Sea level rise and a Florida mortuary pond: how oysters (crassostrea virginica) reveal past climate change at the Manasota key offshore archaeologyical site

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CHAPTER 6: DISCUSSION

6.1 Introduction

The results outlined in the previous chapter set the stage for the larger interpretations about the process of marine transgression at MKO presented here. This chapter is organized by topic, each building on the previous one to create a more detailed picture of MKO's transgression as informed by analysis conducted on oysters. It begins with a discussion of morphometrics of one Archaic and two modern oyster sample sets (section 6.2), followed by a discussion of stable oxygen isotope analysis (section 6.3). Stable carbon isotope analysis follows (section 6.4), with sclerochronological interpretations presented next (section 6.5). The final discussion concerns radiocarbon dating (section 6.6). Using the findings of the oyster study, this chapter then shifts to a broader discussion of how the site was preserved (section 6.7.1), the changing paleoenvironment of the pond during marine transgression (6.7.2), and what that may have meant for the population(s) using this landscape at the time, specifically as it concerns the abandonment of mortuary ponds as a cultural practice in Florida after the Middle Archaic period (section 6.7.3).

6.2 Morphometric Analysis

Morphometric analysis provides the most basic information about the MKO habitat at time of oyster growth. Oyster shell shape is influenced by substrate, density of the oyster bed, salinity, turbidity, water depth, and presence of parasites and epifauna (Boudreaux 2005; Eastern Oyster Biological Review Team 2007; Kingsley-Smith 2015). Atypical substrate (i.e., modified wooden stakes and skeletal material) partially influenced the shape of MKO oyster valves, causing some to deviate from a typical vertical growth position. Most of the MKO oysters fell into the bed HLR classification, suggesting they formed in loose clusters or singly over muddy sand. The presence of mudworms (*P. websteri*) confirms the bottom type, as these parasites prefer a soft and/or muddy-bottomed environment (Brown 2012).

Water currents were swift enough to allow filter feeding and prevent siltation but weak enough that juvenile oyster spat could settle and attach to substrate. Characteristics of some MKO oysters, such as frilling and coloration of the valves, pointed to a more saline environment. Shells are generally thinner in brackish waters, and thicker in more saline water (Galtsoff 1964; Kent 1988). Mean thickness for the MKO oyster left valves was 0.82 to 12.03 mm (up to 17.26 mm for right valves). Strongly sculptured valves may suggest they were also exposed to sunlight, which is further supported by pink striations on the exterior portions of oyster valves (Kent 1988).

Mudworms also provide information on water parameters at time of growth. One study suggested sustained salinity at 20 psu causes stress for this species, and they suffer severely in salinities of 10 psu or below (Brown 2012). *P. websteri* affected most of the MKO oysters. Therefore, salinity must have been high enough for prolific growth but not high enough to cause mudworm mortalities. Mudworms attack both dead and living oysters, so it is difficult to determine which oysters were affected while alive. In the interior units at MKO, however, oyster 2606.1 was located under 32 cm of sediment and found in the life position (still attached at the hinge). Therefore, it can be said with relative confidence that this oyster was affected by mudworms while it was still alive. Barnacles formed prior to oyster settlement but also after oyster settlement as evidenced by their location within attachment scars or on exterior surfaces of oyster valves. The three types of barnacles noted on MKO oyster shells represent varying salinity preferences. *B. eburneus* and *B. improvisus*, for example, prefer lower salinities and protected waters, but *B. amphitrite* prefers higher salinities (Kent 1988; Smith 1964:91). *B. eburneus* and *B. improvisus*, however, tolerate a wide salinity variation, though *B. improvisus* tolerates lower salinity regimes. *B. amphitrite* prefers sheltered marine environments, though it can tolerate down to 10 psu. In general, ranges for *B. amphitrite* and *B. eburneus* are between 5 and 40 psu, and the range for *B. improvisus* is between 0 and 40 psu. It should be noted that barnacles can survive salinity extremes for short periods of time.

6.2.1 Modern versus Archaic Oysters

This research compared MKO oyster morphometrics to modern sample sets from the region. Oysters that formed on skeletal material and wooden stakes were expected to have a similar mean HLR to the LB modern oysters that were collected from mangrove roots. The justification for this reasoning comes from what is known about mortuary ponds in Florida. Based on other examples of these ponds from across the state, archaeologists determined that human remains were placed in peat in a flexed position with modified wooden stakes placed around the interred individual (Doran 2002a, 2002b; Milanich 1994:70; Purdy 1991). This resulted in portions of wooden stakes rising vertically into the water column in an orientation that could be comparable to mangrove roots (refer to Figure 4.3 of LB modern oysters attached to mangrove roots in Lemon Bay). Since 2016, wooden stakes were visible rising vertically from the peat at MKO (BAR 2016b, 2017a, 2017b, 2017c) and provided substrate for oysters. Skeletal material was also exposed at MKO due to erosional processes, providing additional substrate for oysters.

Figure 6.1, using the data from Table 5.1 in Chapter 5, illustrates that the LB modern oysters and MKO Archaic oysters are firmly within the bed oyster classification. The NBR modern oysters are also classified as bed oysters, though they represent the upper cusp of this ratio at 2.0 and somewhat overlap with the reef oyster classification. This is likely attributed to the general clustering of the NBR oysters on manmade dock pilings versus individual oyster attachment to roots or wooden stakes. Interestingly, a study concerning oysters growing on mangrove roots versus manmade structures, like pilings, found differences in their vertical orientation and in general oyster size (Drexler et al. 2014). Oysters on modern structures grew more densely and more upwards than oysters on mangrove roots, but those on mangroves were smaller in overall height and less elongated than those on manmade structures. The difference between NBR modern oysters and MKO Archaic oysters was statistically significant. This was expected, as the NBR sample set originated from a dock piling 18 km north of MKO. The dock piling was a relatively smooth surface that exhibited more oyster crowding and less space for attachment. While the results of the NBR morphometrics still placed them within the bed oyster classification, they trended more towards the reef classification, which would be expected for severely crowded oysters. The NBR oyster sample size was small (n=22), but a larger sample size could reveal a reef oyster classification. Regardless, these findings provide support that MKO oysters did not form on a substrate that was similar to the NBR oysters.

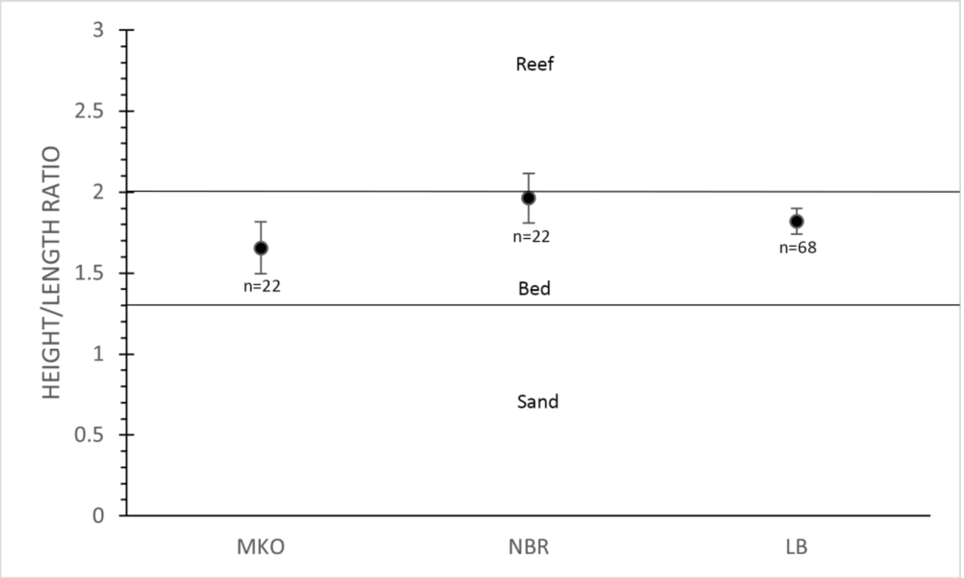

Figure 6.1. Mean and 95% confidence interval of shell height to length ratio for MKO's Archaic oysters and two modern oyster samples (after Kent 1988 and Cannarozzi 2012) (Price 2021).

Statistical analysis of the NBR and LB modern oysters revealed that the difference between the two groups was not significant. This was unexpected given that the substrates were distinct (mangrove roots versus dock pilings). In comparing MKO to LB modern oysters, the difference between the two samples was not statistically significant, which could suggest that they formed on similar substrate or in a similar orientation. This is likely attributed to oyster growth on cylindrical objects and/or density of the oyster bed. The LB oysters appeared more standardized because they originated from the same environment, on the same substrate, and were collected within 1.5 m of each other. The sample size was also large enough to minimize effects of intra-bed variability in the statistical analysis. The MKO assemblage is less standardized, which could be due to varying environments or small sample size. Figure 6.2 illustrates HLR measurement boxplots for all three oyster sample sets. It is clear that the MKO population is small based on the fact that there is a wider range and outliers. A larger sample set would likely minimize these issues. It is also clear that the NBR oysters are trending towards a reef oyster classification, which was their hypothesized classification given the substrate. With a larger sample set, they would likely classify as reef oysters.

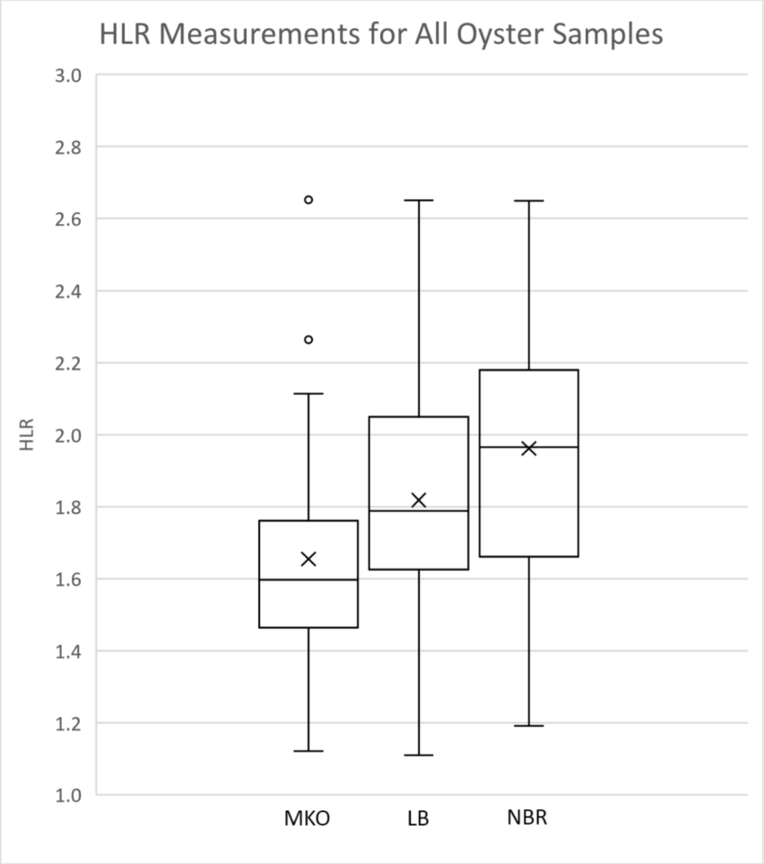

Figure 6.2. HLR box plots with range, mean, median, and outliers for all oyster sample sets (Price 2023).

There are limitations with morphometric analysis of oysters. HLR relies on patterns in a population to make interpretations. Without a large sample size, trends may be obscured by natural variability present in the population. This study examined a small selection of surviving shells from MKO and made assumptions about habitat based on this sample. It is unknown exactly how many oysters were originally present at MKO, and the sampled set does not represent the MKO oyster population as a whole. All morphometric results must be interpreted with care since the MKO and NBR sample sizes were small and, as noted previously, oysters are highly variable. Oysters undergo allometric changes in shell shape during growth, which complicates HLR interpretations (Kent 1988). Very young or small oysters can skew the results of the analysis. Examining more oysters from the site could strengthen confidence in statistical analysis if the oysters are not very young. MKO oysters measured in the sand, bed and reef oyster classifications, but inferences concerning habitat cannot be made based on a single oyster's attributes. Instead, a pattern in the sample, which in the case of MKO points to bed oyster classification, must be used. Due to the effects of intra-bed variability, HLR alone cannot currently answer whether the MKO oysters formed at the same time in the same environment. Instead, the following discussions concerning stable isotope analyses and sclerochronology are used to assess environment in more detail.

6.3 Stable Isotope Analysis: Oxygen

This section discusses results of stable oxygen isotope analyses conducted on modern and Archaic oysters (6.3.1). Within this section, a brief discussion of the differences between transect line and drilled hole sampling methods for MKO oysters 337.1 and 15.01b is presented (6.3.1.1). Next, oyster data are compared to barnacle and gastropod data (6.3.2). Finally, results of water sample analysis are presented (6.3.3) and used in the paleotemperature equation to model past water parameters for the MKO pond as the oysters formed (see section 6.3.3.1).

6.3.1 Oysters

One goal of this research was to determine if oysters could elucidate the type of environment that MKO experienced during transgression and how this affected preservation of organic material. Considering other studies (Bullen et al. 1968; Murphy 1990; Turck 2011) hypothesized that precontact coastal sites survived marine transgression in a back barrier, sheltered, estuarine environment, a modern oyster sample was chosen from one of these environments for comparison to MKO oysters. As Chapter 4, section 4.3.1.3 noted, LB modern oysters were collected from a sheltered estuary as close to

MKO as possible. The goal was to determine if results of stable isotope analyses for LB and MKO oysters were similar. Stable oxygen isotope analysis, however, showed significant paleoenvironmental differences between Archaic and modern oysters, the most significant of which was the seemingly more saline water parameters for some MKO oysters. As Chapter 3, section 3.4.1 noted, oysters from more saline or fully marine environments generally have higher $\delta^{18}O_{shell}$ values and less variation in the plotted profiles (Kirby 2000). Oysters from brackish or estuarine environments typically have lower $\delta^{18}O_{shell}$ values due to freshwater input and exhibit more variation in plotted profiles due to variation in the environment (Kirby 2000). When compared to MKO Archaic oysters, LB modern oysters had lower minimum and maximum $\delta^{18}O_{shell}$ values, a greater range, and a lower mean $\delta^{18}O_{shell}$ value (refer to Table 5.4 in Chapter 5). The greater range for LB modern oysters implies greater variation in the LB modern oyster environment as opposed to the Archaic environment. The lower range in the MKO oysters is attributed to less variability in the environment and less freshwater influx (Kirby 2000; Kirby et al. 1998). More variability in plotted profiles is expected in an estuarine environment, providing additional evidence that the MKO oysters did not form in an environment like the modern Lemon Bay estuary. $\delta^{18}O_{shell}$ values appear less varied in marine environments because the ocean is less variable in terms of temperature and salinity, which typically covaries with $\delta^{18}O_{water}$ (Kirby 2000). The MKO oysters exhibit some variation, though it is not as distinct compared to modern oysters. It is unlikely, however, that the MKO oysters formed in a fully marine environment given variation in the plotted profiles and $\delta^{18}O_{shell}$ values, as well as an indication of a hypersaline environment for some MKO oysters. The MKO pond at the time these oysters formed was thus still affected by precipitation, evaporation, and groundwater sources, though not as drastically as in a modern estuary.

One MKO oyster (39.1a) had minimum and maximum $\delta^{18}O_{shell}$ values similar to LB modern oysters. MKO oysters 15.01b, 39.1a, and 2501.1 had mean $\delta^{18}O_{shell}$ values similar to LB modern oysters. These three MKO oysters also had more negative mean $\delta^{18}O_{shell}$ values than the rest of the sampled MKO oysters (Figure 6.3). While warmer temperatures lead to more negative $\delta^{18}O_{shell}$ values, studies (Surge et al. 2003; Wang et al. 2013) illustrated that the climate was a few degrees cooler in the Early Holocene; it is therefore unlikely that extreme hot temperatures caused lower mean $\delta^{18}O_{shell}$ values in MKO oysters 15.01b, 39.1a, and 2501.1. The negative values are instead attributed to freshwater input or a less saline environment than the one in which the rest of the MKO oysters formed. Figure 6.4 illustrates how there are two separate groupings of MKO oysters representing two different environments as revealed by stable oxygen isotope analysis: three MKO oysters (Group 1) were distinct compared to the other five MKO oysters (Group 2). Interestingly, Group 1 oysters date earlier than the rest of the MKO oysters, which is further discussed in section 6.6.

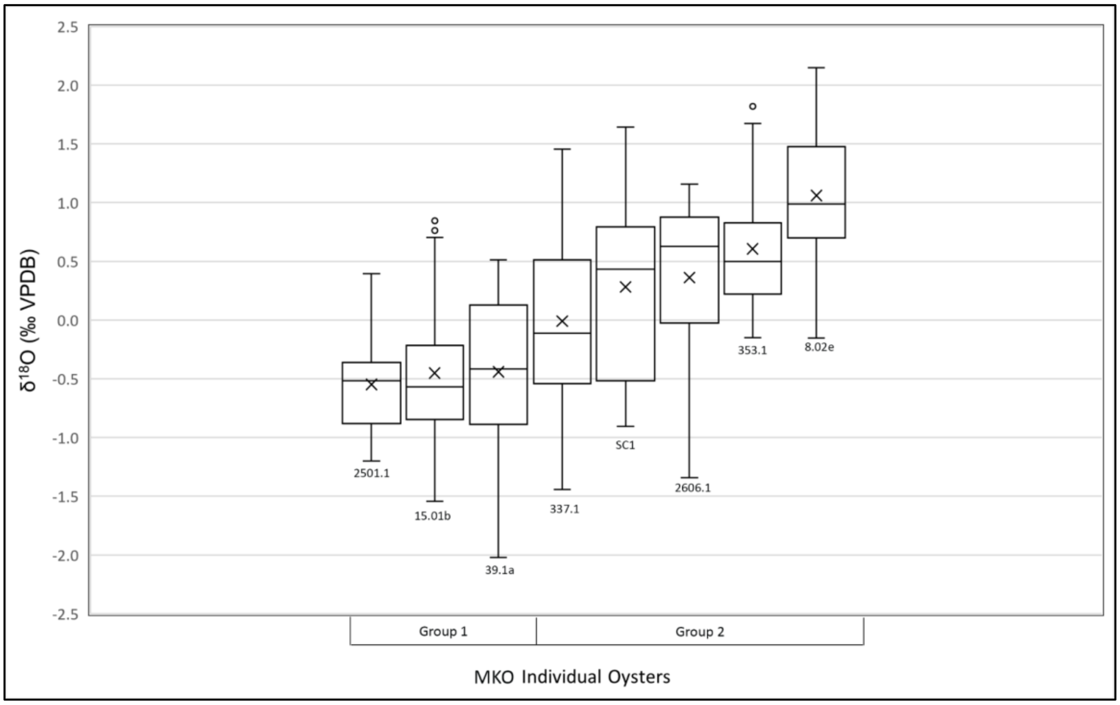

Figure 6.3. Box plots exhibiting mean, median, and range in $\delta^{18}O_{shell}$ values for isotopically sampled Archaic oysters (Price 2023).

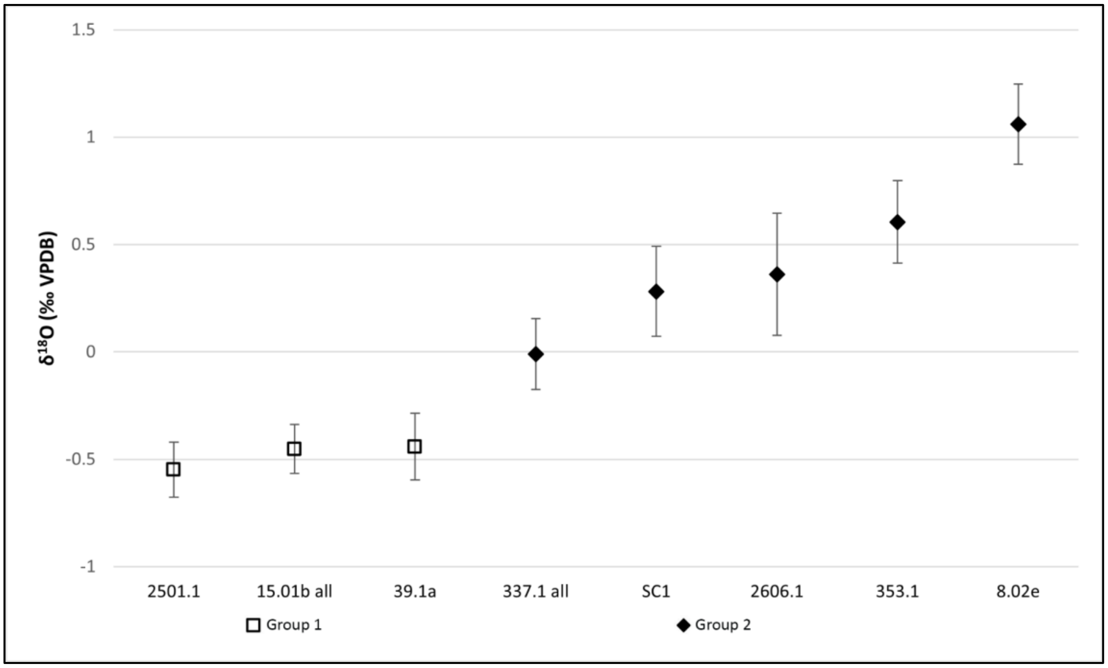

Figure 6.4. Mean $\delta^{18}O_{shell}$ values and 95% confidence interval for Archaic oysters, illustrating Groups 1 and 2 (Price 2023).

If the relationship between salinity and $\delta^{18}O_{water}$ was the same in the past as it is today, then this study's results for Group 2 MKO oysters may suggest they originated from a more saline environment than both Group 1 MKO oysters and the modern Lemon Bay estuary. Mean $\delta^{18}O_{shell}$ values for Group 2 MKO oysters are higher than LB modern oysters. Salinity in the modern estuary was as high as 36.8 psu in 2017 (University of South Florida 2021). Surface seawater is typically between 33 and 37 psu, which could suggest these MKO oysters formed in an at-times hypersaline environment (referring to those environments that are saltier than ocean water) (Oron et al. 2016; Rich and Maier 2015). Additionally, MKO oysters SC1, 8.02e, and 353.1 have greater minimums and maximums than the rest of the Archaic and modern oysters, suggesting less environmental variation at the time of growth. Without knowing past water parameters, however, caution is warranted. To reiterate, it is unknown if the relationship between salinity and $\delta^{18}O_{water}$ was the same in the past as it is today. It is also unknown if the past isotope gradient of the pond was inverted, similar to current conditions in parts of southwest Florida (see section 6.3.3 for further discussions of inverted water parameters). How these unknowns affect interpretations of site formation processes is further discussed in section 6.3.3.1.

There was no pattern when examining $\delta^{18}O_{shell}$ values compared to distribution across the site. Archaic oysters located closer to the interior of the pond (2501.1 and 2606.1) had minimum, maximum, mean, and range $\delta^{18}O_{shell}$ values that overlapped with Archaic oysters located near the periphery of the pond (SC1, 15.01b, 39.1a, 8.02e, 337.1, 353.1). This could suggest that there was no variation in the habitat spatially, or more likely, this could be due to post-depositional disturbances to the site. As Chapter 2, section 2.5.1 noted, post-depositional disturbances were visible in the form of displaced skeletal material and stakes. Furthermore, the oyster valves collected from Area 1 were interspersed with wooden stakes, suggesting they became detached from the stakes during post-depositional disturbances. Some oysters could have moved around the site, thus contributing to a lack of patterning among distribution and $\delta^{18}O_{shell}$ values. A lack of patterning could also be attributed to natural variation in individual oysters.

6.3.1.1 Comparing Drilled Holes versus Transect Lines. Chapter 5, section 5.3.1 noted that MKO oysters 15.01b and 337.1 were sampled twice using varying methods: drilled holes and transect lines. Results of these sampling methods were notable and are worth discussion here. For this research, drilled holes were placed within the chondrophore of the shell, whereas transect lines were placed within the growth bands in the bisected hinge (Figure 6.5). The distance between drilled holes and transect lines was similar (250-300 µm versus 200-250 µm respectively) and guided by drill bit and resultant drilled hole/channel size. The transect lines captured more detail and thus contain more variation, contrary to the drilled hole profiles, which exhibit muted oscillations. It should be noted, however, that this study still captured good resolution for each shell, given that other oyster studies collected an average of 12 to 19 samples per shell [see for example (Andrus and Thompson 2012; Lulewicz et al. 2017b)].

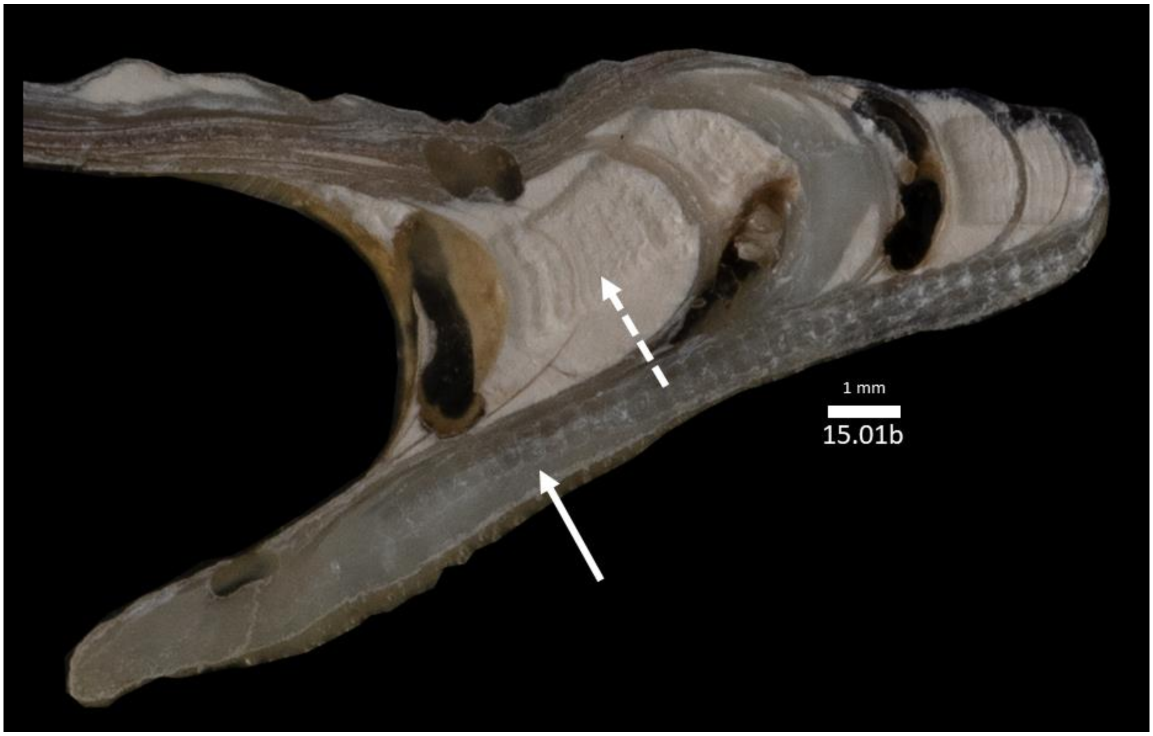

Figure 6.5. MKO oyster 15.01b with drilled holes (solid arrow) and transect lines (dashed arrow) (Price 2021).

Between drilled holes and transect lines, there were variations in carbon isotope values, though each plotted profile had the same general shape (refer to Figures 5.18 and 5.19 in Chapter 5 and Figure 6.11 in this Chapter). The minimum and maximum $\delta^{13}C_{shell}$ values for MKO oyster 15.01b differed (Table 6.1; refer also to Table 5.4 in Chapter 5). For MKO oyster 337.1, minimum $\delta^{13}C_{shell}$ values were similar for drilled holes and transect lines, but maximum $\delta^{13}C_{shell}$ values differed. This difference was significant, as the values fell outside of 2 sigma analytical precision measured for this study. Surge and colleagues (2001) found that there were no differences in $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ values between the resilifer surface and the cross sectioned internal shell structure. This study's results could therefore be a result of sampling biases. For example, the drilled holes may capture wider time averaging or vice versa. The resolution for the holes may be different, and data are missing due to polychaete voids in the hinges.

This highlights the importance of sampling as much of the hinge as possible and being aware of how gaps in the data can skew interpretations. When alternating grey and white bands are present in the hinge, comparing drilled hole and transect line methodologies is complicated. There is currently no mechanism to compare drilled hole location to corresponding transect line in the bisected hinge area. For example, it is not currently possible to associate a transect line in the thickest grey band in oyster 15.01b with its corresponding drilled hole. Regardless, these differences in results do not have a large impact on this study's interpretations of age, growth rate, and salinity of the habitat.

Table 6.1 Minimum and maximum $\delta^{13}C_{shell}$ values for 337.1 and 15.01b.

$\delta^{13}C$ (‰ VPDB)			
Sample ID	**Min**	**Max**	**SD**
15.01b, drilled holes n=46	-1.8	-0.7	0.29
15.01b, transect lines n=45	-2.9	-1.0	0.58
337.1, drilled holes n=31	-2.4	-0.3	0.44
337.1, transect lines n=39	-2.4	-0.9	0.41

6.3.2 Barnacles and Gastropods

Gastropods from the (1) freshwater peat layer that contained skeletal and cultural material and the (2) peat stratum directly below cultural material-containing peat provided a freshwater baseline against which oyster data were compared. Freshwater gastropods had more negative $\delta^{18}O_{shell}$ values than Archaic oysters, Archaic barnacles, and modern oysters (Figure 6.6). $\delta^{18}O_{shell}$ values were similar for gastropods from the interior versus periphery of the pond. The gastropods were amphibious, but the $\delta^{18}O_{shell}$ values may suggest they were breathing mostly water, though temperature has not been controlled for because estimation of $\delta^{18}O_{water}$ is not possible. The $\delta^{18}O_{shell}$ values are similar to what would be expected for freshwater $\delta^{18}O$ parameters in the region. Variation in $\delta^{18}O$ values for precipitation in wider Florida, for example, ranges from -2‰ to -3‰ (IAEA 2013; Terzer et al. 2013). The gastropods likely captured the freshwater end member of the ancient pond water. This is interesting when compared to the predicted $\delta^{18}O_{water}$ for MKO Archaic oysters as revealed by the paleotemperature equation (refer to Table 5.8). The predicted values were much higher (between 0.5‰ and 2.3‰), alluding to the shift in pond $\delta^{18}O_{water}$ at the time of oyster growth. Water temperature for gastropods was likely similar to what the oysters experienced; it is therefore likely that the difference in absolute values between gastropod and oyster results approximates differences in $\delta^{18}O_{water}$. Archaic barnacles fall within the range of mean $\delta^{18}O_{shell}$ values for Archaic oysters, suggesting they formed in a similar environment or at the same time as the oysters (Figure 6.6). There was no pattern between site distribution and $\delta^{18}O_{shell}$ values for barnacles. There were two distinct groupings, however: barnacle 2044.1 tracked with mean $\delta^{18}O_{shell}$ for oysters 15.01b, 39.1a, and 2501.1 and modern oyster LB12 (refer also to Figure 5.13 in Chapter 5). The other two barnacles (2606.28 and F10.2) fell between oysters 353.1 and 8.02e in terms of mean $\delta^{18}O_{shell}$ values. This could suggest barnacle 2044.1 formed in a different environment than barnacles F10.2 and 2606.28.

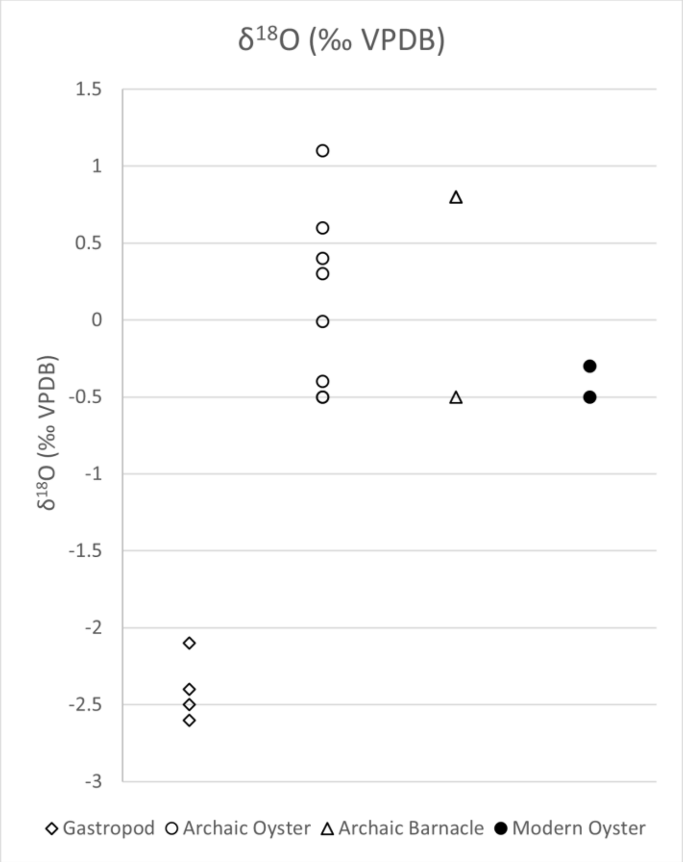

Figure 6.6. Mean $\delta^{18}O_{shell}$ values for oysters; individual $\delta^{18}O_{shell}$ values for barnacles and gastropods. Note one triangle represents two Archaic barnacles for 0.8‰ and one hollow circle represents two Archaic oysters for -0.5‰ (Price 2021).

6.3.3 Water Data

Modern water stations LB-3 and LB-4 in Lemon Bay revealed that seasonal temperature and salinity varied sinusoidally, which is typical for this area of southwest Florida. Based on temperature data, the height of summer occurs from June to August and the height of winter is from January to February. The wet season occurs from June to October (Meyers et al. 1993; Swart and Price 2002; Swart et al. 1996), though some researchers note the wet season occurs from July to November (Surge et al. 2001, 2003). The dry season occurs from November to May, and salinity approaches marine parameters during this time (Meyers et al. 1993). Salinity varied remarkably over the years, as Table 6.2 illustrates via minimum and maximum values each year from 2015 to 2020. These data are important to consider when examining oxygen isotope profiles for oysters. Salinity extremes as revealed by water stations could cause false temperature estimates in modern oyster profiles. In other words, low $\delta^{18}O_{shell}$ values in summer could be due to freshwater input rather than excessive temperatures (Surge et al. 2001, 2003). In the winter, temperature is the dominant factor controlling $\delta^{18}O_{shell}$ values, meaning that the most positive values from this period are due to cooler temperatures. During the wet season, however, the most negative values are due to hotter temperatures and freshwater input (Surge et al. 2001, 2003). As Chapter 3, section 3.4 noted, oysters cease growing in extreme temperatures, meaning some $\delta^{18}O$ information is not captured during the rainy season in Florida (Surge et al. 2003).

Table 6.2 Minimum and maximum salinity readings from water stations for 2015 to 2020.

	LB-3 Station		LB-4 Station	
Year	**Minimum**	**Maximum**	**Minimum**	**Maximum**
2015	18.3	31.9	20	34.3
2016	15	32.9	17.4	33.2
2017	10.7	36.5	13.5	36.8
2018	15.7	34.2	16.8	35
2019	21.9	35	22.9	36.6
2020	24.9	33.3	25.6	35.4

Water samples collected from Lemon Bay, Forked Creek, and MKO for this research were isotopically heavy, yielding surprisingly positive $\delta^{18}O_{water}$ values, especially for the fresher water source from further upstream in Forked Creek. Salinity readings in this area of the freshwater tributary were as low as 15.7 psu, but the corresponding $\delta^{18}O_{water}$ value was 2.1‰. These data were unexpected given that freshwater in this area contained values as low as -4.88‰ as recorded in other studies in the region (Surge et al. 2001). Furthermore, $\delta^{18}O_{water}$ values of precipitation in this region are between -2‰ and -3‰ (IAEA 2013; Terzer et al. 2013), but the values from this study for Lemon Bay and Forked Creek do not fall within this range. Instead, the bay and creek are enriched in ^{18}O, and the resultant $\delta^{18}O_{water}$ values are more positive in some cases than the Gulf of Mexico readings recorded for this dissertation's study, which were between 1.1‰ to 1.9‰. A nearby study in southwest Florida (Surge and Lohman 2002) found similar occurrences of more positive $\delta^{18}O_{water}$ values upstream than in the Gulf of Mexico, a phenomenon known as estuarine inversion. Evaporation is the key cause of this (Meyers et al. 1993; Surge and Lohman 2002). Evaporation preferentially removes lighter molecules, leaving heavier isotopes behind (Meyers et al. 1993). In the Everglades (~290 km from Lemon Bay), extreme evaporation led to heavier isotopes in one study, so much so that even local precipitation was isotopically heavy (Meyers et al. 1993). $\delta^{18}O_{water}$ values in this study were as positive as 2.4‰. It should be noted that the scale of anthropogenic landscape change certainly affected water flow in this region, exacerbating evaporation issues. Since MKO's formation, this area has been profoundly developed, with heavily paved areas, artificial impoundments, groundwater interruption via pumping, and agricultural expansion (Foster and Savage 1989; Meyers et al. 1993; Surge and Lohman 2002).

The extremely heavy $\delta^{18}O_{water}$ values collected for this research hint at the scale of evaporation taking place in Lemon Bay and Forked Creek. Shallow depths in these water bodies (between 1 and 3 m) contribute to increased evaporation during the dry season. That the freshwater end member in Forked Creek contained positive $\delta^{18}O_{water}$ values also suggests limited groundwater contribution and influxes of evaporated water from the surrounding areas [see (Meyers et al. 1993) for similar findings]. This is most extreme between December and April (Surge and Lohman 2002). In March 2022, salinities in Lemon Bay and Forked Creek were the same or at times higher than readings from the Gulf of Mexico (refer to Table 5.7 in Chapter 5), representing near marine salinity during the driest conditions. As Chapter 5, section 5.3.3 noted, linear regression yielded an inverse salinity:$\delta^{18}O_{water}$ relationship ($\delta^{18}O_{water} = -0.04 * S + 2.75$). In a normal relationship, as salinity decreases, $\delta^{18}O_{water}$ decreases. The unfortunate outcome is that the salinity:$\delta^{18}O_{water}$ relationship generated during this research cannot be used to estimate past salinity for the MKO water body.

6.3.3.1 Paleotemperature Equation: Building a Model of Past Water Parameters. Though past salinity at MKO could not be modeled due to an inverse salinity:$\delta^{18}O_{water}$ relationship, Epstein and colleagues' (1953) paleotemperature equation could be used to determine what past $\delta^{18}O_{water}$ was like at the time of oyster growth. Oysters slow or cease growth after 28(±2)°C (Andrus and Thompson 2012; Kirby et al. 1998; Surge et al. 2001). It is possible to use this temperature marker in a paleotemperature equation since water temperature data from modern water stations confirms these temperatures are exceeded in southwest Florida in the summer. The most negative $\delta^{18}O_{shell}$ values may have been precipitated at or near 28(±2)°C, providing justification for using the values in the paleotemperature equation (Epstein et al. 1953). Predicted $\delta^{18}O_{water}$ values for MKO oysters ranged from 0.5‰ to 2.3‰ (refer to Table 5.8 in Chapter 5). The predicted $\delta^{18}O_{water}$ values for MKO oysters 8.02e and 353.1 (at 2.3‰) could suggest the water was quite saline, if the past isotope gradient was not inverted as was found in modern Lemon Bay. The Gulf of Mexico $\delta^{18}O_{water}$ values recorded during this study were 1.1‰ to 1.2‰ at a salinity of 32 psu, though Surge and colleagues (2001) recorded a $\delta^{18}O_{water}$ value of 3.0‰ at a salinity of 37 psu for the Gulf of Mexico in their research. Interestingly, the oldest dated oyster (39.1a) had the lowest predicted $\delta^{18}O_{water}$ value (0.5‰), providing another line of evidence that older MKO oysters are capturing fresher water parameters prior to the pond's total inundation by salt water[4]. The rest of the predicted values fall between 1.0‰ to 1.6‰, suggesting they formed in salinities comparable to the Gulf of Mexico and/or saltier based on the measurements recorded for this dissertation's study. It should be noted that there are confounding variables when using any paleotemperature equation. It is uncertain how the $\delta^{18}O_{water}$ relationship has changed over the Holocene. Furthermore, oysters record average salinity. Therefore, any results presented here are relative rather than absolute.

Perhaps most importantly, the past isotope gradient for the pond is unknown. Given the results of this study's water sampling revealed an inverted salinity:$\delta^{18}O_{water}$ relationship, it could be possible that such a situation existed for the pond, as well. This would mean oysters 8.02e and 353.1 (at 2.3‰) could have had a salinity similar to that measured at Forked Creek (15.7 ppt), which revealed a $\delta^{18}O_{water}$ value of 2.1‰ (refer to Chapter 5, Table 5.7). While it is not currently possible to determine if the past isotope gradient was indeed inverse, there are other lines of evidence that can be considered to support the hypothesis that the oysters utilized in this study captured water parameters that became more saline over time. First, mean $\delta^{18}O_{shell}$ values from gastropods from the freshwater peat strata can be used as a baseline for past water parameters of the pond. These mean values were between -2.1‰ and -2.6‰, values that were much lower than any MKO oyster. Second, modern water samples for the region did not yield $\delta^{18}O_{water}$ values close to the predicted $\delta^{18}O_{water}$ values for MKO oyster 39.1a (at 0.5‰). Third, significant modern anthropogenic modification to the landscape in southwest Florida had not yet occurred thousands of years ago when these oysters formed. Certainly, there is evidence for modern changes to the landscape causing changes to the isotope gradient (Foster and Savage 1989; Meyers et al. 1993; Surge and Lohman 2002). Finally, insight regarding changes to near-coastal freshwater features during marine transgression also provides another line of evidence that the MKO pond became more saline over time: similar findings have been documented at Ray Hole Spring (refer to Chapter 2, section 2.2.1). The sedimentary record at this spring revealed a once-freshwater hammock that became a low energy brackish environment and finally a fully marine environment during marine transgression (Anuskiewicz 1987).

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[4] It is unlikely the values are a result of cold temperatures given this site's location in southwest Florida (Surge et al. 2003).

6.4 Stable Isotope Analysis: Carbon

Chapter 3, section 3.4.1 highlighted how $\delta^{13}C_{shell}$ varies due to a wide variety of environmental factors, making it difficult to interpret carbon results in oysters. Regardless, stable carbon isotope analysis undertaken as part of this dissertation's research reveals paleoenvironmental differences between Archaic and modern oysters. Section 6.4.1 discusses oysters first and compares that information to barnacles and gastropods in section 6.4.2.

6.4.1 Oysters

There was no apparent patterning concerning $\delta^{13}C_{shell}$ values in Archaic oysters when examining location across the site. When compared to the Group 1 Archaic oysters that contained distinct $\delta^{18}O_{shell}$ values (15.01b, 39.1a, and 2501.1), mean $\delta^{13}C_{shell}$ values are somewhat more negative for this group, as well. The modern oyster assemblage exhibits more negative $\delta^{13}C_{shell}$ values than the Archaic oysters. Estuaries like Lemon Bay, where the modern oysters originated, exhibit terrestrial decomposition and benthic community effects that can contribute to lowered $\delta^{13}C_{shell}$ values (Surge et al. 2003). More negative $\delta^{13}C_{shell}$ values suggest decomposition of organic matter, as well as freshwater input (Andrus and Crowe 2000; Kirby 2000) because $\delta^{13}C$ tracks $\delta^{13}C_{DIC}$, which tracks salinity (Surge et al. 2003). Lower $\delta^{13}C_{shell}$ values in the modern oysters could be due to differing aquatic and terrestrial plants, the decay of which contributes distinct carbon isotope compositions to the dissolved inorganic carbon (DIC) of the surrounding water (Surge et al. 2003). Salt-water tolerant mangroves are prevalent in this area and have negative $\delta^{13}C$ values (averaging -27‰) compared to C_4 grasses or aquatic plants. The mangroves on which the LB oysters were attached contribute somewhat to the lower $\delta^{13}C_{shell}$ values.

The higher values in the Archaic assemblage suggest the MKO oysters did not form in an estuarine environment similar to modern day Lemon Bay and that there may have been less terrestrial decomposition in the MKO environment. These data are useful, but caution is required when comparing ancient oysters to a modern assemblage. Lower $\delta^{13}C_{shell}$ values in LB oysters may primarily be attributed to the Suess Effect, in which lower $\delta^{13}C_{shell}$ values in organisms are a result of anthropogenic influences introduced through pollution, runoff, and burning of fossil fuels (Lulewicz et al. 2017b; Surge and Lohman 2002; Surge et al. 2001, 2003). Increases in fossil fuel CO_2 in the atmosphere contribute to decreased $\delta^{13}C_{shell}$ (Swart et al. 1996). Surge and Lohmann (2002) found similar results in their study of the effects of modern activities in an estuary in southwest Florida. Their modern oysters exhibited more negative carbon values due to runoff from sewage and nutrients, burning of fossil fuels, and changes in vegetation in the region (Surge et al. 2003). Burning fossil fuels contributes isotopically light carbon and causes a negative shift in $\delta^{13}C$ compared to pre-industrialization. Sudden negative trends in $\delta^{13}C$ in corals in Florida have also been documented as a result of human modifications to the environment (Swart et al. 2010). The Suess Effect is most obvious when comparing the LB modern oyster data to the gastropod data. Even though the gastropods were from a freshwater pond environment, their values are not as negative as the modern oysters originating from a brackish environment (Figure 6.7). Instead, Archaic barnacles and gastropods tracked with Archaic oysters concerning $\delta^{13}C_{shell}$ values.

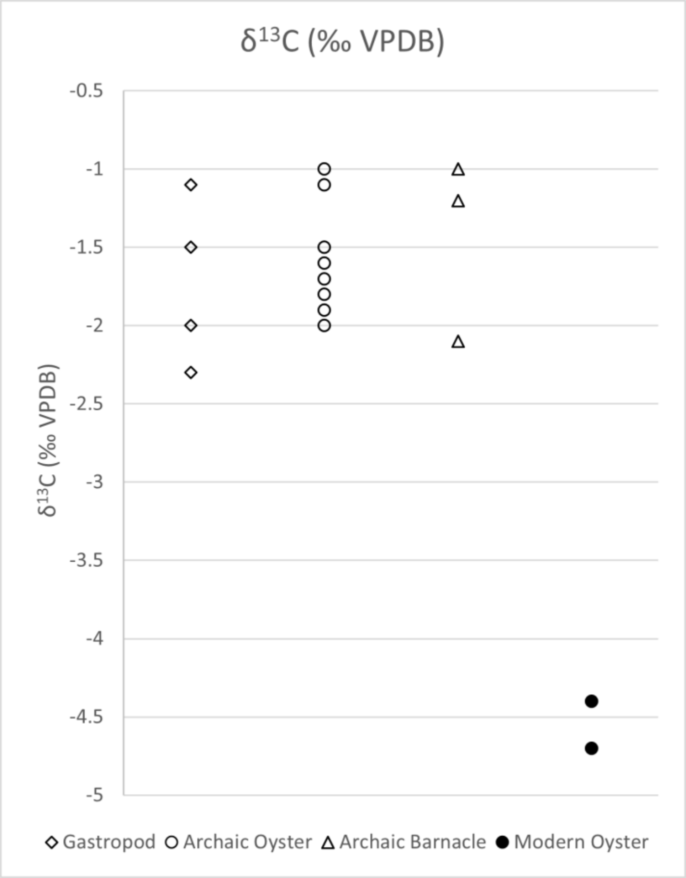

Figure 6.7. Mean $\delta^{13}C_{shell}$ values for oysters; individual $\delta^{13}C_{shell}$ values for barnacles and gastropods (Price 2021).

6.4.2 Barnacles and Gastropods

Mean $\delta^{13}C_{shell}$ of the gastropods is more closely aligned with mean $\delta^{13}C_{shell}$ of Archaic oysters than it is with modern oysters (refer to Figure 6.7). Gastropods from closer to the site periphery (362.1 and 362.2) contained more negative mean $\delta^{13}C_{shell}$ values than those for gastropods from the interior of the site (2659.1 and 2659.2). The 2659 gastropods came from a deeper stratum than the 362 gastropods. The two gastropod sample sets could be capturing varying environments or differing vegetation. These gastropods (genus *Tryonia*) are opportunistic grazers of algae and plant material, so they could also have been consuming different diets, contributing to the differing $\delta^{13}C_{shell}$ values (Johnson et al. 2013; Thompson 1984). Perhaps the gastropods from the shallower depth (362.1 and 362.2) are also capturing more terrestrial decomposition after the pond was well established and organic matter accumulated over time.

The barnacles are closely aligned with mean $\delta^{13}C_{shell}$ for Archaic oysters. Contrary to the gastropods, barnacles from the interior of the site (2606.28 and 2044.1) contained more negative results than the barnacle from the periphery of the site (F10.2). Barnacle F10.2 tracks with 8.02e in terms of mean $\delta^{13}C_{shell}$, and they are from the same unit.

6.5 Sclerochronology

Plotted isotope profiles were compared to internal growth structures of the bisected hinge to determine seasonality of banding, season of death, and growth rate. As Chapter 5, section 5.4.2 noted, MKO oysters 15.01b, 39.1a, 353.1, and SC1 exhibited alternating growth bands that consisted of white and grey bands. MKO oysters 8.02e, 337.1, 2501.1, and 2606.1 did not exhibit internal banding. Lack of banding is an unusual occurrence that could be attributed in part to steady growing conditions or fast growth, especially in early oyster development since rapid shell deposition is needed for protection (Thompson et al. 2015). Some of the MKO oysters (2501.1, 2606.1) appear small, suggesting they were younger. Other oysters (15.01b and 353.1) appear older, which is puzzling. This could suggest smaller, non-banded oysters are actually ontogenetically older but appear small. Prolific *P. websteri* could be a contributing factor to this lack of internal banding. Multiple oysters (15.01b, 39.1a, SC1, 8.02e, 337.1, 2606.1) contained large voids in the hinges due to this predatory parasite, causing strangely shaped growth increments and non-continuous isotopic sampling in the hinge. The purposes of sclerochronology include estimation of growth rate, oyster age, and periodicity of growth band formation. Interpretation is strengthened when compared to plotted isotope profiles. For this research, lack of banding caused challenges with interpretation of isotope analysis results. There were no visual cues to guide sampling placement for certain oysters, nor was resolution for these oysters as good as those with internal banding.

As Chapter 4, section 4.3.4 noted, grey bands are typically deposited in cooler months and had higher $\delta^{18}O_{shell}$ values, which was confirmed in this dissertation's study. There were, however, some deviations from this pattern. Andrus and Crowe (2000) found that some internal growth bands, which should have been white as indicated by lower $\delta^{18}O_{shell}$ values, were grey, suggesting freshwater flooding stressed the oyster and caused it to form dark growth bands. This was found in modern oysters LB12 and LB42, as well as MKO oysters 39.1a and 15.01b (Figure 6.8). In the modern oysters, there were growth disturbances in which grey bands did not align with isotope results for a typical winter band. In other words, the isotope results did not match the color of the band, suggesting the oyster experienced stress due to excessive heat, flooding, tidal exposure, or other factors. This is visible in modern oyster LB12, the most recent growth band of which was grey, though it should have appeared white given it was collected in June. LB42's most recent band was white, matching expected results and illustrating intra-bed variability, given that it was collected from within a meter of LB12. This highlights the importance of sampling multiple oysters from the same bed and for using stable isotope analysis to confirm seasonality of banding. This is also why it is critical to look at overall growth trends in an individual shell and in a population.

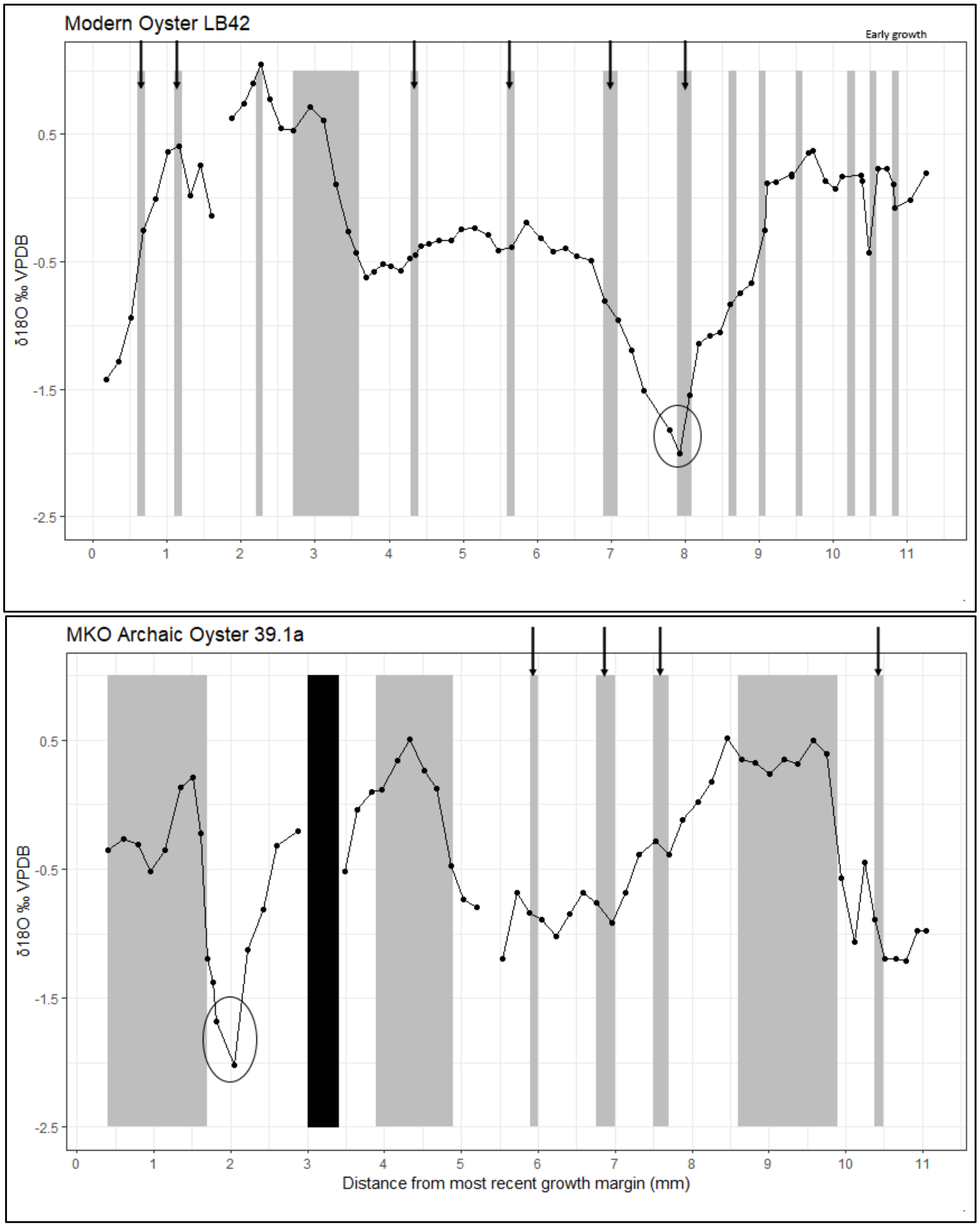

Figure 6.8. Example of growth disturbances (arrows) and heat stress (circles) in modern oyster LB42 and Archaic oyster 39.1a (Price 2023).

Without isotope analysis, it is sometimes possible to identify growth disturbances in the cross section of the hinge. For example, in oysters LB12, LB42, 39.1a and 15.01b, disturbances appear as comparatively thin grey lines or white disturbances inside of a grey line. These white disturbances do not extend all the way to the edge of the chondrophore (refer to Figures 5.19–5.21). This supports other researchers’ findings [see for example (Zimmt et al. 2019)].

A “saw tooth” pattern in the negative oscillation in plotted profiles indicates summer growth cessation. The profile for LB42 contained a sharp change in $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ between lines 51 and 52 (refer to the circle in Figure 6.8). Similar characteristics are visible in MKO oyster 39.1a, which contained a sharp change between lines 10 and 11 (refer to the circle in Figure 6.8). A sharp change in the profile indicates the oyster likely stopped growing due to heat stress, which is common in southwest Florida oysters when temperatures near 28(±2)°C (Andrus and Thompson 2012; Kirby et al. 1998; Surge et al. 2001).

A fast growth rate was indicated by more $\delta^{18}O_{shell}$ values deposited in warm intervals than cold intervals. This was visible in MKO oysters 15.01b, 39.1a, and 353.1. For these three oysters, on average 12 samples were collected from white bands, and 5 samples were collected from grey bands. For LB modern oysters, the average was 21 samples collected from white bands and 7 samples collected from grey bands. Grey bands were typically narrower, providing less sampling area for stable isotope analysis. This excludes MKO oyster SC1, which had an uncharacteristically wide grey band, which could be due to fast early growth.

Oysters with internal banding provided the best assumption of age estimates when comparing plotted profiles to internal growth bands. Table 5.9 in Chapter 5 summarized age estimates for MKO oysters. Extrapolating from this, it is hypothesized that cultural and skeletal material at MKO was exposed for similar periods of time, as oysters are sessile filter feeders. That the oysters are between 1 and 3 years old is astonishing and unexpected given the exceptional preservation of skeletal and cultural material (see section 6.7.1 for discussion concerning this preservation). It is surprising that this sensitive material survived lengthy exposure to the water column. It should be noted that only two of the MKO oysters as part of this study were directly confirmed as attached to skeletal material at the time of excavation (8.02e and 2606.1). Unfortunately, the lack of banding in these oysters leads to less positive age approximations. Based on oscillations in $\delta^{18}O_{shell}$ for these two oysters, a range of 1.5 years is estimated (see Figure 6.9, which contains profiles, age estimates, and season of death estimates for all non-banded MKO oysters).

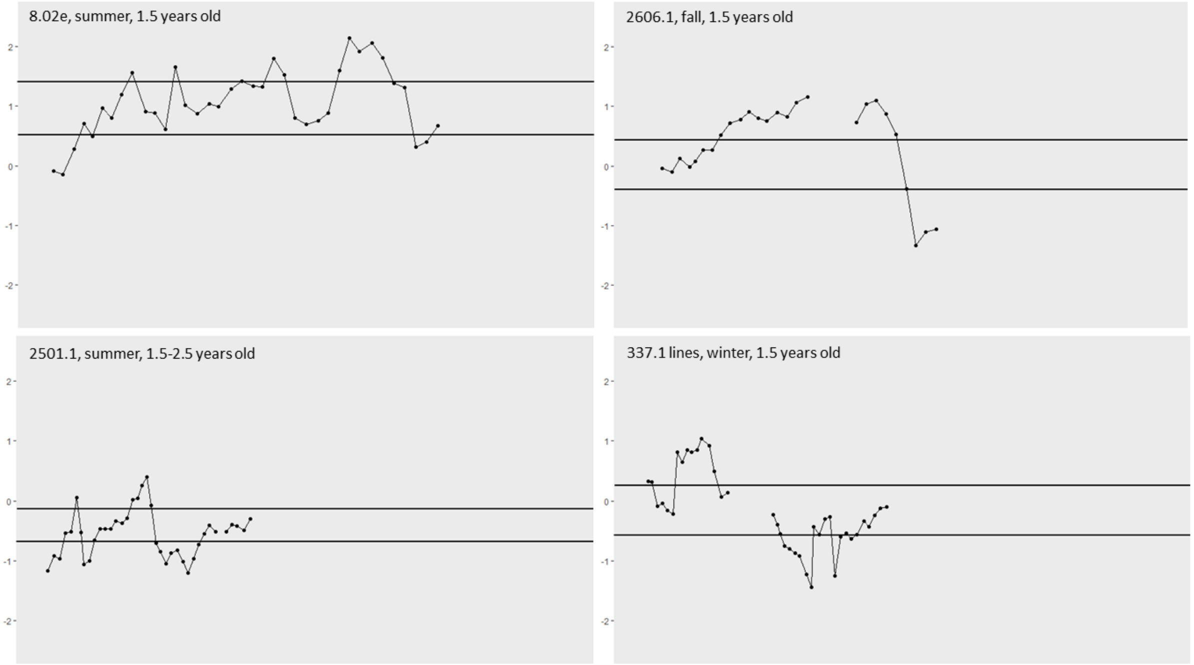

Figure 6.9. Plotted $\delta^{18}O_{shell}$ profiles, estimated season of death, and estimated ages for MKO oysters lacking internal banding. The most recent growth margin is on the left in each graph (Price 2023).

Three of the four MKO oysters exhibiting internal banding expired during warmer months (Figure 6.10). Hurricane season in Florida occurs from June to November and could suggest a storm event capped the site with sediment, thus smothering the oysters and protecting sensitive cultural material. This may explain why the oysters contained preserved proteins (pink striations) on the exterior portions of their shells. Furthermore, after bisecting the shells, there was organic material from *P. websteri* preserved within voids in the shell, supporting a rapid burial occurrence. Section 6.7.1 discusses preservation at MKO in more detail.

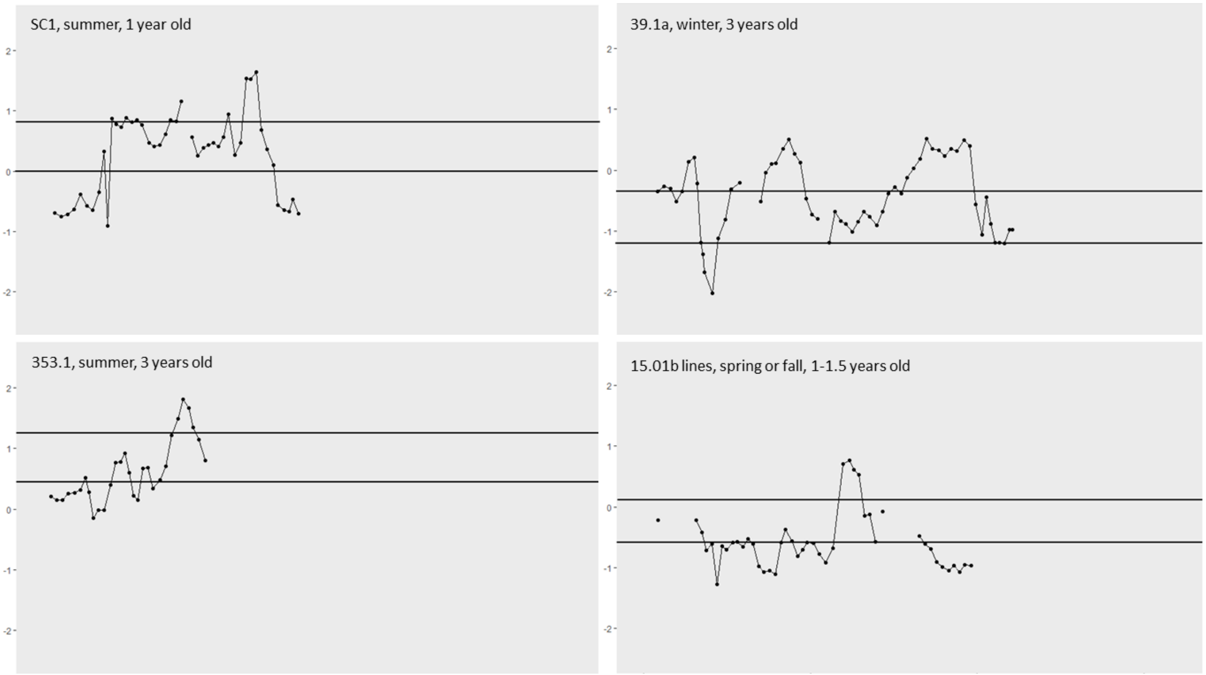

Figure 6.10. Plotted $\delta^{18}O_{shell}$ profiles, estimated season of death, and estimated ages for MKO oysters with internal banding. The most recent growth margin is on the left in each graph (Price 2023).

Season of death provides a rough guideline. Seasons vary, and some months may be uncharacteristically hot. Seasons as exhibited in the oyster data could represent different time periods, and each profile is unique to each shell, (i.e., winter may have a more diminished peak in one shell than in another). Additionally, short-lived oysters may not record a full range of $\delta^{18}O$ over the year, resulting in a divided profile that does not accurately represent a full year (Andrus and Crowe 2000; Thompson et al. 2015). Dividing a profile into thirds facilitates estimations of season of death (Thompson et al. 2015). *P. websteri* voids in some of the MKO oysters likely affected these estimates; missing shell structure and data could diminish overall profile amplitude. The comparison between drilled holes and transect lines in oysters 15.01b and 337.1 revealed that dividing a profile into thirds is not solely reliable to accurately determine season of death for this reason. For MKO oyster 15.01b, the divided profile suggested the oyster expired in the spring or fall; the adjacent sample was lost during analysis (Figure 6.11). For drilled hole data, however, the divided profile suggested the oyster expired in the winter. There was a polychaete void in the hinge near the most recent growth margin, which may have diminished the amplitude in the overall transect line data, thus confounding seasonality interpretations. For oyster 337.1, the profiles were more closely matched and trended similarly. The polychaete void in this valve may have diminished the amplitude of the transect line data, though not as severely as oyster 15.01b.

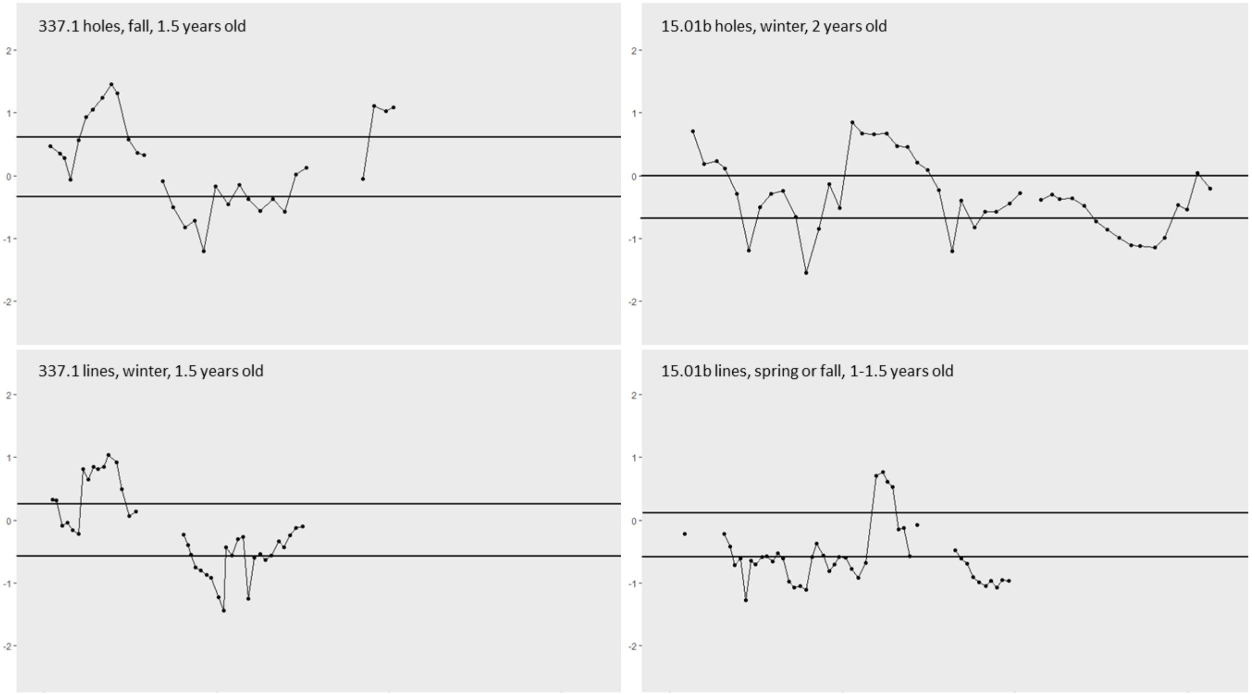

Figure 6.11. Plotted $\delta^{18}O_{shell}$ profiles, estimated season of death, and estimated ages for dual-sampled MKO oysters 15.01b and 337.1. The most recent growth margin is on the left in each graph (Price 2023).

Temperature is the dominant factor controlling $\delta^{18}O_{shell}$, but salinity extremes can alter or obscure seasonal patterns of temperature-driven $\delta^{18}O_{shell}$ (Andrus 2011). This can cause an incorrect identification of the season of death if one relies solely upon data from the terminal portion of the shell. It is therefore critical to consider the oyster's individual life history to correctly interpret the data. Other environmental stressors can also mask temperature readings. Tidal exposure, freshwater intrusion, spawning, and competition can cause increases or decreases in values, complicating profile interpretations. Since oysters may cease growing during extremely hot or cold parts of the year, the overall amplitude of the profile could be affected[5]. This could cause incorrectly assigned season of death, especially if the whole oyster is not sampled. Andrus (2011) notes the necessity of strong seasonal variation in the region from which the oysters originate in order to make accurate season of death estimates. As the salinity and temperature data in Table 6.2 and Appendix C. illustrate, this region experiences wet and dry seasons that are pronounced enough to influence oscillations in $\delta^{18}O_{shell}$ profiles (Andrus and Crowe 2000). Andrus and Thompson (2012) further noted that estimating season of

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[5] Recall modern oyster LB12: the most recent band was grey and the divided profile suggested it expired in spring, though it was collected in June.

death is possible in subtropical regions. The challenge rests in distinguishing the effects of temperature versus salinity on the profiles.

6.6 Radiocarbon Dating

The purpose of radiocarbon dating for this dissertation's study was to establish a timeline of transgression at MKO. While the focus was on carbonates, other material was dated for comparative purposes. Peat sediment samples and unmodified, non-cultural faunal remains from freshwater species, for example, provided a time period for the original freshwater pond environment (Price 2022a, 2022b). Sediment samples from transgressive strata situated atop the peat provide a *terminus ante quem* for the oysters that were embedded within these strata. Peat sediment samples and non-cultural faunal bone reveal the pond was fresh at least until 8,334 cal BP (all calibrated dates reported at 95.4%, refer to Table 5.11 in Chapter 5). Previously dated archaeological material places the cultural use of the pond between 8,328 to 7,029 cal BP (Duggins 2018, 2019; Duggins and Price 2016; Duggins et al. 2018). This was expected, as mortuary ponds in Florida were in use as a cultural practice from about 10,000 to 7,000 cal BP, and do not date after the Middle Archaic period (Doran 2002a). Charred wood and a wood fragment dated for this dissertation fall within the cultural use of the pond (8,195 to 7,434 cal BP) (Price 2022b). Sediment samples from transgressive strata dated as part of this dissertation suggest transgression of the site began as early as 7,437 to 6,915 cal BP (Price 2022b). Samples were collected from sediment core strata situated directly atop of peat and consisted of a silty sand with dense miniscule bivalves (species unknown) and oyster shell.

Shell carbonate dates were less useful in terms of timing transgression at MKO. Oysters and barnacles appear to date older than the transgressive strata in which they were embedded. Shell was also consistently older than cultural material, though there were overlaps in error margins. Given that oyster shell and barnacles were attached to skeletal and cultural material, shell carbonates should date more recently. The challenges inherent in interpreting radiocarbon dated shell carbonates are well documented (Cherkinsky et al. 2014; Hadden and Cherkinsky 2017; Hadden et al. 2018, 2023). The discrepancies in shell radiocarbon dates in this study are due to the marine reservoir effect and the hard water effect, both of which make shell carbonates appear older than they actually are (Cherkinsky et al. 2014; Hadden et al. 2018, 2023; Jones et al. 2010). Reserves of DIC in the ocean are greater than in the atmosphere, and long residence times exist in the deeper ocean. Upwelling contributes old carbon from the deep to surface waters, while newer carbon is contributed from the atmosphere. This mixing of deeper ocean waters with surface waters varies according to region, and this reservoir effect causes surface waters that are depleted in radiocarbon activity compared to the atmosphere. This is one reason organisms that assimilate carbon from the marine environment appear older than they actually are.

This is complicated in areas that are fed by groundwater, especially in this region in Florida. Freshwater systems pass through limestone, further contributing old carbon to water bodies, like the MKO pond (Cherkinsky et al. 2014; Hadden and Cherkinsky 2017; Hadden et al. 2018, 2023). Oysters in brackish waters fed in part by groundwater use this older DIC as they precipitate new layers of shell, thus appearing to date older. Radiocarbon dating of shell carbonate from estuarine settings is further complicated by restricted water circulation, freshwater and oceanic mixing, an abundance of terrestrial organic matter, and influxes of fresh water that complicate estimation of ΔR (Hadden and Cherkinsky 2017), all of which may have been influencing factors at MKO during the time the oysters formed. Interpretation of shell carbonate dating is also complicated by carbonates washing in from freshwater and modern carbon saturating surface waters of the ocean post-bomb 1950 (Carla Hadden personal communication 2020). All of these factors likely affected the MKO pond at the time of oyster growth and contributed to the apparent older ages presented in this study.

Regardless of the difficulties in interpreting dated shell carbonate, interesting patterns are apparent following Bayesian modeling. Figure 6.12 illustrates a uniform phase model implemented in OxCal version 4.4.4 (Bronk Ramsey 2009, 2021) for MKO shell carbonates, peat and transgressive sediment samples, flora, and faunal material. The model parameters include a reservoir correction (ΔR) of -44 ± 49 (updated value for southwest Florida from Hadden and Schwadron 2019), along with the Marine20 curve (Heaton et al. 2020) for carbonates and IntCal20 calibration curve (Reimer et al. 2020) for other organics. The model has a good agreement index (A=116.4), where A=60 is the minimum for an acceptable model. The modeled start boundary is 13,882 to 13,109 cal BP (68.3% highest posterior density range), and the modeled end boundary is 7,268 to 6,355 cal BP (68.3% hpd). Though the model compares three different categories of processes (the freshwater existence of the pond, its cultural use, and the transgressive events), it is still useful as a visual aide to illustrate the scale of time during which these human and geologic processes took place. For a model of only shell carbonate dates, refer to Appendix E.

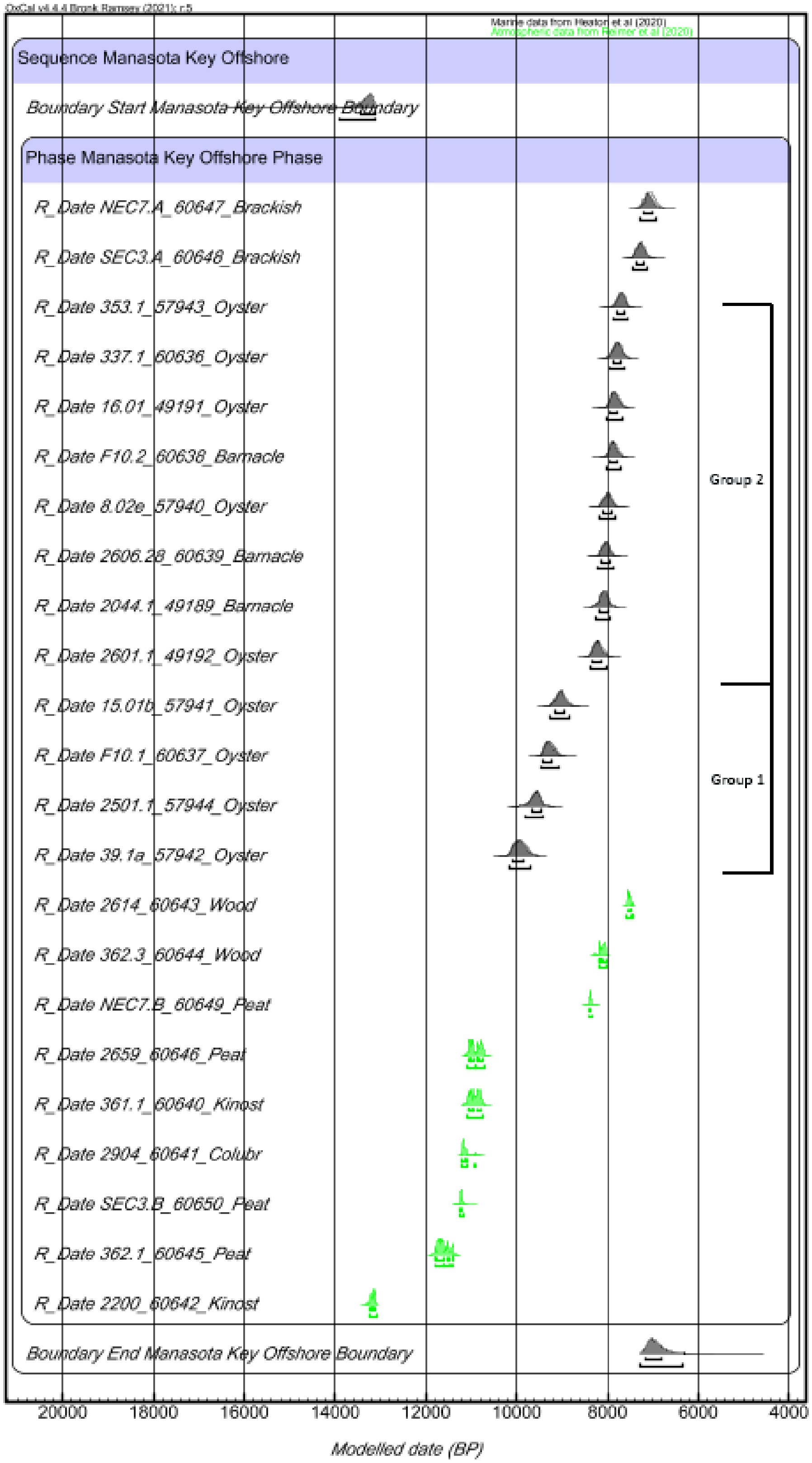

Figure 6.12. Bayesian modeling of radiocarbon dated material from MKO; Groups 1 and 2 delineated with brackets (Price 2022).

The model illustrates how some oysters date older than freshwater peat strata and wood from the cultural use of the pond. Even though reservoir effects cause less precise and accurate shell dates, however, the model also illustrates that shell carbonates cluster into two distinct time periods. Four oysters (15.01b, 39.1a, 2501.1, and F10.1[6]) dated older (10,168 to 8,823 cal BP) than the rest of the oysters and barnacles (8,375 to 7,545 cal BP). These groups are striking when considered with the results of stable isotope analyses: the earlier group of oysters represent fresher water parameters as revealed by $\delta^{18}O_{shell}$ values if it is assumed that the past isotope gradient was not inverted. The two time periods as revealed by shell carbonates are interpreted as representations of two separate inundation/transgressive events that introduced oysters and barnacles into the pond. According to radiocarbon dating, the events are separated by a period of about 448 years. Additional discussion of the carbonate time periods is presented in section 6.7 in the context of inundation events and the changing landscape at MKO.

Generally, MKO barnacle dates cluster more tightly than oyster dates (from 8,269 to 7,699 cal BP) but formed commensurate with oysters. Barnacle 128.1, which was modern (excluded from Bayesian model, refer to Table 5.11 in Chapter 5), was recovered with skeletal material from 2017 unit 0N6E. This material was situated within upper peat strata close to the seabed surface and exhibited erosion and post-depositional disturbance. Skeletal material was highly fragmentary, and portions of wooden stakes protruding above the seafloor were deteriorated. It is uncertain when this area was initially exposed to the environment, how long it has been eroding, or how frequently erosion occurs. The dated barnacle, however, suggests this area was exposed to the surface to allow growth of marine fauna at least once since 1950. The barnacle was from the same context as a human long bone, though it could have come into the site from another source.

6.7 Changing Landscape and Preservation of MKO as Revealed by Oyster Studies

The previous sections in this chapter provided a discussion of the more technical aspects of the various analytical methodologies employed in this dissertation and the results of the oyster study. The remaining portions of this chapter synthesize the main findings of these oyster studies and discuss how they contribute to understanding the process of MKO's transgression and ultimate site abandonment.

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[6] Oyster F10.1 was not sampled ontogenetically like the rest of the MKO oysters. Instead, the mean $\delta^{13}C_{shell}$ and $\delta^{18}O_{shell}$ values were provided commensurate with radiocarbon dating results. Oyster F10.1 was attached to a human temporal bone in Area 1 at the time it was recovered. A juvenile oyster, it also had a barnacle growing inside of it (refer to Figure 4.10 in Chapter 4). F10.1 was originally chosen for radiocarbon dating as a comparison to the date from the barnacle (F10.2) inside of it.

Section 6.7.1 presents what oysters reveal about preservation at MKO during marine transgression. Section 6.7.2 assesses sea level rise and the changing landscape through the lens of oyster data. Finally, section 6.7.3 discusses what archaeologists know about the abandonment of mortuary ponds as a cultural practice in Florida and how this dissertation's research contributes to this subject matter.

6.7.1 Preservation of Sensitive Organics at MKO

Archaeologists do not fully understand how sensitive, precontact sites survive catastrophic effects of marine transgression, but MKO's existence in the Gulf of Mexico proves that site survival is possible in particular conditions. Initial preservation of MKO material is attributed to the saturated pond environment. Continuously inundated or saturated environments preserve organics, as it is the periodic drying and wetting of organics that causes deterioration (Cronyn 1990; Doran 1987; Rodgers 2004). Saturated, anaerobic conditions within the pond at MKO facilitated preservation of skeletal material and delicate organics. As Chapter 2, section 2.4 noted, Windover burials were preserved due to the stable environment of the mortuary pond (Doran 2002a:8). An anoxic, anaerobic environment, neutral peat pH (5.9 to 6.75), and lack of erosional processes protected the material. Windover peat contained a high concentration of freshwater snails, which also likely contributed to preservation due to the calcium carbonate content of their shells (Dickel and Doran 2002:50). Certain peat strata at MKO also contained abundant freshwater snails (BAR 2017c, 2018b, 2018c), some of which were examined as part of this dissertation's study.

Continuous saturation is also supported by the existence of oysters and barnacles attached to MKO material. As section 6.5 noted, the MKO oysters are between one and three years old. As these oysters were either attached to, directly associated with, or contained attachment scars indicative of skeletal material and modified wooden stakes, this suggests material was exposed for a minimum of one to three years. How could human remains survive exposure for this length of time? Organic material in a submerged and subtropical context is often considered at risk of rapid deterioration [given archaeological studies of exposed wooden shipwrecks in open ocean environments, for example (Cronyn 1990; Rodgers 2004)]. Furthermore, the detrimental effects of storms and hurricanes exacerbate deterioration. As a result, the existence of more than 7,000 year old cultural and skeletal material off the coast of Manasota Key was surprising. Studies have, however, noted the preservation potential afforded by hypersaline environments (Mitras, n.d.; Oron et al. 2016; Rich and Maier 2015). Excess salt creates an inhospitable environment for microbial communities, inhibiting bacterial growth. As a result, preservation of biological and organic material is improved in hypersaline water. Section 6.2

presented the characteristics of some MKO oysters that were suggestive of higher salinities, if it is assumed that the past isotope gradient was not inverted. While optimum oyster growth occurs between 14 and 28 psu (Eastern Oyster Biological Review Team 2007; Galtsoff 1964; Kingsley-Smith 2015), they can survive in higher salinities, though parasitic and epifaunal predators increase. The presence of mudworms (*P. websteri*) supported a salinity of at least 10 at the time of MKO oyster growth. Presence of barnacles (*B. eburneus*, *B. improvisus*, and *B. amphitrite*) support salinities between 0 and 40 psu. Stable isotope analysis of the more recent grouping of MKO oysters (SC1, 8.02e, 337.1, 353.1, and 2606.1) also indicated a more saline environment than the modern Lemon Bay estuary, again assuming the past isotope gradient was not inverted. What this means for the changing landscape at the time is explored more fully in section 6.7.2.

How preservation was facilitated can also be extrapolated from the position of oysters within transgressive strata and in relation to cultural and skeletal material. In Area 1 (refer to Chapter 2, Figure 2.5), the orientation of oysters around human crania and associated with wooden stakes (refer to Chapter 2, section 2.5.1) may suggest that the oysters were attached to the stakes, which were subsequently displaced post-depositionally. This is further supported by the presence of a modified wooden stake inside a human cranium in this area (BAR 2016a, 2016b; Duggins and Price 2016). A juvenile oyster (F10.1) was also collected from Area 1 and was attached to a human temporal bone when it was recovered. Its matching right valve was not recovered, and there were barnacles attached to its interior surface. This oyster is part of the older grouping of MKO oysters that represented fresher conditions, but the barnacle on the interior surface (F10.2) dated more recently and represented more saline conditions when isotopically sampled. Based on this information, an event disturbed oyster F10.1 and the skeletal material to which it was attached, the right valve to oyster F10.1 was lost, and barnacles settled and formed afterwards. The Group 2 oysters in general seem to support a storm event that both disturbed and then capped the site with protective sediment. According to season of death analysis, this group died during Florida's hurricane season. It is also interesting that Group 2 included the two oysters that were still attached to human skeletal material (8.02e and 2606.1) at the time of recovery, suggesting this material survived due to obrution.

As mentioned in section 6.6, other post-depositional disturbances were visible across the site. The interior units did not contain *in situ* burials, but a displaced modified wooden stake was recovered from one of these units (BAR 2018c; Duggins 2019). This was the only positively identified wooden stake in the interior units. It likely migrated in from elsewhere during a transgressive episode, especially given that it dates to the same period as other stakes from the periphery of the pond. The displaced wooden stake rested immediately above an oyster shell that was attached to a human long bone. While the oyster (2606.1) was still in the life position, the cultural and skeletal material was clearly out of context. This suggests the oyster formed on the skeletal material, which was then displaced by post-depositional factors. This episode likely capped the area with sediments and facilitated preservation of material.

The position of the units themselves and the modern erosion visible on the site could also reveal details concerning past transgressive episodes. The western portion of the pond is highly affected by erosion due to dominant wave action and currents in the area. Peat strata in Area 1 and 2017 unit 0N6E are at the surface and heavily eroded, containing the base of a burial deposit (Duggins 2018, 2019; Duggins et al. 2018). This portion of the pond was more affected by transgression, and it is possible that cultural material was displaced from the western periphery of the pond and deposited in more interior portions. The fact that there were also more oysters on the periphery than the interior suggests this portion of the site could have been exposed earlier and longer. Sclerochronology of MKO oysters suggests the periphery of the site was exposed longer (up to 3 years) than the interior portion of the site (up to 2.5 years). Given the post-depositional processes affecting the site, however, caution must be exerted as some oysters likely migrated from their original locations of growth.

Archaeologists have suggested the possibility of barrier islands protecting precontact sites during marine transgression (Bullen et al. 1968; Murphy 1990; Ruppé 1980; Stright 1987; Turck 2011), noting that barrier islands migrate shoreward and have the potential to pass over entire archaeological sites, capping them with protective sediments. Evidence of barrier island migration is visible offshore of Manasota Key in the form of organic sediments located below modern sand. These sediments have been documented in the vicinity of MKO (Ruppé 1980; Wells et al. 2018). It was originally theorized that MKO survived sea level rise because it was located in a back-barrier environment and provided the reasoning for choosing a modern oyster sample from a back-barrier environment near the site. Barrier islands in this region, however, began forming after 5000 BP (Stapor et al. 1991; Wells et al. 2018; Wilson et al. 2019). It is certainly possible that later preservation occurred in a back barrier environment and as the barrier island passed over MKO. Given that the oysters were up to 32 cm below the surface and within transgressive sediments, the oysters were likely probably already in place when the barrier island passed over the site. It should be noted that Wells and colleagues (2018) posit the barrier islands in the immediate vicinity of MKO formed close to their current positions.

6.7.2 Sea Level Rise and the Changing Landscape as Revealed by Oysters

This section examines the two groupings of oysters as revealed by radiocarbon dating and stable isotope analyses in more detail and translates these datasets to the changing landscape. Various explanations for these groupings are provided, as well as what that might mean for how the pond environment changed over time. The two distinct oyster groups are interpreted as capturing at least two transgressive episodes, each representing a different period of time and varying environments. The first, evidenced by Group 1 oysters 15.01b, 39.1a, and 2501.1, represents an initial transgressive episode with fresher water parameters than the subsequent transgressive episode (as evidenced by Group 2 oysters SC1, 8.02e, 337.1, 353.1, 2606.1). The oldest three Archaic oysters correspond with the lowest mean $\delta^{18}O_{shell}$ values, which are indicative of fresher water, suggesting these oysters formed first and at a time when the pond was inundated by salt water but not yet completely saline. The paleotemperature equation (section 6.3.3.1) reveals the oldest oyster (39.1a) had the lowest predicted $\delta^{18}O_{water}$ (0.5‰), while two more recent oysters (8.02e and 353.1) had predicted $\delta^{18}O_{water}$ values that suggested an at-times hypersaline environment (at 2.3‰). These interpretations assume that the past isotope gradient was not inverted and that the relationship between salinity and $\delta^{18}O_{water}$ has not changed greatly over time. While there is a less visible pattern of predicted $\delta^{18}O_{water}$ values for the rest of the oysters, the overall trend presented here is significant. The more recent grouping of oysters perhaps captured the pond as it was more fully inundated and thus more saline, and at times hypersaline. It is unlikely these oysters formed in a completely marine environment, however, due to the variability that was present in the plotted profiles. This suggests the MKO pond may have been considerably affected by precipitation, evaporation, and groundwater input. While it is not currently possible to say what the landscape looked like at the time of oyster growth, some potential environments are hypothesized below.

Currently accepted sea level curves for this region suggest the site was fully transgressed by about 6,500 to 6,000 cal BP (Joy 2018, 2019). Prior to total marine transgression by the Gulf of Mexico, the MKO pond may have existed inland as an isolated feature. As rising waters crept eastward and inundated once subaerial landforms, the pond could have been intermittently invaded by high tide, flooding, or storm surge that temporarily harbored barnacles and oysters. Storms and high tides also cause flooding of tributaries, pushing saline or brackish waters upriver (Foster and Savage 1989:12; Murphy 1990; Ruppé 1980:38). The pond may have remained largely separated from the open ocean, but still connected to groundwater sources. In the instance of a shallow and small pond, evaporation could have had more dramatic effects on hydrology, perhaps contributing to higher salinity as is evidenced by stable isotope analyses of some of Group 2 MKO oysters. These oysters also could have formed in a low energy, tidal marsh. Variation in $\delta^{13}C_{shell}$ and $\delta^{18}O_{shell}$ would be expected due to freshwater and saltwater input, evaporation, and terrestrial decomposition. Lagoons also exhibit hypersaline waters, and these environments are affected by coastal tides and rainfall. Water parameters change drastically in these dynamic environments, meaning salinity can vary from fresh to brackish to hypersaline. In these types of coastal landscapes, climatic forces are compounded unlike in an oceanic setting. This could explain how some MKO oysters provide evidence of a more saline environment and yet not a fully marine setting.

6.7.3 Florida's Mortuary Ponds: Cultural Practice and Abandonment

There are six confirmed mortuary ponds in Florida. They were discovered as a result of development, and most were studied in a rescue archaeology context. Windover was studied in detail because developers at the time recognized the importance of the site and agreed to shift development away from the site center (Doran 2002a). Bay West, Republic Groves, and Ryder Pond were not studied in detail; archaeologists instead were only able to collect material from spoil piles as development continued (Milanich 1995:81). As a result of these conditions, what is known about mortuary ponds is fragmentary and draws mostly from Windover. The findings at Windover steered the interpretations concerning mortuary pond practices and are often applied to these other sites. Ryder Pond, for example, is noted as dating to the Middle Archaic period based on similarity to other mortuary pond artifact assemblages (Carr 1998).

Much of archaeologists' understanding of mortuary pond cultural practices in Florida is conjecture. First, it is unknown why communities interred their deceased in ponds during the Middle Archaic period. One hypothesis is that post-Pleistocene drier conditions made scarce water ritually important (Doran 2002a; Milanich 1995:73, 84). Miller (2005:3) questioned whether the purpose of watery burials at Windover were as a security measure to protect the living community from spirits, though this does not address why ponds fell into disuse when water became more abundant across the landscape. Finally, the population utilizing mortuary ponds may have been cognizant that preservation in a humid, subtropical environment such as south Florida could only occur in a few instances, one of which was in freshwater ponds. This could be one reason people in this area in Florida chose to inter their deceased in saturated peat and why examples of mortuary ponds are not found anywhere else in the United States (Kathryn O'Donnell Miyar personal communication 2023).

The use of stakes in interments is also the subject of discussion. Speculation concerning the purpose of these stakes has occurred primarily from a functional standpoint: stakes were reportedly used to keep bodies secured to the pond bottom during decomposition (Anderson and Sassaman 2012:100; Dickel 2002; Doran 2002a). In some cases at Windover, bodies were wrapped in fabric with stakes driven through that fabric, contributing to the hypothesis that stakes served to keep bodies in place (Dickel 2002; Milanich 1995:72). Windover also exhibited a burial in which stakes were driven next to a cranium to pin it in place (Dickel 2002). The stakes directly abutted the cranium but did not damage it. The same was exhibited in Area 1 of MKO: stakes were placed directly around a cranium (BAR 2016b; Duggins and Price 2016).

Stakes may also have served as a visual marker for where graves were located within the pond. At Windover, burials were tightly clustered but not superimposed (Anderson and Sassaman 2012:100; Dickel 2002; Doran 2002a). This led to the hypothesis that the stakes (the longest of which was 1.5 m) must have protruded above the water's surface, though it cannot be said for certain (Adovasio et al. 2002:169; Dickel 2002:79–80). Besides stakes, leaves and unmodified branches and sticks were placed both at the base and on top of burials at Windover and Bay West (Dickel 2002; Milanich 1995:81). Hazeltine also contained burials that were placed on branches, with some examples of bodies wrapped in grass (Milanich 1995:80).

Perhaps these communities were using local materials that were abundant and easily modified for use in interments. Most of the stakes recovered from Windover were constructed of pine (n=61), with some oak (n=29) and ash (n=2) (Adovasio et al. 2002:169; Dickel 2002:80). Researchers suggested the cultural group was cognizant of the qualities and properties of varying woods (Dickel 2002:79). Side branches were removed, stakes were minimally stripped of bark, and the material was sharpened to a point either with a cutting tool or via charring and smoothing (Dickel 2002:79). Stakes were fire-hardened prior to their placement in the peat (Dickel 2002; Doran 2002a).

Other purposes for use of modified stakes that are related to the cosmology of the people using the pond at the time should also be considered. The conical orientation of the stakes around each burial could have served more spiritual purposes, for example to direct or anchor ancestors to other realms. The conical orientation of stakes around a burial may also have been the most straightforward manner in which to hold ancestors in place in a shallow, peat-bottomed water body. It is difficult to hypothesize about events that took place over 7,000 years ago. Miller (2005:2) questioned whether the conical orientation of stakes around burials was reminiscent of mounds that appeared in Florida up to 1,000 years later. The oldest mound used for mortuary purposes was at Tick Island (VO0024; 7,000 to 6,600 cal BP) (Anderson and Sassaman (2012:99). The burials at Tick Island occurred during the end of the Middle Archaic period when pond burials fell into disuse (Milanich 1995:82). Tick Island consisted of a freshwater shell midden with burials placed in shallow depressions. Burials were clustered, similar to those placed in mortuary ponds. Those in deeper strata were within shell with later burials superimposed and occurring within sand. It is interesting that burial deposits shifted from shell contexts to conical sand deposits (Anderson and Sassaman (2012:99). Anderson and Sassaman (2012:100) noted that the shift from pond burials to shell burials and then to sand burials coincided with changes in sea level rise (see also Klingle 2006).

There is less opportunity to place mortuary ponds within their broader landscape or cultural contexts because they were studied in a rescue archaeology context. Mortuary ponds were used as a cultural practice for around 3,000 years before reportedly rapidly falling into disuse by 5,800 cal BP (Anderson and Sassaman 2012:63; Dickel and Doran 2002:57; Doran 2002b; Milanich 1994:73). The middle Holocene (8,000 years ago) marked when sea levels were high enough to affect the overall hydrology of Florida (Wilson et al. 2019), and climatic conditions were certainly wetter after 5950 BP (Milanich 1994:84). This increase in the hydrological supply is often given as an explanation for abandonment of mortuary ponds as a cultural practice and a shift instead to burial mounds (Anderson and Sassaman 2012:100; Doran 2002a; Milanich 1995:84). Milanich (1995:73) in particular noted that Windover was filled with enough water that eventually the burials stopped, as it was too difficult to continue the process. How often, however, do humans engage in ritualistic activities that involve difficult processes? Was burial in mounds not also an intensely physical and challenging process?

MKO is the first mortuary pond found preserved in an offshore context, and there is a unique opportunity to explore the abandonment and post-depositional history of these landscape features, particularly in relation to sea level rise. The wealth of data recovered from MKO adds to archaeologists' understanding of the use and abandonment of mortuary ponds. Based on information from BAR, MKO may have been in use for between 864 to 1,168 years (Duggins 2018, 2019; Duggins and Price 2016; Duggins et al. 2018), indicating the significance of this site to cultural group(s). Figure 6.13 synthesizes information concerning timing of events at MKO. In this illustration, the timeline also marks various pertinent episodes that would have impacted use of the pond, such as when it was transgressed, when mortuary ponds were no longer used, and when barrier islands were reportedly forming in the region. The freshwater period of the pond likely extended more recently than 8,334 cal BP, but these dates are based solely on peat and faunal bone sampled as part of this dissertation's research. The brackish period is represented by two dated sediment samples (refer to section 6.6). The cultural use of the pond is represented by two wood samples dated as part of this research, as well as the most recent date for cultural use reported by BAR (Duggins 2018, 2019; Duggins and Price 2016; Duggins et al. 2018). In the illustration, the length of each labelled box (representing oysters) and bracket (representing barnacles) denotes the radiocarbon age range at 95%. The distinct groupings of oyster dates are represented, though they are at times upwards of 2,500 years older than cultural material to which they were attached.

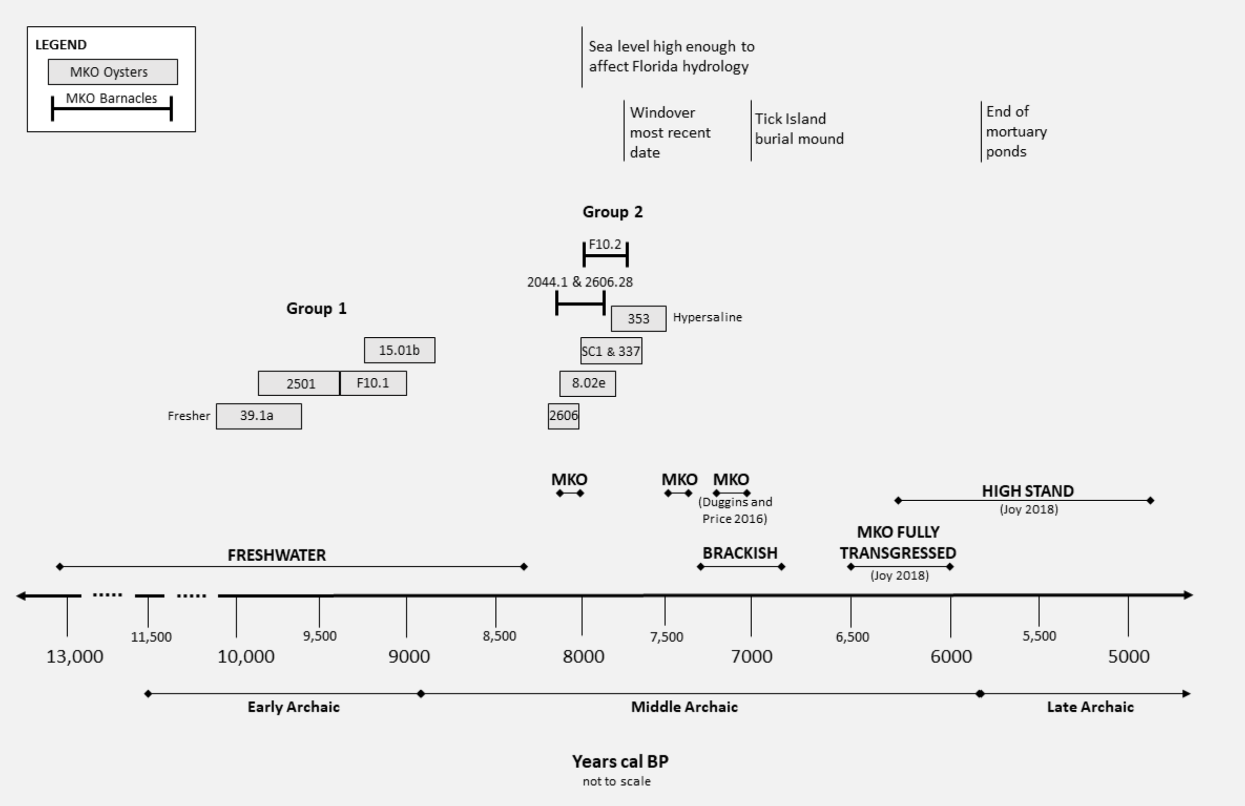

Figure 6.13. Timing of events at MKO based on data generated as part of this dissertation's research with BAR additions (Price 2023).

Additional information concerning abandonment of mortuary ponds can be extrapolated from the comparison of MKO to other ponds and their distances from past coastlines. If sea levels were high enough to affect Florida hydrology 8,000 years ago, why was MKO in use as recently as 7,029 cal BP (Duggins and Price 2016)? To examine this question, MKO's location and distance to past shorelines is compared to Florida's other known mortuary ponds. Figure 6.14 illustrates recorded mortuary ponds and their distances from 6,000, 7,000, 8,000, and 9,000 year shorelines based on Joy (2018, 2019). Table 6.3 provides distances in km to past shorelines, as well as the modern coastline. This allows MKO to be placed within its larger cultural landscape. As Windover is the best-studied mortuary pond, it provides the main comparison to MKO.

Table 6.3. Mortuary Ponds and Distances (km) from Present and Past Shorelines.

Site	**Modern**	**6,000 years ago**	**7,000 years ago**	**8,000 years ago**
Bay West	10.9	19.7	32.3	65.7
Hazeltine	20.1	22.2	29.7	46.5
MKO	-0.3	-0.6	7.5	23
Republic Groves	82.5	92.7	100.3	116.2
Ryder Pond	3.5	11.3	24.3	58.4
Windover	4.79	30.1	34.3	45.9

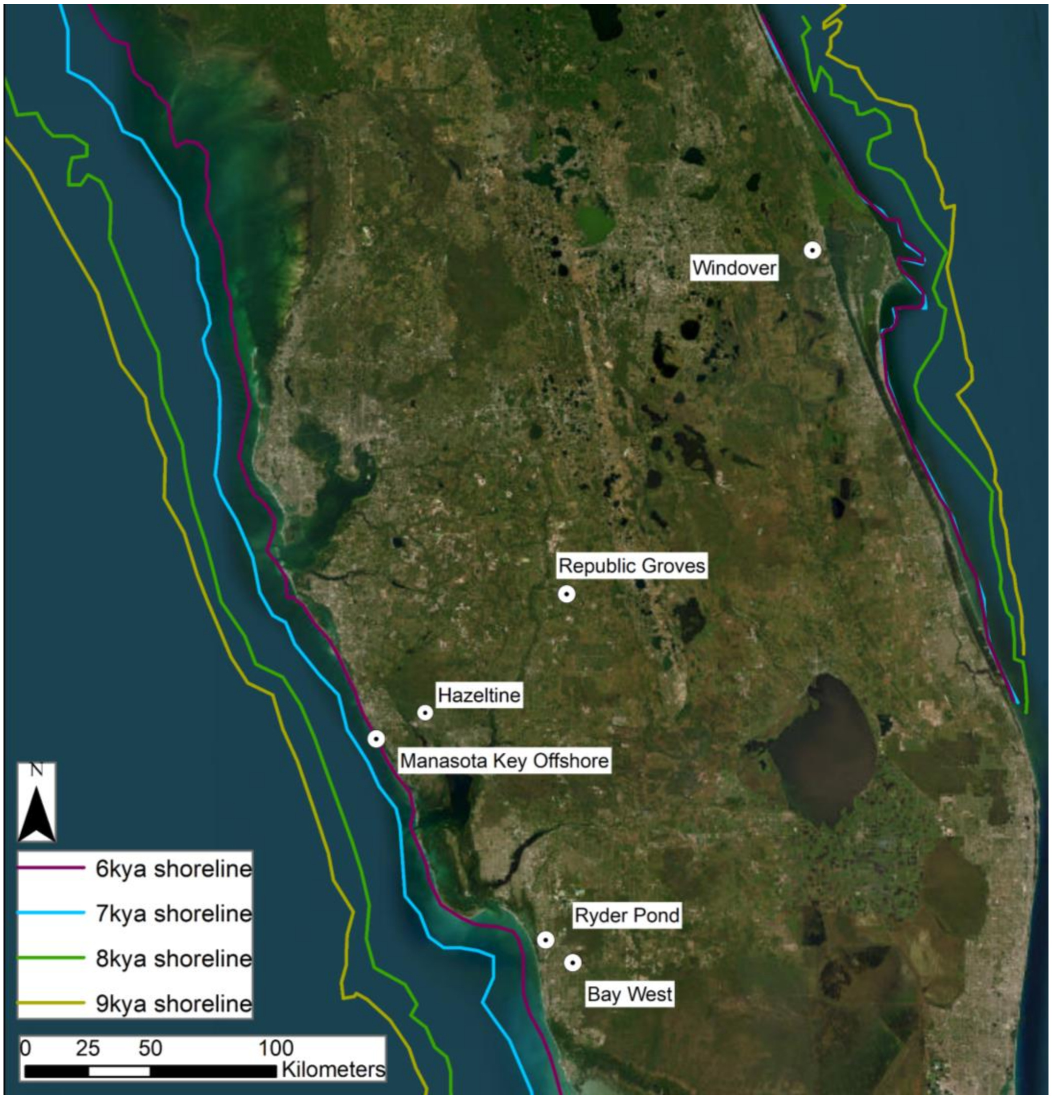

Figure 6.14. Distribution of mortuary ponds across Florida and distance to ancient coastlines (Shapefiles courtesy BAR with Price 2023 additions based on Joy 2018).

Based on peat strata, Windover was a woody marsh fed by rainwater and runoff at the time of its use as a burial pond (Milanich 1994:72). The water table would have been too low for it to be groundwater fed. It is interpreted that a lower water table meant burial in the pond was easier: peat strata were thinner and there was less water in the pond. By 6950 BP, Windover water levels were likely too high for burial to be feasible (Doran 2002b). The latest date for cultural use of Windover[7] was reported as between 8,029 and 7,656 cal BP (Doran 2002b:67–68). Windover would have been between 45.9 to 34.3 km from the coast by 7,600 cal BP. Around this same time, MKO would have been between 23 and 7.5 km from the coast, but its most recent date was 7,029 cal BP (Duggins and Price 2016). It is interesting that Windover was further from the coastline than MKO, and yet it was seemingly abandoned earlier than MKO. If the fundamental explanation for mortuary pond abandonment is an increase in water tables due to sea level rise, why was MKO in use longer than Windover, which was more inland? Based on sea level curve data from Joy (2018, 2019), some of these ponds were upwards of 100 km from the coast when they were in use during the Middle Archaic period (refer to Republic Groves in Figure 6.14)[8].

There must be additional explanations for abandonment of mortuary ponds as a cultural practice. Perhaps these ponds were not abandoned because an increase in hydrology made access to them more difficult. Perhaps instead the increase in hydrology caused a shift in how the population at the time viewed water. Miller (2005) noted his surprise that water burials were not more common given that water sustains all life, transforms and revives, that all humans come from water, and that the human body itself is comprised of mostly water. He noted that Windover provided the best evidence that water was significant to past populations and related the use of wooden stakes as “calling attention to the unsure world (Miller 2005:2).” The stakes were meant to “secure ancestors in this uncertain land (Miller 2005:2).” Miller (2005) suggested the wooden stakes were reminiscent of mounded shapes and thus drew a connection to the burial mounds that replaced mortuary pond burials as a cultural practice. Sassaman (2012) suggested there was a cognitive shift concerning rituals and burial that was commensurate with changes in landscapes following climate change. He further argued that water represents change and a state of flux and thus was important to precontact ritual and burial practices (Sassaman 2012). Given that sea level rise was steeper until about 6,000 years ago (Rivera-Collazo 2015; Wilson et al. 2019), the MKO pond could have been inundated quite rapidly, especially given evidence discussed throughout this chapter. Loss of access to the mortuary pond would have reshaped cultural

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[7] Windover dates from Doran (2002b); calibrations by author used IntCal20 curve (Reimer et al. 2020) implemented in OxCal version 4.4.4 (Bronk Ramsey 2009, 2021).

[8] This discussion is focused on distance to shorelines only and does not include the complexities of groundwater contribution or precipitation.

territories and the use of the landscape, but a shift in burial practice was already occurring prior to the pond's total transgression. If Miller's (2005) and Sassaman's (2012) comments about the significance of water is true, then why do water burials cease at a time when there is an increase in the availability of water? Instead, the suggestion that dryer conditions during the post-Pleistocene made water a more meaningful place of interment from a ritualistic perspective (Doran 2002a; Milanich 1994:84) seems a better explanation for the abandonment of mortuary ponds than an increase in the hydrological supply.

The cultural practice of interring the deceased in ponds may also have been an opportunistic practice at a time when cultural groups were believed to be highly mobile across the landscape (Anderson and Sassaman 1996:27; Austin et al. 2009; Milanich 1994:76; refer also to discussions of Archaic period mobility in Chapter 2, section 2.4). If these groups were mobile across the landscape at the time, ponds may have been used seasonally as places of interment due to their abundance in central Florida, as well as a wide availability of raw materials (e.g., wood for fashioning stakes). Individuals at Windover were interred within 48 hours after death based on preservation of brain tissue and mitochondrial DNA (Dickel 2002; Milanich 1995:72), which could suggest populations were near pond features when community members died. The fact that communities utilized these water bodies for hundreds of years suggests their locations were common knowledge or passed down from generation to generation. There may also have been a collective knowledge of suitable water bodies along common migratory routes. Perhaps these water features were no longer needed as places of interment after the Middle Archaic period because populations increased in size and became less mobile across the landscape. It is notable that those mortuary ponds in Florida exhibiting more recent dates into the Late Archaic period, such as Hazeltine (Luer 2003) and Republic Groves (Milanich 1995:82), are associated with nearby habitation sites. This section illustrates that more investigation into the causes of the abandonment of this cultural practice is warranted. The wholesale acceptance of sea level rise as a main contribution to abandonment of these features is not adequate.

6.8 Summary

This chapter utilized oyster data to make broader interpretations about the paleoenvironment and marine transgression at MKO. To summarize, oysters reveal this site experienced at least two inundation events with varying water parameters. The older Group 1 oysters formed first for between 1.5 and 3 years on cultural and skeletal material in an environment that was fresher than the more recent Group 2 oysters, assuming that the relationship between salinity and $\delta^{18}O_{water}$ has not changed greatly in the past. Group 1 water parameters are not comparable to the modern Lemon Bay estuary, and oysters expired during the hurricane season and into the winter. Group 2 oysters formed afterwards for between 1 and 3 years on cultural and skeletal material in an environment that was more saline, with some oysters exhibiting hypersaline water parameters as revealed by the paleotemperature equation (Epstein et al. 1953) and assuming that the past isotope gradient was not inverted. These oysters expired during the hurricane season and indicate a storm event that capped the site. Group 2 did not form in an oceanic environment; rather, they formed in an isolated environment in which evaporation had more influence on the body of water than in the open ocean (tidal marsh, lagoon, etc.). Furthermore, barnacles formed during the second environment commensurate with Group 2 oysters, providing additional evidence of a shift in environment between Groups 1 and 2 oysters. Based on currently accepted sea level curves for the region (Joy 2018, 2019), MKO is considered fully transgressed by 6,500 to 6,000 cal BP. While it is unknown what the coast in the study area looked like at this time, it is hypothesized that the site was fully marine and in an offshore context by 6,000 cal BP (refer to Figure 6.14). Given the variability present in isotopic profiles and that some Group 2 oysters suggest hypersaline conditions, the MKO oysters likely formed prior to total inundation of the site by the Gulf of Mexico. The MKO water body at the time of oyster growth instead would have been isolated enough to be drastically affected by precipitation, evaporation, and groundwater sources.