Journal of Archaeological Science 80 (2017) 74–82

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Methods for inferring oyster mariculture on Florida's Gulf Coast

Jessica A. Jenkins

University of Florida, Department of Anthropology, University of Florida, 1112 Turlington Hall, P.O. Box 117305, Gainesville, FL, 32611, USA

ARTICLE INFO

Article history:
Received 4 January 2017
Received in revised form
20 February 2017
Accepted 21 February 2017

Keywords:
Mariculture
Oysters
Shell mounds
Woodland period

ABSTRACT

Archaeologists and historians have demonstrated that marine resource management, or mariculture, has been practiced by coastal peoples worldwide for thousands of years. Typically evidence for these practices is in the form of ethnohistoric accounts or associated infrastructure (e.g. clam gardens). This paper presents methods for inferring oyster mariculture by using proxy evidence from attributes of the shell itself. The methods are applied to archaeological shell from a Woodland Period site on Florida's Gulf Coast, where it appears that two techniques of mariculture, shelling and culling, were practiced during a period of intensive large-scale and sustained harvesting.

1. Introduction

Recent archaeological literature on shellfish has addressed how past peoples actively managed marine resources, specifically at sites along the Northwest Coast of North America. Examples of ancient marine management of economically important shellfish include size and age selection of clams (Cannon and Burchell, 2009), selective harvesting of mussels (Whitaker, 2008), and the construction of clam gardens (Lepofsky et al., 2015). Archaeological evidence of traditional marine management systems in place on the Northwest Coast is supported by ethnohistoric accounts that describe a variety of maricultural traditions among indigenous coastal people of the recent past (Brown and Brown, 2009; Lepofsky and Caldwell, 2012). While the Northwest Coast has been the focus of this new research, there is evidence of ancient mariculture and aquaculture worldwide.

Evidence for ancient shellfish management becomes more elusive in areas lacking both infrastructure (e.g. intact clam gardens) and ethnohistoric accounts of shellfishing practices. In the absence of such evidence shellfish mariculture must be inferred from outcomes to archaeological shell, including attributes of the shell itself, as well as the context in which shell is deposited. I argue that methods for determining maricultural practices involving shellfish, especially in areas where ethnohistoric accounts of mariculture are absent, can include, but also go beyond, measurements of size, as uniform size in deposits may be an outcome of other phenomena such as spawning and growth patterns or preference for a particular size of shellfish.

Presented in this paper are methods for inferring the maricultural practice of culling from patterned variation in the condition of shell as it is affected by cluster growth and parasitic infection. Coupled with nonrandom variation in the ratio of left and right valves—a proxy for a maricultural practice known as “shelling”—oyster shells expressing evidence for culling covary positively with intensity of harvesting as expressed in rapid accumulations of archaeological shell. The methods presented here are informed by ecological and biological literature, personal experience with researchers and oystermen practicing mariculture, as well as modern and archaeological literature describing marine management practices (see Jenkins, 2016 for review of this literature). These methods are applied to oysters excavated from Shell Mound (8LV42), a Woodland period site on Florida's northern Gulf Coast, where as many as 1.2 billion oysters were deposited in about 150 years. The results of this study indicate that the inhabitants of Shell Mound were likely employing maricultural methods when the scale and intensity of oyster harvesting were at their peak.

2. Mariculture

Mariculture, as defined by National Oceanic and Atmospheric Administration (2016), is a branch of aquaculture in which marine organisms, often shellfish, are manipulated by humans to sustain or enhance production primarily for food. When applying the term mariculture to ancient populations, I argue that the

E-mail address: jajenkins@ufl.edu.

http://dx.doi.org/10.1016/j.jas.2017.02.001
0305-4403/

definition should be expanded to acknowledge manipulating marine shellfish for purposes aside from simply subsistence to include any intensive use of shell, such as mound building or tool making, which would necessitate a reliable resource pool. Furthermore, I suggest that the term mariculture should be limited to purposeful and deliberate futures planning, as opposed to potentially opportunistic harvesting techniques that have the unintended consequence of sustained production.

Shellfish mariculture today in North America includes restoration projects, habitat enhancement, harvesting restrictions, and oyster farming. Along the Atlantic coast, maricultural endeavors range from multi-million dollar restoration efforts involving the collaboration of state and federal agencies and NGOs to community-based and volunteer projects (ASMFC, 2007). Examples include spawner sanctuaries for hard clams in New York and oyster reef restoration projects in North Carolina, Virginia, Florida, and Maryland (ASMFC, 2007). Similar techniques are being applied to shellfish along the Gulf Coast with oyster reef restoration through cultching, or returning dead shell to extant reefs, in Apalachicola Bay (Camp et al., 2015; Pine et al., 2015) and water leases for the cultivation of clams and oysters in Cedar Key (Colson and Sturmer, 2000). Other maricultural methods used today include the closure of shellfish beds and reefs, legal harvest-size laws and culling of oysters so that dead shell is returned to reefs as substrate and spat, or baby shellfish, are returned to the water to grow as singles.

Maricultural practices today have a long history behind them. People all over the world have been practicing different forms of shellfish mariculture and aquaculture for thousands of years. On the Northwest Coast “harvesting rules” were in place beginning at least 2000 years ago (Grier, 2014; Lepofsky and Caldwell, 2012) and clam gardens were constructed to enhance and protect clam populations (Lepofsky et al., 2015). At the same time, Romans depicted maricultural practices on vases, with drawings of hanging techniques used to grow oysters, a practice which is still used today on Italy's coast (Gunther, 1897). Also, researchers have evidence of management through pest control and size selection of oysters at northern Pacific coastal Neolithic and Early Iron Age sites (Rakov and Brodianski, 2007, 2010).

Despite the body of literature on ancient marine management at sites where shellfish were heavily exploited, there has been no investigation into shellfish management along the Atlantic and Gulf coasts of North America, where massive oyster shell mounds and middens abound. Without intact infrastructure for mariculture or ethnohistoric accounts of maricultural practices, methods for determining oyster mariculture must rely on proxy evidence from the archaeological shell itself as well as the contexts from which shell is excavated.

3. Relevant aspects of oyster biology and ecology

The Eastern Oyster, *Crassostrea virginica*, from here on referred to simply as oysters, are sessile bivalves with an upper, flat valve and a lower, cupped valve (Kennedy, 1996). This species of oyster is found in estuarine environments along the Atlantic and Gulf Coasts of North America. While water 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, creating aggregations of conspecifics in the form of oyster beds or reefs (Kennedy, 1996). 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.

Oysters are often called resilient, as they can withstand a wide range of environmental conditions which influence shell morphology (Supan, 2002). The most important environmental conditions for oyster growth and reproductive success are temperature (Gunter, 1957; Shumway, 1996), salinity (Butler, 1949; Shumway, 1996), substrate (Camp et al., 2015; Kennedy, 1996), and location in the water column (subtidal versus intertidal) (Hopkins, 1957; Lawrence, 1988). These varying environmental conditions affect oysters' shells. For example, shell size and shape are influenced by the location in the water column, shell thickness changes based on salinity, and attachment scars replicate the substrate on which oysters attach and grow (Lawrence, 1988).

Subtidal oysters, those that consistently remain underwater, differ from intertidal oysters, those that are exposed at low tide, in both morphology and quality (Lawrence, 1988). Intertidal oysters grow in tight clumps or burrs, causing their shells to be relatively small, thin, and elongate. Intertidal oysters have refuge from many marine predators and parasites that can only withstand subtidal conditions, although they are typically considered to have poorer meat quality as the organism's energy is more rapidly expended as they are exposed at low tide. In contrast, subtidal oysters often have ovate to subovate shell outlines with thicker shells, and are larger with increased valve cupping. Subtidal oysters are subject to predation and parasitism from subtidal organisms, especially in high salinity waters (Shumway, 1996).

One of the most telling bioindicators of subtidal habitat is the presence of parasitic bore holes on oyster shell. The three most common types of boring predators or parasites that are visible on shell are from the boring sponge, *Cliona*, *Polydora* worms, and the boring clam, *Diplothyhra* (Camp et al., 2015; Kent, 1988). Of these three boring organisms, the presence of holes from the boring sponge relays the most useful information about the environmental conditions of the oyster.

Boring sponges are parasites which attach to and burrow into oyster shells, leaving cylindrical holes on the shell that are easily observed (Hopkins, 1957). Boring sponges can survive in only high-salinity (above 15 parts per thousand), subtidal conditions; therefore, any oyster shell with evidence of sponge parasitism can be assumed to have lived primarily in high-salinity, subtidal areas (deLaubenfels, 1947). Boring sponges do not actually eat the oyster, rather they use the oyster shell as an anchor, chemically etching out the shell, potentially as a means to protect themselves from fluctuating salinity in estuarine environments (deLaubenfels, 1947).

4. Methods: detecting mariculture using oyster shells

There are several attributes of archaeological shell that can serve as proxy data for determining anthropogenic influence on oyster populations. For example, archaeologists use oyster valve height, the longest measurement of the oyster shell, as a measure of overharvesting or resource depression (Erlandson et al., 2008; Kent, 1988; Lightfoot et al., 1993; Savarese et al., 2016). Also, resource niches where past people harvested oysters from, primarily subtidal or intertidal, can be determined by height, height-to-length ratio (HLR), and presence or absence of sponge parasitism (Lawrence, 1988). Similarly, proxies for oyster mariculture are drawn from metric and non-metric observations made of archaeological oyster shell. There is a range of maricultural practices that may have been practiced in the past, two of which, shelling and culling, I have archaeological evidence for and will be the focus of this study.

4.1. Shelling

Shelling, or cultching, is a form of mariculture where dead

Fig. 1. Two views and cross sections of a left (cupped) valve and right (flat) valve.

oyster shells are returned to extant reefs to enhance substrate for larval settlement (Camp et al., 2015). Oyster larvae settle most readily on smooth flat surfaces of their own species (Crisp, 1967). Today, people restore oyster reefs by using recycled oyster shells. A similar practice may have been employed in the past, although oyster shell was also sometimes used to build monumental structures, such as mounds or ridges. If shelling was practiced, it is possible that one valve was returned to oyster reefs as cultch, whereas the other valve was used to build shell structures. One method that could indicate shelling could be the ratio of left (cupped) to right (flat) valves in a sample (Fig. 1). If there is a higher rate of left to right valves in a sample, it could indicate that the right, smoother, flat valve was returned to the water to restore extant reefs, as is done today, and the left valves were added to the mound.

4.2. Culling

Culling is breaking apart oyster clumps, or burrs, keeping some oysters and discarding others back into the water. This is practiced today in order to avoid harvesting dead shell and oysters that are not of legal harvest size. Attributes on archaeological shell that may indicate culling are attachment scars, biofoul, such as spat and barnacles, and the presence or absence of sponge parasitism. If an oyster burr is culled, then the desired oysters would be kept for consumption and the dead shell are returned to the water as substrate 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 with evidence of sponge parasitism or biofoul, then it could be inferred it was returned to the water after being culled from other oysters and substrate to be harvested at a later date (Fig. 2).

Fig. 2. Two examples of left valves with sponge parasitism on the attachment scar with close up views of the scars in the boxes to the right.

Table 1
Description of inferences concerning archaeological oyster shell and associated attributes.

Inference	Evidence	Measurable Attribute	Comments
Source Area Intertidal	Oysters are smaller and more elongate on average; evidence of organisms that can only withstand subtidal environments absent; presence of left attachment areas, which are usually large; oysters deposited in clusters or in burrs.	Height and HLR Presence/absence of sponge parasitism Presence/absence of attachment scar Occurrence of burrs in sample	Local variation can occur in shell morphology
Source Area Subtidal	Oysters are larger and more ovate or subovate on average; evidence of organisms that can only withstand subtidal environments present; smaller or no obvious left attachment areas.	Height and HLR Presence/absence of sponge parasitism Presence/absence of attachment scar	Local variation can occur in shell morphology
Culling	Evidence sponge parasitism on attachment scar; oysters deposited as singles.	Presence/absence of sponge parasitism on attachment scar No burrs in sample	Culling makes the attachment scar more vulnerable to parasites; Oysters may be broken up by non-human agents (e.g. predators, storms)
Shelling	Imbalance of right to left oyster valve ratio.	Number of right and left valves	One valve used to build the reefs, whereas the other was used to build the mound; may be the result of differential depositional practices

4.3. Inferences and evidence

Summarized in Table 1 are inferences concerning oysters and the evidence from archaeological shell that supports those inferences. The inferences that are relevant to the case study presented below are source area as intertidal or subtidal, culling, and shelling. It is important to note that local variation does occur in shell morphology and attributes may be affected by more than one variable.

5. Case study

5.1. Site description and research background

Methods for inferring shelling and culling were applied to samples of oyster shell from Shell Mound, a Woodland period site on Florida's Gulf Coast (Fig. 3). Shell Mound is the largest intact above-ground arcuate shell deposit of 111 recorded archaeological sites in the Lower Suwannee Region of Florida's Gulf Coast (Sassaman et al., 2013). Research at Shell Mound is part of the Lower Suwannee Archaeological Survey (LSAS), an ongoing project conducted by the Laboratory of Southeastern Archaeology (LSA) at the University of Florida. Excavation of 14 test units at Shell Mound between 2012 and 2015 have revealed that the site was occupied in three phases starting at A.D. 200, and abandoned at about A.D. 700.

In the centuries between A.D. 400 and 700, as many as 1.2 billion oysters were added to the arm of a relict sand dune, culminating in the creation of a U-shaped mound 190 × 180 m in plan and 7 m tall. Located on Hog Island to the immediate west of Shell Mound, across a 500-m expanse of shallow intertidal water, was a burial complex known as Palmetto Mound, with a history going back another millennium. Rapid accumulation of oyster shell at Shell Mound from A.D. 500–650 indicates an intensification of resource use concurrent with the rise of the site as a prominent civic-ceremonial center in the region at ca. A.D. 550 (Sassaman et al., 2016).

Along with Garden Patch (Wallis et al., 2015) and Crystal River (Pluckhahn et al., 2015), Shell Mound is one of multiple civic-ceremonial centers established on Florida's northern Gulf Coast after A.D. 200. These civic-ceremonial centers were locations of everyday living as well as ritual activity associated with mortuary facilities. Activities at civic-ceremonial centers involved large gatherings of people, monumental construction, or terraforming, and feasting, which increased the demand on locally available resources. Resource intensification due to a ritualized economy is evidenced at Shell Mound by the scale and diversity of vertebrate and invertebrate fauna, the rapid accumulation of large amounts of oyster shell, and massive pit features filled with extralocal materials and unique assemblages of vertebrate fauna, specifically large numbers of mullet and marine bird (Sassaman et al., 2015, 2016).

The establishment of Shell Mound as a civic-ceremonial center was likely facilitated, in part, by its proximity to large oyster reefs, many of which have been depleted in the last few centuries (Seavey et al., 2011). Oysters of the species *Crassostrea virginica* became available in the intertidal and subtidal waters in the Suwannee Estuary surrounding Shell Mound after the formation of oyster bioherms about 4500 years ago, when sea-level rise slowed and the more-or-less modern coastline was established (Hine et al., 1988; Wright et al., 2005). Aside from meeting subsistence needs, oysters were used as the primary building material for Shell Mound, and potentially carried symbolic importance (*sensu* Claassen, 2008).

5.2. Sampling strategy and excavation

A total of 3252 left oyster valves were analyzed from a continuous 30 × 30-cm column sample excavated from TU8, a test unit near the apex of Shell Mound (Fig. 4). Twenty bulk samples were collected encompassing the entire depth of the unit, 2.1 m below surface. Bulk samples were numbered 1–20 from the top of the unit at surface, increasing in numerical value to the bottom of the unit. Samples were taken in 10-cm increments. 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 fragments were only weighed. Whole left shells were also counted and weighed, and then set aside for further analysis. Whole shells were chosen as the unit of analysis in order to get complete metric data for each sample.

5.3. Depositional sequence

Three macrostratigraphic units are apparent from the

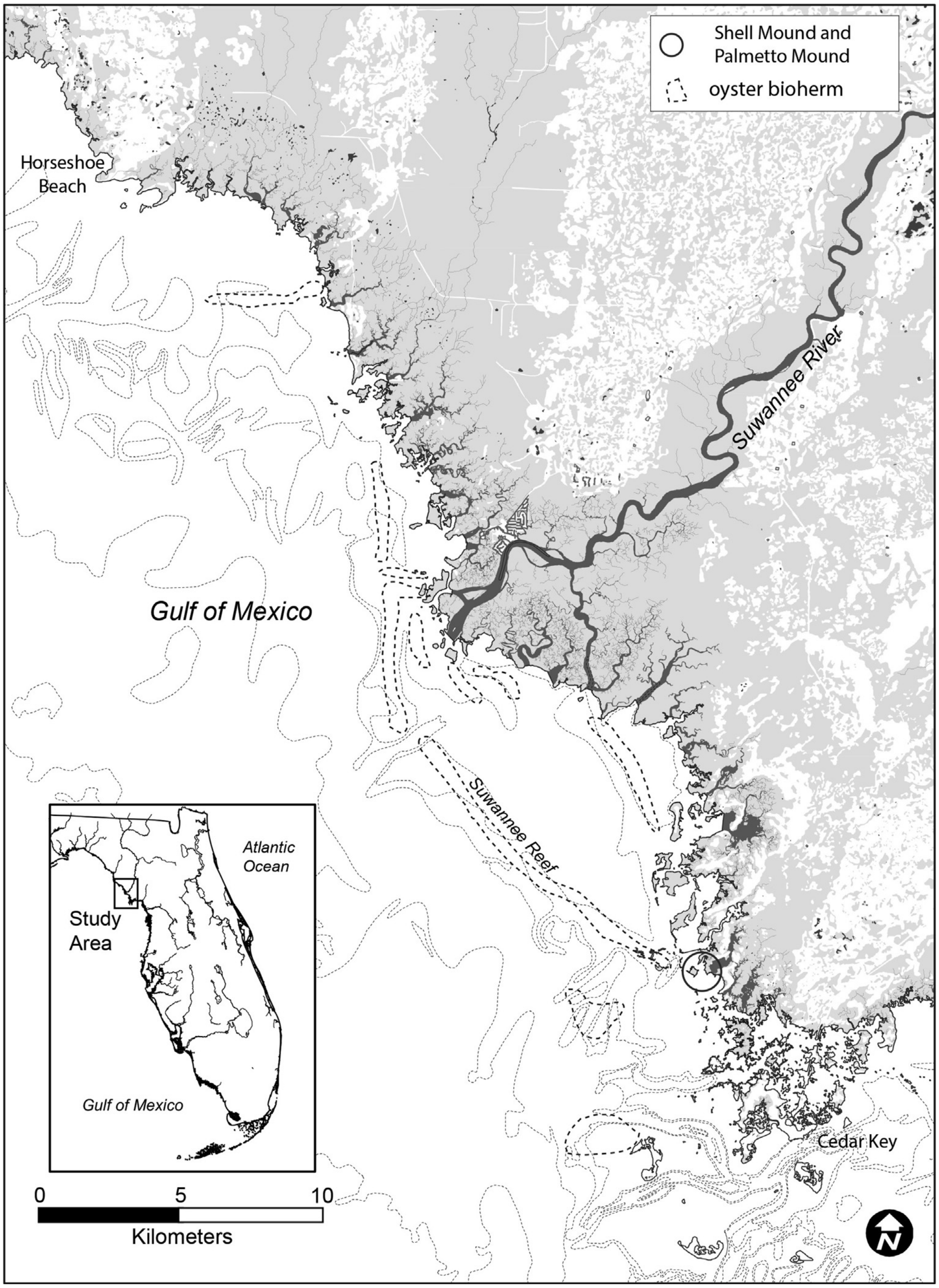

Fig. 3. Map of the Lower Suwannee research area showing oyster bioherms and the location of Shell Mound and Palmetto Mound (adapted from Sassaman et al., 2016).

excavation at TU8: the first macrounit consists of midden that was re-deposited from elsewhere; the second macrounit is primary deposition of whole, clean shell; and the third macrounit is a dark earth midden and associated pit features (Fig. 5). Three radiocarbon dates were taken from the subsistence column indicating the reverse stratigraphy between the first two macrounits. Primary deposition of mounded, unconsolidated whole clean shell occurred at about A.D. 400–550 (Subsistence Column Samples 6–13), with shell that was re-deposited from extant middens placed on top between A.D. 550–700 (Subsistence Column Samples 1–6). The differences between these macrostrata are not only expressed in the profile and radiocarbon dates, but also in the types of oysters being harvested as well as shifts in practices concerning oysters.

All samples from the subsistence column are of equal volume. Attributes coded for each left valve include (1) presence or absence of attachment scars; (2) presence or absence of sponge parasitism; and (3) presence or absence of sponge parasitism on attachment scars. Also enumerated was the ratio of left (cupped) to right (flat) oyster valves.

5.4. Results and discussion

The results of this analysis show that evidence for mariculture covaries with the scale and intensity of oyster harvesting at Shell

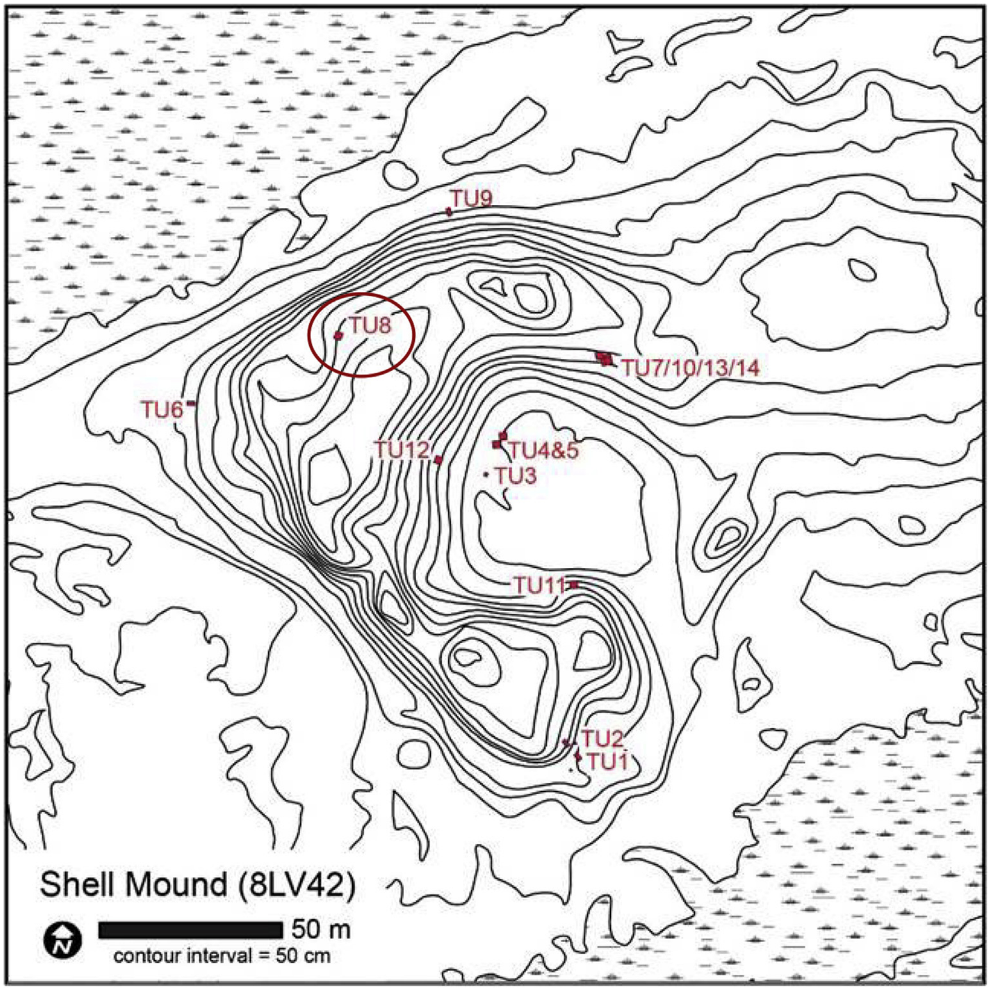

Fig. 4. Topographic map of Shell Mound (8LV42) showing the location of test units. The relevant test unit, Test Unit 8, is circled in red.

Mound. Specifically, 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. A Chi-square test of independence was calculated comparing the instances of parasitism on attachment scars as the proxy for culling, and a significant difference was found between macrounits ($\chi^2 = 16.2858$; $p < 0.5$; $df = 5$). A Chi-square test of independence was also calculated comparing the occurrence of left and right valves as the proxy for shelling, and a significant difference was also found between macrounits ($\chi^2 = 224.7876$; $p < 0.5$; $df = 5$). A shift from intertidal oysters in the submound midden to subtidal oysters used in mound construction is also evident. Patterning for maricultural practices dissipates in the final phase of mound building, during which oyster shell from extant middens was emplaced on the previously mounded shell (Table 2; Fig. 6).

5.4.1. First occupation: the sub-mound midden (samples 14–20)

During the first phase of occupation (A.D. 200–400) the oysters harvested and deposited in the midden are mostly from intertidal conditions. These oysters typically lack sponge parasitism (70 percent without sponge parasitism) and have attachment scars (60 percent with attachment scars). Evidence for culling and shelling is lacking from the oysters deposited in the submound midden, with many of the oysters deposited as burrs. The percentage of left and right valves does not indicate shelling (60 percent right valves and 40 percent left valves) with no consistent trends across samples. Only five percent of the shells in the submound midden have parasitism on the attachment scars, so the oysters do not appear to have been culled and returned to the water for future harvesting.

5.4.2. Intensive harvesting: primary deposition (samples 7–13)

The most compelling evidence for maricultural practices comes from the period of intensive harvesting and deposition of oyster shells at Shell Mound, A.D. 400–550. Unlike the oysters harvested during the initial phase, oysters harvested and deposited on the mound are from mostly subtidal conditions. Almost half of the oysters have sponge parasitism (49 percent) and the majority of oysters have attachment scars (72 percent).

The ratio of left to right valves for this phase of mound construction is 65 percent left valves to 35 percent right valves. When comparing this across subsistence column samples, evidence for shelling spikes at the onset of intensive harvest with 75 percent left valves in Sample 13. The patterning for more left than right valves remains particularly strong in samples 10–13, decreasing incrementally between samples to a low of 58 percent left valves. With the high percentages of left to right valves in these samples, particularly at the start of intensive harvesting, I infer that the left, cupped, valves were being deposited in the mound and the right, flat, valves were returned to the water as cultch for spat recruitment.

Evidence for culling is present in the consistent percentage of shells with evidence of parasitism on the attachment scars. The

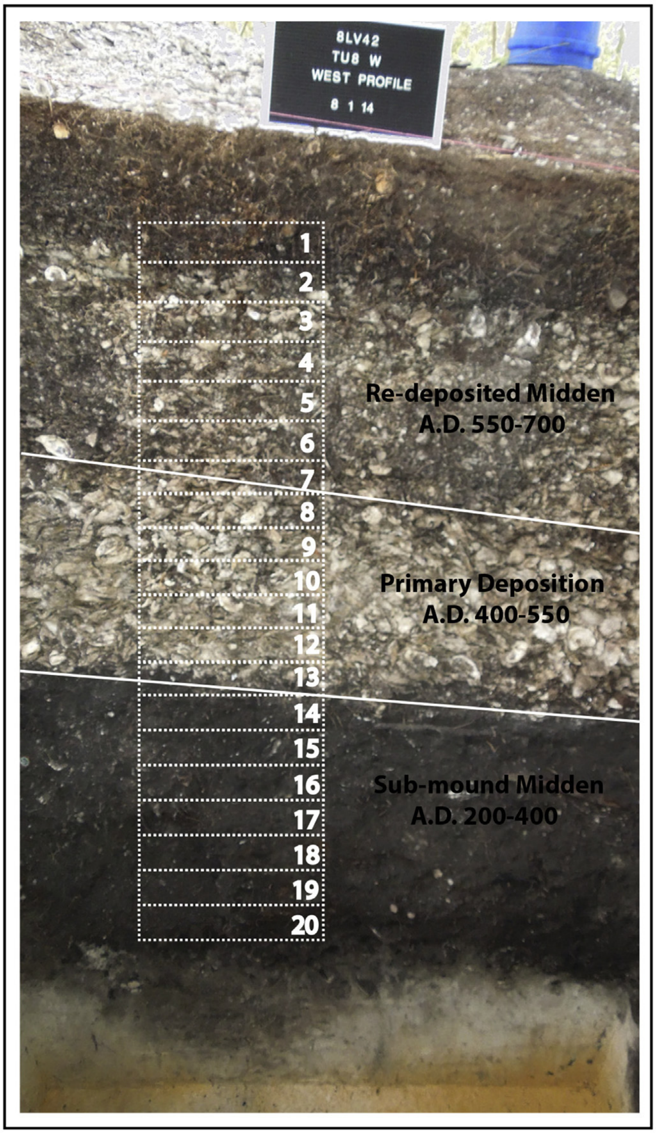

Fig. 5. Profile view of TU8 showing subsistence column samples and chronology of deposition.

most striking evidence is in samples 7–11 where the percentage of oysters with parasitism on their attachment scars increases from 32 to 46 percent and then levels off at about 40 percent.

What makes these data convincing of maricultural practices is not just the relatively high percentage of valves with parasitism on the scar and ratios of left to right shells, but the intersample consistency in trends, with no extreme ranges or outliers between samples.

5.4.3. Abandonment and reoccupation: Re-deposited midden (samples 1–6)

Like the whole clean shell mounded below it, the oysters that were re-deposited on the mound between A.D. 550–700 appear to have been harvested from subtidal conditions. Unlike the shell below, however, there is no compelling evidence for shelling or culling in these upper samples. About half of the oysters in these samples have sponge parasitism (46 percent) and attachment scars (52 percent). Evidence of possible culling drops steadily from 38 to 17 percent of oysters with sponge parasitism on attachment scars, with the exception of Sample 1 which may be a disturbed context. The ratio of left to right oyster valves remains close to 50/50 in all samples, providing no evidence that shelling was being practiced.

5.5. Discussion

At Shell Mound 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 as the shell was procured from an earlier midden. These results are particularly compelling when placed within the culture history of Shell Mound.

When the site was first occupied at around A.D. 200, oysters were harvested at a low rate and it is unlikely that human intervention would be needed to support harvesting practices. With the shift to a ritualized economy beginning around A.D. 400, resource intensification placed increased pressure on oyster populations. In order to ameliorate these pressures, the inhabitants of Shell Mound implemented maricultural practices, specifically shelling and culling. When the site was abandoned as a place of continuous occupation and the harvesting pressure was relieved, maricultural practices would not have been possible without a resident population. Furthermore, the shells were re-deposited from middens elsewhere in the area from a time when mariculture does not seem to have been practiced.

6. Conclusion

The methods proposed here, centered on attributes of archaeological oyster shell and the context in which it is deposited, contribute to a growing body of literature concerning the management of aquatic resources by past people. These methods are unique in their use of examining the shells themselves as well as the context in which they are deposited to make inferences regarding mariculture in an area devoid of ethnohistoric accounts or in infrastructure related to marine management practices.

The application of these methods to a case study from Shell Mound indicate that past people were likely practicing mariculture when the scale and intensity of oyster harvesting increased. It is possible, though, that the patterning seen in these attributes may be due to natural phenomena which could produce similar results. For example, oyster burrs can be broken up by predators or wave action caused by storms, which would make the attachment scars vulnerable to parasitic attack in the same way that culling would. Also, the disparity of right shells in the archaeological samples may be due to differential depositional processes whereby right valves were disposed of elsewhere. In order to further test the likelihood of these patterns being produced by past people practicing mariculture more research needs to be conducted.

Future research should include establishing present-day control data for the instances of sponge parasitism on the attachment scars of oysters that were culled and harvested later. Furthermore, extant reefs whose antiquity is established as contemporaneous with the sites in question should be tested in order to identify if shell of one valve over the other was intentionally added by past people.

While these potential pitfalls and the need for baseline data are important for testing the hypothesized maricultural practices proposed here, the context of deposition in interpreting maricultural practices is also important. In the case study presented here, evidence for maricultural practices at Shell Mound is found only in deposits of intensified oyster harvesting practices, when as many as 1.2 billion oyster shells were rapidly mounded, with no evidence of these practices from the contexts before or after intensification when the scale of harvesting was lower.

Table 2
Table showing descriptive statistics for each sample, macrounit, and all shells. All measurements in millimeters.

Sample	All Valves	Right		Left		Mean	Mean	Mean	Attachement Scars		Sponge Parasitism		Scars with Parasitism	
	n	*n*	%	*n*	%	Height	Length	HLR	*n*	%	*n*	%	*n*	%
1	87	50	57	37	43	50.67	32.39	1.56	32	86	20	54	8	25
2	378	194	51	184	49	52.10	31.83	1.64	112	61	72	39	19	17
3	616	301	49	315	51	55.38	32.73	1.69	155	49	141	45	44	28
4	672	360	54	312	46	53.97	31.08	1.74	133	43	149	48	40	30
5	446	256	57	190	43	55.78	33.23	1.68	100	53	93	49	34	34
6	478	255	53	223	47	54.36	30.26	1.80	128	57	105	47	48	38
Total	**2677**	**1416**	**53**	**1261**	**47**	**54.03**	**31.68**	**1.72**	**660**	**52**	**580**	**46**	**193**	**29**
7	436	190	44	246	56	57.26	33.56	1.71	162	66	131	56	63	39
8	437	183	42	254	58	57.22	31.63	1.81	159	63	116	46	60	38
9	321	134	42	187	58	55.63	31.14	1.79	142	76	95	51	54	38
10	398	140	35	258	65	57.03	32.06	1.78	193	75	141	55	88	46
11	420	128	30	292	70	57.74	32.75	1.76	228	78	142	49	73	32
12	363	87	24	276	76	58.36	32.94	1.77	207	75	125	45	49	24
13	430	106	25	324	75	57.68	32.00	1.80	234	72	149	46	53	23
Total	**2805**	**968**	**35**	**1837**	**65**	**56.45**	**31.87**	**1.78**	**1325**	**72**	**899**	**49**	**449**	**34**
14	6	3	50	3	50	64.48	36.87	1.75	2	67	2	67	0	0
15	36	22	61	14	39	48.08	28.83	1.67	8	57	2	14	0	0
16	37	23	62	14	38	43.20	27.32	1.58	7	50	5	36	1	14
17	22	11	50	11	50	30.54	17.15	1.78	8	73	2	18	0	0
18	117	68	58	49	42	43.48	23.00	1.89	37	76	3	6	0	0
19	49	33	67	16	33	49.60	26.90	1.84	7	44	7	44	1	14
20	114	67	59	47	41	49.19	27.88	1.76	24	51	25	53	5	21
Total	**381**	**227**	**60**	**154**	**40**	**45.73**	**25.60**	**1.80**	**61**	**60**	**46**	**30**	**7**	**5**
Total	**5863**	**2611**	**45**	**3252**	**55**	**55.01**	**31.50**	**1.76**	**2046**	**63**	**1525**	**47**	**649**	**20**

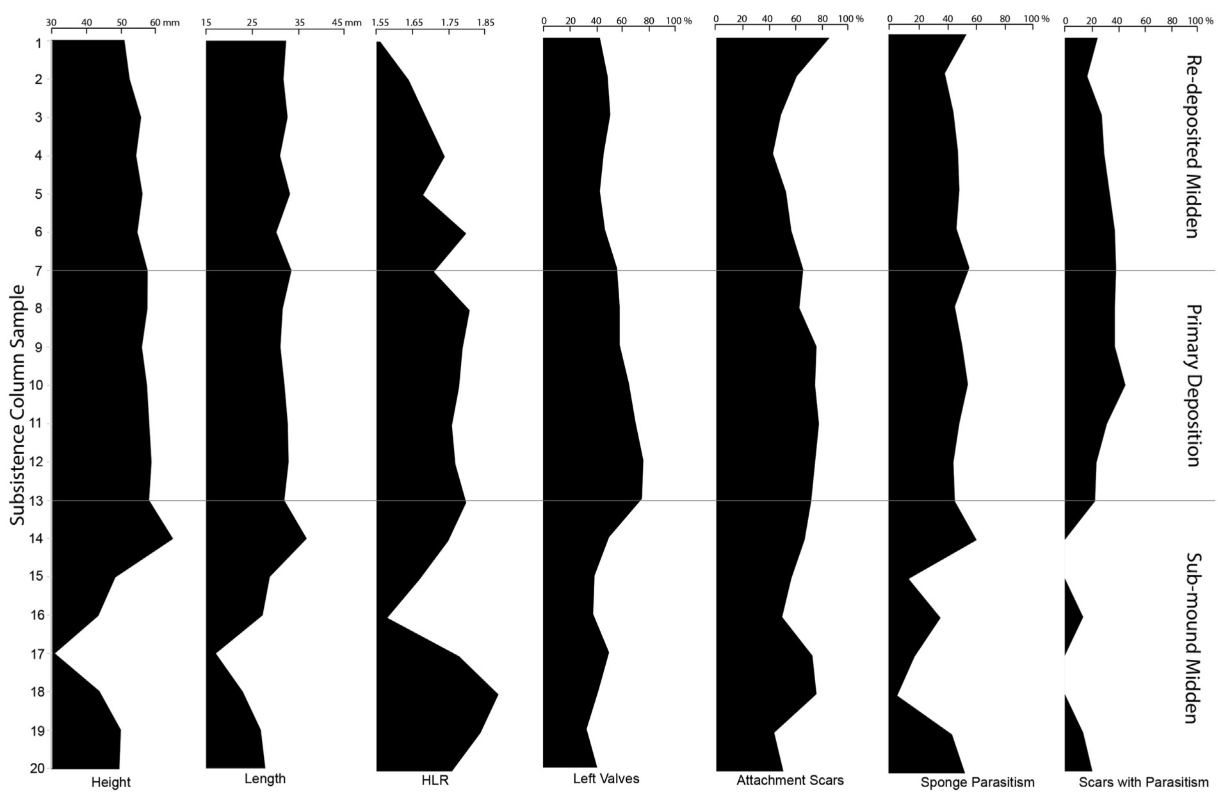

Fig. 6. Depiction of variation in measured attributes by subsistence column sample.

This initial effort at examining maricultural practices of *Crassostrea virginica* on the Gulf Coast is an important step in understanding how coastal people interacted with and impacted the seascape in terms of resource management. These and other similar methods for inferring maricultural practices at coastal and riverine sites worldwide, where oyster shells dominate assemblages either in shellworks or dense middens, allow archaeologists to explore how past people actively engaged and manipulated important resources.

Acknowledgements and funding

I would like to thank Kenneth Sassaman for his input and guidance in writing this, Anthony Boucher for his help with the figures, the 2014 and 2015 Lower Suwannee Archaeological Field School students and staff, and the researchers and oystermen who contributed to my understanding of oyster mariculture. The Lower Suwannee Archaeological Survey is supported by the Hyatt and Cici Brown Endowment for Florida Archaeology. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Atlantic States Marine Fisheries Commission, 2007. The Importance of Habitat Created by Molluscan Shellfish to Managed Species along the Atlantic Coast of the United States. ASMFC Habitat Management Series #8.

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

Butler, P.A., 1949. Gametogenesis in the oyster under conditions of depressed salinity. Biol. Bull. 96, 263–269.

Camp, Edward V., Pine III, William E., Havens, Karl, Kane, Andrew S., Walters, Carl J., Irani, Tracy, Lindsey, Angela B., Glenn Morris Jr., J., 2015. Collapse of a historic oyster fishery: diagnosing causes and identifying paths towards increased resilience. Ecol. Soc. 20 (3), 45.

Cannon, Aubrey, Burchell, Meghan, 2009. Clam growth-stage profiles as a measure of harvest intensity and resource management on the central coast of british columbia. J. Archaeol. Sci. 36, 1050–1060.

Claassen, Cheryl, 2008. Shell symbolism in pre-columbian North America. Early Hum. Impact Megamulluscs 37–43.

Colson, Suzanne, Sturmer, Leslie N., 2000. One shining moment known as clamelot: the cedar Key story. J. Shellfish Res. 19 (1), 477–480.

Crisp, D.J., 1967. Chemical factors inducing settlement in Crassostrea virginica. J. Animal Ecol. 36 (2), 329–335.

deLaubenfels, M.W., 1947. Ecology of the sponges of a brackish water environment, at Beaufort, N.C. Ecol. Monogr. 17 (1), 31–46.

Erlandson, Jon M., Rick, Torben C., Braje, Todd J., Steinberg, Alexis, Vellanweth, Rene L., 2008. Human impacts on ancient shellfish: a 10,000 Year record from San Miguel Island, California. J. Archaeol. Sci. 35, 2144–2152.

Grier, Colin, 2014. Landscape construction, ownership and social change in the southern Gulf islands of British Columbia. Can. J. Archaeol. 38, 211–249.

Gunter, G., 1957. Temperature. In: Treatise on Marine Ecology and Paleoecology Volume 1, Ecology, vol. 67. The Geological Society of America, Memoir, New York, pp. 159–184.

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

Hine, Albert C., Blknap, Daniel F., Hutton, Joan G., Osking, Eric B., Evans, Mark W., 1988. Recent geological history and modern sedimentary processes along an incipient, low-energy, epicontinental-sea coastline: northwest Florida. J. Sediment. Res. 58, 564–579. Hopkins, S.H.

Hopkins, S.H., 1957. Oysters. Geol. Soc. Am. Memoires 67 (1), 1129–1134.

Jenkins, Jessica A., 2016. Archaeological Evidence of Oyster Mariculture in the Lower Suwannee Region of Gulf Coastal Florida. Unpublished Master's thesis. Department of Anthropology, University of Florida, Gainesville.

Kennedy, Victor, 1996. The ecological role of the eastern oyster, *Crassostrea virginica*, with remarks on disease. J. Shellfish Res. 15 (1), 177–183.

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

Lawrence, David R., 1988. Oysters as geoarchaeologic objects. Geoarchaeology 3 (4), 267–274.

Lepofsky, Dana, Caldwell, Megan, 2012. Indigenous marine resource management on the Northwest coast of North America. Ecol. Process. 2, 1–12.

Lepofsky, Dana, Smith, Nicole F., Cardinal, Nathan, Harper, John, Morris, Mary, Gitla (Elroy White), Bouchard, Randy, Kennedy, Dorothy I.D., Salomon, Anne K., Puckett, Michelle, Rowell, Kristen, 2015. Ancient shellfish mariculture on the Northwest coast of North America. Am. Antiq. 80 (2), 236–359.

Lightfoot, K.G., Cerrato, R.M., Wallace, H.V.E., 1993. Prehistoric shellfish-harvesting strategies: implications from the growth of soft- shell clams (*Mya arenaria*). Antiquity 37, 358–369.

National Oceanic and Atmospheric Administration, 2016. What is Aquaculture? Electronic document. http://www.nmfs.noaa.gov/aquaculture/what_is_aquaculture.html (accessed 5 December 2016).

Pine III, William E., Walters, Carl J., Camp, Edward V., Bouchillon, Rachel, Ahrens, Robert, Sturmer, Leslie, Berrigan, Mark E., 2015. The curious case of eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida. Ecol. Soc. 20 (3), 46.

Pluckhahn, Thomas J., Thompson, Victor D., Weisman, Brent R., 2015. Toward a new view of history and process at Crystal River (8Cl1). Southeast. Archaeol. 29 (1), 164–181.

Rakov, V.A., Brodianski, D.L., 2007. Ancient oyster farming in the boisman culture of the primorye neolithic. Archaeol. Ethnol. Anthropol. Eurasia 31 (1), 39–43.

Rakov, V.A., Brodianski, D.L., 2010. Oyster cultivation and Archaeology as producing activities. Archaeol. Ethnol. Anthropol. Eurasia 38 (1), 26–31.

Sassaman, Kenneth E., Palmiotto, Andrea, Mahar, Ginessa, Monés, Micah P., McFadden, Paulette S., 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., Mahar, Ginessa J., Donop, Mark C., Jenkins, Jessica A., Boucher, Anthony, Oliveira, Christina I., Goodwin, Joshua M., 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., Wallis, Neill J., McFadden, Paulette S., Mahar, Ginessa J., Jenkins, Jessica A., Donop, Mark C., Monés, Micah P., Palmiotto, Andrea, Boucher, Anthony, Goodwin, Joshua M., Oliveira, Christina I., 2016. Keeping pace with rising sea: the first six years of the lower suwannee archaeological Survey, Gulf coastal Florida. J. Isl. Coast. Archaeol. http://dx.doi.org/10.1080/15564894.2016.1163758.

Savarese, Michael, Walker, Karen J., Stingu, Shanna, Marquardt, William H., Thompson, Victor, 2016. The effects of shellfish harvesting by aboriginal inhabitants of southwest Florida (USA) on productivity of the eastern oyster: implications for estuarine management and restoration. Anthropocene. http://dx.doi.org/10.1016/j.ancene.2016.10.002.

Seavey, J.R., Pine III, W.E., Frederick, P., Strumer, L., Berrigan, M., 2011. Decadal changes in oyster reefs in the big bend of Florida's Gulf coast. Ecosphere 2 (10), 1–14.

Shumway, Saundra E., 1996. Natural environmental factors. In: Kennedy, Victor S., Newell, Roger I.E., Eble, Albert F. (Eds.), The Eastern Oyster: Crassostrea Virginica, pp. 467–513.

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

Wallis, Neill J., McFadden, Paulette S., Singleton, Hayley M., 2015. Radiocarbon dating the pace of monumental construction and village aggregation at garden Patch: a ceremonial center on the Florida Gulf coast. J. Archaeol. Sci. Rep. 2, 507–516.

Whitaker, Adrian R., 2008. Incipient aquaculture in prehistoric California? Long-Term productivity and sustainability vs. Immediate returns for the harvest of marine invertebrates. J. Archaeol. Sci. 35, 1114–1123.

Wright, Eric E., Hine, Albert C., Goodbred Jr., Steven L., Locker, Stanley D., 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. J. Sediment. Res. 75, 621–635.