



Sclerochronology of *Busycon sinistrum*: late prehistoric seasonality determination at St. Joseph Bay, Florida, USA



Ryan M. Harke^{a,1}, Gregory S. Herbert^{b,*}, Nancy Marie White^a, Jennifer Sliko^{b,2}

^a Department of Anthropology, University of South Florida, 4202 E. Fowler Avenue, Tampa, FL 33620, USA

^b School of Geosciences, University of South Florida, 4202 E. Fowler Avenue, Tampa, FL 33620, USA

ARTICLE INFO

Article history:

Received 19 January 2014

Received in revised form

14 January 2015

Accepted 20 January 2015

Available online 10 February 2015

Keywords:

Busycon sinistrum

Sclerochronology

Florida

Mississippian

Fort Walton

Gastropod

Seasonality

ABSTRACT

Recent archaeological investigations indicate that coastal Fort Walton cultures in the St. Joseph Bay region of northwest Florida emphasized marine and estuarine foraging. These late prehistoric, Mississippian-period (A.D. 1000–1500) peoples collected fish, shellfish, and other aquatic resources. At the Richardson's Hammock site (8Gu10), radiocarbon-dated to about A.D. 1300, large, predatory gastropods were a major subsistence component. This adaptation is in sharp contrast with that of contemporaneous inland Fort Walton societies, who relied on maize agriculture, and raises the question whether coastal groups were separate hunter–gatherer–fisher populations or migrated seasonally from inland farming villages. We perform stable oxygen and carbon isotope sclerochronology on lightning whelks (*Busycon sinistrum*) to determine the seasonality of Fort Walton foraging and to compare the environment of prehistoric St. Joseph Bay with that of the modern bay. Oxygen isotope profiles suggest that shellfish collecting was relegated primarily to the summer months, producing a scheduling conflict with the primary growing season for maize in northwest Florida. Thus, coastal and inland Fort Walton sites probably represent separate culture groups. The relationship between $\delta^{18}\text{O}_{\text{shell}}$ and $\delta^{13}\text{C}_{\text{shell}}$ indicates similar environmental and climatic conditions between prehistoric St. Joseph Bay and today. However, modern whelks are depleted in ^{13}C compared to Fort Walton whelks, which reflects both twentieth century CO_2 emissions and years of dredging and wastewater pollution entering the bay.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Establishing coastal occupation patterns of prehistoric peoples has important implications for our understanding of how past inhabitants affected and were affected by their environments, as well as how mobile they might have been and what that implied for socio-political organization (e.g., Goggin, 1952; Miller, 1988; Widmer, 1988; Jones, 1991:419; Sassaman, 2004; Thomas, 2008; Saunders and Russo, 2011). Some ethnographic studies, particularly those that investigated shellfish harvesting, support the notion that coastal habitats of warmer regions were often occupied at most only during the cool season due to increased hazards (e.g., tropical storms, storm surge), disease risks (e.g., red tide, oyster

parasites), and pests (e.g., mosquitoes) associated with the warm season, in addition to the low caloric content of shellfish relative to other food sources (Waselkov, 1987:119–124; Claassen, 1986, 1991; Erlandson, 1988). In contrast, arguments for year-round coastal occupation have emphasized the fact that shellfish are generally abundant, easily accessible to the young, old, and infirm, and can be exploited throughout the year (Meehan, 1977, 1982:66; Sigler-Eisenberg and Russo, 1986; Russo, 1991; Quitmyer and Jones, 1997).

In prehistoric northwest Florida, coastal Native American habitation in the Apalachicola-lower Chattahoochee River Valley region was widespread by at least the Late Archaic period (3000–1000 B.C.) (White, 2003a,b) and continued through the Spanish contact period during the sixteenth and seventeenth centuries. Recent archaeological investigations around St. Joseph Bay, in the southwest corner of the Apalachicola delta, place primary occupations during both Middle Woodland (A.D. 300–700) and Fort Walton (A.D. 1300) times (White and Fitts, 2001; White et al., 2002; White, 2005). Extensive excavations at inland Fort Walton sites (A.D. 1000–1500) and observations made by contact-period Spaniards indicate that inland, late prehistoric natives were

* Corresponding author.

E-mail address: gherbert@usf.edu (G.S. Herbert).

¹ Current address: Flagler College, 74 King Street, St. Augustine, FL 32084, USA.

² Current address: Pennsylvania State Harrisburg, 777 West Harrisburg Pike, W256 Olmsted, Middletown, PA 17057, USA.

sedentary maize farmers (White et al., 2012). Contemporaneous coastal St. Joseph Bay sites, by comparison, are all shell middens, reflecting the maintenance of a hunter–gatherer–fisher lifeway. However, the seasonality and mobility of coastal Fort Walton foraging has not been determined, nor is it presently known whether coastal and inland Fort Walton cultures represent separate populations. These topics have important implications for our understanding of this regional expression of late prehistoric Mississippian chiefdoms near the edge of the greater Southeast (Ashley and White, 2012).

An unusual aspect of the St. Joseph Bay middens is that they are comprised mostly of large, predatory, marine gastropods, primarily the lightning whelk (*Busycon sinistrum*) but also the Florida horse conch (*Triplofusus giganteus*), rather than the brackish-water bivalves (e.g., oysters, *Rangia* clams) that dominate most other Florida middens (Quitmyer et al., 1997; White et al., 2002; White, 2014). These are among the largest gastropod molluscs in the world, with maximum shell lengths of 40–60 cm. Large predatory gastropods tend to be longer-lived and have longer turnover times and much lower abundances than bivalves, and recent research suggests that a population of long-lived whelks can be severely depleted in less than a month (Shalack et al., 2011). Such unsustainable resources would have discouraged year-round gastropod harvesting activities and coastal sedentism at Richardson's Hammock, although bivalves such as *Rangia cuneata*, *Chione elevata* (Florida cross-barred venus), *Crassostrea virginica* (oyster), and *Macrocallista nimbosa* (sunray venus) account for 35% of recovered shell remains by weight. Large and small mammal, turtle, and fish bones also account for ~10% of the midden matrix by weight. These species would have made a larger contribution to daily food intake than shellfish (White et al., 2002:57–58). Many of these subsistence resources would also have been available year-round.

Relative abundances of *B. sinistrum* and *T. giganteus* in the St. Joseph middens support year-round occupation. Molluscan community assessments at Alligator Harbor (~100 km east of St. Joseph Bay) by Paine (1963) recorded seasonal changes in abundance of predatory gastropods, including species common to St. Joseph Bay middens and characteristic of bays throughout the region. *B. sinistrum* was found to be most abundant during the cooler months, while *T. giganteus* was sighted mainly in the summer. Based upon average sightings per hour reported by Paine, ratios of *T. giganteus* to *B. sinistrum* were 1:10 for cooler months (September–April), 1:1 for summer months (June–August), and 1:6 for a year-round average (Paine, 1963:64–66). By comparison, published shell counts from two primary archaeological excavation units into the middens at Richardson's Hammock on St. Joseph Bay, Test Units A and B, showed that both had a ratio around 1:5 ($n = 200$) (White et al., 2002). Given the close agreement between modern annual relative abundance of these two gastropod species for Alligator Harbor (1:6) and their relative abundance within the prehistoric middens (1:5), St. Joseph Bay fisher-foragers deposited a midden species accumulation pattern we might expect to see if they were collecting year-round rather than only during the cooler months, as suggested by ethnographic studies.

In this study, we test the ethnography-based hypothesis that coastal occupation of Fort Walton peoples was not year-round but restricted to cooler months. To test this hypothesis, we investigated the seasonality of gastropod harvesting activities using stable oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotope profiles of *B. sinistrum* shells excavated from Richardson's Hammock (8Gu10), a Fort Walton-period midden site along the southwest shore of St. Joseph Bay. Isotope sclerochronology is a technique widely applicable to invertebrates that form carbonate skeletons by accretionary growth in freshwater, estuarine, and marine environments (Jones et al., 1989; Lecuyer et al., 2004; Goodwin et al., 2010), including

gastropods (e.g., Wefer and Killingley, 1980; Wefer and Berger, 1991; Geary et al., 1992; Mannino et al., 2003; Bar-Yosef Mayer et al., 2012; Strauss et al., 2014). For molluscs, the oxygen isotopic composition of shell carbonate is determined, in part, by the temperature and oxygen isotopic composition of the water in which the shell was formed (e.g., Epstein et al., 1953; Grossman and Ku, 1986; Lecuyer et al., 2004; Andrus, 2011; Andrus and Thompson, 2012). Because the oxygen isotopic composition of newly deposited increments of shell tracks seasonal temperature, serial micro-sampling of shells along the axis of growth can reveal both the range of temperatures experienced by a mollusc as it grew and the number of years of growth (Krantz et al., 1984; Wefer and Berger, 1991; Geary et al., 1992; Quitmyer and Jones, 1997; Kirby et al., 1998; Schöne et al., 2007). Furthermore, comparison of $\delta^{18}\text{O}$ values of the shell edge (most recent growth prior to death) to the $\delta^{18}\text{O}$ of a short series of samples from the last year of shell growth can be used to determine temperature trends leading up to the time of death (shell lip) and, thus, to infer season of collection (e.g., Kennett and Voorhies, 1996; Culleton et al., 2009; Thompson and Andrus, 2011). Our null hypothesis that gastropod harvesting was restricted to cooler months only can be refuted by finding one or more shells that indicate collection and death during the warm season.

1.1. Fort Walton culture

First defined by Willey (1949), Fort Walton culture is the regional expression of the late prehistoric Mississippian adaptation which extends throughout the Southeast. These peoples were maize agriculturalists who shared certain ceramic and other artifact types, mortuary practices, and symbolism, and participated in long-distance trade. Much like in the rest of the Mississippian world, Fort Walton societies are thought to have been organized in chiefdom-level sociopolitical units. Their material culture occurs in northwest Florida, south Alabama, and southwest Georgia, with the “heartland” occupying the Apalachicola River Valley and the Tallahassee Red Hills. It is thought to have arisen from indigenous late Weeden Island (Late Woodland) roots combined with outside Mississippian influences. Many larger sites have components from prior time periods (Marrinan and White, 2007). Fort Walton culture flourished for several hundred years before contact with the Spanish (and their Old World diseases) caused rapid depopulation (Marrinan and White, 2007; White, 2011:263–264, White et al., 2012).

Inland Fort Walton sites appear to be “classic” Mississippian, with temple mound-village centers constructed near large and small rivers, lakes, and ponds. Such structures are evidenced by clay daub fragments, postmolds, and occasional wall trench features. Hearths, storage pits, and refuse pits are also common among all Fort Walton sites (Willey, 1949). Coastal Fort Walton sites are generally smaller and more scattered, defined by shell middens that resemble hunter–gatherer–fisher occupations throughout the earlier Archaic and Woodland periods, though some may have temple mounds (e.g., Pierce Mounds) (Marrinan and White, 2007; White et al., 2012). While evidence for maize agriculture is found at several inland sites, no maize has been recovered in coastal contexts in the Apalachicola region, though some maize has been excavated farther to the west on Choctawhatchee Bay (Mikell, 1992), and in coastal Alabama (Brown, 2003). For Fort Walton inland villages and mound complexes, maize agriculture appears to be the adaptive mainstay, while coastal middens exhibit heavy exploitation of molluscs, fish, turtles, and other aquatic fauna. However, both coastal and inland sites produce a variety of wild floral and faunal subsistence remains such as acorns, fruits, and

deer and small mammal bones (Willey, 1949; Marrinan and White, 2007; White et al., 2012).

1.2. Study area

St. Joseph Bay lies on the western side of the lower Apalachicola River delta, in present-day Gulf County. Today, the bay is nearly enclosed by a barrier peninsula, and does not have any major freshwater sources spilling into it, creating an unusual bay habitat with full marine salinity (Rupert, 1991; Davis, 1997:166–167). Richardson's Hammock is an oak/palm grove situated on the coast of St. Joseph Bay, on the southeast side of a smaller peninsula attached to the long barrier peninsula (Fig. 1). The north-south extent of the site is some 350 m, along the beach ridge closest to the bay, while east-west it measures 40 m or less. The site has two components, a later Fort Walton occupation, radiocarbon-dated to A.D. 1300 (White, 2005:30) restricted mostly to the southern end of the site and an earlier Woodland occupation and burial mound at the north end. The distribution of whelks and conchs is more continuous in the southern Fort Walton portion of the site (White et al., 2002:13). Most of the Fort Walton shells at the site, as well as at other prehistoric sites on St. Joseph Bay, appear to be ecofacts, such as food garbage, with very few modified to make artifacts (White et al., 2002:16). *B. sinistrum* and *T. giganteus* are the most common midden shells at this site (Fig. 2). Most of the bone is fish spines, vertebrae, or pneumatized bone, with some turtle as well. Today, St. Joseph Bay is an important scallop fishery (Greenawalt-Boswell et al., 2007), but few scallops have been found in the archaeological record. Given that there are no proximal fresh water sources near the site today, Fort Walton peoples living at Richardson's Hammock may have had to travel some distance for drinking water and to obtain brackish water oysters and *Rangia* clams (White et al., 2002). Alternatively, the hydrodynamic regime of this area may have changed over the past several hundred years, and



Fig. 2. North wall stratigraphy of Test Unit B showing the high density of *B. sinistrum*.

freshwater flow into the bay may once have been greater than it is today. Seasonal swales between dune ridges might also have been potential local fresh-water sources.

2. Materials and methods

2.1. Sampling

Season of collection was inferred from stable oxygen isotope profiles of individual midden shells. Archaeological shells selected for stable isotope analysis were excavated from Test Unit A (TUA) and Test Unit B (TUB) at the Richardson's Hammock site in June 2000. Placed on a mild backslope of the shoreline ridge near the

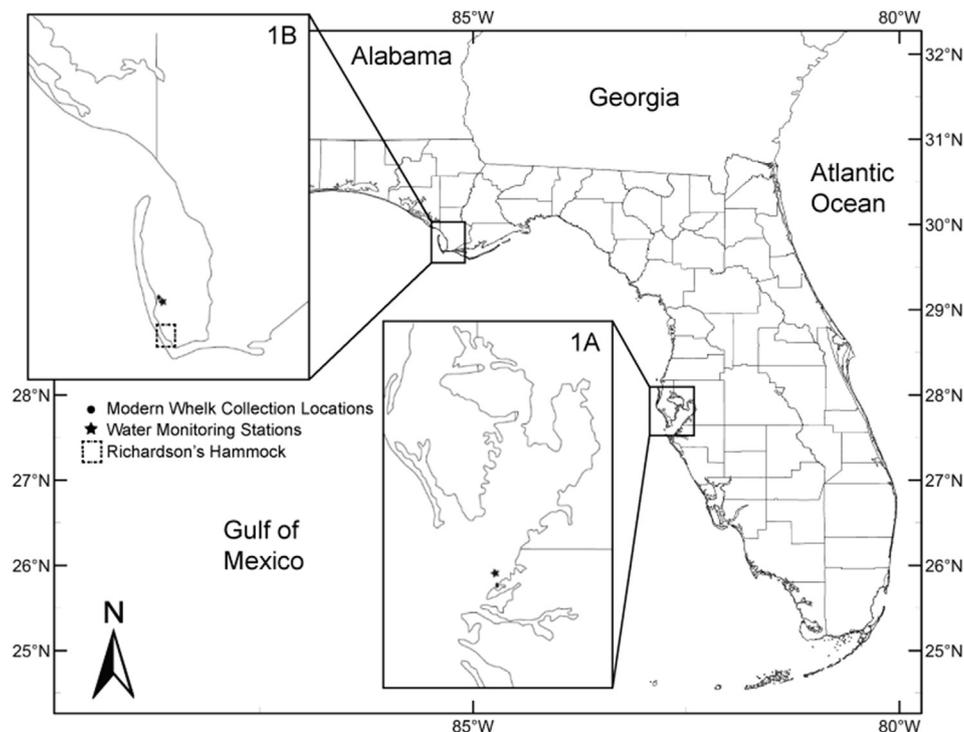


Fig. 1. Study location map. Location of Florida Department of Environmental Protection Site LW5 in St. Joseph Bay and the Richardson's Hammock Site (1A), and the Environmental Protection Commission of Hillsborough County Water Monitoring Site #24 in Tampa Bay (1B) Modern *B. sinistrum* collections took place near water monitoring stations.

edge of the Bay, TUA was the southernmost unit at the site, located ~30 m west of the water's edge, while TUB was placed ~70 m north of TUA. Both units were dug in 10-cm levels to achieve good provenience control within the shallow prehistoric cultural stratum. Charcoal from Level 3 of TUB produced the radiocarbon date of cal. A.D. 1300 (95% probability range = A.D. 1280–1400; Beta 191276; White, 2005:30). Similar soil deposition patterns and diagnostic Fort Walton ceramics indicate the archaeological shells chosen for study are contemporaneous with that Fort Walton date (White et al., 2002). Five *B. sinistrum* were selected from Floor 3 of TUA for isotopic sampling. Six *B. sinistrum* were selected from TUB, three each from Levels 1 and 3. Shells excavated from TUA and TUB were named AA through EE, and FF through KK, respectively. The two-letter designations were given during isotope analysis so as to not conflict with earlier names given during archaeological excavation.

To test whether *B. sinistrum* secretes new shell close to expected thermodynamic isotopic equilibrium with ambient seawater and records seasonal temperature change, we also analyzed two modern whelks, both collected alive. The first specimen (shell length 152 mm) was collected from a shallow subtidal seagrass bed offshore of Mosquito Trail (29.759° N, 85.391° W) in St. Joseph Bay in June 2007, and a second specimen (shell length 164 mm) was collected in January 2006 from Miguel Bay (27.588° N, 82.619° W), near the mouth of Tampa Bay. The St. Joseph Bay shell was chosen based on close proximity to the shell midden. The Tampa Bay shell was chosen to provide a second reference specimen from a site that differs in experiencing greater freshwater input from rivers, streams, and groundwater discharge in order to test whether environmental factors influence seasonality of growth in whelks. The modern shells used in this study are slightly smaller and younger than the mean for the archaeological shells observed in northwest Florida, and were selected because younger whelks in this size range are less likely to exhibit long growth breaks (Krauter et al., 1989). Modern *B. sinistrum* shells can reach 450 mm in shell length (Abbott, 1954), but the mean length of *B. sinistrum* in northwest Florida is 250 mm (Paine, 1963).

After collection, modern specimens were frozen, and the snails were removed from their shells. Archaeological shells were rinsed free of sediment with water and a brush and inspected visually for evidence of diagenetic alteration, such as deposition of secondary cements or recrystallization. Prior to sampling, all shells were submersed in a 3% sodium hypochlorite solution for 30 min and then thoroughly rinsed in deionized water and scrubbed with a soft-bristled brush to remove the periostracum and any biotic organisms. After shells were dried for 24 h, a 0.5 mm carbide dental drill bit was used to remove approximately 300 µg of powdered aragonite from the outermost layer of the shells for isotopic analysis following the sampling methodology of Wefer and Berger (1991).

We sampled modern shells at 5 mm increments along the entire axis of growth, from the uppermost whorls on the spire to the shell lip, to obtain a high resolution record of multi-season, multi-year growth from birth to death. With this approach, we collected 68 samples from the St. Joseph Bay shell and 54 samples from the Tampa Bay shell and achieved a sample resolution for modern shells of around 18 samples per year, capturing a full year within the last 5 cm of spiral growth. Fort Walton-period *B. sinistrum* shells were similarly sampled at ~5 mm increments, with drilling beginning at the shell's final growth edge (lip) and extending back across approximately 5 cm of growth increments. This sampling resolution captured the isotopic profile for at least the final year of growth for each shell, including sub-monthly intervals needed to estimate season of collection. Aragonite powders were stored individually after drying in a low temperature oven (~60 °C) for 24 h to remove any excess moisture.

2.2. Stable isotope analysis

Stable isotope concentrations are expressed in standard delta (δ) notation, where

$$\delta = \left[R_{\text{sample}} / R_{\text{standard}} - 1 \right] \times 1000$$

and all values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ are reported in per mil units (‰) with respect to the Vienna PeeDee Belemnite (VPDB) isotopic standard. Carbonate powders from the modern and Fort Walton-period St. Joseph Bay specimens were dissolved in 100% H_3PO_4 at 25 °C for 24 h, and the resulting gas was analyzed using a GasBench device coupled to a Thermo Finnigan Delta V Advantage IRMS, located at the School of Geosciences, University of South Florida. Analytical precision for these samples based on repeated measurements of the reference standard NBS-18 ($n = 40$) is $\pm 0.14\text{‰}$ for oxygen and $\pm 0.10\text{‰}$ for carbon. Samples from the modern Tampa Bay shell were analyzed on a GasBench device attached to a Thermo Finnigan Delta + XL IRMS in dual-inlet mode coupled to a Kiel-III carbonate preparation system, located in the College of Marine Science, University of South Florida. Analytical precision is based on daily measurements of laboratory standards ($n > 500$) over the 12 months preceding analysis, and was $\pm 0.06\text{‰}$ for oxygen and $\pm 0.03\text{‰}$ for carbon. Ten random, duplicate samples analyzed at the USF School of Geosciences were re-run at the USF College of Marine Science. Sample replicate precision for $\delta^{18}\text{O}$ measurements was $\pm 0.5\text{‰}$.

To test whether the modern *B. sinistrum* faithfully records the full range of summer and winter temperatures experienced in its environment, we calculated the predicted seasonal range of $\delta^{18}\text{O}$ aragonite deposited in isotopic equilibrium with the ambient water based on *in situ* temperature measurements near each of the sites of specimen collection (Fig. 3). Predicted $\delta^{18}\text{O}$ values were calculated using the molluscan aragonite paleotemperature equation derived empirically by Grossman and Ku (1986), where equation coefficients have been adjusted for acid- CO_2 fractionation factors calculated for a 25 °C temperature reaction (Kim et al., 2007):

$$T(^{\circ}\text{C}) = 21.8 - 4.69 \left(\delta^{18}\text{O}_{\text{aragonite}} + 0.32 - \delta^{18}\text{O}_{\text{seawater}} \right)$$

where $T(^{\circ}\text{C})$ is the temperature of seawater at the time of calcification, $\delta^{18}\text{O}_{\text{aragonite}}$ is the isotopic composition of shell aragonite (in ‰) and $\delta^{18}\text{O}_{\text{seawater}}$ is the isotopic composition of seawater relative to Vienna Standard Mean Ocean Water (VSMOW) at the time of shell formation. Calculated predicted $\delta^{18}\text{O}$ aragonite values were obtained by solving for $\delta^{18}\text{O}_{\text{aragonite}}$ and using daily $T(^{\circ}\text{C})$ from instrumental temperature observations near the site of specimen collection with a constant $\delta^{18}\text{O}_{\text{seawater}}$ value of 0.75‰ for Tampa Bay and 0.50‰ for St. Joseph Bay, which were derived from regional data in the NASA GISS Global Seawater Oxygen-18 database (Schmidt et al., 1999). The analytical precision of $\delta^{18}\text{O}$ measurements in this study is equivalent to a potential error of $\pm 0.4^{\circ}\text{C}$ when estimated using the Grossman and Ku paleotemperature equation.

St. Joseph Bay instrumental temperature data were collected from Site LW5 maintained by the Florida Department of Environmental Protection in St. Joseph Bay (29.760° N, 85.384° W), which is located ~200 m from the Mosquito Trail location. Because stable isotope profiles of the shells revealed that these specimens lived 3.0 and 4.5 years prior to collection, five years of ambient water data prior to collection for each site (2001–2006 for Tampa Bay, 2003 to 2008 for St. Joseph Bay) are presented (Fig. 3).

Correlations between $\delta^{18}\text{O}_{\text{shell}}$ and $\delta^{13}\text{C}_{\text{shell}}$ of modern *B. sinistrum* were compared using Pearson's Product Moment

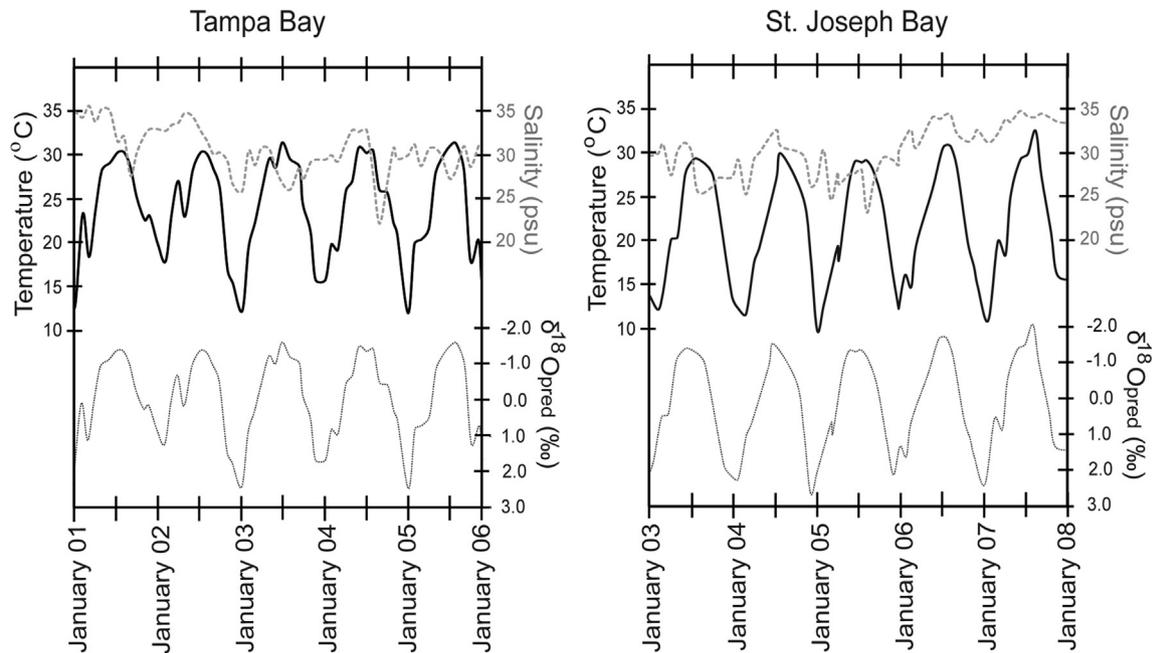


Fig. 3. Historic water quality parameters. Sea surface temperature (black), sea surface salinity (dashed gray), and calculated $\delta^{18}\text{O}_{\text{pred}}$ (gray) for each collection site (data from the Environmental Protection Commission of Hillsborough County and from the Florida Department of Environmental Protection).

Correlation Coefficient. Because it is useful for comparing normally-distributed datasets, Hotelling's Trace coefficient was selected to test whether $\delta^{18}\text{O}_{\text{shell}}$ and $\delta^{13}\text{C}_{\text{shell}}$ values of modern St. Joseph Bay, prehistoric St. Joseph Bay, and modern Tampa Bay could have come from the same distribution. Levene's Test of Equality of Error Variances was used to test whether the homogeneity of variance for $\delta^{18}\text{O}_{\text{shell}}$ and $\delta^{13}\text{C}_{\text{shell}}$ differs among the three groups. All p -levels were set at 0.05. Analyses were performed using PAST software (Hammer et al., 2001) and SPSS.

3. Results

3.1. $\delta^{18}\text{O}$ of modern *B. sinistrum* shell

The $\delta^{18}\text{O}$ profiles of both modern shells exhibit a sinusoidal trend with fewer than five cycles (Fig. 4). The mean $\delta^{18}\text{O}$ value for the St. Joseph Bay shell is -0.7‰ ($n = 68$, $1\sigma = 1.0\text{‰}$) with a mean amplitude of 3.1‰ over 3.0 cycles ($1\sigma = 0.2\text{‰}$) (Fig. 4). By comparison, the mean annual $\delta^{18}\text{O}_{\text{pred}}$ amplitude for St. Joseph Bay in the five years preceding specimen collection is 3.9‰ ($1\sigma = 0.3\text{‰}$). On average, $\delta^{18}\text{O}$ minima for the St. Joseph Bay shell are offset by 0.4‰ relative to $\delta^{18}\text{O}_{\text{pred}}$ summer values, whereas $\delta^{18}\text{O}_{\text{shell}}$ maxima are offset from $\delta^{18}\text{O}_{\text{pred}}$ winter values by an average of 1.2‰ .

The mean $\delta^{18}\text{O}$ of the Tampa Bay specimen is -0.8‰ ($n = 52$, $1\sigma = 0.7\text{‰}$) with a mean amplitude of 2.0‰ over 4.5 cycles ($1\sigma = 0.4\text{‰}$). The mean annual $\delta^{18}\text{O}_{\text{pred}}$ amplitude for Tampa Bay in the five years preceding specimen collection is 3.5‰ ($1\sigma = 0.6\text{‰}$). $\delta^{18}\text{O}_{\text{shell}}$ minima for the Tampa shell are offset by 0.2‰ relative to $\delta^{18}\text{O}_{\text{pred}}$ summer values, and $\delta^{18}\text{O}_{\text{shell}}$ maxima are offset from $\delta^{18}\text{O}_{\text{pred}}$ winter values by an average of 1.9‰ .

3.1.1. $\delta^{13}\text{C}$ of modern *B. sinistrum* shell

Neither of the modern shells exhibits a strong correlation between $\delta^{13}\text{C}_{\text{shell}}$ and $\delta^{18}\text{O}_{\text{shell}}$ (St. Joseph Bay, $r^2 = 0.08$; Tampa Bay, $r^2 = 0.14$), although there was a general pattern for inverse directional trends between $\delta^{13}\text{C}_{\text{shell}}$ and $\delta^{18}\text{O}_{\text{shell}}$ in the Tampa Bay specimen. Although the mean values of $\delta^{18}\text{O}_{\text{shell}}$ from St. Joseph Bay

and Tampa Bay are similar (-0.8‰ ; -0.7‰ , respectively), the ranges of $\delta^{13}\text{C}_{\text{shell}}$ values from the two shells do not overlap (Fig. 5). The mean $\delta^{13}\text{C}_{\text{shell}}$ is -1.0‰ ($n = 68$, $1\sigma = 0.5\text{‰}$) for the modern shell from St. Joseph Bay and -3.3‰ ($n = 54$, $1\sigma = 0.6\text{‰}$) for the modern shell from Tampa Bay.

3.2. $\delta^{18}\text{O}$ of Fort Walton-period *B. sinistrum*

Isotope profiles of the last quarter to half whorl of eleven midden shells (Figs. 6 and 7) record one to two cycles in $\delta^{18}\text{O}_{\text{shell}}$. Values of $\delta^{18}\text{O}_{\text{shell}}$ for prehistoric specimens range from -4.6‰ to 0.7‰ , although three of the lightest samples are considered outliers; 97% ($n = 108$) of all samples are tightly constrained between -2.31‰ and 0.67‰ , with a mean value of -0.97‰ . Values of $\delta^{18}\text{O}_{\text{shell}}$ for archaeological and modern datasets (including modern Tampa Bay) overlap and are statistically indistinguishable ($df = 2233$; $F = 36.487$, $p < 0.001$).

Both warming and cooling trends are evident in the $\delta^{18}\text{O}_{\text{shell}}$ values of the prehistoric specimens. Shells AA, DD, and II each record a summer peak followed by a cooling trend, at which point the profiles end. The $\delta^{18}\text{O}_{\text{shell}}$ profile for shell EE ends within what could be a warming trend, but the temporal resolution of the profile and the low amplitude of $\delta^{18}\text{O}$ values are too low to determine season of collection with confidence. Profiles for BB and JJ end during a warming interval but at values that are isotopically heavier (i.e., cooler) than the peak summer values of the previous cycle. The remaining whelks, CC, FF, GG, HH, and KK, exhibit warming trends in $\delta^{18}\text{O}$ values leading up to the shell lip and are among the isotopically lightest (i.e., warmest) of the Fort Walton samples (-1.5‰ to -2.2‰).

Four shells exhibit markedly low annual profile amplitudes. Shells DD, EE, HH, and JJ have reduced amplitudes that range from 1.4‰ to 0.7‰ , with a mean profile amplitude of 1.1‰ . By comparison, the remaining seven shells in the sample have amplitudes ranging from 5.1‰ to 1.9‰ , with a mean profile amplitude of 3.1‰ . The shells with either low or high profile amplitudes are not specific to either of the two units; DD and EE are from Test Unit A,

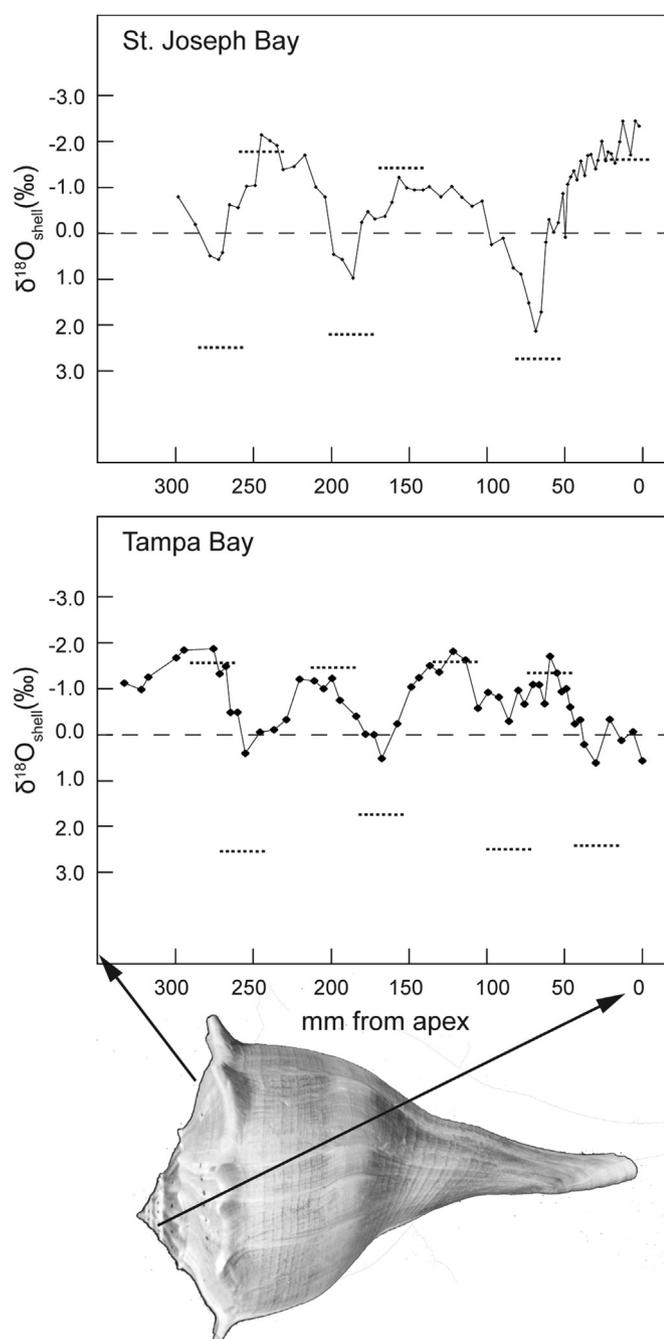


Fig. 4. Sample locations and isotope profiles for modern *B. sinistrum* from Tampa Bay and St. Joseph Bay. The $\delta^{18}\text{O}_{\text{shell}}$ samples (black lines) and $\delta^{13}\text{C}_{\text{shell}}$ (gray lines) are plotted on an inverse y-axis and distance is measured in mm from the apex along the spiral growth axis. Dotted lines represent the predicted $\delta^{18}\text{O}$ summer minima and winter maxima for each year.

while HH and JJ are from Test Unit B (~100 m apart). However, within Test Unit A, DD and EE were excavated from the same provenience, Floor 3. In contrast, HH and JJ came from different proveniences within Test Unit B, Level 1 and Level 3, respectively.

3.2.1. $\delta^{13}\text{C}$ of Fort Walton-period *B. sinistrum*

Values of $\delta^{13}\text{C}_{\text{shell}}$ for *B. sinistrum* from St. Joseph Bay, Tampa Bay, and the Ft. Walton period middens form three distinct clusters based upon location and temporal period (Fig. 5) (Hotelling's Trace,

$F = 1637.592$, $df = 4462$; $p > 0.001$). Fort Walton-period $\delta^{13}\text{C}_{\text{shell}}$ values range from 3.3‰ to -0.1 ‰ ($n = 108$) with a mean of 1.7‰ ($1\sigma = 0.5$ ‰), while modern $\delta^{13}\text{C}_{\text{shell}}$ values from St. Joseph Bay are on average, lighter by 2.7‰. Differences between $\delta^{13}\text{C}_{\text{shell}}$ values of prehistoric and modern shells are significant ($df = 2233$; $F = 0.113$, $p = 0.893$). Oxygen values, however, do not differ significantly between prehistoric and modern shells.

4. Discussion

4.1. Interpreting $\delta^{18}\text{O}$ time series in modern and prehistoric *B. sinistrum*

Cyclical variations of $\delta^{18}\text{O}$ in serially sampled modern shells of *B. sinistrum* from Florida indicate that shells around 150 mm in length provide seasonality data for approximately four years. $\delta^{18}\text{O}_{\text{shell}}$ minima for both the modern Tampa and St. Joseph Bay shells nearly match $\delta^{18}\text{O}_{\text{pred}}$ summer values at each respective bay, slightly surpassing the most extreme $\delta^{18}\text{O}_{\text{pred}}$ summer values five out of eight cycles. However, the mean $\delta^{18}\text{O}_{\text{shell}}$ maxima observed for shells from both bays are offset by -1.6 ‰ compared to corresponding $\delta^{18}\text{O}_{\text{pred}}$ winter maxima. Thus, *B. sinistrum* shell growth occurs primarily during the warmer half of the year and potentially records the warmest local conditions of summer, while shell growth slows or ceases for most of the cooler months. Given that modern *B. sinistrum* shells record the complete range of warm season temperatures, prehistoric *B. sinistrum* are ideally suited for testing whether prehistoric *B. sinistrum* were harvested between late spring and early autumn. However, we also conclude that $\delta^{18}\text{O}$ isotope profiles of this species do not provide reliable information on season of collection between late autumn and early spring.

Our confidence in the conclusion that *B. sinistrum* grows primarily in warmer months and records warm season temperatures in the isotopic composition of its shell is supported by independent field and laboratory observations. Paine (1963) reported that whelks from the northern Gulf of Mexico have reduced feeding activity in the warm season, which we assert from our isotopic profiles of modern whelks from the Gulf of Mexico coincides with the season of rapid shell extension (growth). Cessation of feeding activity and rapid shell extension should coincide in *B. sinistrum*, because whelks feed by using their own shell lip to hammer or chip

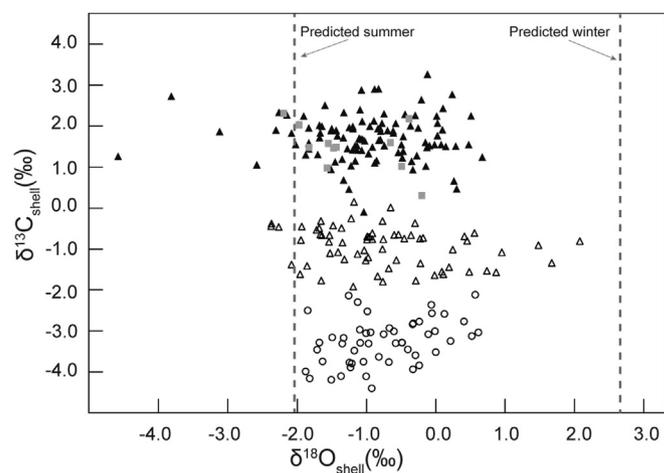


Fig. 5. Scatterplot of $\delta^{13}\text{C}$ versus $\delta^{18}\text{O}$ for *B. sinistrum* samples representing archaeological specimens collected at St. Joseph Bay (solid symbols, with \blacksquare representing terminal lip samples and \blacktriangle representing all other archaeological samples), and modern specimens collected from St. Joseph Bay (open triangles Δ) and Tampa Bay (open circles \circ). Dotted lines represent maximum and minimum $\delta^{18}\text{O}_{\text{pred}}$ values for modern St. Joseph Bay.

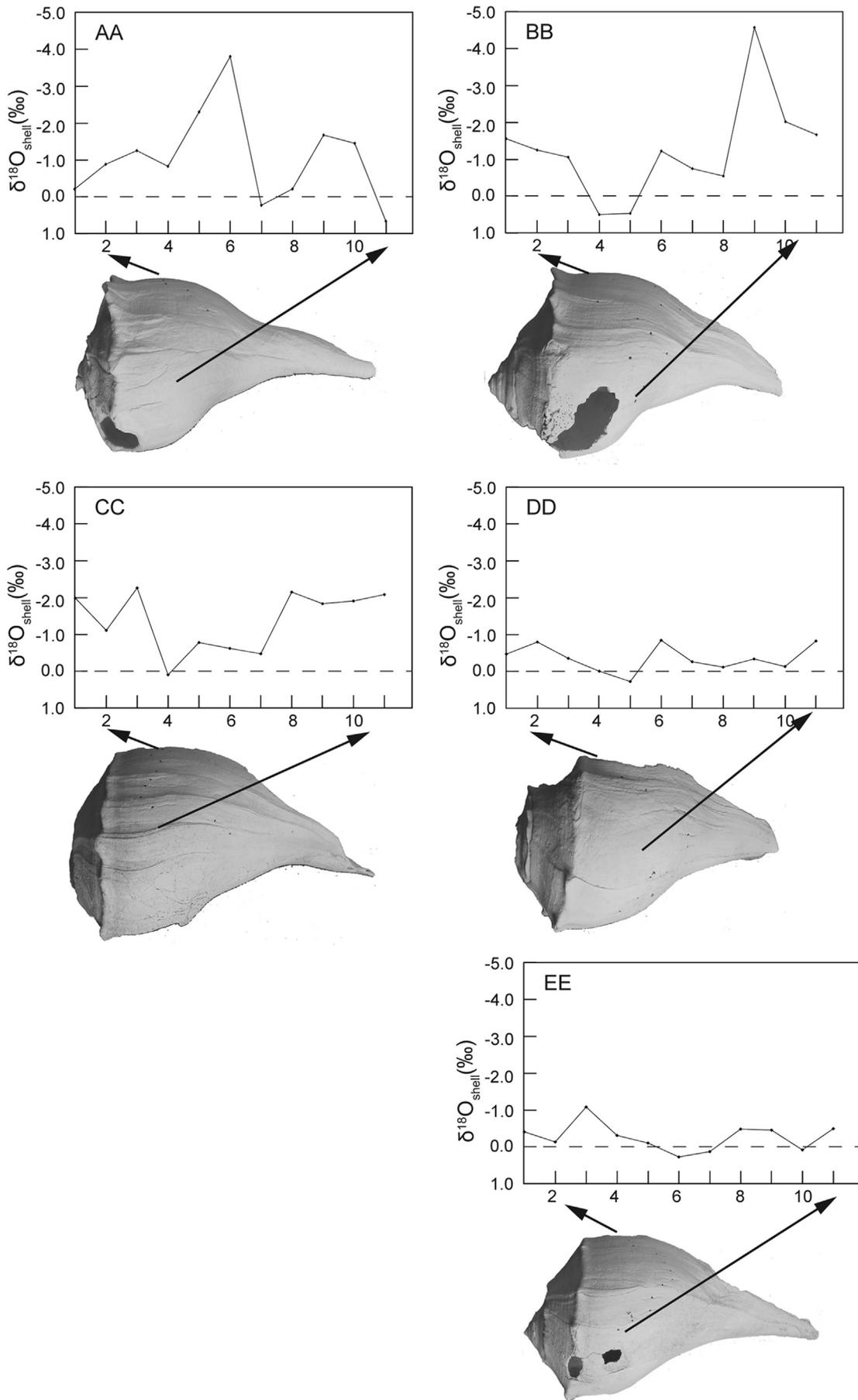


Fig. 6. Measured $\delta^{18}\text{O}_{\text{shell}}$ seasonality data for *B. sinistrum* from Test Unit A (AA-EE), excavated from Floor 3 at ~28 cm below surface.

open the shells of prey clams. Because rapid shell extension produces only thin shell, the use of the shell as a hammering or chipping tool during feeding would only be effective in the winter, after the lip has had sufficient time to thicken (Dietl, 2003a,b).

We found abnormally low amplitudes in four of our 11 prehistoric $\delta^{18}\text{O}_{\text{shell}}$ time series. One explanation for this phenomenon is that these specimens each experienced growth breaks during the summer in addition to winter, thus truncating the isotopic peaks

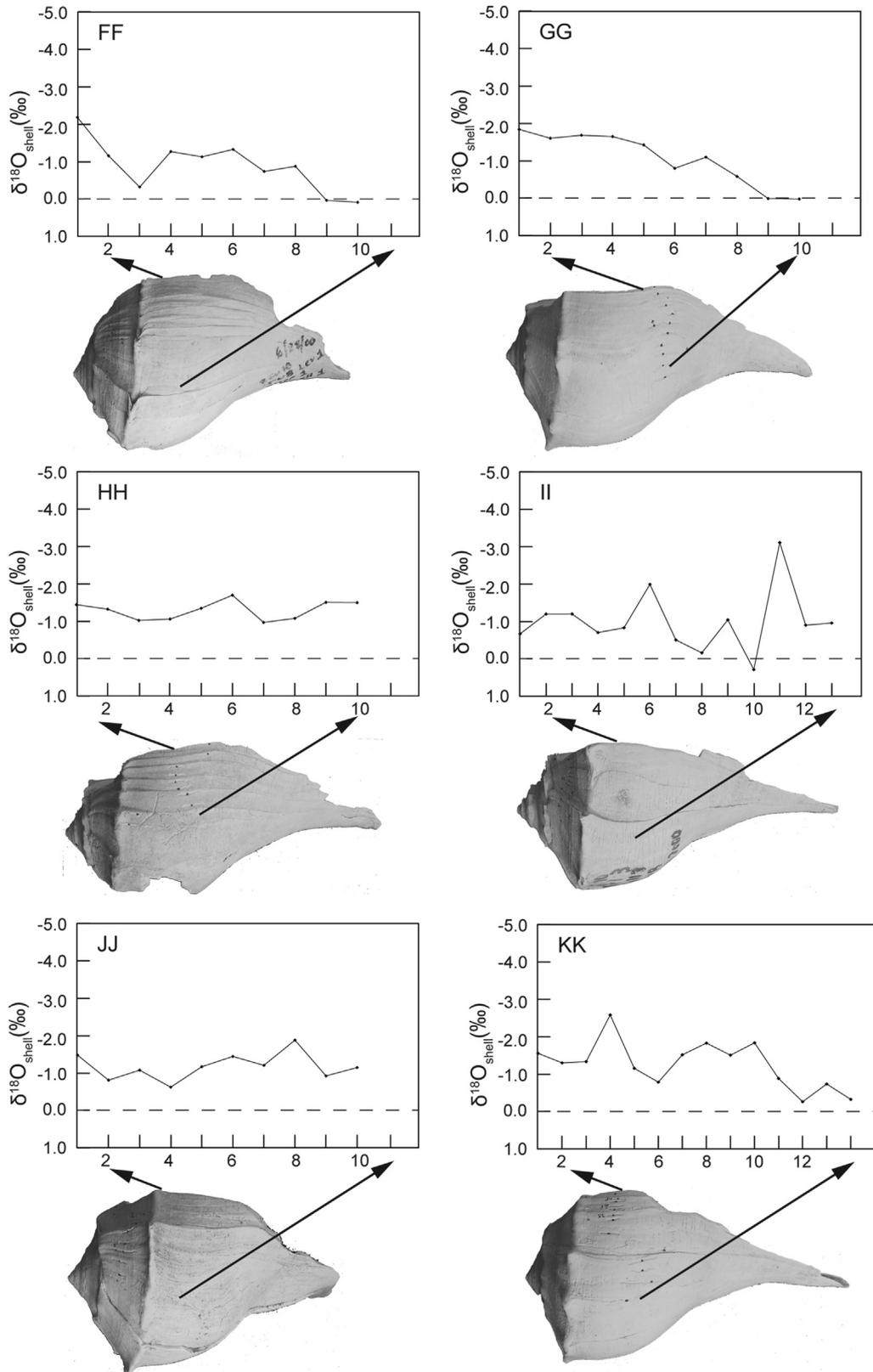


Fig. 7. Measured $\delta^{18}\text{O}_{\text{shell}}$ seasonality data for *B. sinistrum* from Test Unit B (FF–KK); FF–HH were excavated from Level 1 (surface), II–KK from Level 3 (~20 cm below surface).

and valleys of the paleoenvironmental archive and potentially limiting the value of *B. sinistrum* for collection season studies. Summer and winter growth breaks might be expected in the large midden whelks used in our study, as these had grown large enough to resist predation and could afford to direct energetic resources to reproduction rather than size increase. However, the low $\delta^{18}\text{O}$ amplitudes of the four prehistoric shells could instead reflect climate variation without the need to invoke summer growth breaks. Drought conditions, for example, result in less runoff of isotopically light rainfall to coastal environments where whelks live. If drought conditions occurred during summer in prehistoric Florida, the effect of relatively higher $\delta^{18}\text{O}_{\text{seawater}}$ values on $\delta^{18}\text{O}_{\text{shell}}$ values would offset the seasonal trend in kinetic fractionation, which favors the incorporation of isotopically lighter $\delta^{18}\text{O}$ in carbonate as temperature increases. Future studies could begin to address these alternative hypotheses with high-resolution, serial sampling of prehistoric *B. sinistrum* from birth to death, to test whether low amplitude is characteristic of late ontogeny only or occurs randomly with respect to ontogeny.

4.2. Prehistoric exploitation of shellfish at St. Joseph Bay

Of the eleven prehistoric shells analyzed, two (AA, II) indicate cessation of shell growth following a cooling trend, which is consistent with harvest any time between late autumn and the following spring. Four shells (CC, FF, GG, KK), however, exhibit warming trends leading up to the shell lip, with lip values including some of the isotopically lightest (warmest) of the Fort Walton samples. These four shells were most likely collected during summer. Isotope profiles of the remaining five shells are either difficult to interpret (DD, EE, HH) but consistent with spring harvest or have terminal values that are isotopically heavier (cooler) than peak summer values of the previous year but end on a warming trend (BB, JJ). Thus, we conclude that shellfish harvesting occurred during the warm half of the year, including during the time of peak summer temperatures, contrary to our initial hypothesis that summer habitation of the coastline would have been avoided due to increased hazards, disease risks, and pests associated with tropical and sub-tropical summers.

This finding is unexpected, particularly in light of the fact that ecological studies of *B. sinistrum* have shown that this species is most active on estuarine and bay tidal flats during the cool months and becomes increasingly rare as water temperatures increase (Paine, 1963). In other words, *B. sinistrum* should have been relatively easy for prehistoric peoples to collect in large quantities during the cool months but perhaps not during warmer conditions when the whelks are known to bury themselves in the sediment. The abundance of whelks in the middens and the occurrence of isotope profiles indicating summer collection from multiple shells suggest that warm season shellfish harvesting was not uncommon. Perhaps a shellfish harvest that included the warm season when *B. sinistrum* is least active and, therefore, least common helps explain how Fort Walton peoples managed to fish such a large-bodied, high trophic level species without driving it to extinction locally.

This new perspective helps clarify subsistence and settlement patterns of coastal Fort Walton peoples in northwest Florida. Recent archaeological research (White et al., 2002; White, 2005) at the Richardson's Hammock site reveals a high density of postmolds, which are probably the remnants of ephemeral housing or food-processing structures. Because shellfishing occurred between spring and autumn, we infer that the Richardson's Hammock site represents at least a semi-permanent fishing and shellfishing camp, where transient Native American populations foraged along the coastlines, relying heavily on estuarine resources. The retention of a

fisher–gatherer economy within a larger cultural sphere is not unique; prehistoric maritime foragers of northern Chile adopted goods and absorbed traditions of intra-societal, inland agriculturalists, but maintained their basic subsistence strategy (Roberts et al., 2014). Since our isotope data are ambiguous on the question of cool season shellfish foraging (autumn-to-spring), we are unable to reject the hypothesis that Fort Walton middens represent the year-round activities of a sedentary village. However, our results support the growing body of literature that indicates summer or perennial habitation of coastal Mississippi (Blitz et al., 2014), Georgia and Florida's subtropical Atlantic coast (e.g., Quitmyer et al., 1985; Sigler-Eisenberg and Russo, 1986; Quitmyer et al., 1997; Russo, 1991), as well as Florida's Gulf coast (Claassen, 1986; Quitymyer et al., 1997).

4.3. Implications for Fort Walton culture

Fort Walton culture was undoubtedly a part of the larger Mississippian interaction sphere. Inland, these people constructed temple mounds and villages, practiced maize agriculture and long-distance trade, shared Mississippian pottery and other artifact designs, and featured complex, ranked, and possibly stratified chiefdoms (White et al., 2012:231; Marrinan and White, 2007). Coastal Fort Walton culture is known to have featured all of these characteristics with the exception of maize agriculture, leading researchers to question whether the shell middens deposited by these foragers are the product of seasonal forays by inland peoples to the coast or represent a separate population entirely (Marrinan and White, 2007:297).

B. sinistrum collection schedules identified herein demonstrate that these prehistoric foragers, minimally, occupied and harvested shellfish in St. Joseph Bay during three seasons of the year. Agriculture, however, requires a tremendous time investment, usually occupying a period of six to eight months. In northwest Florida, maize is generally planted between March and April and is harvested during September or October (USDA, 1997). This time span overlaps with the warm-season collection period identified for shellfish harvest at St. Joseph Bay. Thus, time constraints alone suggest that it is unlikely that the inland farmers and coastal fishers represent some intra-annual migratory population(s). Instead, coastal Fort Walton cultures utilized semi-permanent (possibly year-round) coastal settlements to exploit aquatic fauna effectively, accessing the numerous year-round subsistence resources and operating independently of their inland farming contemporaries. Perhaps St. Joseph Bay fisher–foragers lived on and operated from a “central place,” selecting an optimal arrangement of camps to exploit coastal resources from both the Bay and Gulf, the two highest-ranking catchment patches in the area (Thomas, 2008). However, the presence of the brackish *Rangia* clam in Richardson's Hammock middens indicates that foragers occasionally traveled outside predicted “optimal” ranges to collect riverine resources, a collection strategy also observed at Sapelo Island (Andrus and Thompson, 2012).

Other evidence that interior and coastal peoples belonged to independent populations comes from the consideration of time and energy invested into constructing temple mounds and villages. It may not be realistic to expect that inland villagers would abandon their settlements seasonally to collect coastal resources, although periodic abandonment for durations longer than a season might occur under extreme environmental and/or socio-political pressures (e.g., maize crop failure; intra- or inter-cultural conflict). Additionally, it would have been impractical for inland villagers to travel long distances to harvest fish and shellfish at the coast, when terrestrial mammals, riverine aquatic species, and agricultural staples were generally plentiful at their home locations. It is also possible that

coastal groups may have moved dried or smoked shellfish, as well as the shells and other resources, inland in exchange for other commodities, even processed maize (c.f. Brown, 2003).

4.4. Paleoenvironmental change in St. Joseph Bay since Fort Walton time

Prehistoric St. Joseph Bay $\delta^{13}\text{C}_{\text{shell}}$ values were enriched by an average of 2.7‰ over modern St. Joseph Bay $\delta^{13}\text{C}_{\text{shell}}$ values (Fig. 5). This change highlights a dramatic decrease in mean $\delta^{13}\text{C}_{\text{shell}}$ over the past 700 years, without a concomitant change in $\delta^{18}\text{O}_{\text{shell}}$. Gillikin et al. (2006) showed that $\delta^{13}\text{C}_{\text{shell}}$ values can record large scale changes (>2‰) in the stable carbon isotopic composition of dissolved inorganic carbon ($\delta^{13}\text{C}_{\text{DIC}}$) in seawater. In general, there are three processes by which $\delta^{13}\text{C}_{\text{shell}}$ values for estuarine and marine molluscs have been shown to decrease over time. The first, called the Suess Effect (Friedli et al., 1986; Sonnerup et al., 1999) is the result of anthropogenic contributions to atmospheric CO_2 from the burning of isotopically light fossil fuels. This effect has been documented globally and is thought to account for a mean decline of 1.0–1.5‰ between pre- and post-industrial samples. The second effect, a change in local contributions to seawater DIC from plants with different $\delta^{13}\text{C}$ values (e.g., terrestrial C_4 or aquatic plants, mangrove C_3 plants), has been documented in many sub-tropical and tropical regions of the world (Saenger, 2002), including southwest Florida (Surge et al., 2003; Wang et al., 2011). Finally, construction activities that result in suspension of organic-rich sediments could drive down values of $\delta^{13}\text{C}_{\text{DIC}}$, thereby also reducing $\delta^{13}\text{C}_{\text{shell}}$. Such negative effects were documented on a coral growing in Florida Bay during the construction of the Florida East Coast Railway (Swart et al., 1996).

Even if the Suess effect can be assumed to account for approximately 1.0–1.5‰ of observed decline in $\delta^{13}\text{C}_{\text{shell}}$, other factors must be invoked to account for the total 2.7‰ decline. Ecological transformation of coastal vegetation from C_4 grasses to mangrove forests occurred in southwest Florida around the same time interval (Surge et al., 2003; Wang et al., 2011) but not northwest Florida, as this more seasonal latitude is not suitable for mangrove forests. However, the St. Joe Paper Company (now the St. Joe Co.) paper mill was constructed in 1936 along the shores of St. Joseph Bay at the city of Port St. Joe. A thirty-foot-deep channel was dredged from the deep portion of the bay to the mill site, and the mill itself was constructed on dredge spoil, making it easier for soil contaminants to spill into the bay waters. Moreover, a second canal was dug to connect the mill site with the Intracoastal Waterway ~3 miles outside of town, a shipping lane that doubled as an industrial wastewater deposit for local industries and municipalities in Port St. Joe (Ziewitz and Wiaz, 2004:52). Terrestrial plants are lighter than marine and estuarine plants isotopically (averaging –14.0 to –27.0‰) (Ehleringer, 1991), and their direct input into the bay via the paper mill channel probably lowered the isotopic composition of DIC in St. Joseph Bay. The sewage and pollution from coastal Port St. Joe likely compounded this effect. Further isotopic research on mid-twentieth century shells may shed more light on the timing and magnitude of changes to $\delta^{13}\text{C}$ in St. Joseph Bay and offer greater possibilities for the use of archaeological data to address modern issues of environmental change.

Acknowledgments

Modern *B. sinistrum* used in this study were collected under the conditions of Special Activity License # 045R-901 to G. Herbert (issued by the Florida Fish and Wildlife Commission). The authors wish to thank Sigma Xi for funding; I. Quitmyer, R. Tykot, and B. Weisman for providing insight during the formative stages of this

project; Z. Atlas and E. Goddard for managing our carbonate sample analysis; K. Kemp for editing our site map, and two anonymous reviewers for their comments on an earlier version of the manuscript.

References

- Abbott, R.T., 1954. American Seashells. Van Nostrand, New York.
- Andrus, C.F.T., 2011. Shell midden sclerochronology. *Quat. Sci. Rev.* 30, 2892–2905.
- Andrus, C.F.T., Thompson, V., 2012. Determining the habitats of mollusk collection at the Sapelo Island shell ring complex, Georgia, USA using oxygen isotope sclerochronology. *J. Archaeol. Sci.* 39, 215–228.
- Ashley, K.H., White, N.M. (Eds.), 2012. Late Prehistoric Florida, Archaeology at the Edge of the Mississippian World. University Press of Florida, Gainesville.
- Bar-Yosef Mayer, D.E., Leng, M.J., Aldridge, D.C., Arrowsmith, C., Gümüş, B.A., Sloane, H.J., 2012. Modern and early-middle Holocene shells of the freshwater mollusc *Unio*, from Çatalhöyük in the Konya Basin, Turkey: preliminary palaeoclimatic implications from molluscan isotope data. *J. Archaeol. Sci.* 39, 76–83.
- Blitz, J.H., Andrus, C.F.T., Downs, L.E., 2014. Sclerochronological measures of seasonality at a Late Woodland mound on the Mississippi Gulf Coast. *Am. Antiq.* 79, 697–711.
- Brown, I.W. (Ed.), 2003. Bottle Creek: a Pensacola Culture Site in South Alabama. University of Alabama Press, Tuscaloosa.
- Claassen, C., 1986. Shellfishing seasons in the prehistoric southeastern United States. *Am. Antiq.* 51, 21–37.
- Claassen, C., 1991. Normative thinking and shell-bearing sites. *Archaeol. Method Theory* 3, 249–298.
- Culleton, B.J., Kennett, D.J., Jones, T.L., 2009. Oxygen isotope seasonality in a temperate estuarine shell midden: a case study from the CA-ALA-17 on the San Francisco Bay, California. *J. Archaeol. Sci.* 36, 1354–1363.
- Davis Jr., R.A., 1997. Geology of the Florida coast. In: Randazzo, A., Jones, D. (Eds.), *The Geology of Florida*. University Press of Florida, Gainesville, pp. 155–168.
- Dietl, G.P., 2003a. Interaction strength between a predator and dangerous prey: *Sinistrolfulgur* predation on *Mercenaria*. *J. Mar. Biol. Ecol.* 289, 287–301.
- Dietl, G.P., 2003b. Coevolution of a marine gastropod predator and its dangerous bivalve prey. *Biol. J. Linn. Soc.* 80, 409–436.
- Ehleringer, J.R., 1991. $^{13}\text{C}/^{12}\text{C}$ fractionation and its utility in terrestrial plant studies. In: Coleman, D.C., Fry, B. (Eds.), *Carbon Isotope Techniques*. Academic Press, San Diego, pp. 187–206.
- Epstein, S., Buchsbaum, R., Lowenstam, H.A., Urey, H.C., 1953. Revised carbonate-water isotopic temperature scale. *Bull. Geol. Soc. Am.* 64, 1315–1325.
- Erlanson, J.M., 1988. The role of shellfish in prehistoric economies: a protein perspective. *Am. Antiq.* 53, 102–109.
- Friedli, H., Lötscher, H., Oeschger, H., Siegenthaler, J., Stauffer, B., 1986. Ice core record of the $^{13}\text{C}/^{12}\text{C}$ ratio of atmospheric CO_2 in the past two centuries. *Nature* 324, 237–238.
- Geary, D.H., Brieske, T.A., Bemis, B.E., 1992. The influence and interaction of temperature, salinity, and upwelling on the stable isotopic profiles of strombid gastropod shells. *Palaios* 7, 77–85.
- Gillikin, D.P., Lorrain, A., Bouillon, S., Willenz, P., Dehairs, F., 2006. Stable carbon isotopic composition of *Mytilus edulis* shells: relation to metabolism, salinity, $\delta^{13}\text{C}_{\text{DIC}}$ and phytoplankton. *Org. Geochem.* 37, 1371–1382.
- Goggin, J., 1952. Space and Time Perspective in Northern St. Johns Archaeology, Florida, vol. 47. Yale University Pub. Anthropol., New Haven.
- Goodwin, D.H., Cohen, A.N., Roopnarine, P.D., 2010. Forensics on the half shell: a sclerochronological investigation of a modern biological invasion in San Francisco Bay, United States. *Palaios* 25, 742–753.
- Greenawalt-Bosell, J., Frazer, T.K., Jacoby, C.A., Arnold, W.S., 2007. Mortality and exploitation rate estimates for the recreational bay scallop fishery off the Gulf Coast of Florida, USA. *N. Am. J. Fish. Manag.* 27, 1230–1242.
- Grossman, E.L., Ku, T.-L., 1986. Oxygen and carbon isotope fractionation in biogenic aragonite: temperature effects. *Chem. Geol.* 59, 59–74.
- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* 4. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.
- Jones, D.S., Arthur, M.A., Allard, D.J., 1989. Sclerochronological records of temperature and growth from shells of *Mercenaria mercenaria* from Narragansett Bay, Rhode Island. *Mar. Biol.* 102, 225–234.
- Jones, T.L., 1991. Marine resource value and the priority of coastal settlement: a California perspective. *Am. Antiq.* 56, 419–443.
- Kennett, D.J., Voorhies, B., 1996. Oxygen isotopic analysis of archaeological shells to detect seasonal use of wetlands on the southern Pacific coast of Mexico. *J. Archaeol. Sci.* 23, 689–704.
- Kim, S.-T., O'Neil, J.R., Hillaire-Mercel, C., Mucci, A., 2007. Oxygen isotope fractionation between synthetic aragonite and water: influence of temperature and Mg^{2+} concentration. *Geochim. Cosmochim. Acta* 71, 4704–4715.
- Kirby, M.X., Spero, H.J., Soniat, T.M., 1998. Stable isotope sclerochronology of Pleistocene and recent oyster shells (*Crassostrea virginica*). *Palaios* 13, 560–569.
- Kraeuter, J.N., Castagna, M., Bisker, R., 1989. Growth rate estimates for *Busycos carica* in Virginia. *J. Shellfish Res.* 8, 219–222.
- Krantz, D.E., Jones, D.S., Williams, D.F., 1984. Growth rates of the sea scallop, *Placopecten magellanicus*, determined from the $^{18}\text{O}/^{16}\text{O}$ record in shell calcite. *Biol. Bull.* 167, 186–199.

- Lécuyer, C., Reynard, B., Martineau, F., 2004. Stable isotope fractionation between mollusc shells and marine waters from Martinique Island. *Chem. Geol.* 213, 293–305.
- Mannino, A.M., Spiro, B.F., Thomas, D.K., 2003. Sampling shells for seasonality: oxygen isotope analysis on shell carbonates of the inter-tidal gastropod *Monodonta lineata* (da Costa) from populations across its modern range and from a Mesolithic site in southern Britain. *J. Archaeol. Sci.* 30, 667–679.
- Marrinan, R., White, N.M., 2007. Modeling Fort Walton culture in northwest Florida. *Southeast. Archaeol.* 26, 292–318.
- Meehan, B., 1977. Hunters by the seashore. *J. Hum. Evol.* 6, 363–370.
- Meehan, B., 1982. Shell Bed to Shell Midden. Australian Institute of Aboriginal Studies, Canberra.
- Mikell, G.A., 1992. The Fort Walton Mississippian variant on the northwest Florida Gulf coast. *Southeast. Archaeol.* 11, 51–65.
- Miller, J.J., 1988. *An Environmental History of Northeast Florida*. University Press of Florida, Gainesville.
- Paine, R.T., 1963. Trophic relationships of 8 sympatric gastropods. *Ecology* 44, 63–73.
- Quitmyer, I.R., Hale, H.S., Jones, D.S., 1985. Paleoseasonality determination based on incremental shell growth in the hard clam, *Mercenaria mercenaria*, and its implications for the analysis of three southeast Georgia coastal shell middens. *Southeast. Archaeol.* 4, 27–40.
- Quitmyer, I.R., Jones, D.S., 1997. The sclerochronology of hard clams, *Mercenaria* spp., from the southeastern U.S.A.: a method of elucidating the zooarchaeological records of seasonal resource procurement and seasonality in prehistoric shell middens. *J. Archaeol. Sci.* 24, 825–840.
- Roberts, A., Pate, F.D., Petruzzelli, B., Carter, C., Westaway, M.C., Santoro, C.M., Swift, J., Maddern, T., Jacobsen, G.E., Bertuch, F., Rothhammer, F., 2014. Retention of hunter-gatherer economies among maritime foragers from Caleta Vitor, northern Chile, during the late Holocene: evidence from stable carbon and nitrogen isotopic analysis of skeletal remains. *J. Archaeol. Sci.* 40, 2360–2372.
- Rupert, F.R., 1991. *Geology of Gulf County, Florida*. Florida Geological Survey, Tallahassee.
- Russo, M., 1991. A method for the measurement of season and duration of oyster collection: two case studies from the prehistoric south-east U.S. coast. *J. Archaeol. Sci.* 18, 205–221.
- Saenger, P., 2002. *Mangrove Ecology, Silviculture and Conservation*. Springer Press, New York.
- Sassaman, K.E., 2004. Common origins and divergent histories in the early pottery traditions of the American Southeast. In: Saunders, R., Hays, C.T. (Eds.), *Early Pottery: Technology, Function, Style, and Interaction in the Lower Southeast*. The University of Alabama Press, Tuscaloosa, pp. 23–39.
- Saunders, R., Russo, M., 2011. Coastal shell middens in Florida: a view from the archaic period. *Quat. Int.* 239, 38–50.
- Schmidt, G.A., Bigg, G.R., Rohling, E.J., 1999. Global Seawater Oxygen-18 Database. <http://data.giss.nasa.gov/o18data/>.
- Schöne, B., Rodland, D.L., Wehrmann, A., Heidel, Oschmann, W., Zhang, Z., Fiebig, J., Beck, L., 2007. Combined sclerochronologic and oxygen isotope analysis of gastropod shells (*Gibbula cineraria*, North Sea): life-history traits and utility as a high resolution environmental archive for kelp forests. *Mar. Biol.* 150, 1237–1252.
- Shalack, J.D., Power, A.J., Walker, R.L., 2011. Hand harvesting quickly depletes intertidal whelk populations. *Am. Malacol. Bull.* 29, 37–50.
- Sigler-Eisenberg, B., Russo, M., 1986. Seasonality and function of small sites on Florida's central-east coast. *Southeast. Archaeol.* 5, 21–31.
- Sonnerup, R.E., Quay, P.D., McNichol, A.P., Bullister, J.L., Westby, T.A., Anderson, H.L., 1999. Reconstructing the oceanic ¹³C suess effect. *Glob. Biogeochem. Cycles* 13, 857–872.
- Strauss, J., Oleinik, A., Swart, P., 2014. Stable isotope profiles from subtropical marine gastropods of the family Fasciolaridae: growth histories and relationships to local environmental conditions. *Mar. Biol.* 161, 1593–1602.
- Surge, D.M., Lohmann, K.C., Goodfriend, G.A., 2003. Reconstructing estuarine conditions: oyster shells as recorders of environmental change, southwest Florida. *Estuar. Coast. Shelf Sci.* 57, 737–756.
- Swart, P.K., Healy, G.F., Dodge, R.E., Kramer, P., Hudson, J.H., Halley, R.B., Robblee, M.B., 1996. The stable oxygen and carbon isotopic record from a coral growing in Florida Bay: a 160 year record of climatic and anthropogenic influence. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 123, 219–237.
- Thomas, D.H., 2008. Native American landscapes of St Catherine's Island, Georgia. In: *Anthropological Papers*, vol. 88. American Museum of Natural History.
- Thompson, V.D., Andrus, C.F.T., 2011. Evaluating mobility, monumentality, and feasting at the Sapelo Island shell ring complex, USA using oxygen isotope sclerochronology. *Am. Antiq.* 76, 315–344.
- U.S. Dept. of Agriculture, 1997. Usual Planting and Harvesting Dates for U.S. Field Crops. http://www.nass.usda.gov/Publications/Usual_Planting_and_Harvesting_Dates/uph97.pdf.
- Wang, T., Surge, D., Walker, K.J., 2011. Isotopic evidence for climate change during the vandal minimum from *Ariopsis felis* otoliths and *Mercenaria campechiensis* shells, southwest Florida, USA. *Holocene* 21, 1081–1091.
- Waselkov, G.A., 1987. Shellfish gathering and shell midden archaeology. *Adv. Archaeol. Method Theory* 10, 93–210.
- Wefer, G., Berger, W.H., 1991. Isotope paleontology: growth and composition of extant calcareous species. *Mar. Geol.* 100, 207–248.
- Wefer, G., Killingley, J.S., 1980. Growth histories of Strombid snails from Bermuda recorded in their O-18 and C-13 profiles. *Mar. Biol.* 60, 129–135.
- White, N.M., 2003a. Testing partially submerged shell middens in the Apalachicola estuarine wetlands, Franklin County, Florida. *Fla. Anthropol.* 56, 15–45.
- White, N.M., 2003b. Late Archaic in the Apalachicola/lower Chattahoochee valley, northwest Florida, southwest Georgia, and southeast Alabama. *Fla. Anthropol.* 56, 69–90.
- White, N.M., 2005. Archaeological Survey of the St. Joseph Bay State Buffer Preserve, Gulf County, Florida. Report to Apalachicola National Estuarine Research Reserve, East Point, and the Division of Historical Resources, Tallahassee.
- White, N.M., 2011. Middle Woodland and protohistoric Fort Walton at the lost Chipola Cutoff mound, northwest Florida. *Fla. Anthropol.* 64, 241–273.
- White, N.M., 2014. Apalachicola Valley riverine, estuarine, bayshore, and saltwater shell middens. *Fla. Anthropol.* 67, 77–104.
- White, N.M., Fitts, M.B., 2001. Richardson's Hammock Site, 8Gu10, Gulf County, Florida: Report of the 2000 Archaeological Investigations. Report to Apalachicola National Estuarine Research Reserve, Eastpoint, and Bureau of Archaeological Research, Division of Historical Resources, Tallahassee.
- White, N.M., Rodriguez, N.D., Smith, C., Fitts, M.B., 2002. St. Joseph Bay Shell Middens Test Excavations, Gulf County, Florida, 2000-2002. Report Submitted to Division of Historical Resources, Tallahassee.
- White, N.M., Du Vernay, J.P., Yuellig, A.J., 2012. Fort Walton culture in the Apalachicola valley, northwest Florida. In: Ashley, K.A., White, N.M. (Eds.), *Late Prehistoric Florida. Archaeology at the Edge of the Mississippian World*. University Press of Florida, Gainesville, pp. 231–274.
- Widmer, R.J., 1988. *The Evolution of the Calusa: a Non-agricultural Chiefdom on the Southwest Coast of Florida*. The University of Alabama Press, Tuscaloosa.
- Willey, G.R., 1949. Washington D.C., Reprinted University Press of Florida, Gainesville, 1999. *Archaeology of the Florida Gulf Coast*. Smithsonian Miscellaneous Collections, 113.
- Ziewitz, K., Wiaz, J., 2004. *Green empire: the St. Joe Company and the Remaking of Florida's Panhandle*. University Press of Florida, Gainesville.