coupled with heavy, non-sustainable, exploitation (Walker 2013). At around the same time, Shell Mound (8LV42) came online as a place of habitation and ritual activity, culminating in the erection of a massive U-shaped mound, constructed primarily of clean oyster shell.

This series of events likely had important consequences for oyster populations in the Lower Suwannee. Although sea-level rise at A.D. 200–300 may have been one of the causes for abandonment of coastal sites in the Lower Suwannee, it likely had a positive effect on oysters, creating more subtidal conditions under which oysters flourish due to the steady supply of food. Whereas the change in tidal conditions may have initially negatively impacted oysters, populations could have easily rebounded, especially as rising sea level and warmer temperatures created more subtidal and saline conditions for oysters to flourish. Furthermore, as the sites were largely abandoned, human predation pressure on oyster populations was relieved, allowing them to proliferate. Unlike those proximate to Garden Patch or Crystal River, the oysters in unpopulated locations in the Lower Suwannee may not have been as vulnerable to a period of cooling, as their populations were less stressed than those which were regularly harvested. In fact, the interplay of salinity and temperature on oysters could be very important, as oysters are able to survive in extreme salinity conditions, but their chances of survival are increased when accompanied by lower temperatures (Heilmayer et. al 2008).

The evidence of sustained oyster harvesting at Shell Mound begins at about A.D. 500, with the accumulation of a dense shell midden on the distal arm of the relict dune. Oyster harvesting at Shell Mound likely intensified, reaching its peak at about A.D. 550–600, with the build-up of the mound into a monument through the emplacement of massive amounts of clean shell. Although there are myriad reasons for resource collapse today, overharvesting is still cited as the primary cause (National Research Council 1992; Jackson et al. 2001). With changing environmental conditions coupled with such intensive oyster harvesting in the Lower Suwannee at sites such as Shell Mound as well as other contemporaneous sites in the vicinity, it is likely that the effects of environmental instability and overharvesting were offset by maricultural practices in order to sustain oyster reefs, not only for subsistence, but also as building material for monumental architecture. This hypothesis is supported with archeological and ethnographic evidence that mariculture during this time was practiced by various groups around the world.

Archaeological Evidence of Mariculture

Examples of Ancient Mariculture World-Wide

Ethnographic accounts of mariculture exemplify their importance for coastal communities. For example, ethnographic research in Canada concerning traditional ecological knowledge passed down among the First Nations peoples conclusively demonstrates that mariculture and management techniques have always been a part of how coastal peoples interacted with their environment (Brown and Brown 2009). Also, experts in marine aquaculture, fisheries biology, fisheries management, and ocean and coastal management, among others, agree that mariculture in some form is necessary to sustain regular exploitation of marine resources (National Resource Council 1992:29). The management of shellfish for coastal people is also of particular importance as they occupy a peculiar space in terms of subsistence: they share many characteristics of a plant in that they are sessile, easy to harvest, and usually grow in large patches, but, unlike plants, they offer the protein benefits of an animal (Whitaker 2008:1115). Therefore, if sedentary coastal communities relied on harvesting large amounts of shellfish as a major source of protein, then mariculture may have been used to sustain those important resources.

Recent archaeological investigation on the Northwest Coast of North America has shown the use of mariculture in the form of clam gardens and “harvesting rules” beginning at least 2,000 years ago (Grier 2014; Lepofsky and Caldwell 2013; Lepofsky et al. 2015). Clam gardens are constructed of rock walls in the lowest intertidal zone and tidal flats which have been cleared of boulders. These archaeological features exemplify many aspects of management and culturing; clam gardens enhance the marine resource by creating niches in which clams were highly productive and readily available. Also on the Northwest Coast, there is evidence of “harvesting rules” in place, as often clams only of certain sizes or ages were collected, perhaps in an attempt to allow clam beds to repopulate and reach harvestable size to avoid resource collapse (Lepofsky and Caldwell 2013:6). Management techniques such as these are concrete evidence of culturing marine resources through human choices and practices and, “the marine management system resulted in long-term sustained and sometimes enhanced production of targeted resources” (Lepofsky and Caldwell 2013:9).

Similarly, morphometric analysis of archaeological mussel shells from middens on the West Coast show that past local inhabitants were manipulating shellfish resources for greater return and sustainability with the use of “pseudo-aquaculture” (Whitaker 2008). Instead of “stripping” mussel beds, coastal peoples who were harvesting this resource “plucked” the beds, harvesting small patches of mussels. The plucked beds were then left fallow for about two years while other beds were being exploited so to not deplete the resource. This culturing technique allowed coastal peoples to invest in long-term sustained yields of mussels through the sacrifice of maximum immediate returns (Whitaker 2008:1121).

Like clams and mussels, oysters have also been manipulated through time using mariculture. The Romans of 2,000 years ago are often attributed with the fist definitive cultivation of oysters, as observed from hanging techniques depicted on vases. Based on the artwork, the oysters were cultured using hanging ropes of hearty material attached to a framework of sticks or poles in the water, a practice still used in the same location today (Gunther 1897:364). Using archaeological oyster shell to interpret potential signs of culturing in the past, Rakov and Brodianski (2007, 2010) have analyzed oyster shells from middens of several northern Pacific coastal Neolithic and Early Iron Age sites in Russia, as well as ancient and modern oyster farms and argue that the existence of incipient oyster cultivation on the coast of Peter the Great Bay can be considered an “established fact” (Rakov and Brodianski 2010:26). The authors argue that the core of aquaculture is in pest control and the sorting of mature individuals by size and age. They argue that both of these aspects are evidenced in the Boisman and Yankovsky shell middens, and also demonstrate that certain morphological features of on-bottom cultivation distinguish the oysters in the middens from natural oyster populations; these morphological features include smooth shells lacking in radial ribbing caused by sunlight, unscalloped edges, and small attachment scars (Rakov and Brodianski 2007:40–41).

Archaeological evidence also reveals the cultivation of marine fishes. In Hawaii, for example, integrated farming approaches were used by native people where extensive agricultural endeavors were accompanied by equally as extensive maricultural activities. For example, large numbers of fish were raised in salt and freshwater ponds. Once the ponds were created, they were managed and controlled by the elite (Costa-Pierce 1987).

The decisive evidence of mariculture has broader interpretive worth than simply understanding subsistence practices. For example, Grier (2014) discusses how the cultivation of clams and the creation of clam gardens on the Northwest Coast can be used as a means to address issues of complexity among non-agricultural communities. Purposeful manipulation of abundant, predictable, and aggregated resources and the shaping of the “natural” world strongly influenced the organization of Northwest Coast societies; specifically, the successful cultivation of important marine resources to create surplus is one of the conditions deemed necessary for the emergence of Northwest Coast cultural complexity (Grier 2014:211). The author argues that through the manipulation of the environment and resources, food production and diversity were sustained and social dynamics were transformed, particularly in regard to resource (clam garden) ownership (Grier 2014:212).

Methods in the Archaeological Literature

Shellfish management has been investigated by researchers on the Northwest Coast (Cannon and Burchell 2009; Grier 2014; Lepofsky et al. 2015; Whittaker 2008) and Eurasia (Rakov and Brodianski 2007; Rakov and Brodianksi 2010), and methods have devised for interpreting management in the archaeological record that are comparable to present-day management techniques (Table 2-2). Similar methods will also be used to determine oyster mariculture at Shell Mound (see Chapter 4). Some methods of discerning mariculture include measurement of shells to determine size/age selection (Cannon and Burchell 2009; Whittaker 2008) and selective harvest location (Whittaker 2008), and examination of parasitism and attachment scars to determine pest control and off-bottom cultivation (Rakov and Brodianski 2007, 2010).

Table 2-1. Methods for determining mariculture in the archaeological record.

TYPE OF CULTURING	ARTICLE AUTHOR(S), YEAR	SHELLFISH	ARCHAEOLOGICAL METHODS	SIMILAR PRESENT-DAY TECHNIQUES
Gardens	Lepofsky et al. 2015	Clams	Evidence of beach clearing and ancient clam gardens still in place	Specific areas leased to growers, habitat construction
Size/Age Selection	Cannon and Burchell 2009	Clams	Consistency in size/ages of shellfish; low frequency of juvenile shellfish in a context	Legal size restrictions (3 inches)
Selective Harvest Location ("plucking")	Whittaker 2008	Mussels	Consistency in size/ages of shellfish; low frequency of juvenile shellfish in a context	Closure of beds/reefs to commercial harvesting; legal size restrictions (3 inches)
"Pest Control"	Rakov and Brodianski 2007, 2010	Pacific Oysters	Low frequency of biofouling or parasitic attack	Grow houses
Off-bottom Cultivation	Rakov and Brodianski 2007, 2010	Pacific Oysters	morphological features include smooth shells lacking in radial ribbing caused by sunlight, unscalloped edges, and small attachment scars	Off-bottom cultivation

Discussion

As we live in what is being called the “Anthropocene,” it is becoming clear just how much humans impact the world around us. Today we are seeing this world-wide and on a huge scale, with effects such as global warming, but people have been significantly impacting the environment at various scales since the beginning of human history. Scholars such as John Erlandson and Torben Rick (2008), along with several of their colleagues, are investigating the archaeological residues of human impacts, specifically on marine ecosystems, in deep history. They, along with other scholars in the field, have seen how dramatically people can alter the environment by acts such as overharvesting marine resources and disrupting the food web.

In terms of oyster habitat, today, 85 percent of the world’s oyster reefs have collapsed from both “natural” and anthropogenic causes (Seavey et al. 2011). In the “Big Bend” region of Florida’s Gulf Coast, multiple off-shore reefs have collapsed, and in Cedar Key, which was once the world’s leading exporter of oysters to Cuba, local peoples are left with a fraction of what were once prolific bars and reefs. Many coastal communities on Florida’s Gulf Coast who have relied on harvesting oysters for their livelihood have had to find ways to manipulate the resource to sustain their livelihood by implementing maricultural practices. It is necessary to try to rebound oyster populations, not only as a food resource, but because they are a keystone species that provide many essential ecological functions such as habitat for numerous other organisms, shoreline protection, and increasing water quality through filter-feeding.

The primary factors affecting oyster populations are temperature, salinity, substrate, and location in the water column, which are variable within and between Florida’s coastal estuaries (Supan 2002). The ideal natural conditions for oysters are subtidal environments with salinities between 14–28 ppt, temperatures close to 15° C, in areas with muddy sand bottoms. Although conditions today can be close to ideal, such as in Apalachicola Bay, during times of environmental change and heavy exploitation, humans must intervene in natural conditions using maricultural practices such as relaying, culling, shelling, size/age selection, selective harvest location, and off-bottom techniques to sustain the resource.

In pre-Columbian history, coastal people may have struggled with the same challenges of oyster depletion due to environmental and anthropogenic influences. Intensive and sustained oyster harvesting, which may have been done in quantities even greater than that of today, is evidenced by huge oyster mounds and numerous middens (Sassaman et al. 2011). Furthermore, based on limited paleoclimatic data, it appears that the ecological history of the Lower Suwannee is one of significant change, which would have impacted marine resources to a large degree (Sassaman and Wallis 2015).

Environmental conditions in the some of the earliest years of occupation were possibly ideal for estuarine production. Archaeological proxies for environmental conditions indicate that there were high salinities and warm temperatures which allowed for high species diversity and conditions under which oysters naturally flourish (McFadden and Palmiotto 2013). If these were in fact the early ecological conditions, oysters would have been large and deeply cupped with rapid growth and reproduction, especially when coupled with the lack of previous significant human predation pressure. Following this period, from ca 3200–2500 BP, environmental conditions became far from optimal for oysters. Significant changes in temperature, salinity, and sea-level may have killed off the previously flourishing natural oyster populations. If oysters did rebound, it would be in small populations of small, round oysters. At 2500 BP, conditions in the Lower Suwannee changed again, although this time to the benefit of oysters, with warmer temperatures, higher salinity, and relative stability (Wright et al. 2005). At around 200–300 BP, a pulse in sea level rise drove coastal communities from vulnerable shorelines, possibly aggregating at more protected civic-ceremonial centers such as Garden Patch or Crystal River (Goodbred et al. 1998; McFadden 2015; Sassaman and Wallis 2015). A period of cooling at about A.D. 600 roughly coincided with abandonment of these centers, as people returned to previously occupied sites on the coast, creating centers of ritualized activity and terraforming such as at Shell Mound. Upon return to previously abandoned sites, subtidal oyster reefs, which had remained more or less unexploited for the last few centuries, in the Lower Suwannee were likely prolific as salinity was likely high and temperatures were cool.

Although conditions were relatively good for oyster populations upon reoccupation of Shell Mound, regular harvest, especially when punctuated by periods of intensification, would likely quickly negatively impact natural oyster reefs in the immediate vicinity. Maricultural techniques may have been used to offset loss or to intensify production. It is archaeologically and ethnographically evident in many other coastal habitation sites around the world that maricultural practices were used to sustain marine resources for present and future use, especially during times of heavy exploitation (Brown and Brown 2009; Lepofsky et al. 2015). Archaeological evidence of early shellfish maricultural techniques include habitat creation, size selection, and selective harvesting on the Northwest Coast (Lepofsky and Caldwell 2013; Lepofsky et al. 2015; Whittaker 2008), off-bottom hanging techniques in Ancient Rome (Gunthier 1897), and size selection, transplanting, and culling in the Neolithic Far East (Rakov and Brodianski 2007). Not only does the archaeological evidence provide insight into subsistence practices, but also into larger issues of complexity and social organization (Costa-Pierce 1987; Grier 2014; Lepofsky and Caldwell 2015).

Shellfish in the Lower Suwannee have been significant in one way or another since human occupation at least 4,500 years ago; gastropod and bivalves were consumed in large quantities and their shells were used as building material, tools, ornamentation, and part of funeral practices as is indicated by the archaeological record of Florida’s Gulf Coast (Willey 1949). Shell is the most conspicuous aspect of many coastal archaeological sites whether in extensive deep middens, small pits, or mounded into monumental architecture. The consumption and use of shell through time in the Lower Suwannee has fluctuated not only with changing environmental conditions, but also with changing cultural traditions, which is the subject of the following chapter.

CHAPTER 3
ARCHAEOLOGY AND CULTURE HISTORY AT SHELL MOUND

Introduction

Through the aegis of the Lower Suwannee Archaeological Survey (LSAS), members of the Laboratory of Southeastern Archaeology (LSA) and associates at the Florida Museum of Natural History (FLMNH) have been refining the culture-history previously established on Florida's Gulf Coast by researchers such as Gordon Willey (1949) and Jerald Milanich (1994). Based on radiocarbon assays from multiple sites in the Lower Suwannee, it has become evident that previous typologies are not necessarily as time-sensitive as they may have thought, nor can they be extrapolated across large areas or regions because many of the processes that led to material cultural changes were time-transgressive. Seventy-nine new radiocarbon assays for sites tested by the LSAS spanning 3,900 years, from 2600 B.C. to A.D. 1300, enable us to transition from talking about the culture-history of the area in broad periods, to discussing it on a century-scale (Sassaman et al. 2015:175).

After providing an overview of archaeological investigation in the Lower Suwannee, the following discussion of the region's culture history will focus on the five centuries of Shell Mound's occupation (A.D. 200–700), incorporating general cultural traditions and transitions, specific events at the site itself, as well as major environmental changes. The chapter will conclude with a detailed discussion of excavations at Shell Mound and the associated burial complex, Palmetto Mound on Hog Island.

Overview of the Archaeology of the Lower Suwannee

The 47-km coastline of the Lower Suwannee study area has at least 111 known archaeological sites. Research by members of the Laboratory of Southeastern Archaeology (LSA) in the Lower Suwannee region began in 2009 with the initiation of the Lower Suwannee Archaeological Survey (LSAS). The LSAS is a long-term partnership between the LSA and the U.S. Fish and Wildlife Service to inventory and assess archaeological resources in its Lower Suwannee and Cedar Keys National Wildlife Refuges, as well as private and state inholdings within the study area (Sassaman et al. 2011). Through the LSAS, members of the LSA and FLMNH are committed to a sustained program of research, reconnaissance, and rescue, efforts that are designed to preserve and document important cultural heritage. Furthermore, through this research contributions are being made to the understanding of environmental change and sea-level fluctuation in the area, issues that are as important to coastal communities today as they likely were to coastal dwellers of the past.

Since 2009, members of the LSA and its affiliates have conducted various levels of archaeological investigation at 25 sites in the Lower Suwannee area. For the purposes of this thesis, details of the history of archaeological investigation will be somewhat limited to Shell Mound as well as the neighboring mortuary complex, Palmetto Mound (8LV2) on Hog Island, as the proximity of these two sites suggests they were likely related to each other in terms of ceremonialism or ritual practices, although the specifics of their cultural relationship is yet to be defined.

Before the initiation of the LSAS, the Lower Suwannee as part of the greater Gulf Coastal region has been of interest to antiquarians, amateur archaeologists, as well as professional archaeologists due to the long history of occupation and accessibility of burial mounds in the region housing exotic “curiosities.” Although many sites along the Gulf Coast have been described and reported (e.g. Kohler 1975; Kohler and Johnson 1986; Milanich 1994; Moore 1902; Willey 1949) the archaeology of the Lower Suwannee was comparatively under-researched and underreported.

Results of the LSAS to date show that the archaeological potential of the area is substantial (Sassaman et al. 2016). It is clear that the study area was most pervasively settled during the Early and Middle Woodland Periods (ca. 500 B.C. to A.D. 750), with no evidence for sites predating 5,000 years ago due to transgressive seas. Archaeological findings and interpretations relevant to Shell Mound are summarized below; it is important to note that the inferences made are the best interpretation based on the data available, and are continually being refined and reinterpreted by members of the LSAS based on the addition of new data from the study area.

Culture History

The record of practically unbroken occupation of the Lower Suwannee starts at about A.D. 200, the same time that major cultural and environmental shifts ensued region wide. Specifically, a pulse in sea level documented in nearby Waccasassa Bay from A.D. 200–300 (Goodbred et al. 1998) which coincided with the start of the cultural tradition of terraforming, or manipulation of the landscape involving fixed infrastructure such as massive shell mounds and ridges. Two nearby coastal sites, Garden Patch and Crystal River, were established as major civic-ceremonial centers, and A.D. 200 also marks the beginning of the occupation at Shell Mound which emerged as another civic-ceremonial center a few centuries later (A.D. 550).

Milanich (1994) and Milanich et al. (1984) point to the interior sites of McKeithen and Lake Jackson as civic-ceremonial centers exemplifying high levels of social complexity unique to the interior. Not only do excavations at village and mound complexes on the coast, such as Garden Patch, Crystal River, and Shell Mound, show similar complexity, but there is an inherent sampling bias against coastal sites due to the fact that they have often been leveled for urban development (i.e. Cedar Key), and other sites may be submerged due to transgressive seas along a low-gradient coastline.

Continued research on coastal sites in Florida challenge the idea that “complex” Woodland sites are lacking; excavation has shown that the multiple mound complexes, or civic-ceremonial centers, on the coast were home to year-round occupants as well as guests from the larger region, elaborate mortuary practices, feasting events, and ritual infrastructure (Sassaman and Wallis 2015). For example, Garden Patch was a coastal multi-mound center with accompanying circular village plaza where people aggregated for ritual and ceremonial purposes (Wallis et al. 2015). Not only does this site exemplify interior connections through the analysis of “paddle matches” (Wallis 2011), but also shows further signs of complexity, as defined by Milanich (1994). Specifically, Garden Patch is a large village site comprised of a U-shaped midden and cleared plaza, as well as six mounds, including multiple burial mounds and a platform mound (Wallis et al. 2015). Furthermore, not only is Garden Patch roughly contemporaneous with complex interior sites such as McKeithen, the history of the site in terms of the site plan, population aggregation, monumental construction, and mortuary ritual is comparable to that of McKeithen (Wallis et al. 2015:514). In short, both coastal and interior sites were the home of large civic-ceremonial centers and were joined together through regional interaction.

The establishment of Shell Mound as a civic-ceremonial center at about A.D. 550 coincides with the decrease of mound building activity at both Garden Patch and Crystal River. Shell Mound was first occupied in A.D. 200 and functioned as a place of low-elevation encampments. During the next century, people shifted their settlements to the remnant dune ridge, possibly to ameliorate the effects of the rising sea. The use of the landscape for small-scale settlements transitioned into the construction of a U-shaped ridge, 180 x 170 m in plan and 7 m tall. The mounded shell accumulated over a 300-year period (A.D. 400-700), with shell accumulating rapidly between A.D. 500–600 (Sassaman et al. 2016).

Increased demand on resources due to a ritualized economy at Shell Mound resulted in intensification of the maritime economy. Evidence for intensification not only comes from the rapid accumulation of oyster shell, but also massive pits (some 2 m wide and 2 m deep), increased harvesting of big fish and mullet, and large cooking and serving vessels (Sassaman et al. 2015).

Shell Mound, Garden Patch, and Crystal River were all abandoned between 600 and 750. Around this time, Hughes Mound was filled with extralocal persons and vessels that have indications of being related to civic-ceremonial centers such as Kolomoki and Block-Sterns (Sassaman and Wallis 2015). Also, after Shell Mound was abandoned as a place of habitation, people apparently returned to the area, continuing to add shell, likely from extant middens, to the structure at the same time they were depositing pottery and, presumably, burials at Palmetto Mound. Connections between the coast and interior, reflected in burial ritual, continued to intensify in the proceeding centuries (Sassaman and Wallis 2015).

Archaeology at Shell Mound (8LV42)

Shell Mound is the tallest anthropogenic feature in the Lower Suwannee study area and the largest, most formalized, and best preserved arcuate shell ridge in the center of nearly two dozen known archaeological sites in the Shell Mound Tract. The mound was constructed by emplacing massive amounts of mostly oyster shell on the distal end of the relict arm of a parabolic dune between about A.D. 500 and 650 (Sassaman et al. 2013:67; Sassaman et al. 2015:5). The structure is more-or-less intact, aside from instances of looting, shell mining, road construction, and erosion.

The first systematic below-ground testing of Shell Mound was done on the summit of the ridge by Dolan in 1959 and reported on by Bullen and Dolan in 1960. No further testing has been reported until the 2012 excavation of the site by staff and volunteers of the LSAS (Sassaman et al. 2013). Since initial excavation by the LSA, fourteen test units have been excavated in six areas of the site, including excavation on the outside perimeter of the ridge, the central open area, the apex of the ridge, and the interior of the slope (Figure 3-2). Based on the results of widespread testing at the site, four phases of site use over five centuries (A.D. 200–700) have been identified (Sassaman et al. 2015:5).

Early Excavation

Early excavation of Shell Mound by Dolan (Bullen and Dolen 1960) and, recently, the LSA, shows deeply stratified deposits spanning five centuries of site use (Sassaman et al. 2013; Sassaman et al. 2015). The inaugural systematic testing by Dolan was a single 10 x 10 foot (~3 x 3-meter) test unit placed near the apex of the mound. Based on the recovered pottery sherds, initial testing suggested that the upper two meters of the mound likely formed no earlier than 2,000 years ago. Within the well-stratified sequence of organic soil matrix that was unearthed was abundant oyster shell, vertebrate fauna, and shell tools. The maximum depth of the test unit did not exceed ~3 meters.

Recent Excavation

Shell Mound was excavated by the LSA with the goals of obtaining radio carbon dates and exposing the stratified sequence of construction and habitation at the mound (Sassaman et al. 2013). The overarching goals of excavation at the site include understanding variations in occupational sequence and site use across the mound area, and have since been expanded by the research questions of graduate students in the LSA.

In 2012 a team of archaeologists from the LSA excavated two 1 x 2-m test units (TU1 and TU2). Testing also encompassed bucket auguring in the interior of the mound as well as the excavation of one 1 x 1-m unit (TU 3) in the interior opening. Results of this initial investigation indicated that the mound accumulated over at least two centuries (~1500–1300 cal. B.P. or ~cal. A.D. 450–650), and that the arcuate shape of the mound is original, not the result of shell mining, as previously thought. The LSA continued excavation at Shell Mound in 2013 with three 2 x 2-m test units, Test Unit 4 (TU4) and Test Unit 5 (TU5), in the western portion of the interior of the mound, and Test Unit 6 (TU6) on the outside perimeter (Figure 3-1). TU4 and TU5 were placed in an effort to locate evidence of residential areas, as it is assumed that houses were arranged in a semi-circular fashion surrounding the plaza.

In 2014, the first archaeological field school was held at Shell Mound, excavating three test units, Test Unit 7 (TU7), Test Unit 8 (TU8) and Test Unit 9 (TU9). To further the goal of defining site use, these units were placed in three separate areas of the mound: the interior slope (TU7), the apex of the mound (TU8), and the outside perimeter (TU9).

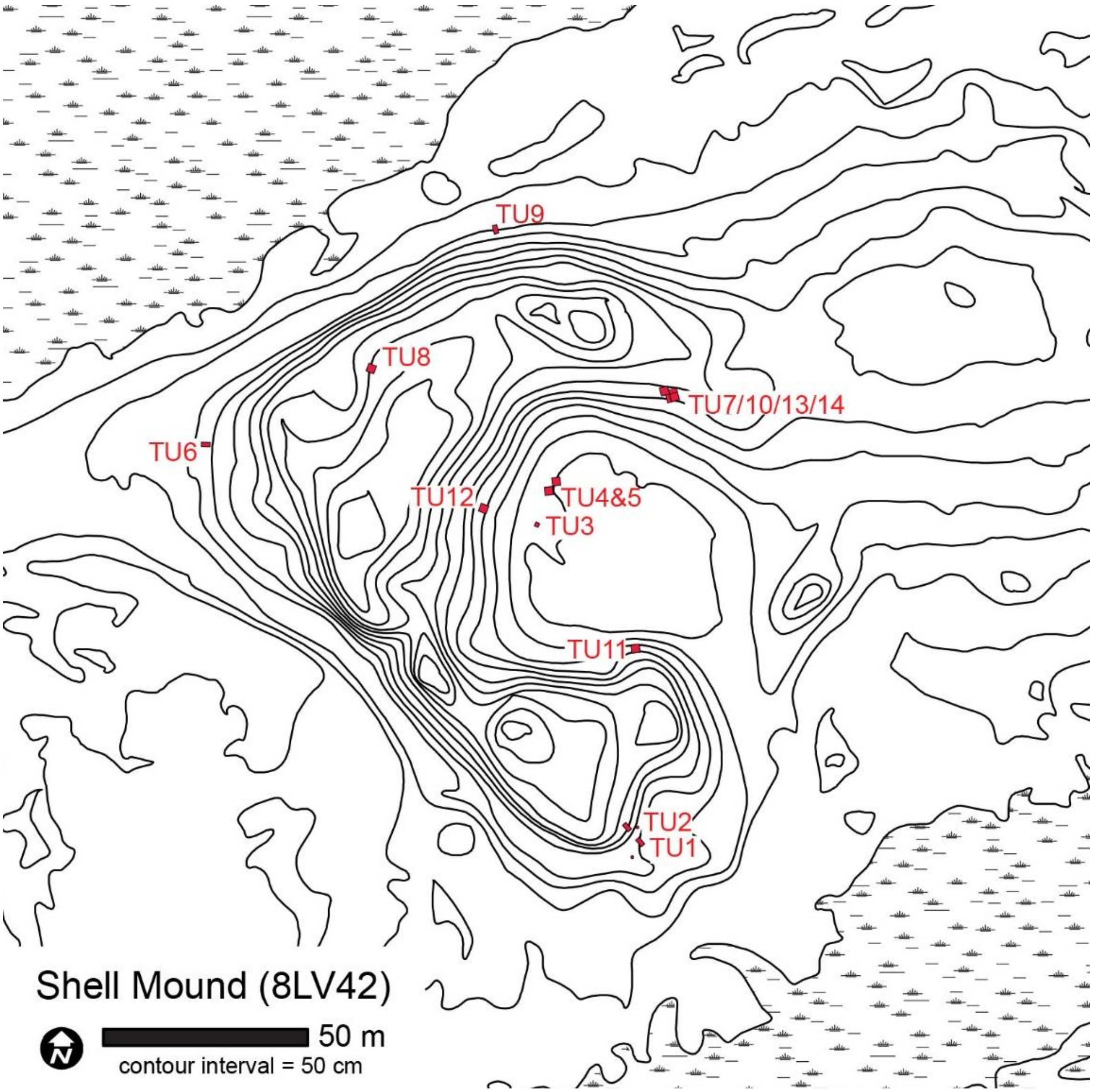

Figure 3-1. LiDAR topographic map of Shell Mound showing excavation units (from Sassaman et al. 2015).

In 2015, the LSA held the second archaeological field school at Shell Mound, opening five units at various parts of the site, focusing on the interior slope. Three units, Test Units 10, 13, and 14 (TU10, TU13, and TU14), were located adjacent to TU7, Test

Unit 12 (TU12) was located in the central area of the interior slope in the west, and Test Unit 11 (TU11) was located on the interior slope of the southern arm of the ridge. Each of these three areas revealed very different composition, with large shell-free pits to the north (TU10, TU13, and TU14), dense oyster midden and pit features to the west (TU12), and deeply stratified deposits (~2 m) of bedded clean whole oyster shell to the south (TU11).

Excavation on the Outside Perimeter of the Ridge

Four test units have been excavated on the outside perimeter of the ridge: TU1, TU2, TU6, and TU9. Sherds of the Pasco, Swift Creek, and Deptford traditions were recovered in TUs 1 and 9. These same two units also showed evidence of a large-scale burning of the area, which occurred a few centuries before the emplacement of the dense shell deposits comprising the mound (Sassaman et al. 2015:26). Charred hickory nut shell from this burned stratum in TU9 was estimated by AMS assays to date from ca. A.D. 180–340. TU6, on the western outer perimeter, expressed a lower artifact density and lacked the charcoal-rich stratum seen in the other test units on the outside perimeter, likely due to its marginal proximity to the shell ridge (Sassaman et al. 2015:21). Based on the dates and pottery sequences from the outside perimeter of the mound, it seems as though this was the location of the initial phase of Woodland-era settlement, ca. A.D. 200–400.

Excavation on the Apex of the Ridge

Excavation on the apex of the ridge has revealed that the basal strata of TU8 is likely indicative of the second major phase of occupation at Shell Mound, ca. A.D. 400–550. The third phase of occupation also expresses itself in TU8, with the emplacement of mass amounts of shell between A.D. 550 and 650. TU8 was situated near the highest point of the mound in order to access some of the deepest stratigraphy at the site. The unit was situated in one of several circular depressions, about 10 m in diameter, which was hypothesized to be an accumulation of shell around a domestic structure. The unit was placed on the southeast portion of the depression, to examine the flatter area where it met a steep incline (Figure 3-2). The stratigraphy of TU8 consists of three "macrounits," or macrostratigraphic units; from the top down: a 1.6 m thick mantle of bedded oyster shell dating to the sixth century A.D., organically enriched sands with moderate to sparse shell dating to the fifth century A.D., and submidden sand into which pit features were dug and backfilled (Sassaman et. al 2015). TU8 was the deepest of the units dug by the LSA, revealing that the elevation of the northern arm of the shell ridge is both anthropogenic, with the addition of shell, and geological, with the underlying sands being part of the relict dune on which Shell Mound is constructed. TU8 will be discussed further in the next chapter, as it is the location from which samples of oysters used in this study were obtained.

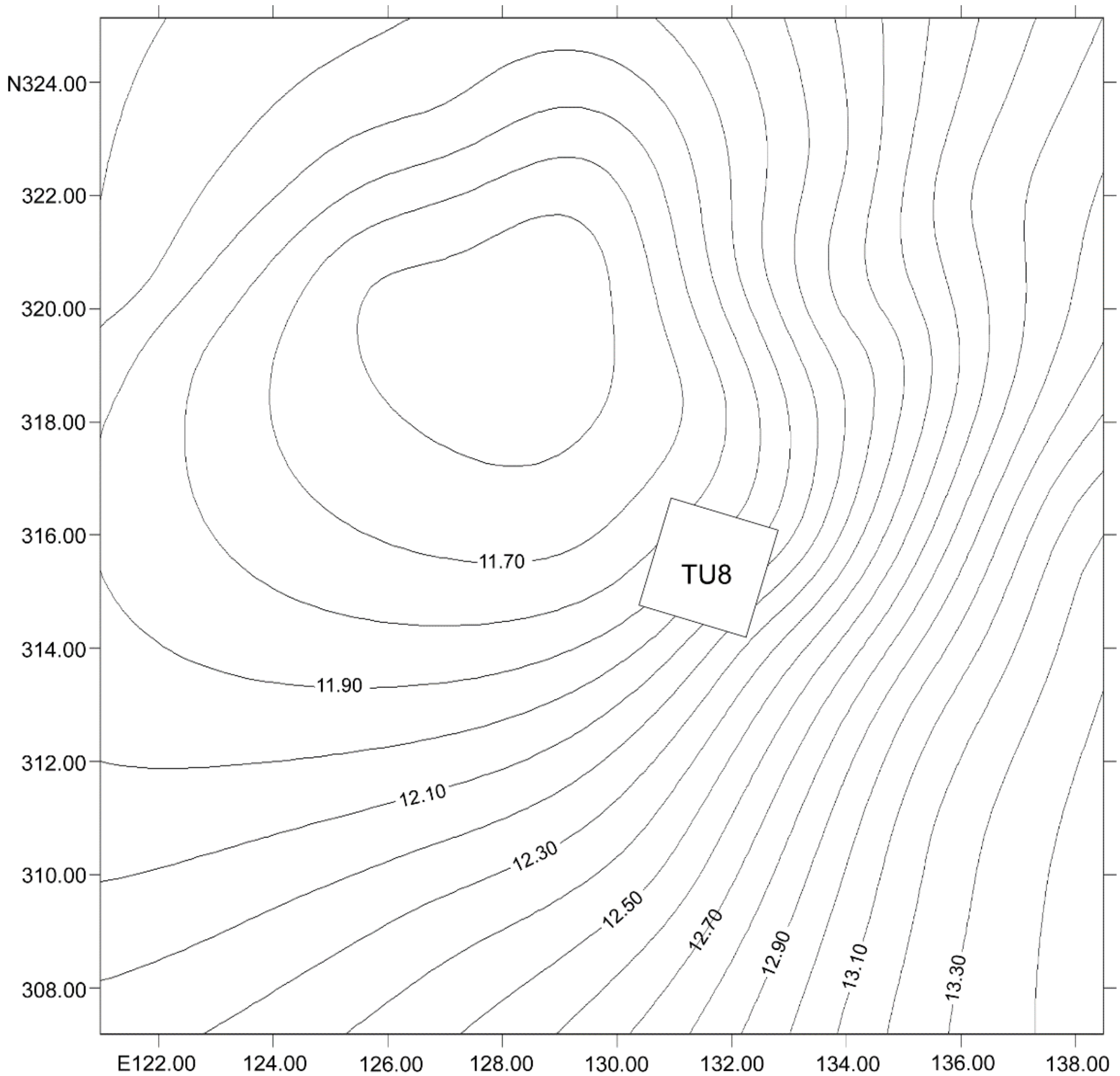

Figure 3-2. Topographic map showing the location of TU8 (Sassaman et al. 2015:38).

Excavation on the Interior of the Slope

TU7 was the first unit to be excavated on the interior of the slope, and was sited to locate evidence of domestic architecture related to the second phase of occupation at Shell Mound. What was unearthed was an amalgam of massive intersecting pit features with little to no shell, postholes, and exotic cultural materials. TU10, 13, and 14 were excavated adjacent to TU7 to expand upon the earlier findings. Although some of the pits were similar to those seen elsewhere on the site, several of them, in terms of size and content, were unique among pits from all other excavations at Shell Mound. These large pits suggest that Shell Mound, at least at times, went beyond the realm of domestic activities, likely to include large-scale social gatherings involving the consumption of large quantities of food (Sassaman et al. 2015:65). Furthermore, as the pits intersected one another, this location was returned to on more than one occasion for pit-digging activities (Sassaman et al. 2015:66).

TU11 was excavated on the interior slope of southern arm of the ridge to compare activities at this part of the site to those to the north (TU7, 10, 13, and 14). Revealed was a deeply stratified sequence of clean, whole oyster shell placed on top of earlier highly organic sands (midden), a pattern similar to that of TU8 at the apex of the mound. It is likely that this unit also reveals the activity of the third phase of occupation at Shell Mound which included the building up of the southern arm of the relict dune. Flooding from heavy rains in 2015 precluded excavation below the top of the subshell midden.

The final test unit excavated on the interior was TU12 located on the western portion of the interior of the mound, about equidistant from the units to the north and south. This unit was comprised of a dense organic shell midden emplaced over large refuse pits.

Excavation of the Central Open Area

Test Units 3, 4, and 5 were excavated in the central open area, or “plaza,” of the mound, with evidence of the fourth phase of occupation at the site which lasted about 50 years. TU4 and TU5 were placed in a checkered-board fashion to expose possible continuous architectural features in the unit floors and profiles. Most of the exposed pit features were ambiguous, with the exception of a single posthole, but indicate that it is likely that stronger architectural evidence exists in the vicinity (Sassaman et al. 2015).

Conclusion

Based on the recent work of the LSAS, four phases of occupation at Shell Mound have been described by Sassaman et al. (2015:100): (1) an early phase spanning the second and third centuries A.D. During this time most activity at the site was from the occupation of the outside perimeter of a relict dune; (2) an intermediate phase spanning the fifth and early sixth centuries A.D. During this time there was intensive occupation primarily on top of the dune; (3) a mid-sixth to mid-seventh century A.D. phase. During this phase the bulk of oyster shell was emplaced on the dune to the south, creating the U-shape of the mound; and (4) a final century spanning the mid-seventh to mid-eighth centuries A.D. During this phase, occupation was concentrated on the interior opening of the ridge with continual deposition of shell on the ridge.

Palmetto Mound on Hog Island (8LV2)

Palmetto Mound (8LV2) is a heavily damaged mortuary facility on Hog Island, just to the west of Shell Mound. The site has been excavated by both amateur and professional archaeologists, as well as compromised by looters. The burial complex on Hog Island was started as early as 300 B.C., preceding Shell Mound as a place of importance. This 55 x 25 m sand and shell mound is located directly 500 m west of Shell Mound, and is likely a related site, especially given their proximity (Sassaman et al. 2015). The 2-m-tall mound contained hundreds of burials, ceramic vessels, many of which were intact, and other artifacts, many of which have been donated to the Florida Museum of Natural History (FLMNH).

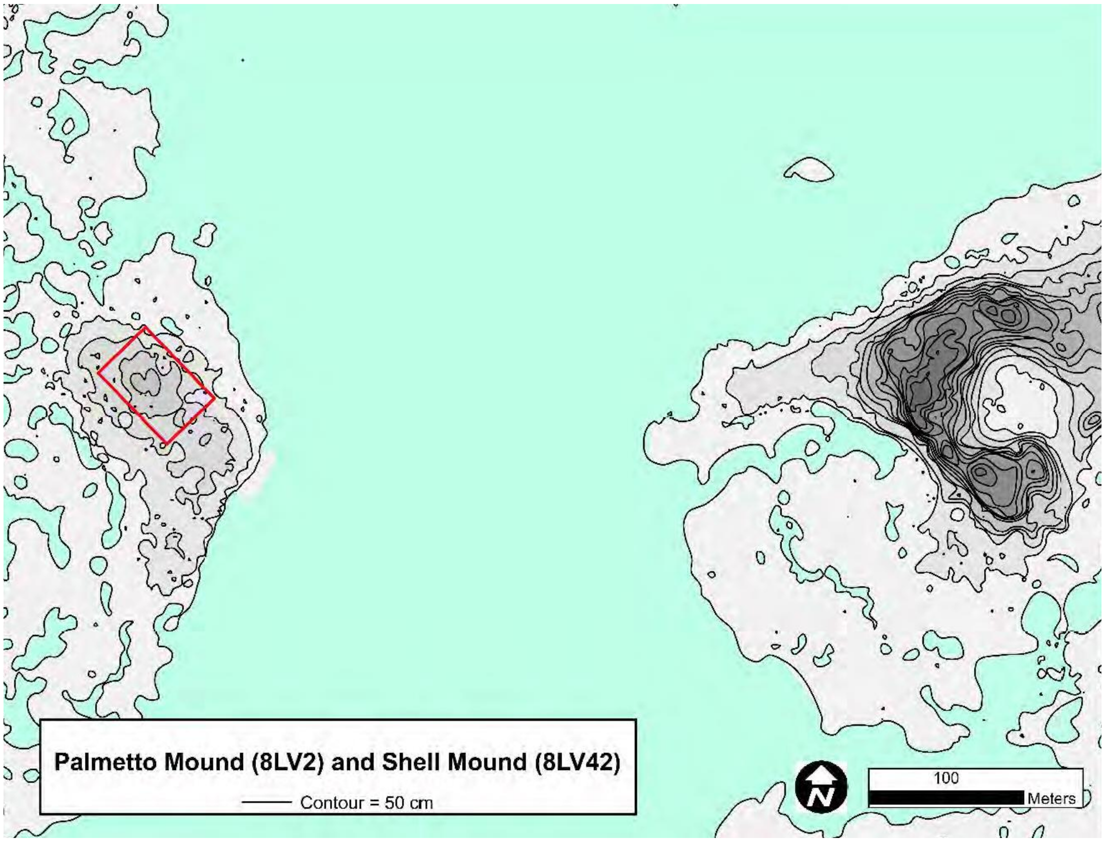

Figure 3-3. LiDAR topographic map of Palmetto Mound and Shell Mound (Sassaman et al. 2015).

Some of the earliest known work on the island was in the 1880s by Decatur Pittman, an amateur archaeologist. Montague Tallant, another amateur archaeologist, also dug at the site in the 1930s, followed by archaeologist Dr. John Goggin in 1952 and 1962 (Willey 1949). This early work contributed to the large collection of artifacts now housed at the FLMNH and South Florida Museum, including over 5,000 sherds from at least 600 vessels from Pittman's excavation, information regarding the construction of the mound and associated ramps from Tallant's observations, as well as field notes and artifacts from Goggin's excavation, including description of a "sherd path" southeast of the mound (Donop 2015).

Recent work at Palmetto Mound was conducted by the LSA as part of graduate research as well as the 2014 archaeological field school. Since 2014, members of the LSA along with field school students have mapped the topography of the mound, systematically tested the site with shovel test pits, and excavated a 2 x 2-m test unit on the northwestern edge of the mound. The test unit was placed in a former looter hole, in an effort to find intact deposits and stratigraphy below the looter disturbance. The excavation of the test unit revealed intact deposits below a shell “cap,” a human burial, and material culture including shell beads (Donop 2015).

Discussion

Continued archaeological projects in the Lower Suwannee are redefining the culture-history of the area and providing new insight to the lifeways of Florida’s Gulf Coastal peoples. Shell Mound is adding to data relating to coastal civic-ceremonial centers by contributing to the narrative of regional interaction and ceremonialism.

Proximity and orientation of Shell Mound and Palmetto Mound indicate that they were likely related sites of gathering and ritualized activity involving terraforming, burial of the dead, and large-scale consumption of food and intensification of shellfish harvesting. This inference is based on the massive pits found on the northern arm of the ridge which include nonlocal materials and large quantities of mammal, fish, and bird remains; the proximity of the monumental architecture at Shell Mound and the mortuary facility on Hog Island; and the large volume of oyster shell at Shell Mound and purposeful placement of oyster shell at both sites. Oyster shell is present, in varying quantities, in every test unit excavated at Shell Mound, and was used as a capping material at Palmetto Mound. It is evident from the deep, dense shell deposits excavated from the apex and southern arm of Shell Mound that oyster was harvested and consumed in large quantities, perhaps surpassing that of daily consumption, and purposefully placed in such a way as to form the mound's U-shape which was created in only a couple of centuries. This intensification of resource use may have led to the need for sustainable shellfish harvesting strategies in the form of mariculture due to increased daily subsistence demand as well as the cultural traditions of ritualized consumption, gathering, and terraforming. Methods for determining evidence for mariculture in Shell Mound's archaeological record is the subject of the following chapter.

CHAPTER 4
SAMPLING, HYPOTHESES AND METHODS

Although some researchers have stated that it should be an accepted fact that people of the ancient past were using some form of mariculture (e.g., Caldwell and Lepofsky 2013; National Research Council 1992; Rakov and Brodianski 2010), these claims must be empirically tested. The objective of this thesis is to determine if it is possible to infer the use of mariculture during the Woodland period in the Lower Suwannee by analysis of archaeological oyster shell from Shell Mound (8LV42).

The types of oyster maricultural practices in consideration are shelling, relaying, size/age selection, selective location of harvest, culling, and off-bottom techniques. Researchers investigating marine management have developed methods for determining size/age selection (Cannon and Burchell 2009; Lepofsky and Caldwell 2013), selective harvest location (Whittaker 2008), and off-bottom techniques (Rakov and Brodianski 2007). I have adapted and incorporated the methods of these researchers while also developing methods for interpreting all six of these practices, primarily based on morphological attributes of archaeological shell. These six maricultural practices were chosen for two primary reasons: first, because of their likelihood of being practiced on the Gulf Coast 2,000 years ago; and second, because there are comparable archaeologically identified practices of shellfish management from other cultures in the past. Shell Mound was chosen as the site used to determine these practices because of the rate at which shell was accumulated (within a century or two) and the probable ritual importance of the site where shellfish, specifically oysters, were harvested for more than daily subsistence activities.

Proxies for these maricultural practices are drawn from multiple morphological attributes apparent on whole, left oyster valves from relatively temporally continuous bulk samples spanning the Woodland period occupation of Shell Mound (A.D. 200–700). The aims of my research are twofold: first, to use and create methods to determine what culturing practices would look like on oyster shells recovered from archaeological contexts; and second, to apply those methods to determine if maricultural practices were used by inhabitants of Shell Mound.

Patterned variation in samples from a stratified midden is inherently diachronic and thus have the potential to reveal changes in oysters attending maricultural practices. There are three periods that are of particular interest: early occupation (~A.D. 200–550), mound building or intensification (A.D. 550–650), and abandonment as residential center (A.D. 650–700). Similarities and differences in patterns between these periods at Shell Mound provide meaningful diachronic data related to the processes of shellfish harvesting and management.

It must be acknowledged that there are limitations to the interpretations, most notably discerning environmental processes affecting shell morphology versus human intervention affecting shell morphology (e.g., Claassen 1998; Erlandson and Rick 2008; Swadling 1976). Measurements of attributes used to infer mariculture are meaningful when there is patterning observed in the context of broader social processes and site formation. For example, it would follow that during early occupation (A.D. 200–550) mariculture would not have been a necessary practice as populations would be low and the primary reason for oyster harvesting would be subsistence. In contrast, maricultural practices may have been necessary during times of intensification (A.D. 550–650) associated with increased shellfish demand due to a “ritualized economy” (Spielmann 2002), involving population increase, the construction of monumental architecture, and possible coalescent and/or feasting events. Finally, evidence of mariculture would dissipate once the site was abandoned as a place of residence (A.D. 650–700); although oyster shell was still mobilized at this time for mound construction, people would not be at the site to tend to local reefs. Furthermore, based on radiocarbon dating, it appears that the shell used in the final depositional events were taken from nearby middens and re-deposited on the underlying strata of unconsolidated shell. Archaeological evidence of culturing and management processes during the same time period and social context elsewhere on the Northwest Coast provide comparable material to inferring mariculture at Shell Mound (i.e. Lepofsky and Caldwell 2013; Lepofsky et al. 2015; Whittaker 2008).

Premises

This research is predicated on four premises:

Premise 1: Oyster shells used in the construction of Shell Mound were harvested locally (i.e., within a day’s travel by canoe). Changes in attributes on oyster shell are assumed to be a function of local environmental circumstances as well as human procurement and intervention within a limited area of resource niches that would be impacted by regular and intensified procurement strategies.

Premise 2: Oyster shell was harvested by the inhabitants of Shell Mound. It is assumed that the people living at Shell Mound were the ones who procured oysters from resource niches within the vicinity of the site, and oysters were not brought to the mound and deposited from elsewhere in the region.

Premise 3: Shell Mound was a place of ritual importance and symbolic significance likely related to the burial complex at Palmetto Mound. It is assumed that resource intensification was a function of an increased demand on oyster resources due to ritual activity likely involving feasting or ritual consumption, mound building activity, and increased sedentism.

Premise 4: Shell Mound was transformed from a place of quotidian habitation to a civic-ceremonial center with a purposefully constructed ridge of shell forming a U-shape. It is assumed that the shell was harvested with the intention, beyond consumption, of being placed within a pre-determined monumental structure.

Hypotheses and Implications

Hypotheses and test implications are listed below for each of the procurement and maricultrual strategies that may have been used by the residents of Shell Mound.

Hypothesis 1 (H1): The location of collection (i.e., subtidal versus intertidal) will covary with the scale and intensity of oyster procurement.

Hypothesis 2 (H2): There will be no change in the location of harvest in accordance with changes in the scale and intensity of oyster procurement.

Implications: If the scale and intensity of oyster harvesting increased for daily subsistence as well as feasting events and mound-building activities, then subtidal oysters would be preferred due to their larger size and generally better quality. If H1 is true, then the majority of oysters in samples associated with Shell Mound as a civic-ceremonial center would be subtidal, whereas those associated with daily subsistence activities would be intertidal due to the ease of access of intertidal oysters. If H2 is true, then there would be no difference in the percentage of subtidal or intertidal oysters between occupational phases.

Hypothesis 3 (H3): The amount of right oyster valves used for cultch (shell returned to the water to enhance oyster reefs) will covary with the scale and intensity of oyster procurement.

Hypothesis 4 (H4): There will be no change in the ratio of left to right oyster shells in accordance with changes in the scale and intensity of procurement.

Implications: If right valves were used as cultch for the maricultural practice of shelling, then there would be a disproportionate number of left and right valves, with less right valves in a sample associated with an increase in the scale and intensity of oyster procurement. In the first phase of occupation, where mariculture was not likely to be practiced, there would be an equal number of left and right valves, as no shell would be returned to the water to enhance oyster reefs. If H3 is true, then the ratio of left to right valves would be high. If H4 is true, then there would be an equal ratio of left to right valves.

Hypothesis 5 (H5): The amount of oysters that were transplanted from suboptimum conditions to optimal conditions through relaying will covary with the scale and intensity of oyster procurement.

Hypothesis 6 (H6): There will be no indication that oysters were transplanted in accordance with the scale and intensity of oyster procurement.

Implications: If oysters were being transplanted from one resource patch to another environmentally distinct resource patch in order to increase the growth rate or quality of the oysters, then there would likely be indications of multiple environmental sources on the shell. If H5 is true, then there would be a large number of shells with evidence of relaying. If H6 is true, then there would be no evidence of this practice, or the same amount of evidence of this practice between occupational phases.

Hypothesis 7 (H7): Evidence of oyster culling will covary with the scale and intensity of oyster procurement.

Hypothesis 8 (H8): There will be no indication that oysters were culled in accordance with the scale and intensity of oyster procurement.

Implications: If the maricultural practice of culling was being used, and live oysters were being returned to the water to maintain oyster populations, there will be evidence of culling on the oyster shells during phases of occupation associated with large-scale intensive harvesting. If H7 is true, then the amount of oysters being culled will be high during the mound-building phase of occupation. If H8 is true, then there will be no evidence of culling, or the evidence of culling would be equal between the phases of occupation.

Hypothesis 9 (H9): The size range of oysters will covary with the scale and intensity of oyster procurement.

Hypothesis 10 (H10): There will be no change in the size range of oysters in accordance with the scale and intensity of oyster procurement.

Implications: If oysters were being selected based on size/age in order to maintain and stabilize oyster populations then evidence of that would be apparent in the height of oysters from a sample. If H9 is correct, then during the phases of occupation in which oysters were harvested quickly and intensively, the range of the size of oysters would be very small. If H10 is correct, then the range of the oyster sizes would not change between different occupational phases.

Hypothesis 11 (H11): The amount of oysters grown using off-bottom techniques will covary with the scale and intensity of oyster procurement.

Hypothesis 12 (H12): There will be no evidence of off-bottom techniques being used in accordance with the scale and intensity of oyster procurement.

Implications: Oysters grown using off-bottom techniques will show evidence of this in the form of their attachment scar. If H11 is true, then there will be a large number of oysters in samples from the intensive phases of occupation that show evidence of being grown using off-bottom techniques. If H12 is true, then there will be no variation of oysters that show evidence of being grown off the bottom at all, or between occupational phases.

Sampling

A total of 3,252 left oyster valves were analyzed from a continuous 30 x 30-cm column sample taken from TU8, near the apex of Shell Mound. Twenty bulk samples were collected encompassing the entire depth of the unit, 2.1 m below surface. Based on the stratigraphy, TU8 was separated into three macrostratagraphic units, or "macrounits" (Sassaman et al. 2015:40-47): the first, uppermost macrounit (Strata I–III) is comprised of unconsolidated bedded oyster shell; the second macrounit (Strata IV–V) consists of organically enriched sands with moderate to sparse shell; the third, deepest macrounit (Strata VI–VII) is primarily submidden sand, into which pit features were dug and subsequently backfilled. The first two macrounits (Strata I–V) are anthropogenic, whereas the last microunit is natural dune sand, with the exception of the pit features.

The upper 1.4 m of unconsolidated shell was excavated in column bulk samples taken from the east profile, and the samples from the ~80 cm of subshell midden were taken from the west profile. Bulk samples were numbered 1–20 from the top of the unit at surface, increasing in numerical sequence to the bottom of the unit. Samples were taken in 10-cm increments.Bulk samples 1–13 were taken from the upper macrounit (Strata I–III) of unconsolidated shell, and bulk samples 14–20 were taken from the second macrounit (Strata IV–V) of sand and sparse shell. All matrix from these bulk samples were returned to the LSA in Gainesville, Florida, and processed with a Dausman Flote-Tech flotation machine and then fractionated for secondary analysis.

All oyster shell was separated from the rest of the material in the bulk samples and then sorted into whole left valves, whole right valves, and fragments. Whole right valves were counted and weighed and the fragments were only weighed. Whole left shells were also counted and weighed, and then set aside for further analysis, described below.

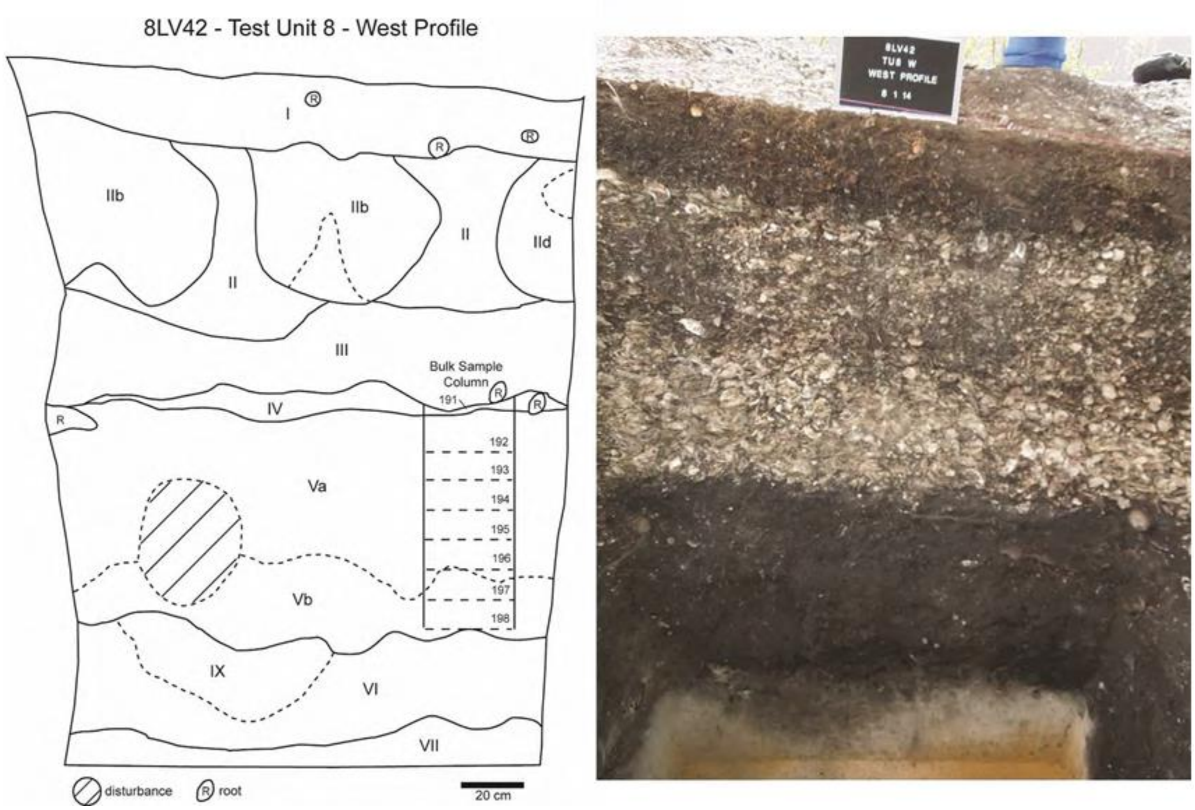

Figure 4-1. Drawing and photograph of TU8 east profile (Sassaman et al. 2015)

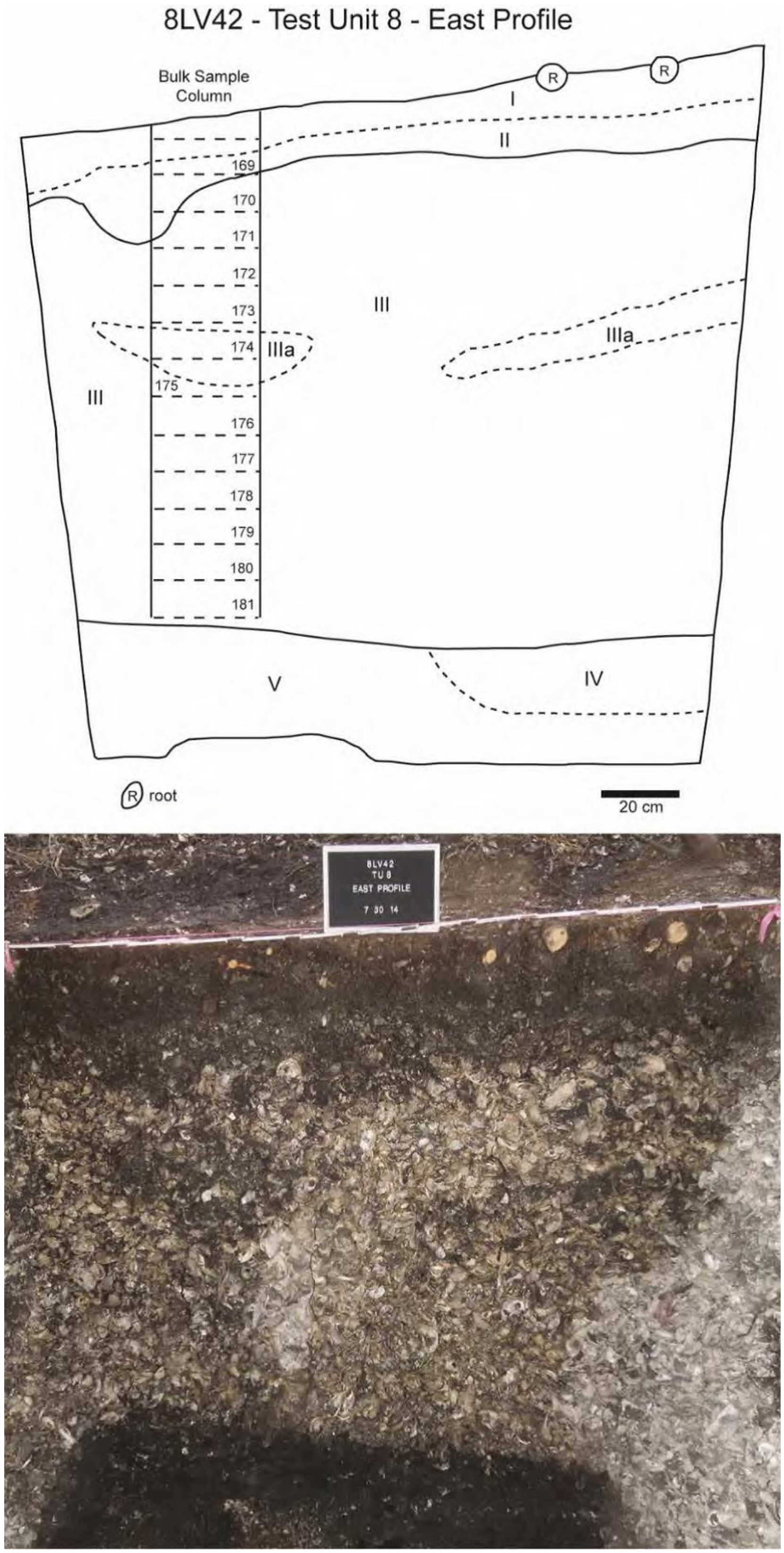

Figure 4-2. Drawing and photograph of TU8 east profile (Sassaman et al. 2015: 41).

Methods and Techniques

The methods used for inferring mariculture and harvesting strategies from the archaeological record at Shell Mound have been drawn from archaeological literature on ancient mariculture/management techniques, the biological and ecological literature on oyster biology and ecology, as well as first-hand experiences in the field with oystermen and oyster biologists in Apalachicola Bay and the Suwannee Sound (see Chapter 2). Described below are the methods and associated hypotheses.

Harvesting Location

In a study done in Maryland, Brett Kent (1988) classifies oysters based on harvesting location. In order to determine this, Kent (1988) used the height-to-length ratio (HLR). The height-to-length ratio is determined by dividing the height, or the measurement of the dorsal end to the ventral end, and the length, or the measurement from the posterior end to the anterior end. Shell height, length, and HLR were determined based on Kent's methods, although a different classification system was used to determine the environment of harvest for the shells from Shell Mound.

Whereas Kent's classification system may be applicable to oysters from Maryland and the greater Chesapeake area, in Florida and the southeast, the best way to classify the environment from which oysters were harvested would be to differentiate between intertidal oysters and subtidal oysters (Lawrence 1988). Oysters harvested from the intertidal will show evidence of extreme clustering with large left valve attachment scars indicative of attachment to other oysters, have thinner shells, and be elongate (Lawrence 1988:267). Oysters harvested from subtidal conditions are more likely to grow singly, therefore not always having attachment scars or having small attachment scars, have more ovate or subovate shell outlines, have thicker shells, and increased valve cupping due to less crowding (Lawrence 1988:267). Subtidal oysters are also often larger than intertidal oysters, as they are constantly exposed to food, whereas intertidal oysters cannot feed during low tide. Furthermore, as many organisms associated with oysters in a fouling community, including predators and parasites, are not adapted to living in intertidal conditions, the frequency of biofoul living upon or within oyster shells will be higher on oysters harvested from subtidal environments.

Based on these distinctions, the attributes I recorded from the oyster shells include the height, HLR, presence or absence of attachment scars, presence or absence of biofoul, presence or absence of parasitism, and left valve concavity.

Shell height and length were both measured to the hundredth of a millimeter (two places after the decimal) using electronic calipers. The height was taken at the longest measurement from the dorsal to the ventral, and length was measured at the widest point of the shell from the anterior to the posterior. All measurements were recorded and then the height of the shell was divided by the length of the shell to produce the HLR, rounded to the nearest hundredth of a millimeter. Presence or absence of attachment scars, biofoul, and parasitism were recorded for each shell. The type of biofoul and/or parasite was specified for each shell in which they were present. Each shell was also give a left valve concavity value between one and three, one being almost flat, two being average, and three being extremely cocave. The left valve concavity value was determined based on the ratio of depth to the height and length of the valve.

Inferring whether oysters were harvested from intertidal or subtidal environments is strongest when these attributes appear in concert, as variations do naturally occur in dynamic estuarine environments (Lawrence 1988). Summarized in Table 4-1 below are the attributes associated with environmental source areas from which oysters were harvested.

Table 4-1. Inferences regarding environment of harvest and associated attributes evident on archaeological shell (adapted from Lawrence 1988:268).

Inference	Height	HLR	Presence/Absence of Biofoul	Presence/Absence of Parasitism	Concavity
Source area Intertidal	Smaller on average	Elongate	Biofoul that cannot live in intertidal environments absent	Evidence of parasitism from organisms that cannot live in intertidal environments absent	Flatter, less concave shells-value mostly 1 and 2
Source area Subtidal	Larger on average	Ovate or subovate	Presence of biofoul that can live only subtidally	Evidence of parasitism from organisms that can live only subtidally	Shells that are very concave-value mostly 3 with some 2

The differences between intertidal or subtidal environments provide insight into how people were harvesting oysters. Intertidal oysters are available at the water's edge and can be harvested easily and locally at low tide. Conversely, harvesting subtidal oysters requires a larger expenditure of energy to collect the resource from reefs farther out in the water that would likely require a boat to access.

In terms of how this differentiation relates to mariculture lies in the quality and productivity of the oysters. Subtidal oysters often produce higher quality meat (plump, with a creamy white color, and fills out the shell) primarily because they can "fatten" with regular exposure to food (Korringa 1952). Also, subtidal oysters are often more prolific.

Therefore, if oysters were managed in order to produce large quantities of high quality oysters, the oysters in a cultured deposit would likely be primarily subtidal.

Shelling

Shelling enhances oyster reef productivity by building habitat through returning shell to the water for oyster larvae to settle on. In order to discern this archaeologically, it would be best to test extant reefs for evidence of this practice. To discern this practice simply by looking at the shells in a sample, the ratio of left (cupped) to right (flat) valves could be used as a possible measure. In terms of ecology, oyster larvae settle most readily on smooth flat surfaces of their own species (Crisp 1967) and, since right valves are flatter than left valves, they would be ideal cultch. If shelling was being practiced, it is likely that there would be more left valves in a sample than right. Also, if oysters were being processed on the water, right valves would be shucked and then immediately returned to the water, as the oyster meat sits in the cupped left valve. Also, if there are many dead shells, those with heavy parasitic encrustation or with biofoul present on the inside of the shell, it may be indicative that they were collected and deposited in the sample because they were attached to desired oysters that were collected for consumption (Lawrence 1988:267).

Relaying

The best way to determine relaying in the archaeological record would likely be through the use of isotopic analysis. In order to discern relaying in the absence of isotopic data, morphological evidence of two distinct environments would be present on the shell if oysters were transferred from one set of environmental conditions to another. For example, if a high fraction of oysters in a sample are elongate with HLRs close to 2 mm, but also have evidence of biofoul or parasites that are only associated with subtidal conditions, it could be inferred that at a certain point in the oysters' lifecycle, they were taken from the intertidal, which is a suboptimum environment, and transferred to a subtidal environment, which provide oysters with more resources for fast growth and reproduction. Another practice of relaying may be to take oysters from one salinity regime to another, based on the desired results, in which high-salinity biofoul, such as barnacles, are more likely to be present. The relevant attributes to be used to infer relaying would be height, HLR, presence/absence and type of parasites, presence/absence and type of biofoul, and left valve concavity. These attributes are used to indicate salinity regimes as well as intertidal or subtidal conditions, as described above. Inferring relaying involves a multivariate approach, where the relevant attributes vary in a way contradictory than what would be expected if the oysters only grew and lived in one type of environment.

Off-Bottom Techniques

Off-bottom techniques include growing oysters on lines or poles to protect them from sedimentation which may be harmful for the growth and reproduction of oysters. Oysters are xenomorphic, meaning that they faithfully replicate the substrate on which they grow (Lawrence 1988). Because of this, if attachment scars are shaped in a way that is indicative of cordage, rope, or twigs and branches, it would indicate that they were not naturally settling on other shells. Aside from protection from sedimentation, growing oysters off the bottom allows for placement in optimum and controlled areas of the estuary. The type or shape of attachment scar would be the attribute used to distinguish this type of culturing technique.

Culling

Culling is visible on archaeological shell by examining attachment scars, biofoul, and parasitism. If an oyster burr is culled, then the desired oysters would be kept for consumption and the dead shell and smaller oysters and spat are returned to the water to continue growing. If an oyster is returned to the water after being removed from other oysters in a burr, then the oyster would have an attachment scar. Once returned to the water, the attachment scar becomes more vulnerable to parasitic attack and settling of biofoul, whereas it would be protected from these organisms when attached to other oyster shells. If an oyster has an attachment scar that has evidence of parasitism or biofoul, then it could be inferred it was returned to the water after being separated from other oysters and substrate (Figure 4-3).

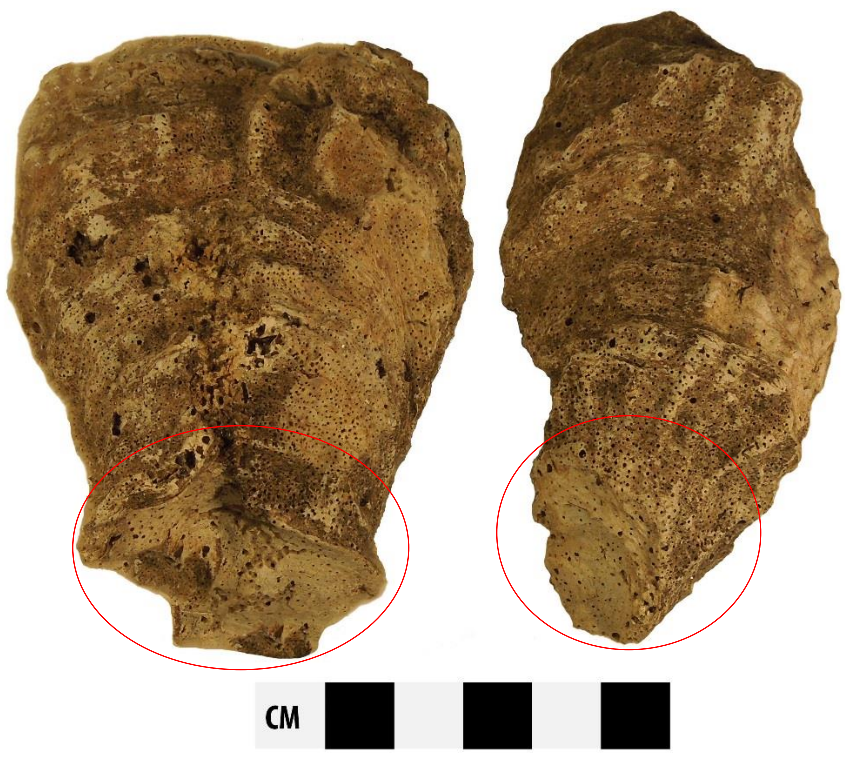

Figure 4-3. Photograph of two left valves showing sponge parasitism on attachment scars.

Size/Age Selection

Size and age selection as culturing strategies largely relate ecologically to the reproduction of oysters. If coastal inhabitants were selectively harvesting for size or age, larger and older oysters were harvested first in order to give smaller juvenile oysters time to mature through reproductive cycles. If large oysters were routinely collected it could be evidence of “plucking” instead of “stripping” beds, therefore shellfish harvesters could be selectively harvesting based on resource patch (Whittaker 2008). To determine this, both height and age can be determined from archaeological oyster shell. Height can be used as a proxy for age, where the larger oysters are thought to be older and the younger oysters are thought to be smaller, but this is not always the case when increased predation pressure affects the biology and morphology of oysters (Swadling 1976).

Discussion

Using shell from archaeological contexts as the primary means to infer mariculture requires the close examination of morphological attributes of shell that serve as proxies for various practices or environmental conditions. An understanding of the natural conditions, including the dynamic nature of estuaries in which oysters grow, the variation of estuaries in a region, and the biological and environmental factors that affect oyster growth and reproduction is essential in interpretation. Those natural factors, when combined with the equally dynamic and variable social processes of the coastal populations in question, can provide insight into if, how, and why maricultural practices were in place.

In a highly dynamic estuarine environment oyster populations are vulnerable. Although oysters are conditioned to be resilient and prolific, able to withstand a broad range of salinity, temperature, turbidity, and dissolved oxygen, as well as predation pressure, sudden and dramatic shifts in salinity or temperature for prolonged periods of time make oyster reefs and beds susceptible to collapse and morphological change (Rick and Lockwood 2013). Because of the possibility of shifting morphology due to environmental shifts and/or storm events, the methods used in determining mariculture also lie in the context of procurement, in this case, ritual consumption, intensification, and/or increased demand for subsistence or architectural resources. These methods were devised based on other archaeologists' studies of determining shellfish management in the archaeological record, the ecological literature concerning oyster morphology and ecology, as well as experiences in both Apalachicola Bay and the Suwannee Sound with oystermen engaging in mariculture. Specifically, the observation of oyster harvesting and culturing practices in Apalachicola Bay influenced the methods devised for determining culling and the technology involved in harvesting subtidal oysters.

The multiple variables used to in these methods were recorded for 3,252 oysters from Shell Mound and statistically analyzed, the results of which are described in the following chapter.

CHAPTER 5
RESULTS AND ANALYSIS

Reported below are the results of the analysis of all of the whole left oysters from the subsistence column from Test Unit 8 near the apex of Shell Mound. Twenty bulk samples were recovered from TU8 in a subsistence column from the east and west profiles. The samples were then floated and all oyster shell was removed for further analysis.

In the previous chapter I described the methods for analysis and the relevant variables. The variables used for analysis are height, length, height-to-length ratio (HLR), attachment scars, sponge parasitism, left valve concavity, and biofouling. The number of left to right valves is also compared. Each variable is divided below by subsistence column sample number (1–20) and some are grouped by macro unit for comparison, where there is the Upper Macrounit (Samples 1–13, *n* = 3,098) and the Lower Macrounit (Samples 14–20, *n* = 154). The Upper Macrounit was then further subdivided into two subunits, Upper Macrounit 1 (Samples 1–6, *n* = 1,261) and Upper Macrounit 2 (Samples 7–13, *n* = 1,837). The Upper Macrounit was divided into the two subunits based on a stratigraphic break as well as breaks in patterning of fauna and material culture. Radiocarbon dates at the base of each macrounit show that there may be reverse stratigraphy, where the Upper Macrounit 1(A.D. 405–550) accumulation of shell may have been redeposited on top the Upper Macrounit 2 (A.D. 545–645) from an older midden. Also, in some cases, extremely small sample sizes in the subsistence column samples, specifically Sample 14 (*n* = 3), created potentially false anomalies, therefore the comparison of macrounit may be more meaningful. Before addressing the hypotheses defined in Chapter 4, the descriptive statistics are presented by variable, as multiple variables are used in conjunction to test the hypotheses.

Height, Length, and Height-to-Length Ratio

For each of the 20 samples, the mean, minimum, maximum, and standard deviation of those three variables is listed and graphed below (Tables 5-1, 5-3, and 5-4, and Figures 5-1–5-3). The range of oyster height is also presented by number of oysters per macrounit as well as percent of oysters per macrounit within 20 mm size ranges (Table 5-2).

The total range of the height of the oysters sampled is 130.95 mm, ranging from a minimum of 14.96 mm (Sample 11) to a maximum of 145.91 mm (Sample 12). The mean height is the smallest in samples 15–20, being less than 50 mm on average (30.54–49.60 mm). In Samples 1–13, the oysters remain in 50 mm range, with an outlier in Sample 14, where the mean height is 64.48 mm. In Samples 7–20 the average remains between 55 and 59 mm (55.63–58.36 mm), dropping to between 50 and 56 mm (50.67–55.78 mm) in Samples 1–6.

The total range of the length of the oysters sampled is 70.89 mm, ranging from a minimum of 6.23 (Sample 18) to a maximum of 77.12 (Sample 12). Similar to the mean height, the mean length is the smallest in Samples 15–20, not exceeding 30 mm (17.15–28.83 mm). Again, there is an increase in mean length in samples 1–13, ranging from about 30 mm to about 33 mm (30.26–33.23 mm). Like with mean height, the mean length of Sample 14 is anomalous at 36.87 mm. The mean height-to-length ratio ranges between 1.56–1.81. The mean remains within a range of 9 percent in sample 6–13 (1.71–1.80). In Samples 1–5, the mean HLR ranges 18 percent (1.56–1.74), and in Sample 14–20, the HLR ranges 31 percent (1.58–1.89).

Table 5-1. Descriptive statistics for oyster height by subsistence column sample.

Sample	*n* =	Height (mm) Mean	SD	Minimum	Maximum
1	37	50.67	9.61	31.19	77.34
2	184	52.10	12.17	26.67	96.62
3	315	55.38	13.09	23.18	93.67
4	312	53.97	14.73	20.26	112.19
5	190	55.78	15.73	18.40	95.95
6	223	54.36	14.93	21.82	95.92
7	246	57.26	16.05	15.68	14.77
8	254	57.22	17.95	19.40	110.03
9	187	55.63	18.76	18.55	115.77
10	258	57.08	16.91	24.30	109.96
11	292	57.74	18.77	14.96	104.87
12	276	58.36	20.56	19.82	145.91
13	324	57.68	19.02	20.01	129.95
14	3	64.48	10.20	52.73	70.99
15	14	48.08	16.58	26.52	82.23
16	14	43.20	10.89	27.26	60.56
17	11	30.54	10.97	17.39	49.39
18	49	43.48	16.68	19.50	82.64
19	16	49.60	17.71	26.54	84.06
20	47	49.19	15.22	26.08	85.25

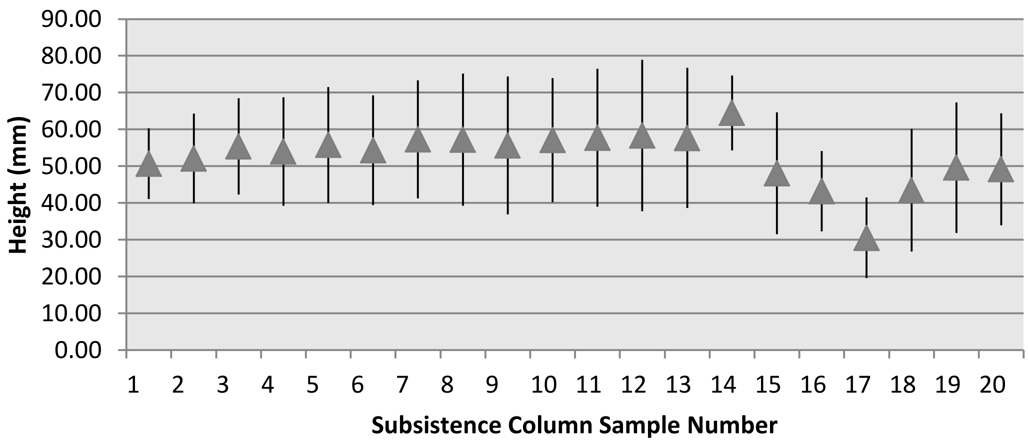

Figure 5-1. Mean and range oyster height by subsistence column sample.

Table 5-2. Number and percent of oysters in each macrounit by size range.

Range	Height By Size Range (mm) Upper Macrounit 1		Upper Macrounit 2		Lower Macrounit	
	n =	%	*n* =	%	*n* =	%
0.1 - 20	2	0.16	9	0.49	4	2.60
20.01 - 40	188	14.91	337	18.35	54	35.06
40.01 - 60	676	53.61	765	41.64	70	45.45
60.01 - 80	342	27.12	542	29.50	21	13.64
80.01 - 100	52	4.12	146	7.95	5	3.25
100.01 - 120	1	0.08	38	2.07	0	0.00
Total	1261	100	1837	100	154	100

Table 5-3. Descriptive statistics for oyster length by subsistence column sample.

Sample	*n* =	Length (mm) Mean	SD	Minimum	Maximum
1	37	32.39	5.88	21.43	44.12
2	184	31.83	6.81	16.74	55.87
3	315	32.73	7.92	14.19	58.08
4	312	31.08	8.01	12.71	62.30
5	190	33.23	8.75	11.76	57.14
6	223	30.26	7.64	12.33	52.08
7	246	33.56	9.33	11.16	62.95
8	254	31.63	9.82	10.09	61.65
9	187	31.14	9.58	11.60	57.35
10	258	32.06	8.17	13.10	59.14
11	292	32.75	10.11	10.44	60.69
12	276	32.94	10.72	11.37	77.12
13	324	32.00	10.00	9.66	67.91
14	3	36.87	8.77	27.07	43.97
15	14	28.83	8.21	13.71	42.01
16	14	27.32	7.40	17.16	40.14
17	11	17.15	5.07	11.30	25.10
18	49	23.00	7.17	6.23	37.02
19	16	26.90	8.52	13.65	47.16
20	47	27.88	7.74	13.55	50.92

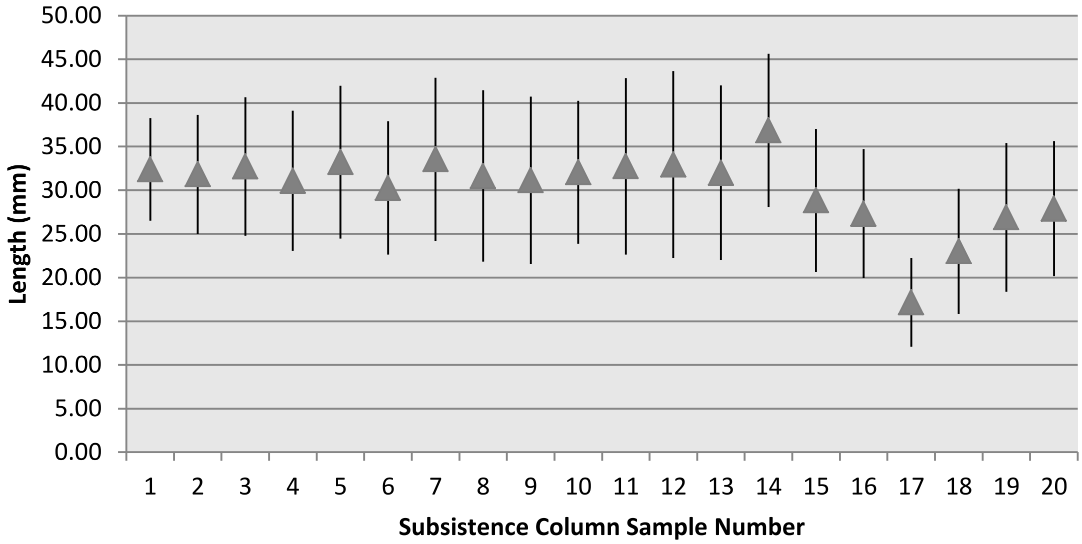

Figure 5-2. Mean and range oyster length by subsistence column sample.

Table 5-4. Descriptive statistics for oyster HLR by subsistence column sample.

		Height-to-Length Ratio			
Sample	*n* =	Mean	SD	Minimum	Maximum
1	37	1.56	0.17	1.16	1.87
2	184	1.64	0.20	1.17	2.23
3	315	1.69	0.24	1.20	2.50
4	312	1.74	0.28	1.19	3.21
5	190	1.68	0.29	1.08	3.00
6	223	1.80	0.30	1.14	2.93
7	246	1.71	0.27	1.23	2.63
8	254	1.81	0.28	1.29	2.81
9	187	1.79	0.30	1.17	2.92
10	258	1.78	0.28	1.14	2.79
11	292	1.76	0.28	1.13	2.76
12	276	1.77	0.31	1.14	3.05
13	324	1.80	0.30	1.11	3.09
14	3	1.75	0.17	1.61	1.95
15	14	1.67	0.28	1.33	2.38
16	14	1.58	0.21	1.25	1.88
17	11	1.78	0.45	1.28	2.88
18	49	1.89	0.39	1.21	3.13
19	16	1.84	0.30	1.04	2.49
20	47	1.76	0.32	1.42	2.35

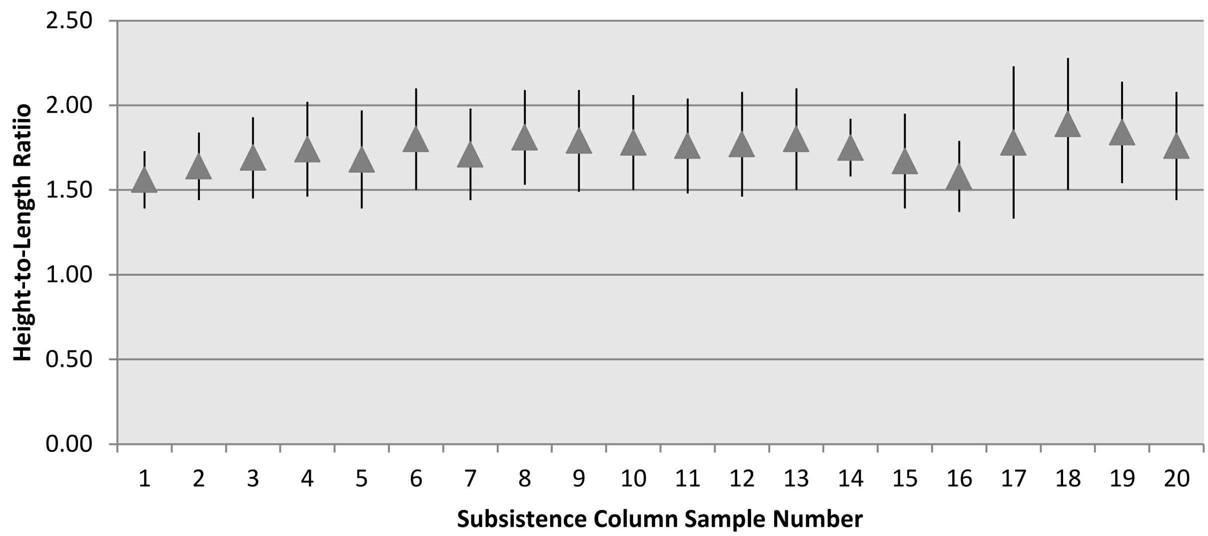

Figure 5-3. Mean and range oyster HLR by subsistence column sample.

Presence/Absence and Type of Attachment Scars

The presence/absence of attachment scars is shown for Samples 1–20 in the table and figure below (Table 5-5 and Figure 5-4) and then divided into the Upper Macrounit and Lower Macro Unit (Table 5-6), as well as Upper Macrounit 1 and Upper Macrounit 2 (Table 5-7). Both the number of shells in each sample with and without attachment scars as well as the percentage of shells in each sample with and without attachment scars are listed.

The lowest percentage of oyster shells with attachment scars is 43 percent (Sample 4), and the highest percentage of oyster shell with attachment scars is 86 percent (Sample 1). With the exception of Samples 3, 4, and 19, the amount of oyster shells with attachment scars in a sample does not fall below 50 percent. In the Upper Macrounit, 64 percent of the shells have attachment scars, and in the Lower Macrounit, 60 percent of the shells have attachment scars. In the Upper Macrounit 1, 52 percent of the oyster shells have attachment scars, and in the Upper Macrounit 2, 60 percent of the shells have attachment scars.

The type of substrate, shell or “line” is quantified (Table 5-8). The sample with the highest number of oysters that may have been grown on line or cordage is 6 percent (Sample 3), and 11 out of 20 samples have no shells that appear to be grown on line or cordage. Because of this extremely low number, no further analysis was done on this attribute, as it seems as though it does not apply to this sample.

Table 5-5. Presence or absence of attachment scar by subsistence column sample.

Presence/Absence of Attachment Scar					
	n =	Present		Absent	
Sample		*n* =	%	*n* =	%
1	37	32	86	5	14
2	184	112	61	72	39
3	315	155	49	160	51
4	312	133	43	179	57
5	190	100	53	90	47
6	223	128	57	95	43
7	246	162	66	84	34
8	254	159	63	95	37
9	187	142	76	45	24
10	258	193	75	65	25
11	292	228	78	64	22
12	276	207	75	69	25
13	324	234	72	90	28
14	3	2	67	1	33
15	14	8	57	6	43
16	14	7	50	7	50
17	11	8	73	3	27
18	49	37	76	12	24
19	16	7	44	9	56
20	47	24	51	23	49

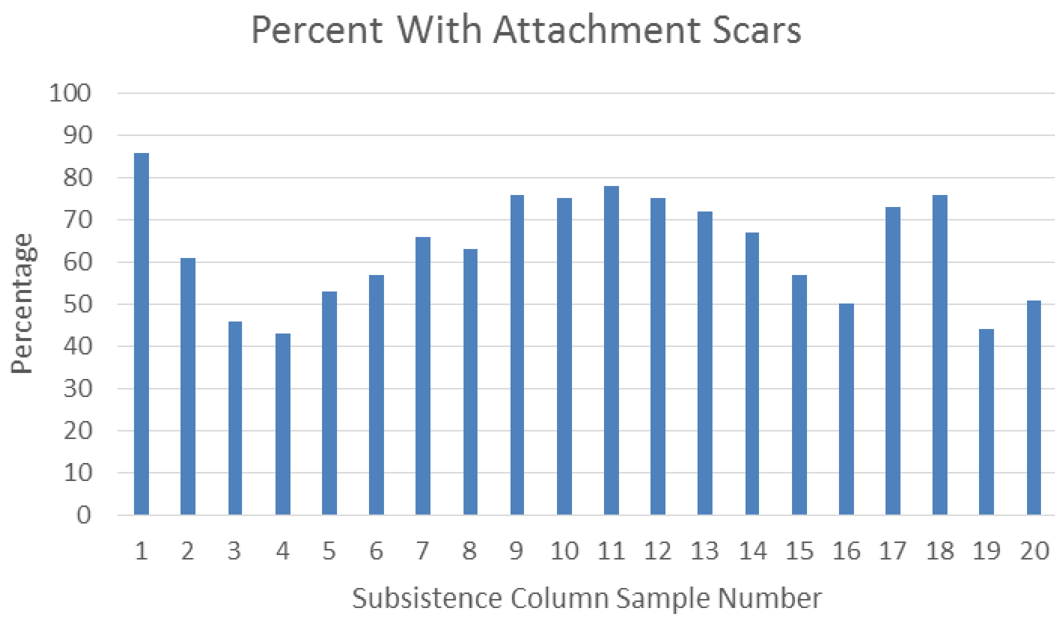

Figure 5-4. Percentage of oyster shells with parasitism by subsistence column sample.

Table 5-6. Presence or absence of attachment scars Upper and Lower Macrounits.

	Presence/Absence of Attachment Scar				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit	3098	1985	64	1113	36
Lower Macrounit	154	61	60	93	40

Table 5-7. Presence or absence of attachment scars by Upper Macrounits 1 and 2 and the Lower Macrounit.

	Presence/Absence of Attachment Scar				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit 1	1261	660	52	601	48
Upper Macrounit 2	1837	1325	72	512	28
Lower Macrounit	154	61	60	93	40

Table 5-8. Type of substrate by subsistence column sample.

Sample	*n* =	Type of Substrate: Shell		Line		None or Unknown	
		n =	%	*n* =	%	*n* =	%
1	37	32	86	0	0	5	14
2	184	104	57	8	4	72	39
3	315	132	42	18	6	165	52
4	312	131	42	4	1	177	57
5	190	93	49	5	3	92	48
6	223	122	55	5	2	96	43
7	246	155	63	5	2	86	35
8	254	157	62	0	0	97	38
9	187	130	70	9	5	48	26
10	258	195	76	0	0	63	24
11	292	220	75	9	3	63	22
12	276	202	73	4	1	70	25
13	324	233	72	0	0	91	28
14	3	2	67	0	0	7	33
15	14	7	50	0	0	7	50
16	14	7	50	0	0	7	50
17	11	8	73	0	0	3	27
18	49	37	76	0	0	12	24
19	16	7	44	0	0	9	56
20	47	23	49	0	0	24	51

Presence/Absence of Sponge Parasitism

The presence/absence of parasitism is shown for Samples 1–20 in the table below (Table 5-9 and Figure 5-5) and then divided into the Upper Macrounit and Lower Macro Unit (Table 5-10), as well as Upper Macrounit 1 and Upper Macrounit 2 (Table 5-11). Both the number of shells in each sample with and without sponge parasitism as well as the percentage of shells in each sample with and without sponge parasitism are listed.

The lowest percentage of oyster shells with sponge parasitism is 6 percent (Sample 18), and the highest percentage of oyster shell with sponge parasitism is 67 percent (Sample 14). The percent of oysters with sponge parasitism for Sample 14 is anomalous likely due to the small sample size (*n* = 3). The percentage of oyster shells with sponge parasitism in Samples 1–13, the Upper Macrounit, ranges from 39 percent to 61 percent, whereas Samples 14–20, the Lower Macrounit, range from 6 percent to 67 percent of oysters with sponge parasitism per sample. In the Upper Macrounit, 48 percent of the shells have sponge parasitism, and in the Lower Macrounit, 30 percent of the shells have sponge parasitism. In the Upper Macro Unit 1, 46 percent of the oyster shells have sponge parasitism, and in the Upper Macro Unit 2, 49 percent of the shells have sponge parasitism.

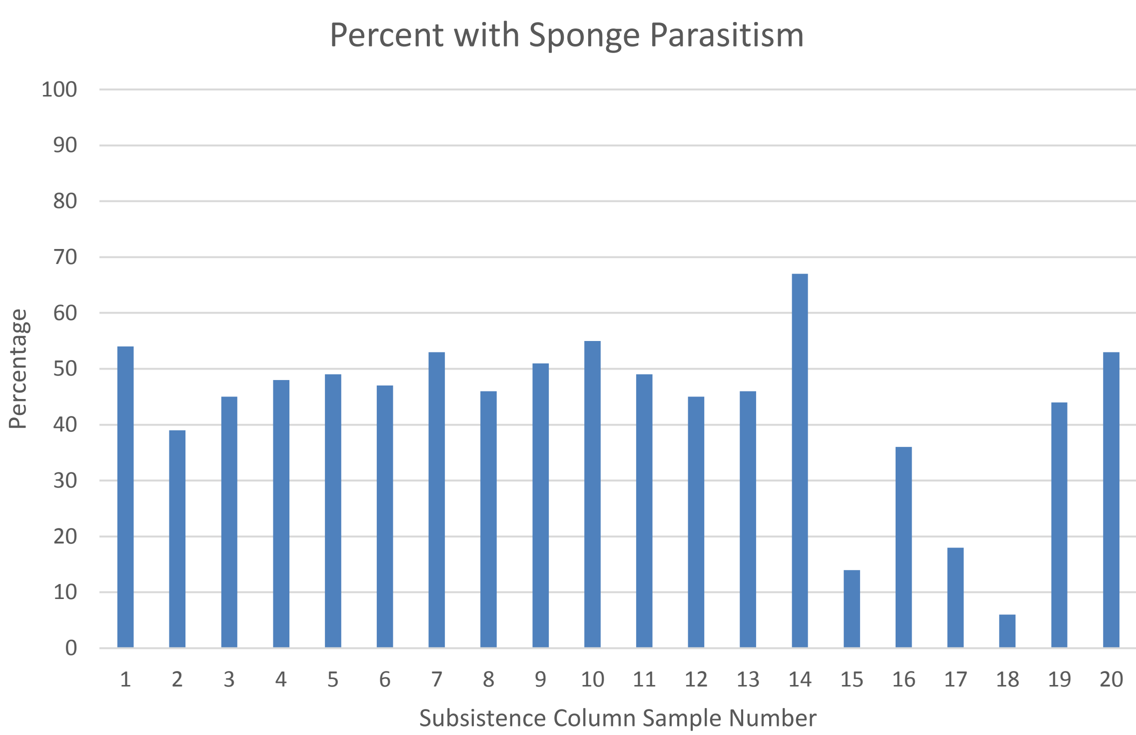

Figure 5-5. Percent of oyster with sponge parasitism by subsistence column.

Table 5-9. Presence or absence of parasitism by subsistence column sample.

Sample	n =	Presence/Absence of Parasitism: Present n =	Present %	Absent n =	Absent %
1	37	20	54	17	46
2	184	72	39	112	61
3	315	141	45	174	55
4	312	149	48	163	52
5	190	93	49	97	51
6	223	105	47	118	53
7	246	131	56	115	47
8	254	116	46	138	54
9	187	95	51	92	49
10	258	141	55	117	45
11	292	142	49	150	51
12	276	125	45	151	55
13	324	149	46	175	54
14	3	2	67	1	33
15	14	2	14	12	86
16	14	5	36	9	64
17	11	2	18	9	82
18	49	3	6	46	94
19	16	7	44	9	56
20	47	25	53	22	47

Table 5-10. Presence or absence of parasitism by Upper and Lower Macrounits.

	n =	Presence/Absence of Parasitism: Present n =	Present %	Absent n =	Absent %
Upper Macrounit	3098	1479	48	1619	52
Lower Macrounit	154	46	30	108	70

Table 5-11. Presence or absence of sponge parasitism by Upper Macrounits 1 and 2 and the Lower Macrounit.

	n =	Presence/Absence of Parasitism: Present n =	Present %	Absent n =	Absent %
Upper Macrounit 1	1261	580	46	681	54
Upper Macrounit 2	1837	899	49	938	51
Lower Macrounit	154	46	30	108	70

Presence/Absence of Parasitism on the Attachment Scar

The presence/absence of parasitism on attachment scars is shown for Samples 1–20 in the table below (Table 5-12 and Figure 5-6) and then divided into the Upper Macrounit and Lower Macro Unit (Table 5-13), as well as Upper Macrounit 1 and Upper Macrounit 2 (Table 5-14). Both the number of shells in each sample with and without parasitism on the scar as well as the percentage of shells in each sample with and without parasitism on the scar are listed. Furthermore, tables showing percentage of shells with scars with parasitism and with scars without parasitism is displayed for Samples 1–20 (Table 5-15 and Figure 5-7), the Upper Macrounit and Lower Macrounit (Table 5-16), and Upper Macrounit 1 and Upper Macrounit 2 (Table 5-17), in both numeric and percentage form.

The lowest percentage of oyster shells with parasitism on the scar is 6 percent (Sample 19), and the highest percentage of oyster shell with parasitism on the scar is 34 percent (Sample 10). Samples 14, 15, 17, and 18 have no shells with parasitism on the scar. The percentage of oyster shells with parasitism on the scar in Samples 1–13, the Upper Macrounit, ranges from 13 percent to 34 percent, whereas Samples 14–20, the Lower Macrounit, range from 0 percent to 11 percent of oysters with parasitism on the scar per sample. In the Upper Macrounit, 20 percent of the shells have parasitism on the scar, and in the Lower Macrounit, 5 percent of the shells have parasitism on the scar. In the Upper Macro Unit 1, 15 percent of the oyster shells have parasitism on the scar, and in the Upper Macro Unit 2, 24 percent of the shells have parasitism on the scar.

Of the shells that have attachment scars, the lowest percentage of oyster shells with parasitism on the scar is 14 percent (Sample 19), and the highest percentage of oyster shell with parasitism on the scar is 46 percent (Sample 10). Samples 14, 15, 17, and 18 have no shells with scars with parasitism on the scar. The percentage of oyster shells with sponge parasitism in Samples 1–13, the Upper Macrounit, ranges from 17 percent to 46 percent, whereas Samples 14–20, the Lower Macrounit, range from 0 percent to 21 percent of oysters with scars with parasitism on the scar per sample. In the Upper Macrounit, 32 percent of the shells that have scars have parasitism on the scar, and in the Lower Macrounit, 8 percent of the shells that have scars have parasitism on the scar. In the Upper Macro Unit 1, 29 percent of the oyster shells that have scars have parasitism on the scar, and in the Upper Macro Unit 2, 34 percent of the shells that have scars have parasitism on the scar.

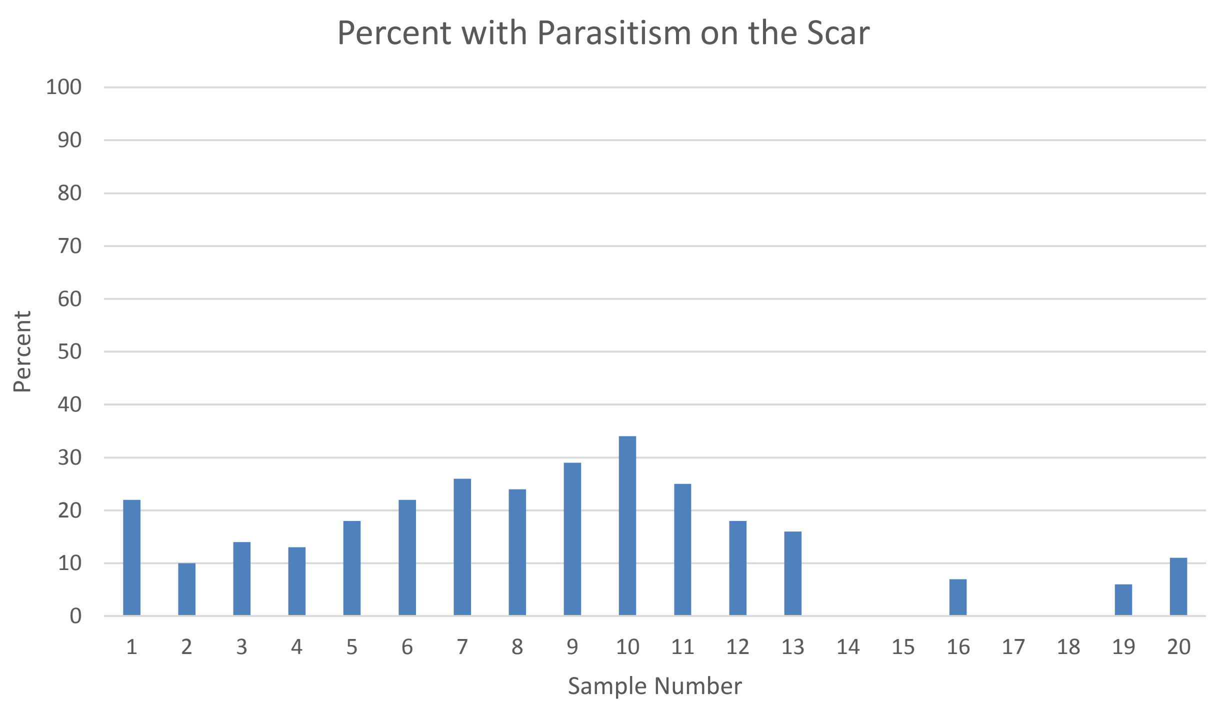

Figure 5-6. Percent of oyster with sponge parasitism on attachment scar by subsistence column.

Table 5-12. Presence or absence of sponge parasitism on the attachment scar by subsistence column sample.

	Presence/Absence of Parasitism on Scar				
	n =	Present		Absent	
Sample		*n* =	%	*n* =	%
1	37	8	22	29	78
2	184	19	10	165	90
3	315	44	14	271	86
4	312	40	13	272	87
5	190	34	18	156	82
6	223	48	22	175	78
7	246	63	26	183	74
8	254	60	24	194	76
9	187	54	29	133	71
10	258	88	34	170	66
11	292	73	25	219	75
12	276	49	18	227	82
13	324	53	16	271	84
14	3	0	0	3	100
15	14	0	0	14	100
16	14	1	7	13	93
17	11	0	0	11	100
18	49	0	0	49	100
19	16	1	6	15	94
20	47	5	11	42	89

Table 5-13. Presence or absence of sponge parasitism on attachment scars by Upper and Lower Macrounits.

	Presence/Absence of Parasitism on Scar				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit	3098	633	20	2465	80
Lower Macrounit	154	7	5	147	95

Table 5-14. Presence or absence of sponge parasitism on attachment scars by Upper Macrounits 1 and 2 and the Lower Macrounit.

	Presence/Absence of Parasitism on Scar				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit 1	1261	193	15	1068	85
Upper Macrounit 2	1837	449	24	1388	76
Lower Macrounit	154	7	5	147	95

Table 5-15. Presence or absence of sponge parasitism on the attachment scar on shells with attachment scars by subsistence column sample.

	Shells With Scars	With Parasitism			
	n =	Present		Absent	
Sample		*n* =	%	*n* =	%
1	32	8	25	24	75
2	112	19	17	93	83
3	155	44	28	111	72
4	133	40	30	93	70
5	100	34	34	66	66
6	128	48	38	80	63
7	162	63	39	99	61
8	159	60	38	99	62
9	142	54	38	88	62
10	193	88	46	105	54
11	228	73	32	155	68
12	207	49	24	158	76
13	234	53	23	181	77
14	2	0	0	2	100
15	8	0	0	8	100
16	7	1	14	6	86
17	8	0	0	8	100
18	37	0	0	37	100
19	7	1	14	6	86
20	24	5	21	19	79

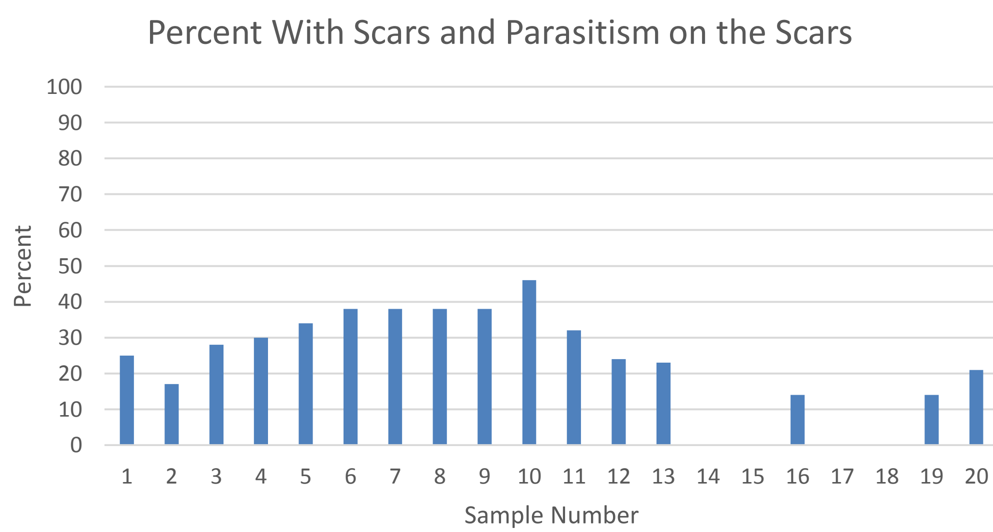

Figure 5-7. Percent of shells with attachment scars that have sponge parasitism on the attachment scar by subsistence column sample.

Table 5-16. Presence or absence of sponge parasitism on attachment scars on shells with attachment scars by Upper and Lower Macrounits.

	Shells With Scars With Parasitism				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit	1985	633	32	1352	68
Lower Macrounit	93	7	8	86	92

Table 5-17. Presence or absence of sponge parasitism on attachment scars on shells with attachment scars by Upper Macrounits 1 and 2 and the Lower Macrounit.

	Shells With Scars With Parasitism				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit 1	660	193	29	467	71
Upper Macrounit 2	1325	449	34	876	66
Lower Macrounit	154	7	5	147	95

Left versus Right Shells

The amount of left versus right oyster shells is shown for Samples 1–20 in the table and graph below (Table 5-18 and Figure 5-8) and then divided into the Upper Macrounit and Lower Macro Unit (Table 5-19), as well as Upper Macrounit 1 and Upper Macrounit 2 (Table 5-20). Both the number of left and right shells in each sample as well as the relative and absolute frequencies of left and right shells in each sample are listed. Generally, left oysters predominate the samples in the Upper Macrounit, especially in Macrounit 2, the sample is comprised of 65 percent left oyster shells. The ratio of left to right valves is also displayed below by subsistence column sample number (Table 5-21 and Figure 5-9).

Table 5-18. Number and percentage of left and right oyster valves by subsistence column sample.

Right Versus Left Oyster Shells					
	n =	Right		Left	
Sample		*n* =	%	*n* =	%
1	87	50	57	37	43
2	378	194	51	184	49
3	616	301	49	315	51
4	672	360	54	312	46
5	446	256	57	190	43
6	478	255	53	223	47
7	436	190	44	246	56
8	437	183	42	254	58
9	321	134	42	187	58
10	398	140	35	258	65
11	420	128	30	292	70
12	363	87	24	276	76
13	430	106	25	324	75
14	6	3	50	3	50
15	36	22	61	14	39
16	37	23	62	14	38
17	22	11	50	11	50
18	117	68	58	49	42
19	49	33	67	16	33
20	114	67	59	47	41

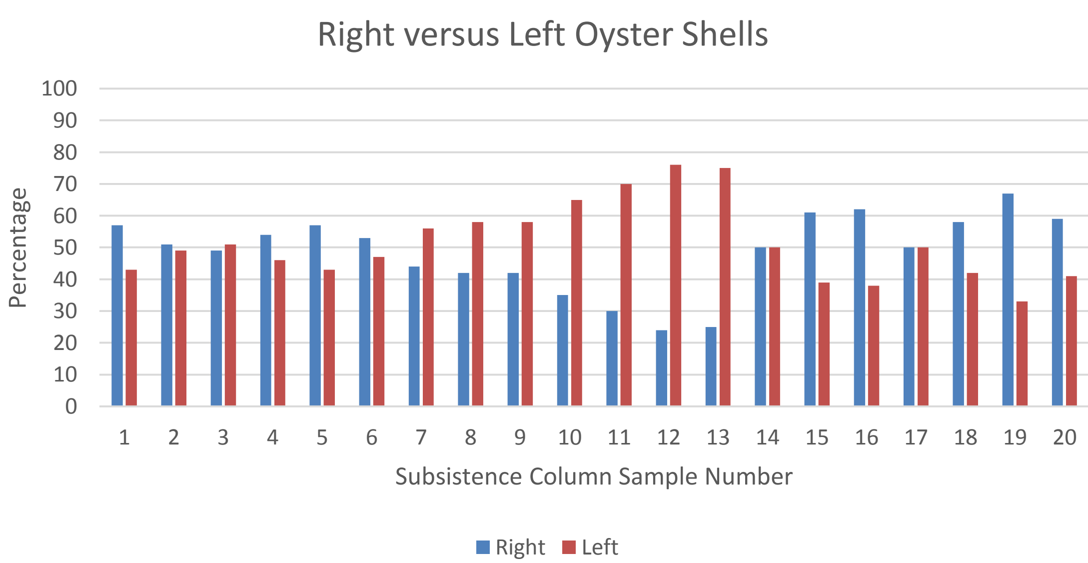

Figure 5-8. Percentage of left and right oyster valves by subsistence column sample.

Table 5-19. Percent of right and left valves by Upper and Lower macrounit.

Right Versus Left Oyster Shells					
	n =	Right		Left	
		n =	%	*n* =	%
Upper Macrounit	5482	2384	43	3098	57
Lower Macrounit	381	227	60	154	40

Table 5-20. Percent of right and left valves by Upper Macrounits 1 and 2 and Lower Macrounit.

Right Versus Left Oyster Shells					
	n =	Right		Left	
		n =	%	*n* =	%
Upper Macrounit 1	2677	1416	53	1261	47
Upper Macrounit 2	2805	968	35	1837	65
Lower Macrounit	381	227	60	154	40

Left Valve Concavity

The left valve concavity ranking, 1–3 with 1 being the least concave and 3 being the most concave, is displayed below by subsistence column sample number (Table 5-21 and Figure 5-9) and by Upper and Lower Macrounit (Table 5-22) and Upper Macrounit 1 and Upper Macrounit 2 (Table 5-23). Both the number of shells in each sample as well as the percentage of shells in each sample with the left valve concavity value are listed. The shells in samples 14–20 are the most concave, with 70 percent of the shells having a left valve concavity value of 3, 25 percent having a left valve concavity value of 2, and only 5 percent having a left valve concavity value of 1. The next most concave shells are from the Upper Macrounit 2, with 44 percent of the shells having a left valve concavity value of 3, 46 percent having a left valve concavity value of 2, and 10 percent having a left valve concavity value of 1. The Upper Macrounit 2 has the least concave shells on average, with 30 percent having a left valve concavity value of 3, 55 percent having a left valve concavity value of 2, and 15 percent having a left valve concavity value of 1.

Table 5-21. Number and percentage of shells with each left valve concavity value by subsistence column sample.

		Left Valve Concavity					
Sample	*n* =	Value of 1		Value of 2		Value of 3	
		n =	%	*n* =	%	*n* =	%
1	37	5	14	24	68	8	22
2	184	33	18	106	58	45	24
3	315	33	17	191	61	71	23
4	312	50	16	172	56	88	28
5	190	21	11	93	49	76	40
6	223	35	16	103	46	85	38
7	246	20	8	94	38	132	54
8	254	16	6	124	49	114	45
9	187	19	10	72	39	96	51
10	258	27	10	113	44	118	46
11	292	28	10	151	52	113	36
12	276	42	15	122	44	112	41
13	324	32	10	173	53	119	37
14	3	0	1	0	0	3	100
15	14	0	1	4	29	10	71
16	14	0	1	4	29	10	71
17	11	3	27	2	18	6	55
18	49	4	8	11	22	34	69
19	16	0	0	4	25	12	75
20	47	1	2	13	28	33	70

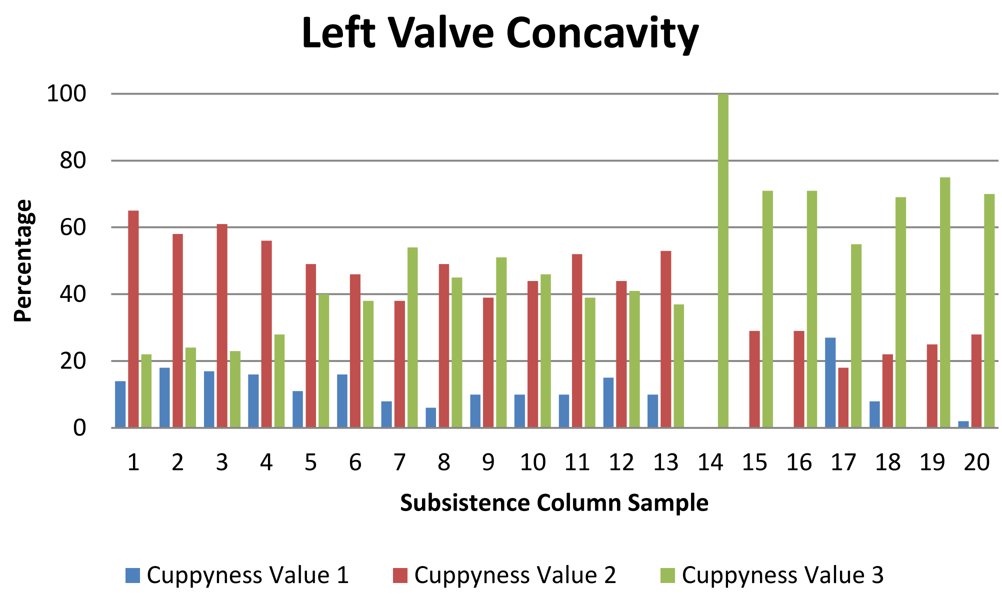

Figure 5-9. Percent of oyster shells with each left valve concavity value by subsistence column sample.

Table 5-22. Number and percentage of shells with each left valve concavity value by Upper and Lower macrounit.

		Left Valve Concavity					
	n =	Value of 1		Value of 2		Value of 3	
		n =	%	*n* =	%	*n* =	%
Upper Macrounit	3098	381	12	1540	50	1177	38
Lower Macrounit	154	8	5	38	25	108	70

Table 5-23. Number and percentage of shells with each left valve concavity value by Upper Macrounits 1 and 2 and the Lower Macrounit.

		Left Valve Concavity					
	n =	Value of 1		Value of 2		Value of 3	
		n =	%	*n* =	%	*n* =	%
Upper Macrounit 1	1261	197	16	691	55	373	30
Upper Macrounit 2	1837	184	10	849	46	804	44
Lower Macrounit	154	8	5	38	25	108	70

Biofouling

The presence or absence of barnacle biofouling is displayed below by subsistence column sample number (Table 5-24) and by Upper and Lower Macrounit

(Table 5-25) and Upper Macrounit 1 and Upper Macrounit 2 (Table 5-26). Both the number of shells in each sample as well as the percentage of shells in each sample are listed for the presence and absence of biofouling. The highest percentage of shells that show evidence of biofouling is in the Upper Macrounit (6 percent), particularly Upper Macrounit 2 (7 percent), and almost no shells (1 percent) have evidence of biofouling in the Lower Macrounit. The highest percentage of shells with evidence of biofouling from the subsistence column samples is Sample 9 (11 percent), and the lowest is 0 percent in Samples 1 and 14–18.

Table 5-24. Number and percentage of shells with biofouling present and absent by subsistence column sample.

	Presence/Absence of Biofouling				
	n =	Present		Absent	
Sample		*n* =	%	*n* =	%
1	37	0	0	37	100
2	184	5	3	179	97
3	315	6	2	309	98
4	312	15	5	297	95
5	190	13	7	177	93
6	223	14	6	209	94
7	246	12	5	234	95
8	254	24	9	230	91
9	187	21	11	166	89
10	258	20	8	238	92
11	292	21	7	271	93
12	276	15	5	261	95
13	324	22	7	302	93
14	3	0	0	3	100
15	14	0	0	14	100
16	14	0	0	14	100
17	11	0	0	11	100
18	49	0	0	49	100
19	16	1	6	15	94
20	47	1	2	46	98

Table 5-25. Number and percentage of shells with biofouling present and absent by Upper and Lower Macrounit.

	Presence/Absence of Biofouling				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit	3098	188	6	2910	94
Lower Macrounit	154	2	1	152	99

Table 5-26. Number and percentage of shells with biofouling present and absent by Upper Macrounit 1 and 2, and Lower Macrounit.

	Presence/Absence of Biofouling				
	n =	Present		Absent	
		n =	%	*n* =	%
Upper Macrounit 1	1261	53	4	1208	96
Upper Macrounit 2	1837	135	7	1702	93
Lower Macrounit	154	2	1	152	99

Hypotheses 1 and 2: Location of Harvest

In order to test Hypotheses 1 (H1), the location of collection (i.e., subtidal versus intertidal) will covary with the scale and intensity of oyster procurement, and Hypothesis 2 (H2), there will be no change in the location of harvest in accordance with changes in the scale and intensity of oyster procurement, the relevant variables to consider are height, length, HLR, attachment scars, biofouling, parasitism, and left valve concavity.

The mean height of the oyster shells is 54.03 mm in the Upper Macrounit 1 and 56.46 mm in the Upper Macrounit 2. The shells in Upper Macrounit 2 are, on average, 2.43 mm smaller in height than the shells in the Upper Macrounit 1. This difference was tested with the t-Test function of Excel (Version: 14.0.6129.5000) assuming unequal variances and unequal sample sizes (results of all t-Tests are provided in the Appendix). Results indicate the differences in mean height between the Upper

Macrounit 1 and Upper Macrounit 2 are statistically significant at less than 0.01 probability ($t = -4.14$; $df = 3,059$). The oysters from the Upper Macrounit 2 are on average 10.73 mm larger in height than those in the Lower Macrounit, with a difference in means that is statistically significant at less than 0.01 probability ($t = 8.24$; $df = 192$). The oyster shells from Upper Macrounit 1 are on average 8.3 mm larger in height than those in the Lower Macrounit, with a difference of means that is also statistically significant at less than 0.01 probability ($t = 6.43$; $df = 186$).

The mean length of the Upper Macrounit 1 is 31.68 mm and the mean length of the Upper Macrounit 2 is 31.86 mm, where the Upper Macrounit 2 is 0.18 mm longer than the Upper Macrounit 1. Using the same t-Test that was used to determine the significance of the difference of means for height, results indicate the differences in mean length between the Upper Macrounit 1 and Upper Macrounit 2 in not statistically significant ($p = 0.29$; $t = -0.57$; $df = 3,016$). The oysters in the Upper Macrounit 2 are on average 6.27 mm longer than in the Lower Macrounit. The difference in mean length between the Upper Macrounit 2 and the Lower Macrounit is statistically significant at less than 0.01 probability ($t = 9.25$; $df = 194$). The oysters in the Upper Macrounit 1 are on average 6.08 mm longer than the Lower Macrounit, and the difference in mean length is statistically significant at less than 0.01 probability ($t = 9$; $df = 192$).

Both the mean height and length of the oysters in the Upper Macrounits, especially Upper Macrounit 2, are larger than in the Lower Macrounit. Further, based on the results of t-tests performed on the measurements of height and length, it appears that the oysters in the Upper Macrounits and Lower Macrounit were not drawn from the same population.

In terms of shell shape, the mean HLR of the Upper Macrounit 1 is 1.72, the Upper Macrounit 2 is 1.78, and the Lower Macrounit is 1.80, so as the intensity of harvest increases the shells become less elongate. Further evidence that the oysters harvested during times of large-scale intensive harvesting are subtidal include the increase in percentage of shells with sponge parasitism from 30 percent in the Lower Macrounit to close to 50 percent in the Upper Macrounits (46 percent in Upper Macrounit 1 and 49 percent in Upper Macrounit 2), and the increase in percentage of shells with evidence of barnacle biofouling from 1 percent in the lower Macrounit to 7 percent in Upper Macrounit 2 and 4 percent in Upper Macrounit 1.The final variable, left valve concavity, is opposite from what was expected, where subtidal oysters are more concave than intertidal oysters. Seventy percent of the oysters in the Lower Macrounit have a left valve concavity value of 3, whereas in Upper Macrounit 2, 44 percent of oysters have a left valve concavity value of 3, and in Upper Macrounit 1, only 30 percent of the oysters have a left valve concavity value of 3.

Based on the results, H1 is proven true and H2 is proven false; as the scale and intensity of oyster procurement increases, the oysters in the samples and macrounits shift from intertidal oysters in the Lower Macrounit to more subtidal oysters in the Upper Macrounits. This observation is supported by a shift from the Lower Macrounit to the Upper Macrounit 2, where there are generally larger oysters, shell shape changes from elongate shells to rounder shells (HLR), and the increase in the percentage of shells with biofoul and sponge parasitism.

Hypotheses 3 and 4: Shelling

To test Hypothesis 3 (H3), that the amount of right oyster valves used for cultch (shell returned to the water to enhance oyster reefs) will covary with the scale and intensity of oyster procurement, and Hypothesis 4, that there will be no change in the ratio of left to right oyster shells in accordance with changes in the scale and intensity of procurement, the amount of right and left valves per sample and macrounit were counted and compared.

The ratio of left to right valves is particularly high in the transition from the Lower Macrounit to Upper Macrounit 2 (Samples 10–13), when the scale and intensity of harvest increases. The ratio in the Lower Macrounit stays around 50:50, whereas, at some points, the ratio of left to right valves is 3:1 in Upper Macrounit 2, when the scale and intensity of oyster procurement increases. Based on these results, H3 is proven true, there number of right vlaves used for cultch does covary with the scale and intensity of oyster procurement, and H4 is proven false.

Hypotheses 5 and 6: Relaying

To test Hypothesis 5 (H5), that the amount of oysters that were transplanted from suboptimum conditions to optimal conditions through relaying will covary with the scale and intensity of oyster procurement, and Hypothesis 6 (H6), that there will be no indication that oysters were transplanted in accordance with the scale and intensity of oyster procurement, the variables tested were height, HLR, presence or absence of sponge parasitism, presence or absence of biofoul, and left valve concavity. Many of these variables were discussed when testing H1 and H2 above, and it appears that there is little to no evidence of transplanting when the scale and intensity of oyster harvesting increases, therefore proving H5 false and H6 true.

Hypotheses 7 and 8: Culling

Hypothesis 7 (H7), evidence of oyster culling will covary with the scale and intensity of oyster procurement, and Hypothesis 8 (H8), there will be no indication that oysters were culled in accordance with the scale and intensity of oyster procurement, were tested by comparing the percent of attachment scars with evidence of parasitism on them. Oysters from Upper Macrounit 2 have the most evidence of culling, with 24 percent of oysters having parasitism on the attachment scars, an increase from five percent in the Lower Macrounit. The percent of shells that show evidence of culling again decreases to 15 percent in Upper Macrounit 1. Based on the results, H7 is proven true as evidence of culling increases with the increase in the scale and intensity of oyster procurement, and H8 is proven false.

Hypotheses 9 and 10: Size Selection

Hypotheses 9 (H9), that the size range of oysters will covary with the scale and intensity of procurement, and Hypothesis 10 (H10), that there will be no change in the size range of oysters in accordance with the scale and intensity of oyster procurement, were tested based on the height of the oysters in each sample and macrounit. Based on the t-Tests performed between macrounits, it appears as though, based on height, the oysters from the three macrounits are likely drawn from different populations (Appendix). Based on the size ranges of harvested oysters in each of the macrounits, the height for the majority of the oysters is from 20 mm to 80 mm, with the height range of 40 mm to 60 mm having the highest percentage for each population. It does not appear that there is any major change in the size range of oysters being harvested based on an increase of intensity of harvest, but the consistency in height range throughout the macrounits may indicate a consciousness of size selection throughout time, regardless of the scale and intensity of harvest. Based on these results H9 is proven false, and H10 is proven true.

Hypotheses 11 and 12: Off-Bottom Growing

In order to test Hypothesis 11 (H11), that the amount of oysters grown using off-bottom techniques will covary with the scale and intensity of oyster procurement, and Hypothesis 12 (H12), that there will be no evidence of off-bottom techniques being used in accordance with the scale and intensity of oyster procurement, the type of attachment scar was compared. Because of the very small number of shells that appear to have an attachment scar representing substrate other than shell (*n* = 67 of 3,252), H12 is proven to be true and H11 is proven to be false.

Palmetto Mound

In order to test the assumption that Shell Mound and Palmetto Mound were related to each other, oyster shell from Test Unit 1 (TU1) at Palmetto Mound was analyzed. Furthermore, data were collected from three other sites spanning from north to south in the study area: Bird Island (8DI52), Cat Island (8DI29), and North Key (6LV65). In the table below (Table 5-27), descriptive statistics for Palmetto Mound are listed for the height, length, and height-to-length ratio. The mean height is 53.54 mm, with a minimum of 13.93 mm and a maximum of 111.59, the mean length is 30 mm, and the mean HLR is 1.80, with a minimum of 1.17 and a maximum of 3.67.

Table 5-27. Descriptive statistics for oyster height, length, and HLR for Palmetto Mound.

	8LV2 Height, Length, HLR (mm)			
	Mean	SD	Minimum	Maximum
Height	53.54	16.16	13.93	111.59
Length	30.00	8.46	6.56	69.94
HLR	1.80	0.29	1.17	3.67

When compared to the rest of the sites, what is particularly striking is the similarity of the percentage of shells with parasitism in Upper Macrounit 1 and 2 and

Palmetto Mound. The percent of shells with parasitism for those three samples are close to fifty percent, whereas for all other midden sites, including the Lower Macrounit in TU8 at Shell Mound are close to thirty percent (Table 5-28). Other than that, the means of the height, length, and HLR are all similar, with the exception of Cat Island which has larger shells on average that are more elongate.

Table 5-28. Comparison of mean height, length, HLR, and percentage of parasitism between five sites in the Lower Suwannee research area.

Height, Length, HLR, and Parasitism for Five Sites in the Lower Suwannee						
Site	*n* =	Mean Height	Mean Length	Mean HLR	With Parasitsim	
					n =	%
8DI29	373	62.80	33.07	1.91	114	31
8DI52	1275	52.55	30.47	1.74	364	29
8LV65	1081	52.98	30.04	1.78	328	30
8LV2	519	53.54	30.00	1.80	256	49
8LV42 Lower Macrounit	154	45.73	25.60	1.80	46	30
8LV42 Upper Macrounit 1	1261	54.03	31.68	1.72	580	46
8LV42 Upper Macrounit 2	1837	56.46	31.86	1.78	899	49

Discussion

Based on the results presented above, it appears that the location of collection (i.e., subtidal versus intertidal), the amount of right oyster valves used for cultch, and the evidence of culling covary with the scale and intensity of oyster harvesting at Shell Mound, and there is little to no evidence that oysters were transplanted or grown using off-bottom techniques in accordance with the scale and intensity of oyster harvesting at Shell Mound. Evidence of size selection remains relatively consistent across samples, and may have been a practice used throughout Shell Mound’s occupation. Furthermore, the comparison of oyster size and the amount of oysters with evidence of sponge parasitism indicates that oysters were possibly taken from Shell Mound, particularly the

Upper Macrounit 1, and used to cap burials at Palmetto Mound. These results will be discussed in more detail below.

The data have been divided three different ways for the purpose of this analysis: by sample number which corresponds to the subsistence column which was excavated by 10-cm arbitrary levels, by upper and lower macrounits that separate the submound midden from the mounded shell, and then the Upper Macrounit was further divided into Upper Macrounit 1 and Upper Macrounit 2, following a break in stratigraphy of the mounded shell. Dividing the data into macrounits for analysis is helpful to separate different phases of occupation and construction at Shell Mound; this is particularly true of Samples 14–20 in the submound midden, or the Lower Macrounit, where the sample sizes are so small and some data are anomalous almost certainly due to small sample size (i.e., Sample 14 where $n = 3$). For the purposes of the following discussion, I discuss the data in their relationship to Macrounits to make the comparisons more meaningful. As the macrounits are divided based on stratigraphy, I start with the oldest samples or the Lower Macrounit of submound midden. I then discuss the Upper Macrounit 2, and finally the Upper Macrounit 1. I then compare the results of the analysis of each of the macrounits to the data obtained from oyster shells taken from capping of burials from Palmetto Mound.

Lower Macrounit (Samples 14–20)

The Lower Macrounit has far fewer shells ($n = 154$) in comparison to the Upper Macrounit 1 ($n = 1{,}261$) and the Upper Macrounit 2 ($n = 1{,}837$). In general, these oysters are small (mean height = 45.73 mm; mean length = 31.87 mm) and elongate (mean HLR = 1.80 mm), lacking in parasitism (70 percent without sponge parasitism), the majority of which have attachment scars (60 percent). These attributes are all strong indicators that these oysters came from intertidal conditions. The high left valve concavity value of these shells is surprising (70 percent with a left valve concavity value of 3), given that all other variables indicate that the oysters were harvested from intertidal conditions. What could account for this is more selection in harvesting, as the amount that were harvested and deposited into the submound midden were far fewer than what was accumulated on top during the intensive phase of mound building.

Evidence for any form of mariculture is lacking from the Lower Macrounit; the percentage of right and left valves does not indicate shelling (60 percent right valves and 40 percent left valves), there seems to be no signs of relaying, as all attributes are generally indicative of intertidal conditions, only five percent of the shells have parasitism on the attachment scars, so the oysters do not appear to be culled and returned to the water. There is also no convincing patterning between samples in the Lower Macrounit where attributes are widely varied.

Upper Macrounit 2 (Samples 7–13)

On average the shells in Upper Macrounit 2 are larger (mean height = 56.45 mm; mean length = 31.87 mm) and rounder (mean HLR = 1.78) in the Upper Macrounit 2 than in the Lower Macrounit or Upper Macrounit 1, and almost half of the oysters have evidence of sponge parasitism (49 percent). The combination of these attributes indicates that the oysters in Upper Macrounit 2 were likely primarily from subtidal conditions.

Indications of mariculture are strongest in this macrounit. On average, 65 percent of the total shell count are left valves, meaning that on average, there are 15 percent more left valves in a sample than right valves. The patterning of more left than right valves is particularly strong in Samples 10–13 which where the percentage of left valves ranges from 65 to 76. These high percentages are indicative of shelling practices, where the right valves are not present in the samples as they were returned to the water for spat recruitment. Evidence of culling is present in the consistent percentage of shells with evidence of parasitism on the attachment scars. The most striking evidence of this is in Samples 7–11 where the percentage of oysters with parasitism on their attachment scars ranges from 32 to 46 percent. What makes these data convincing of maricultural practices is not just the numbers or percentages, but that there is a strong patterning of consistency in almost every variable with no extreme ranges or outliers between samples.

Upper Macrounit 1 (Samples 1–6)

Like in Upper Macrounit 2, the oysters from Upper Macrounit 1 appear to be harvested primarily from subtidal areas. This is evident due to the larger size (mean height = 54.03 mm; mean length = 31.68 mm), low mean HLR (1.72 mm), and high percentage of parasitism (46 percent).

In this macrounit, evidence of maricultural practices declines through time from Sample 6 to Sample 2, where Sample 1 is sometimes an outlier which may be the result of disturbance due to its proximity to the present-day ground surface. Through time the mean height decreases from about 55 mm to about 50 mm, mean length increases from about 30 mm to 32 mm, and the mean HLR decreases from 1.80 mm to 1.56 mm, indicating that the harvested oysters are becoming smaller and rounder. Evidence of culling also drops off from 38 percent to 17 percent of shells with sponge parasitism on the attachment scar, and finally, the ratio of right to left valves remains close to 50 percent in all samples, with an average of 47 percent right valves and 53 percent left valves.

Palmetto Mound

The oyster shells recovered from Palmetto Mound are assumed to be purposefully placed as capping material over individual burials, rather than the concentrated effect of consumption on the island. In order to test if the shells at Palmetto Mound were transferred from Shell Mound, the samples were compared. When comparing height, the difference between the mean of the Upper Macrounit and Palmetto Mound is statistically significant at less than 0.01 probability ($t = 2.45$; $df = 711$). Further dividing the Upper Macrounit into Upper Macrounit 1 and Upper Macrounit 2, the difference in mean height between Palmetto Mound and the Upper Macrounit 1 is not statistically significant ($p = 0.28$; $t = 0.59$; $df = 846$), whereas the difference in mean height between Palmetto Mound and the Upper Macrounit 2 is statistically significant at less than 0.01 probability ($t = 3.46$; $df = 915$). The results of the t-Tests are reported in the Appendix.

Of particular interest is the high percentage of oysters with parasitism within the samples of the Upper Macrounits 1 and 2 and Palmetto mound, all being close to 50 percent. This is convincing of the transferal of oyster shell from Shell Mound to Palmetto Mound because at three other sites, Bird Island, Cat Island, and North Key, as well as the submound midden or Lower Macrounit at Shell Mound, the percentage of shell with parasitism from middens is close to 30 percent. Based on this data, it appears as though shell may have been taken from the Upper Macrounits at Shell Mound, particularly Upper Macrounit 2, and placed over burials at Palmetto Mound, a hypothesis that needs further testing with additional data, as the differences may be attributed to microhabitats.

Based on the results of this analysis I would argue that there is a distinct pattern of no evidence of mariculture in the submound midden, compelling evidence of mariculture in the initial phase of mound building, and a steady decline in evidence of mariculture in the last phase of mound building, perhaps when the site was abandoned and returned to periodically leaving no one to manage the oysters or because the shell was procured from an earlier midden and then placed ontop of the Upper Macrounit 2, creating reverse stratigraphy.

The oysters from the Lower Macrounit appear to be the refuse from meals in which intertidal oysters were used to supplement meals and there was no real need for any sort of maricultural practices. Based on the data from the Upper Macrounit 2, I would argue that during the initial phase of mound building at Shell Mound, right shells were returned to the water to shell reefs and beds, a practice which was sustained, but less so as time went by. The initial practice of shelling may have been to prepare the existing reefs for heavy exploitation during mound building events. The practice may have fallen out of favor due to the environment of the area, where shelling may not prove effective because the reefs are not protected like they are in Apalachicola Bay and Tampa Bay, therefore storm events may have washed the loose shell from the reefs back to the shore, defeating the purpose. With the decline in shelling came a rise of culling where smaller oysters were broken away from burrs and returned to the water to continue growing and living through reproductive cycles. During this phase of intensive mound building mostly subtidal oysters were harvested, and size and age selection appear to be a usual consideration, where mostly juvenile and adult oysters were harvested and very few spat made it out of the water and into the mound. During the second phase of mound construction, evidence of mariculture dissipates gradually, but the oysters remain large and subtidal.

The association of Shell Mound and Palmetto Mound is argued with evidence suggesting that oyster shell may have been taken from the mound at Shell Mound and then placed over burials at Palmetto Mound. Both height and the percentage of shell with parasitism are strikingly similar between the samples taken from the two sites.

The combination of the data analysis, environmental considerations, and culture history of the Lower Suwannee provide compelling evidence of mariculture during the intensive phase of mound building at Shell Mound. The concluding remarks in the following final chapter provide a summary, concluding discussion, and suggestions future directions for this work.

CHAPTER 6
SUMMARY AND CONCLUSION

Oyster shell from bulk samples from Test Unit 8 near the apex of Shell Mound on Florida's Gulf Coast were analyzed for evidence of maricultural practices during the fifth and sixth centuries A.D. Although shell mounds, ridges, and middens are ubiquitous in the Lower Suwannee study area, Shell Mound was chosen as the site used to test the hypothesis that humans were engaged in oyster maricultural practices due to the size of the mound, the speed at which the mound was constructed (~200 years), the cultural and environmental factors at play during the occupation of the site, and the potential symbolic importance of the site in relation to the nearby burial complex, Palmetto Mound. Test Unit 8 is representative of three main phases of occupation or activity, with a submound midden, a strata of unconsolidated, mounded shell, and a strata of mostly oyster shell which may have been deposited from nearby middens in the final phase of mound construction. A total of 3,252 left oyster valves were analyzed for morphological attributes including height, length, height-to-length ratio, presence of sponge parasitism, presence of attachment scars, presence of parasitism on attachment scars, left valve concavity, and ratio of left to right valves. Each of these attributes is indicative of environmental circumstances and/or human influence on local populations.

In order to devise methods of analysis, a detailed understanding of oyster biology and ecology as well as the local environment is important and was discussed in Chapter 2. Based on paleoenvironmental data, it appears that the environmental conditions on Florida's Gulf Coast have been highly variable with periods of sea level rise and regression creating changes in water temperature and salinity, which are extremely influential in oyster growth and reproduction. These shifts in environmental conditions or harvesting niches are visible on the morphological aspects of oyster shells.

As well as environmental variability, the changing cultural traditions, which are discussed in Chapter 3, impacted oyster harvesting practices, especially in regard to the intensity of harvesting. Shell Mound is one of three well-documented civic-ceremonial centers on Florida's Gulf Coast, including Crystal River and Garden Patch, which were in place starting at about 200 A.D. The civic-ceremonial centers are argued to be places of year-round occupation, aggregation events and feasting, and increased populations, all of which would increase the amount of oysters being harvested from local populations which may have had a negative impact on oyster reefs, potentially leading to overharvesting or collapse.

I argue that, in order to offset environmental variability and cultural practices resulting in increased harvesting, the inhabitants of Shell Mound employed maricultural practices. Based on ethnographic, ethnohistoric, and archaeological data from around the world, people have been engaged in maricultural practices since at least 2,000 years ago, although it has never been investigated at shell bearing sites on the East or Gulf coasts of North America. Because of the lack of archaeological studies investigating oyster mariculture, methods were devised based on oyster biology, ecology, previous studies of shellfish management practices, and personal experiences with present-day oyster mariculturalists and oyster biologists in Cedar Key and Apalachicola Bay. The methods used were discussed in Chapter 4.

In order to infer oyster mariculture, morphological attributes which are indicative of environmental conditions and human intervention were analyzed. The recorded attributes provide information regarding the salinity of the water from which the oysters were harvested, if the oysters were harvested from intertidal or subtidal areas, the size of the harvested oysters, and the overall quality in terms of the oysters' health and meat size based on the left valve concavity of the shells. Furthermore, indications of five different maricultural practices were assessed including shelling, relaying, size or age selection, culling, and off-bottom growing.

Based on the results described in Chapter 5, it appears that the inhabitants of Shell Mound were practicing shelling and culling during the initial phase of mound building which involved sustained intensive harvesting of oysters. Also, during this time there was a shift from intertidal oysters from the submound midden to subtidal oysters used in mound construction. Patterning for these practices dissipates in the final phase of mound building, where oyster shell from nearby middens may have been emplaced on the mounded shell after the site was abandoned as a place of residential occupation. The results also indicate an association of Shell Mound to the burial complex, Palmetto Mound, where shell, especially from the final phase of mound construction at Shell Mound, is very similar to that excavated from Palmetto Mound in terms of size and percentage of shell with sponge parasitism. Of particular interest is the high percentage of shells with parasitism from the mounded shell at Shell Mound and the shells from Palmetto Mound when compared to the relatively low percentage of shell with sponge parasitism from midden sites distributed across the study area. The similarities of the shell recovered from Shell Mound and Palmetto Mound may be indicative of using the mounded shell at Shell Mound as capping material during burial practices at Palmetto Mound, further supporting the assumption of the relationship of the two sites.

Since this analysis has revealed compelling evidence of maricultural practices in place at Shell Mound, it is important to replicate the patterns in order to test the validity and secure the interpretation. The next step for investigating mariculture at Shell Mound would be to conduct the same analysis, using the same methods, on oyster shell recovered from another subsistence column from another test unit on the mound and compare the results. Then, the methods should be applied to various other sites in the study area, in particular Garden Patch and Crystal River, in order to test if mariculture was happening at other civic-ceremonial centers in the region. Another important step in oyster research at Shell Mound, and in the Lower Suwannee in general, would be to obtain seasonality data from the shells.

I also argue that a detailed analysis such as this one, where all aspects of the oyster shells are recorded and compared, could be useful in addressing questions other than those related to mariculture, including questions of feasting, mound-building activities, environmental change, and shell symbolism.

Not only does this research provide insight into the practices and lifeways of the inhabitants of Shell Mound during the fifth and sixth century A.D., but it also addresses important challenges that coastal communities are facing today, with oyster populations dwindling to a tenth of what they once were world-wide. Mariculture has been taking off in places such as the Chesapeake Bay as well as along the Gulf Coast in order to revitalize this economically and environmentally important resource. Using the truly deep time perspective that archaeology can offer, as well as the insights into past practices used to sustain oyster populations such as those discussed in this thesis, contributions could be made to broader research aims of environmental reconstruction and restoration.

APPENDIX
T-TESTS

Table A-1. t-Test: Two-Sample Assuming Unequal Variances-Height

	Upper Macrounit 1	*Upper Macrounit 2*
Mean	54.03374306	56.44986391
Variance	198.2686922	337.9054387
Observations	1261	1837
Hypothesized Mean Difference	0	
df	3059	
t Stat	-4.1364687	
P(T<=t) one-tail	1.81094E-05	
t Critical one-tail	1.645351905	
P(T<=t) two-tail	3.62189E-05	
t Critical two-tail	1.960739792	

Table A-2. t-Test: Two-Sample Assuming Unequal Variances-Height

	Upper Macrounit 2	*Lower Macrounit*
Mean	56.44986391	45.72623377
Variance	337.9054387	232.6619818
Observations	1837	154
Hypothesized Mean Difference	0	
df	192	
t Stat	8.237411584	
P(T<=t) one-tail	1.33934E-14	
t Critical one-tail	1.652828589	
P(T<=t) two-tail	2.67868E-14	
t Critical two-tail	1.972396491	

Table A-3. t-Test: Two-Sample Assuming Unequal Variances-
Height

	Upper Macrounit 1	*Lower Macrounit*
Mean	54.03374306	45.72623377
Variance	198.2686922	232.6619818
Observations	1261	154
Hypothesized Mean Difference	0	
df	186	
t Stat	6.432351451	
P(T<=t) one-tail	5.16826E-10	
t Critical one-tail	1.653087138	
P(T<=t) two-tail	1.03365E-09	
t Critical two-tail	1.972800114	

Table A-4. t-Test: Two-Sample Assuming Unequal Variances-
Length

	Upper Macrounit 1	*Upper Macrounit 2*
Mean	31.68486915	31.86527382
Variance	61.9610077	95.07529818
Observations	1261	1837
Hypothesized Mean Difference	0	
df	3016	
t Stat	-0.567961737	
P(T<=t) one-tail	0.285051614	
t Critical one-tail	1.645359012	
P(T<=t) two-tail	0.570103228	
t Critical two-tail	1.960750857	

Table A-5. t-Test: Two-Sample Assuming Unequal Variances- Length

	Upper Macrounit 2	*Lower Macrounit*
Mean	31.86527382	25.59707792
Variance	95.07529818	62.81719467
Observations	1837	154
Hypothesized Mean Difference	0	
df	194	
t Stat	9.245372026	
P(T<=t) one-tail	2.13805E-17	
t Critical one-tail	1.652745977	
P(T<=t) two-tail	4.27611E-17	
t Critical two-tail	1.972267533	

Table A-6. t-Test: Two-Sample Assuming Unequal Variances- Length

	Upper Macrounit 1	*Lower Macrounit*
Mean	31.68486915	25.59707792
Variance	61.9610077	62.81719467
Observations	1261	154
Hypothesized Mean Difference	0	
df	192	
t Stat	9.004975138	
P(T<=t) one-tail	1.06866E-16	
t Critical one-tail	1.652828589	
P(T<=t) two-tail	2.13732E-16	
t Critical two-tail	1.972396491	

Table A-7. t-Test: Two-Sample Assuming Unequal Variances- Height

	Upper Macrounit	*Palmetto Mound*
Mean	55.46641382	53.54533719
Variance	282.3951877	270.9013558
Observations	3098	519
Hypothesized Mean Difference	0	
df	711	
t Stat	2.453416334	
P(T<=t) one-tail	0.007194805	
t Critical one-tail	1.646999574	
P(T<=t) two-tail	0.014389611	
t Critical two-tail	1.963306103	

Table A-8. t-Test: Two-Sample Assuming Unequal Variances-Height

	Upper Macrounit 1	*Palmetto Mound*
Mean	54.03374306	53.54533719
Variance	198.2686922	270.9013558
Observations	1261	519
Hypothesized Mean Difference	0	
df	846	
t Stat	0.592628155	
P(T<=t) one-tail	0.2767942	
t Critical one-tail	1.646656758	
P(T<=t) two-tail	0.553588399	
t Critical two-tail	1.962772035	

Table A-9. t-Test: Two-Sample Assuming Unequal Variances-Height

	Upper Macrounit 2	*Palmetto Mound*
Mean	56.44986391	53.54533719
Variance	337.9054387	270.9013558
Observations	1837	519
Hypothesized Mean Difference	0	
df	915	
t Stat	3.457005444	
P(T<=t) one-tail	0.000285682	
t Critical one-tail	1.646520646	
P(T<=t) two-tail	0.000571363	
t Critical two-tail	1.962560005	

LIST OF REFERENCES

Anderson, David G., and Kenneth E. Sassaman
2012 *Recent Developments in Southeastern Archaeology: From Colonization to Complexity*. Society for American Archaeology Press, Washington, D.C.

Andrus, C. Fred T., and Victor D. Thompson
2012 Determining the Habitats of Mollusk Collection at the Sapelo Island Shell Ring Complex, Georgia, USA Using Oxygen Isotope Sclerochronology. *Journal of Archaeological Science* 39:215-228.

Beck, Michael W., Robert D. Brumbaugh, Laura Airoldi, Alvar Carranza, Loren D. Coen, Christine Crawford, Omar Defeo, Graham J. Edgar, Boze Hancock, Matthew C. Kay, Hunter S. Lenihan, Mark W. Luckenbach, Caitlyn L. Toropova, Guofan Zhang, and Ximing Guo
2011 Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *Bioscience* 61 (2): 107-114.

Bergquist, Derek, Jason Hale, Patrick Baker, and Shirley Baker.
2006 Development of Ecosystem Indicators for the Suwannee River Estuary: Oyster Reef Habitat Quality along a Salinity Gradient. *Estuaries and Coasts* 29(3):353-360.

Bird, Douglas W., Rebecca Bliege Bird, and Jennifer L. Richardson.
2004 Meriam Ethnoarchaeology: Shellfishing and Shellmiddens. *Memoirs of the Queensland Museum, Culture* 3(1):183.

Bledsoe, Erin L., and Edward J. Phlips.
2000 Relationships Between Phytoplankton Standing Crop and Physical, Chemical, and Biological Gradients in the Suwannee River and Plume Region, USA. *Estuaries* 23(4):458-473.

Borremans, Nina Thanz
n.d. Unpublished records of archaeological excavations at North Key and Seahorse Key, Florida, ca. 1989. Records on file, Florida Museum of Natural History, University of Florida, Gainesville.

Brose, David S., and George W. Percy
1974 Weeden Island Settlement—Subsistence and Ceremonialism: A Reappraisal in Systemic Terms. Paper presented at the 37th Annual Meeting of the Society for American Archaeology, Washington D.C.

Brown, Frank, and Y. Kathy Brown
2009 *Staying the Course, Staying Alive. Coastal First Nations Fundamental Truths: Biodiversity, Stewardship and Sustainability.* Biodiversity British Columbia, Victoria, British Columbia.

Bullen, Ripley P., and Edward M. Dolen
1960 Shell Mound, Levy County, Florida. *The Florida Anthropologist* 13:17-23.

Butler, P.A.
1949 Gametogenesis in the Oyster Under Conditions of Depressed Salinity. *Biology Bulletin* 96:263-269.

Cannon, Aubrey and Meghan Burchell
2009 Clam Growth-Stage Profiles as a Measure of Harvest Intensity and Resource Management on the Central Coast of British Columbia. *Journal of Archaeological Science*36:1050-1060.

Castagna, Michael, Mary C. Gibbons, and Kenneth Kurkowski
1996 Culture: Application. In *Eastern Oyster*, edited by Victor S. Kennedy and Roger I.E. Newell, pp. 675-690. Maryland Sea Grand College, College Park, Maryland.

Chanton, Jeffrey and F. Graham Lewis
2002 Examination of Coupling Between Primary and Secondary Production in a River-Dominated Estuary: Apalachicola Bay, Florida, U.S.A. *Limnology and Oceanography* 47(3):683-697.

Claassen, Cheryl.
1998 *Shells.* Cambridge: Cambridge University Press.

2008 Shell Symbolism in Pre-Columbian North America. *Early Human Impact on Megamollsuscs*:37-43.

Costa-Pierce, Barry A.
1987 Aquaculture in Ancient Hawaii. *BioScience* 37(5):320-331.

Crisp, D.J.
1967 Chemical Factors Inducing Settlement in *Crassostrea virginica*. *Journal of Animal Ecology* 36(2):329-335.

Crook Jr, Morgan R.
1992 Oyster Sources and their Prehistoric Use on the Georgia Coast. *Journal of Archaeological Science* 19 (5):483-496.

Custer, Jay F., and Keith R. Doms.
1990 Analysis of Microgrowth Patterns of the American Oyster (*Crassostrea virginica*) in the Middle Atlantic Region of Eastern North America: Archaeological Applications. *Journal of Archaeological Science* 17(2):151-160.

Dame, R. F.
1972 The Ecological Energies of Growth, Respiration and Assimilation in the Intertidal American Oyster *Crassostrea virginica*. *Marine Biology* 17(3):243-250.

2009 Shifting Through Time: Oysters and Shell Rings in Past and Present Southeastern Estuaries. *Journal of Shellfish Research* 28(3):425-430.

2012 *Ecology of Marine Bivalves: An Ecosystem Approach*. CRC Press, Boca Raton.

Dietler, Michael, and Brian Hayden
2001 Digesting the Feast: Good to Eat, Good to Drink, Good to Think: An Introduction. In *Feasts: Archaeological and Ethnographic Perspectives on Food, Politics, and Power,* edited by Michael Dietler and Brian Hayden, pp. 1-20. The University of Alabama Press, Tuscaloosa.

Dietler, Michael
2001 Theorizing the Feast: Rituals of Consumption, Commensal Politics, and Power in African Contexts. In *Feasts: Archaeological and Ethnographic Perspectives on Food, Politics, and Power,* edited by Michael Dietler and Brian Hayden, pp. 65-114. The University of Alabama Press, Tuscaloosa.

Donop, Mark C.
2015 Palmetto Mound (8LV2). In *Lower Suwannee Archaeological Survey 2013-2014 Shell Mound and Cedar Key Tracts.* Technical Report 23, Laboratory of Southeastern Archaeology, Department of Anthropology, University of Florida.

Doucet, Julie Ann
2012 *Oysters and Catfish: Resource Exploitation at Rollins Shell Ring, Ft. George Island, Florida.* Master's thesis, Department of Anthropology, Louisiana State University, Baton Rouge.

Dragovich, Alexander and John A. Kelly
1964 Ecological Observations of Macro-Invertebrates in Tampa Bay, Florida 1961-1962. *Bulletin of Marine Science of the Gulf and Caribbean* 14(1):74-102.

Eble, Albert F., and Robert Scro
1996 General Anatomy. In *The Eastern Oyster: Crassostrea virginica*, eds Victor S. Kennedy, Roger I.E. Newell, and Albert F. Eble. Pp. 19-73.

Erlandson, Jon M.
1988 The Role of Shellfish in Prehistoric Economies: A Protein Perspective. *American Antiquity* 53(1):102-109.

Erlandson, J.M., T.C. Rick, and R.L. Vellanoweth
2004 Human Impacts on Ancient Environments: A Case Study from California's Northern Channel Islands. In *Voyages of Discovery: The Archaeology of Islands,* edited by S.M. Fitzpatrick, pp. 51-83. Praeger, New York.

Erlandson, J.M., T.C. Rick, J.A. Estes, M.H. Graham, T.J. Braje, and R. L. Vellanoweth
2005 Sea Otters, Shellfish, and Humans: A 10,000 Year Record from San Miguel Island, California. In *Proceedings of the Sixth California Islands Symposium*, edited by D. Garcelon and C. Schwemm, pp. 9-21. National Park Service Technical Publication, Arcata, California.

Erlandson, Jon M., and Torben C. Rick
2008 Archaeology, Marine Ecology, and Human Impacts on Marine Environments. In *Human Impacts on Ancient Marine Ecosystems: A Global Perspective*, edited by Torben C. Rick and Jon M. Erlandson, pp. 1-19. University of California Press, Berkeley.

Goodbred, S.L. and A.C. Hine.
1995 Coastal Storm Deposition: Salt Marsh Response to a Severe Extratropical Storm. *Geology* 23:679-682.

Goodbred, Steven L., Albert C. Hine, and Eric E. Wright
1998 Sea-Level Change and Storm Surge Deposition in a Late Holocene Florida Salt Marsh. *Journal of Sedimentary Research* 68:240–252.

Goodell, H.G., and D.S. Gorsline
1961 *The Hydrography of Apalachicola and Florida Bays, Florida.* No. GFDI-CONTRIB-1. Florida State University, Tallahassee.

Grier, Colin
2014 Landscape Construction, Ownership and Social Change in the Southern Gulf Islands of British Columbia. *Canadian Journal of Archaeology* 38:211-249.

Gunther, R.T.
1897 *The Oyster Culture of the Ancient Romans*. Cambridge: Cambridge University Press.

1957 Oysters. *Geological Society of America Memoirs* 67(1):1129-1134.

Harding, Juliana M., Howard J. Spero, Roger Mann, Gregory S. Herbert, and Jennifer L. Sliko.
2010 Reconstructing Early 17th Century Estuarine Drought Conditions from Jamestown Oysters. *Proceedings of the National Academy of Sciences* 107 (23): 10549-10554.

Heilmayer, Olaf, Julian Digialleonardo, Lianfen Quan, Guritno Roesijadi
2008 Stress Tolerance of a Subtropical *Crassostrea virginica* Population to the Combined Effects of Temperature and Salinity. *Estuarine, Coastal, and Shelf Science* 79:197-185.

Hine, Albert C., Daniel F. Belknap, Joan G. Hutton, Eric B. Osking, and Mark W. Evans
1988 Recent Geological History and Modern Sedimentary Processes along an Incipient, Low-Energy, Epicontinental-Sea Coastline: Northwest Florida. *Journal of Sedimentary Research* 58:567–579. Hopkins, S.H.

Jackson, Jeremy B.C., Michael X. Kirby, Wolfgang H. Berger, Karen A. Bjornal, Louis W. Botsford, Brocue J. Bourque, Roger H. Bradbury, Richard Cooke, Jon Erlandson, James A. Estes, Terence P. Hughes, Susan Kidwell, Carina B. Lange, Hunter S. Lenihan, John M. Pandolfi, Charles H. Peterson, Robert S. Stenec, Mia J. Tegner, Robert R. Warner
2001 Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 27(293):629-637.

Kennedy, Victor.
1996 The Ecological Role of the Eastern Oyster, *Crassostrea Virginica*, with Remarks on Disease. *Journal of Shellfish Research* 15 (1):177-183.

Kent, Bretton.
1988 *Making Dead Oysters Talk: Techniques for Analyzing Oysters from Archaeological Sites*. Annapolis: Maryland Historical Trust, Historic St. Mary's City, Jefferson Patterson Park and Museum.

Kidder, Tristram R.
2006 Climate Change and the Archaic to Woodland Transition (3000–2600 cal B.P.) in the Mississippi River Basin. *American Antiquity* 71:195-231.

Kilgen, Ronald H., and Ronald J. Dugas.
1989 *The Ecology of Oyster Reefs of the Northern Gulf of Mexico: An Open File Report*. US Department of the Interior, Fish and Wildlife Service, Research and Development, National Wetlands Research Center.

Kirby, Michael Xavier.
2004 Fishing Down the Coast: Historical Expansion and Collapse of Oyster Fisheries Along Continental Margins. *Proceedings of the National Academy of Sciences of the United States of America* 101(35):13096-13099.

Korringa, Pieter
1952 Recent Advances in Oyster Biology. *The Quarterly Review of Biology* 27(3):266-308.

1976 *Farming the Cupped Oysters of the Genus Crassostrea: A Multidisciplinary Treaties.* Elevier Scientific Publishing, New York.

Lawrence, David R.
1988 Oysters as Geoarchaeologic Objects. *Geoarchaeology* 3(4):267-274.

Lepofsky, Dana and Megan Caldwell
2012 Indigenous Marine Resource Management on the Northwest Coast of North America. *Ecological Processes* 2:1-12.

Lepofsky, Dana, Nicole F. Smith, Nathan Cardinal, John Harper, Mary Morris, Gitla (Elroy White), Randy Bouchard, Dorothy I.D. Kennedy, Anne K. Salomon, Michelle Puckett, and Kirsten Rowell
2015 Ancient Shellfish Mariculture on the Northwest Coast of North America. *American Antiquity* 80(2):236-359.

Lightfoot, K.G., R. M. Cerrato, and H.V.E. Wallace
1993 Prehistoric Shellfish-Harvesting Strategies: Implications from the Growth of Soft-Shell Clams (*Mya arenaria*). *Antiquity* 37:358-369.

Livingston, R. J., F.G. Lewis, G. C. Woodsum, X.-F. Niu, B. Galperin, W. Huang, J. D. Cristensen, M. E. Monaco, T. A. Battista, C. J. Klein, R. L. Howell IV, and G. L. Ray
2000 Modelling Oyster Population Response to Variation in Freshwater Input. *Estuarine, Coastal and Shelf Science* 50: 655-672.

Mannino, Marcello A., and Kenneth D. Thomas
2002 Depletion of a Resource? The Impact of Prehistoric Human Foraging on Intertidal Mollusc Communities and Its Significance for Human Settlement, Mobility and Dispersal. *World Archaeology* 33(3):452-474.

Mattson, Robert A.
2002 A Resource-Based Framework for Establishing Freshwater Inflow Requirements for the Suwannee River Estuary. *Estuaries* 25 (6): 1333-1342.

McFadden, Paulette S.
2015 *Late Holocene Coastal Evolution and Human Occupation on the Northern Gulf Coast of Florida, Horseshoe Cove, Dixie County, Florida.* Ph.D. dissertation, Department of Anthropology, University of Florida, Gainesville.

McFadden, Paulette S., and Andrea Palmiotto
2013 *Archaeological Investigations at Ehrbar (8LV282), Levy County, Florida*. Technical Report 17. Laboratory of Southeastern Archaeology, Department of Anthropology, University of Florida, Gainesville.

McKee, Alexander
1969 *Farming the Sea*. New York: Thomas Y. Crowell Company.

McNulty, J. Kneeland, William N. Lindall Jr., and James E. Sykes.
1972 Cooperative Gulf of Mexico Estuarine Inventory and Study, Florida: Phase I, Area Description.

Milanich, Jerald T.
1994 *Archaeology of Precolumbian Florida*. Gainesville: University Press of Florida.

2002 Weeden Island Cultures. *The Woodland Southeast.* University of Alabama Press, Tuscaloosa: 352-372.

Milanich, Jerald T., Ann S. Cordell, Vernon J. Knight, Jr., Timothy A. Kohler, and Brenda J. Sigler-Lavelle
1984 *McKeithan Weeden Island: The Culture of Northern Florida, A.D. 200-900.* New York: Academic Press.

Nash, Colin E.
2011 *The History of Aquaculture*. Wiley-Blackwell, Ames, Iowa.

National Research Council (U.S.) Committee on Assessment of Technology and Opportunities for Marine Aquaculture in the United States
1992 *Marine Aquaculture: Opportunities for Growth.* Washington D.C.: National Academy Press.

Patillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco
1997 Distribution and Abundence of Fishes and Invertebrates in Gulf of Mexico Estuaries. *Volume II. Species Life History Summaries. ELMP Rep. 11.*

Pearse, A.S. and Gordon Gunter
1957 Salinity. *Geological Society of America Memoirs* 1:129-158.

Rakov, V.A. and D.L. Brodianski
2007 Ancient Oyster Farming in the Boisman Culture of the Primorye Neolithic. *Archaeology, Ethnology, and Anthropology of Eurasia* 31(1):39-43.

Rakov, V.A. and D.L. Brodianski
2010 Oyster Cultivation and Archaeology as Producing Activities. *Archaeology Ethnology & Anthropology of Eurasia* 38(1):26-31.

Randall, Asa R., Micah P. Mones, and Kenneth E. Sassaman
2010 Visit Shell City: Another Coastside Attraction. Paper presented at the 67th Annual Meeting of the Southeastern Archaeological Conference, Lexington, Kentucky.

Rick, Torben C., and Jon M. Erlandson, eds
2008 *Human Impacts on Ancient Marine Ecosystems: A Global Perspective*. Berkley: University of California Press.

Rick, Torben C., and Rowan Lockwood.
2013 Integrating Paleobiology, Archeology, and History to Inform Biological Conservation. *Conservation Biology* 27(1):45-54.

Russo, Michael.
1991 A Method for the Measurement of Season and Duration of Oyster Collection: Two Case Studies from the Prehistoric South-East US Coast. *Journal of Archaeological Science* 18(2):205-221.

Sampson, Christina Perry
2015 Oyster Demographics and the Creation of Coastal Monuments at Roberts Island Mound Complex, Florida. *Southeastern Archaeology* 34(1):84-94.

Sassaman, Kenneth E., Paulette S. McFadden, and Micah P. Monés
2011 *Lower Suwannee Archaeological Survey 2009–2010: Investigations at Cat Island, Bird Island, and Richards Island.* Technical Report 10. Laboratory of Southeastern Archaeology, Department of Anthropology, University of Florida, Gainesville.

Sassaman, Kenneth E.
2012 Futurologists Look Back, *Archaeologies: Journal of the World Archaeological Congress* 250-2268.

Sassaman, Kenneth E., Andrea Palmiotto, Ginessa Mahar, Micha P. Monés, and Paulette S. McFadden
2013 *Archaeological Investigations at Shell Mound (8LV42), Levy County, Florida: 2012 Testing*. Technical Report 16, Laboratory of Southeastern Archaeology, Department of Anthropology, University of Florida.

Sassaman, Kenneth E. and Neill J. Wallis
2015 Crisis of Opportunity: How Rapid Sea-Level Rise at A.D. 200-300 Relates to the Structural Realignment of Communities of the Northern Gulf Coast of Florida and Beyond. Paper presented at the 47th Annual Meeting of the Canadian Archaeology Association, Newfoundland.

Sassaman, Kenneth E., Ginessa J. Mahar, Mark C. Donop, Jessica A. Jenkins, Anthony Boucher, Christina I. Oliveira, Joshua M. Goodwin
2015 *Lower Suwannee Archaeological Survey 2013-2014 Shell Mound and Cedar Key Tracts.* Technical Report 23, Laboratory of Southeastern Archaeology, Department of Anthropology, University of Florida.

Sassaman, Kenneth E., Neill J. Wallis, Paulette S. McFadden, Ginessa J. Mahar, Jessica A. Jenkins, Mark C. Donop, Michah P. Monés, Andrea Palmiotto, Anthony Boucher, Joshua M. Goodwin, and Cristina I. Oliveira
2016 Keeping Pace with Rising Sea: The First Six Years of the Lower Suwannee Archaeological Survey, Gulf Coastal Florida. *Journal of Island and Coastal Archaeology* DOI: 10.1080/15564894.2016.1163758.

Saunders, Rebecca W., and Michael Russo
2011 Coastal Shell Middens in Florida: A View from the Archaic. *Quaternary International* 239:38-50.

Seavey, J.R., W.E. Pine III, P. Frederick, L. Strumer, and M. Berrigan
2011 Decadal Changes in Oyster Reefs in the Big Ben of Florida’s Gulf Coast. *Ecosphere* 2(10):1-14.

Schmidt, Daniel and Dexter Haven
2004 A Pilot Study on the Origins of Oysters at James Fort. *The Journal of Jamestown Rediscovery Center* 2:1-6.

Schmidt, Nancy and Mark E. Luther
2002 ENSO Impacts on Salinity in Tampa Bay, Florida. *Estuaries* 24(5):976-984.

Shumway, Saundra E.
1996 Natural Environmental Factors. In *The Eastern Oyster: Crassostrea virginica*, eds Victor S. Kennedy, Roger I.E. Newell, and Albert F. Eble. Pp. 467-513.

Speilmann, Katherine A.
2002 Feasting, Craft Specialization, and the Ritual Mode of Production in Small-Scale Societies. *American Anthropologist* 104(1):195-207.

Stapor, F.W., T.D. Mathews, and F.E. Lindofors-Kearns
1991 Barrier Island Progradation and Holocene Sea-Level History in Southwest Florida. *Journal of Coastal Research* 7:815-838.

Supan, John
2002 Extensive Culture of *Crassostrea virginica* in the Gulf of Mexico Region. Southern Regional Aquaculture Center.

Swalding, P.
1976 Changes Induced by Human Exploitation in Prehistoric Shellfish Populations. *Mankind* 10(3):156-162.

Thomas, David H., and Matthew C. Sanger (editors)
2011 *Trend, Tradition, and Turmoil: What Happened in the Southeastern Archaic?* Anthropological Papers 93. American Museum of Natural History, New York.

Thompson, Victor D., and John E. Worth
2011 Dwellers by the Sea: Native American Adaptations along the Southern Coasts of Eastern North America. *Journal of Archaeological Research* 19:51-101.

Twiss, K.C.
2008 Transformations in an Early Agricultural Society: Feasting in the Southern Levantine Pre-Pottery Neolithic. *Journal of Anthropological Archaeology* 27:418-442.

Walker, Karen J., Frank W. Stapor, Jr., and William H. Marquardt
1995 Archaeological Evidence for a 1750–1450 BP Higher-Than-Present Sea Level along Florida's Gulf Coast. *Journal of Coastal Research Special Issue* 17:205-218.

Wallis, Neill J.
2011 *The Swift Creek Gift: Vessel Exchange on the Atlantic Coast.* Tuscaloosa: University of Alabama Press.

Wallis, Neill J., and Meggan E. Blessing
2015 Big Feasts and Small Scale Foragers: Pit Features as Feast Events in the American Southeast. *Journal of Anthropological Archaeology* 39:1-18.

Wallis, Neill J., Paulette S. McFadden, Hayley M. Singleton
2015 Radiocarbon Dating the Pace of Monument Construction and Village Aggregation at Garden Patch: A Ceremonial Center on the Florida Gulf Coast. *Journal of Archaeological Science: Reports* 2:507-516.

Wells, Harry W.
1961 The Fauna of Oyster Beds, with Special Reference to the Salinity Factor. *Ecological Mongraphs* 31(3):239-266.

Whitaker, Adrian R.
2008 Incipient Aquaculture in Prehistoric California? Long-Term Productivity and Sustainability vs. Immediate Returns for the Harvest of Marine Invertebrates. *Journal of Archaeological Science* 35:1114-1123.

Willey, Gordon R.
1949 *Archaeology of the Florida Gulf Coast* 113*.* Washington D.C.: Smithsonian Institution Press.

Wright, Eric E., Albert C. Hine, Steven L. Goodbred, Jr., and Stanley D. Locker
2005 The Effect of Sea-Level and Climate Change on the Development of a Mixed Siliciclasti-Carbonate, Deltaic Coastline: Suwannee River, Florida, U.S.A. *Journal of Sedimentary Research* 75:621-635.

BIOGRAPHICAL SKETCH

Jessica Jenkins attended the College of William and Mary, graduating with her B.A. in anthropology in 2012. As an undergraduate, Jessica worked for three years with Dr. Martin Gallivan at aboriginal sites on the York River, sparking her interest in subsistence practices, specifically shellfish gathering and use. After graduating from William and Mary, Jessica worked with Dr. Frederick Smith at historic archaeological sites in Barbados and was employed with several cultural resource management firms, working in Louisiana and Virginia.

Jessica began her graduate career at the University of Florida in 2013 with Dr. Kenneth Sassaman, continuing her research on coastal peoples’ practices involving shellfish use, procurement, and deposition at archaeological sites on Florida’s Gulf Coast.