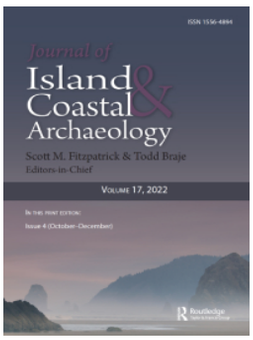

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Terrestrial snails from archaeological sites as proxies for relative sea level on the Gulf Coast of Florida, USA

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ABSTRACT

Archaeological evidence for local environmental change is obscured by the tendency for humans to remove natural resources from places of procurement and deposit them elsewhere, sometimes at great distance. This is especially problematic for changes in relative sea level, which clearly affected the inhabitability of low-elevation coastal landforms but not necessarily the regional availability of resources of cultural or economic value. Needed are proxies for relative sea level from non-dietary taxa. One genus of terrestrial snails, *Truncatella*, offers good potential in this respect because of its specific niche at the interface between seawater and land. However, like food resources displaced by people, *Truncatella* shells are displaced by storms and redistributed landward of the coastline. Distinguishing between autochthonous and allochthonous deposits is essential to inferring relative sea level from the occurrence of this taxon alone. To this end, assemblages of *Truncatella* shell from stratified sites along the north Gulf Coast of Florida, USA are compared to associated archaeological snails of other taxa and to snail shells from the wrack of proximate foreshores to infer changes in relative sea level over the past four millennia. Variation in the morphology of shorelines and in the accumulation rates of archaeological midden mitigates any direct relationship between terrestrial snail frequencies and sea level, but the results of this study suggest that our approach can be applied to other non-dietary taxa occupying marginally terrestrial niches to refine estimates for sea level derived from the sedimentary records of geological cores.

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Sea-level change; archaeomalacology; coastal settlement

Introduction

The impact of sea-level rise on coastal settlement is a matter of considerable interest in this era of accelerated global warming. Archaeologists worldwide have access to material records of coastal dwelling over prior millennia, some of which may be relevant to conditions going forward (e.g., Bailey and Cawthra 2021; Sandweiss and Kelley 2012). However, much of the material record of any archaeological site consists of matter that was relocated by people from places of procurement, notably the remains of species of

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plants and animals that factored into human diets or technologies (e.g., Ainis et al. 2014; Peacock et al. 2012). As is the case for paleoenvironmental reconstructions in general, data used to infer changes in sea levels must come from sources independent of human intervention.

In this paper, we explore the potential use of non-dietary terrestrial snails from coastal archaeological sites in Florida, USA to infer changes in relative sea level over the past four millennia. One taxon in particular offers good potential for tracking the shifting interface between coastal land and tidal water. Species of the genus *Truncatella* colonize the upper foreshores of subtropical and tropical coasts in the wrack zone (Hubricht 1985, 4), the accumulation of organic matter and other debris at the high-tide line.[1] It follows that *Truncatella* shells recovered from archaeological sites are a potential proxy for relative sea level. However, a direct relationship between the frequency of shells of this taxon and sea level is unexpected because storm surges displace wrack landward from the upper foreshores of coastal landforms (Marquardt and Walker 2013, 816; Palmiotto 2015). To discriminate between allochthonous (secondary) and autochthonous (primary) deposits, we compare the frequency of *Truncatella* shell from archaeological contexts to those of other non-dietary taxa of terrestrial snails whose distribution is also affected, if not determined, by tidal conditions. We also examine terrestrial snails from modern wrack samples to establish a demographic profile for *Truncatella* in reproductive contexts proximate to archaeological sites we sampled. We find that the ratio of juvenile to adult *Truncatella* is particularly diagnostic of primary depositional context.

Although *Truncatella* are pantropical in distribution, the utility of this species for inferring sea level is limited to low-gradient coastlines with foreshore morphology conducive to the accumulation of wrack. We thus do not propose that species of this genus alone are sufficient to model sea-level variations, but suggest that the method used here can be applied to other non-dietary taxa occupying marginally terrestrial niches to refine estimates for sea level derived from sedimentary records and related proxies taken from geological cores.

Samples of terrestrial snails reported here come from archaeological deposits of offshore islands along the northern Gulf Coast of Florida (Figure 1). Since 2009, the Lower Suwannee Archaeological Survey has located and tested sites dating from the fifth millennium BP, many of which are currently eroding along active shorelines (Sassaman et al. 2017). Offshore island sites in the study area include stratified sequences of buried surfaces, anthropogenic deposits (i.e., middens), and occasional sandy strata of presumed storm events. Bulk samples from three such sites on two offshore islands (North Key, Seahorse Key) contained thousands of shells of *Truncatella* and other terrestrial snails whose variation in frequency and association arguably register changes in sea level (Figure 2). Details on these samples and the snails they contained follow a review of the ecology of *Truncatella* and archaeological occurrences of this unusual snail.

Truncatella in natural and archaeological deposits

Few terrestrial snails have an ecological niche as specific as members of the genus *Truncatella*. Distributed across tropical and subtropical coastal regions of both

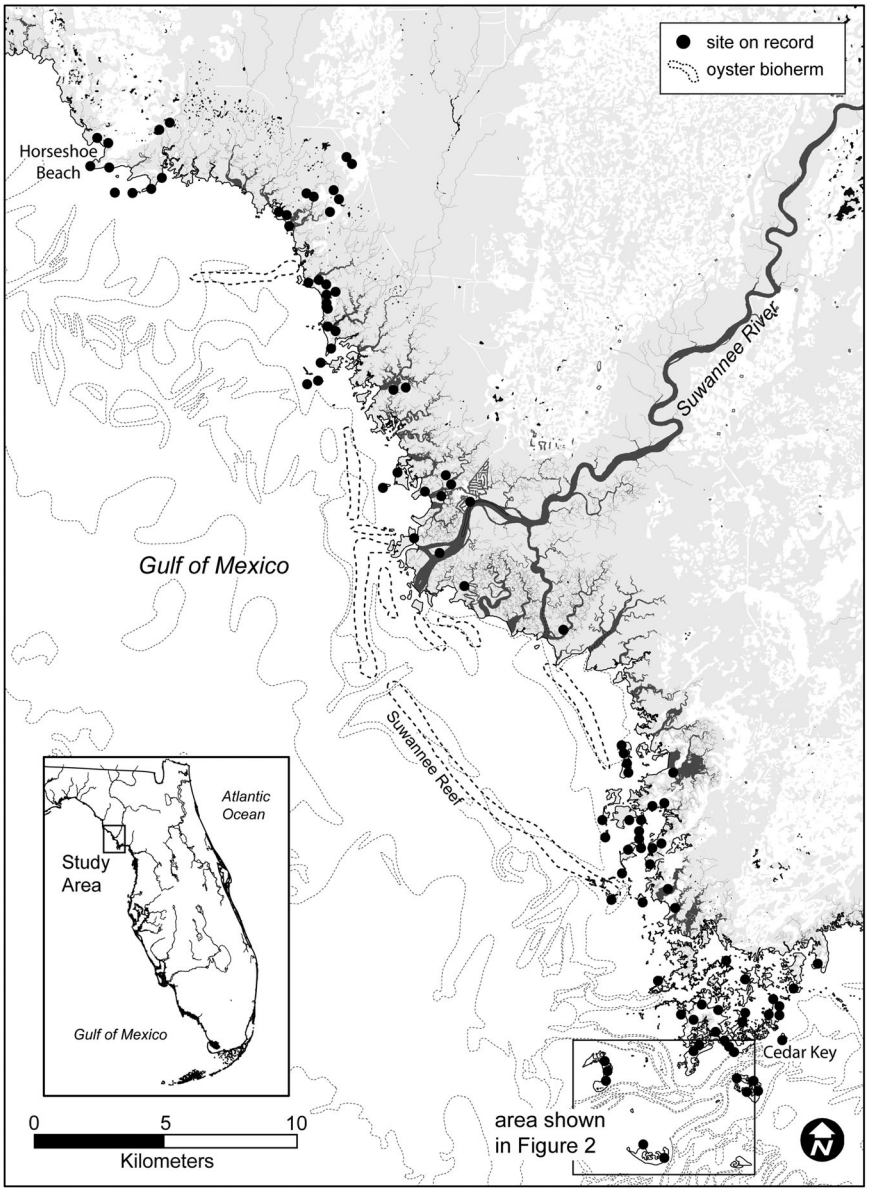

Figure 1. Locator map of the study area of the Lower Suwannee Archaeological Survey, showing archaeological sites and offshore islands (Figure 2 inset) producing abundant assemblages of *Truncatella* and other terrestrial snail shells.

hemispheres, all but two of 30 species of *Truncatella* inhabit the detritus that accumulates at or above the high-tide line of shorelines in the wrack zone. Several species have been documented in Florida, the most common being *T. pulchella* (Hubricht 1983, 1985, 4–6, 56). According to Hubricht (1985, 4), another Florida species, *T. floridana*, is found in both high-tide wrack and "in the storm-strand, which may be 100 ft or more back from the high-tide strand." He adds that this is the only species of *Truncatella* that survives in storm debris, which dries out and is leached of salt by rain. However, *T.*

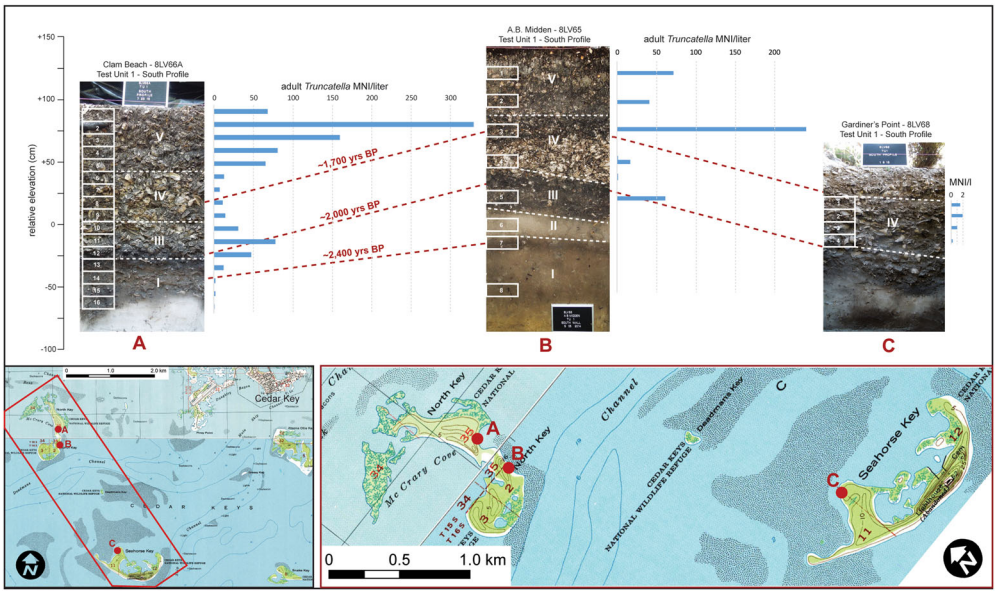

Figure 2. Stratified archaeological sites on North Key and Seahorse Key from which *Truncatella* shell and other terrestrial snail shell were collected. Note locations of bulk samples taken from profiles, chronological phases (Roman numerals), and the relative frequency (MNI/liter of bulk sample) of adult *Truncatella* shells in 2-mm fractions. Dashed lines between profiles mark roughly contemporaneous surfaces.

floridana is currently treated as a synonym of *T. pulchella* (Rosenberg 1996). It is not clear if any species of *Truncatella* in Florida thrives in storm-surge wrack far from the shore, but they certainly occur in such debris, and presumably washed in with it, rather than colonizing it from proximate, fully terrestrial habitats. Another Florida species, *T. caribaeensis,* clearly occupies the high-tide wrack zone along the Gulf (Reeve 1842). Both *T. caribaeensis* and *T. pulchella* are known to exist in our study area along the northern Gulf Coast (Burch and Van Devender 1980; Clench and Turner 1948). Given the common niche of these species and the purpose of this study, we hereafter refer to them collectively as *Truncatella*.

As pervasive as *Truncatella* may be in the coastal tropics and southern temperate regions across the globe, they are not present everywhere, even when conditions are favorable for their propagation. According to Clench and Turner (1948, 158), they usually exist in isolated colonies that were established by flotsam, proliferated for a while, and later dispersed by storms. Because *Truncatella* occupies a portion of the shoreline that is occasionally wetted by salt water (i.e., supratidal zone), its niche is only marginally terrestrial. They are attracted to the wrack that accumulates at the high-tide line after water recedes. Beyond the food potential of its rotting vegetation, the wrack zone provides fertile grounds for reproduction. Adults lay their egg capsules in supratidal detritus, which is rich in cellulose that can be digested by baby snails (Schmelz and Portell 2016).

Truncatella are notable for their ribbed and decollate shells (Figure 3). As juveniles, those whorls end with an apical point, however as they mature from juvenile to adult,

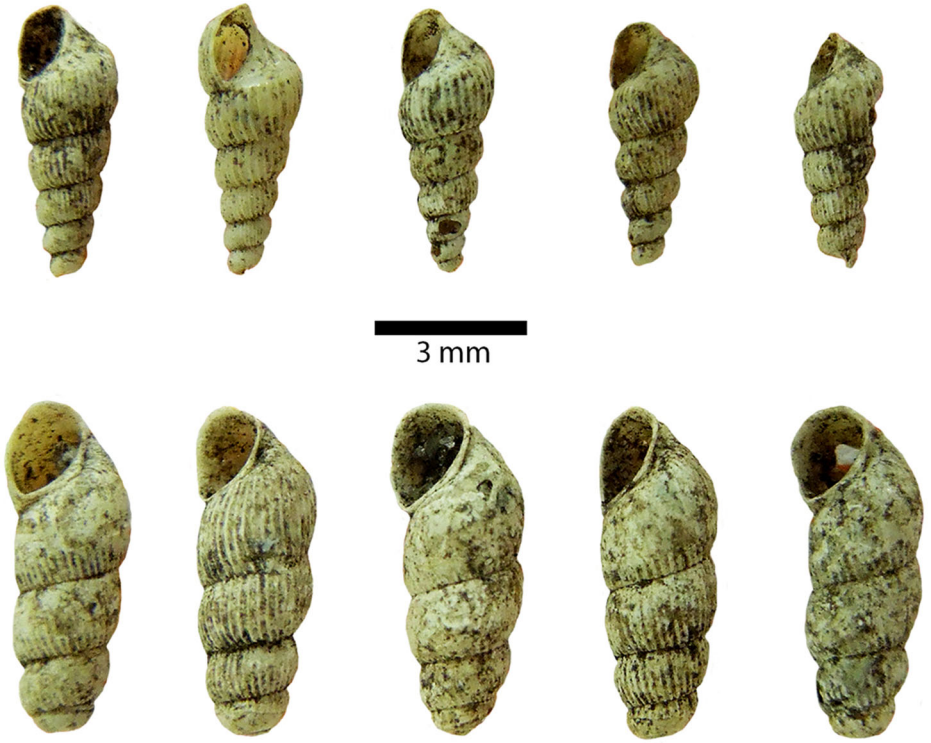

Figure 3. Examples of juvenile (top row) and adult (bottom row) *Truncatella* shells from Clam Beach (8LV66a), Sample 2.

the snail forms a "septum, a rounded and concave plug, in the region of the mid-whorls. Fracture of the early whorls takes place along the outer margin of this septum where it joins the side of the shell" (Clench and Turner 1948, 157). The apex of their shell breaks off at about the fourth or fifth whorl, leaving a smooth seal for the remainder of the shell (Burch and Van Devender 1980).

This genus is also notable for a peculiar form of locomotion. They are commonly called Looping Snails and they move similarly to a looper caterpillar (Fretter and Graham 1962, 584). Their proboscis first reaches out from the shell and searches for a firm grip. After a stable grip is established, the foot is released and it slides up to meet the proboscis. Each "step" takes around four seconds and therefore they are able to move around 16 "steps" in a minute, a distance of around 20–25 mm (Pilsbry and Brown 1914).

Little is known about the self-propelled movements of *Truncatella* in and out of wrack and mobile swimming and floating larval stages are suppressed in the group (Fretter and Graham 1962). *Truncatella* and their eggs are presumably passively moved with wrack that is displaced by tidal flow. Wrack that forms twice a lunar month just beyond the elevation of mean high-high tide, during spring tides, provides two weeks of undisturbed opportunity for *Truncatella* to forage and spawn. Barring storms, subsequent spring tides will wet stranded detritus without appreciable displacement, enabling *Truncatella* to continue inhabiting wrack it colonized. Optimum salinity for species of

this genus is between 11.0 and 20.7 parts per thousand (ppt), which is indicative of intertidal to marine conditions (Gaiser et al. 2006, 246).

To the extent that the natural distribution of *Truncatella* tracks its wrack-zone habitat, its shells have potential to serve as a proxy for relative sea level. Unfortunately, a transgressive sea has submerged pre-4500 BP habitat and the shells contained therein, truncating the historical record. However, in places where deposits accreted vertically through natural and anthropogenic agents, records of encroaching sea over centuries and millennia are potentially preserved as stratified deposits. In these cases, we are challenged to calibrate the pace of vertical accretion with the rate of sea-level rise. Hypothetically, shells of *Truncatella* would be found in strata that were deposited proximate to the shoreline, and they would be absent in strata deposited distant from the shore. This expectation has guided the interpretation of *Truncatella* distributions at various sites in the study area (e.g., McFadden 2015; Palmiotto 2015; Sassaman et al. 2015, 77).

Under the force of storm surge, wrack is expected to be displaced landward well beyond the range of even spring tides. It is likely that live *Truncatella*—along with the shells of dead snails—would be redeposited landward with displaced wrack. It is unlikely, however, that other live *Truncatella* would colonize the wrack of a storm surge deposited far from the supratidal zone. For that to be the case, live *Truncatella* would have to inhabit fully terrestrial habitat, which it does only marginally. Rather, *Truncatella* shell found some distance from active shorelines would alternatively indicate: (a) higher-than-present sea levels; (b) individuals displaced from shoreline habitat by storm surge but unable to propagate; or (c) another agent of transport, such as humans collecting seaweed from the wrack zone and delivering it to places landward (Palmiotto 2015; see also Ainis et al. 2014).

Realizing the potential of archaeological *Truncatella* shell as a proxy for sea level means controlling for all other variables that affect its distribution and density. To this end, we consider here a series of observations from archaeological contexts to assist in discriminating between secondary and autochthonous deposition, notably associations with the shells of other terrestrial snail taxa. We compare these observations with data on controlled samples of modern wrack in proximity to archaeological deposits, all of which contain shells of *Truncatella* and other mollusks. Juvenile *Truncatella* from modern wrack provide further grounds for distinguishing reproductive habitat from places of secondary deposition. Moreover, geomorphic differences among modern collection sites afford some control over the effects of foreshore slope and associated escarpments on shell accumulation. Our analysis begins with a description of the stratified archaeological sites containing *Truncatella* and associated snail shells from the northern Gulf Coast of Florida in the context of sea-level rise.

Stratified archaeological deposits and rising sea on the northern Gulf Coast of Florida

The northern Gulf Coast of Florida has witnessed over 80 m of sea-level rise and 250 km of shoreline retreat since people arrived in the late Pleistocene (Donoghue 2011; Joy 2019). Unfortunately, the archaeological record of early coastal living in this region

is truncated at about 4500 years ago, when sea level rose to within a few meters of its current stand. In general, coastal sites predating 4500 years are either inundated by the sea or were long ago eroded, although offshore surveys are too few to gauge the scope of an underwater record (Faught 2004). Notwithstanding this bias, the Lower Suwannee Archaeological Survey (LSAS) launched in 2009 with the intent of sampling the diminishing remains of terrestrial coastal sites to develop data on human responses to changing sea levels (Sassaman et al. 2017).

Today the Lower Suwannee study area consists of an open-marine biome of salt marshes, seagrass beds, oyster beds and reefs, and tidal creeks along a crenulated shoreline with many low-relief islands, tree hammocks, and relict dunes. Surface geology in the area is influenced by structural variations in shallow, low-relief limestone substrate (Davis 1997, 165–6). In addition to karst-related features such as embayment depressions, hammocks formed on bedrock nubs, and marsh islands on flooded bedrock planes, the Lower Suwannee area contains a large number of relict dunes that formed during the Pleistocene (Ivester, Leigh, and Godfrey-Smith 2001). Besides offering high, dry land for human settlement, dunes provided a source of sediment for marsh aggradation and the formation of sandy shoals on which seagrass beds thrived.

Programs of geological coring along the northern Gulf Coast document changes in relative sea level over the past few millennia (Goodbred, Hine, and Wright 1998; Hine et al. 1988; McFadden 2015, 2016; Wright et al. 2005). None of these studies has detected evidence for higher-than-present stands during the Holocene (see Donoghue 2011; Walker, Stapor, and Marquardt 1995), nor evidence for major regressions in recent millennia, like those observed in south Florida (Stapor, Mathews, and Lindfors-Kearns 1991; Walker, Stapor, and Marquardt 1994) and the south Atlantic (e.g., Colquhoun and Brooks 1986; DePratter and Howard 1981; Gayes et al. 1992). However, documented in these studies are multiple instances of overstepping of the shoreline, when the sea transgressed rapidly after multi-century periods of relative stability.

The punctuated nature of shoreline transgression in the study area is owed largely to occasional imbalances between marsh aggradation and rising sea. As water rose at the end of the Pleistocene, the relatively flat shelf of the Gulf was quickly flooded, bringing the shoreline within 8 km of its current position about 5400 years ago. As documented by Wright et al. (2005), the rate of rise slowed considerably after this time, leading to the formation of oyster reefs that trapped marine and other biogenic sediments landward. For a millennium, sediment accretion kept pace with rising sea until about 4400 years ago, when the shoreline was overstepped and the sea transgressed another 2 km. Reefs formed proximate to the new shoreline by 3600 years ago. The modern marsh system took form after about 2350 years ago, following a transgression of unspecified magnitude. Another transgression of 2–3 km occurred several centuries later (Goodbred, Hine, and Wright 1998), when the shoreline reached its near-modern configuration (Wright et al. 2005, 634).

In sum, the study area has long been vulnerable to changes in sea level, primarily because of the low gradient of its bedrock platform. Transgression of the shoreline was eventful, even as sea level rose incrementally, because of imbalances among freshwater input, oyster health, and sediment supply. Like marshes in the study area, places of repeated human occupation tended to aggrade over time as deposits accumulated,

keeping pace with rising sea. Among the better stratified sites are those on the offshore islands of the Cedar Keys, particularly North Key, from which large assemblages of *Truncatella* and other terrestrial snails have been recovered. These were among the first landforms to be impacted by rising sea in the Holocene and are thus some of the best archives we have for change elapsing over millennia.

Snail shell in archaeological deposits and wrack

Details on the stratigraphy and chronology of sites on offshore islands of the study area are provided in online Supplemental File 1. Also provided in this supplement are the details of sampling and processing archaeological matrix for analysis of terrestrial snails, as well as the methods we used to identify and quantify snail shell.

Archaeological snail shell

Available for analysis are the shells of terrestrial snails and other matter from 30 bulk samples of archaeological matrix collected from the stratified deposits described in Supplemental File 1. Identified and counted in total were the shells of 38,271 terrestrial snails distributed across 13 taxa. Slightly more than half of these (50.3%, $n = 19{,}245$) consist of the shells of *Truncatella*. Identifications reported below come from the 2-mm fraction of all samples, and from the 1-mm fraction of a subsample.

Snail shells in the 2-mm fraction

Table 1 provides an inventory of terrestrial snail shells identified in the 2-mm fraction of all samples, divided by site. The shells of adult *Truncatella* dominate all but a few samples, notably all of those from Gardiner's Point and the basal strata of the other two sites. Juvenile *Truncatella* are not well represented in the 2-mm fraction owing to their small size; although juvenile shells longer than 2 mm are occasionally recovered in mesh this size, the width of all juvenile shells is <2 mm and thus most pass through when oriented perpendicular to the screen. As shown below, the 1-mm fraction captures these individuals, often in abundance.

Nine other taxa of terrestrial snails are counted in the 2-mm fractions of the collective sample, six at appreciable frequency and ubiquity. Two of these—*Polygyra septemvolva* and *Melampus bidentatus*—mirror *Truncatella* in its overall trend toward greater frequency over time. Shells of both of these taxa increase in number after about ~2100 years ago (Phase III; see Supplemental File 1 for phase designations), lending support for an overstep event that resulted in shoreline transgression and the development of a salt-marsh habitat in proximity to the sample locations. *Polygyra septemvolva*, the Florida flatcoil, is usually found on Gulf shorelines above the high strand line and on the margins of salt marshes; it enjoys slightly salty areas (Hubricht 1985, 36). *Melampus bidentatus*, the common marsh snail, is an amphibious salt-marsh dweller of bays and estuaries. It can survive for extended periods upon vegetation above or beyond the water, and consumes rotten vegetation, especially salt-marsh cordgrass. Although adult *Melampus bidentatus* can survive in a terrestrial environment, its larvae require aquatic habitat.

Table 1. Absolute frequency of terrestrial snail shell >2mm by taxon and bulk sample at Clam Beach, A. B. Midden, and Gardiner's Point, Levy County, Florida.

	Clam Beach (8LV66a)																
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Phase	V	V	V	V	V	IV	IV	IV	IV	III	III	III	I	I	I	I	Total
Volume (L)	11.0	11.0	9.0	13.0	14.0	14.5	10.0	15.0	12.0	16.0	16.0	6.0	4.0	7.0	7.0	7.0	172.5
Truncatella Adult	745	3623	1437	1043	908	178	72	159	169	489	1239	282	48	11	10	1	10,414
Truncatella Juvenile	22	104	10	50	56	15	3	6	4	10	18	8					306
Polygyra septemvolva	85	83	42	60	42	8	3	4	11	20	101	17	6	1	3	2	488
Melampus bidentatus	5	36	10	20	12		1	4	8	5		1					102
Oligyra orbiculata	9	29	9	10	21	10	1		2	6	12	3					112
Lobosculum pustula	46	11	10	12	13	9	5	6	17	65	77	10	4	1	8		294
Glyphyalinia umbilicata	47	8	32	47	98	56	13	29	36	79	68	11	5		1		530
Zonitoides arboreus	6	3	8	9	4	2		1	1	4	8			1		1	48
Strobilops texasiana	5			1				1				1					8
Euglandina sp.	4			1	4				1								10
Total	974	3897	1558	1253	1158	278	98	210	249	678	1523	333	63	14	22	4	12,312
MNI/liter	88.5	354.3	173.1	96.4	82.7	19.2	9.8	14.0	20.8	42.4	95.2	55.5	15.8	2.0	3.1	0.6	71.4
MNI *Truncatella*/liter	69.7	338.8	160.8	84.1	68.9	13.3	7.5	11.0	14.4	31.2	78.6	48.3	12.0	1.6	1.4	0.1	62.1

	A.B. Midden (8LV65)											Gardiner's Point (8LV68)				
Sample	X1*	X2*	1	2	3	4	5	6	7	8		1	2	3	4	
Phase	V	V	V	V	IV	IV	III	II	I	I	Total	IV	IV	IV	IV	Total
Volume (L)	4.0	9.0	9.0	6.0	9.0	12.0	9.0	10.0	9.0	11.0	77.0	12.0	11.0	10.0	12.0	45.0
Truncatella Adult	20	968	583	244	2158	197	546	4	3		4723	18	21	10	3	52
Truncatella Juvenile		16	1	3	20	3	7				50		1			1
Polygyra septemvolva	13	86	97	32	90	11	61		1		391	50	27	13	3	93
Melampus bidentatus	2	7	7	3	6	1	1				27		1			1
Oligyra orbiculata	11	10	19	17	10		2				69	17	9	6		32
Lobosculum pustula	33	8	8	16	19	2	16				102	3				3
Glyphyalinia umbilicata	2	22	41	4	21	5	13				108	24	2	4		30
Zonitoides arboreus	2	7	2	9	1						21	9	2			11
Strobilops texasiana				1							1	1				1
Euglandina sp.	1	1									2	1	1			2
Total	84	1125	758	329	2325	219	646	4	4	0	5494	123	64	33	6	226
MNI/liter	21.0	125.0	84.2	54.8	258.3	18.3	71.8	0.4	0.4	0.0	71.4	10.3	5.8	3.3	0.5	5.0
MNI *Truncatella*/liter	5.0	109.3	64.9	41.2	242.0	16.7	61.4	0.4	0.3	0.0	62.0	1.5	2.0	1.0	0.3	1.2

*Samples from discontinuous strata near surface not shown in Figure 2.

Other taxa common in the 2-mm fraction includes one, *Oligyra orbiculata*, that is absent in strata predating 2100 BP and thereafter fluctuates around moderate to low frequency. Commonly known as the globular drop, *Oligyra orbiculata* (synonym *Helicina orbiculata*) is semiarboreal and a calciphile that prefers sunny locations. It sometimes occurs in wooded locations, but it is not as abundant as it is in open habitat (Hubricht 1985, 3).

Most of the remaining taxa occupy woodland niches and were recovered in the oldest strata of Clam Beach but not at A.B. Midden, and in later strata at generally greater, but irregular frequency. The most frequent are shells of the Texas glyph, *Glyphyalinia umbilicata*, which is "usually found under logs and leaf litter in woods bordering streams" (Hubricht 1985, 25). Also common are shells of *Lobosculum pustula*, the grooved liptooth, a species common to Florida and the coastal regions of Georgia and South Carolina. It is "usually found in sandy woods, under logs and dead palm fronds, and in leaf litter" (Hubricht 1985, 38). Occurring at modest frequency in the 2-mm samples are shells of *Zonitoides arboreus*, the quick gloss. According to Hubricht (1985, 32), it is "usually found on rotting logs and in floodplains, as well as upland woods." The recovery bias of 2-mm mesh sharply affects the frequency of a fourth woodland species, *Strobilops texasiana*, the southern pinecone. Members of this minute species are "usually found in sandy woods, under logs and dead palm fronds, and in leaf litter" (Hubricht 1985, 38). Finally, a few shells of a woodland taxon, *Euglandina* sp., appeared in the later strata of all three sites.

Snail shells in the 1-mm fraction

Two-millimeter mesh is sufficient to capture most of the shells of adult *Truncatella*, but it is too coarse for juveniles of this species, and it biases against the recovery of several other taxa. To alleviate this bias, we sorted the 1-mm fractions of select bulk samples to identify and quantify terrestrial snails. Selected for further analysis were eight samples that contained large numbers of *Truncatella* shell, six from Clam Beach and two from A.B. Midden.

Provided in Table 2 are the frequencies of terrestrial snail shell by taxa and sample, along with ratios of shell per liter and *Truncatella* shell per liter. Taxa in this table are ranked by frequency, from high to low. Frequencies include all shells >1 mm, including shells >2 mm listed in Table 1. An additional 20,247 shells ranging between 1 and 2 mm in size bring the >2-mm count of 10,590 shells for these eight samples to a grand total of 30,837.

The frequency of adult *Truncatella* shells in the 1-mm fractions of all eight samples ($n = 10{,}366$) increased by 13.1% over its 2-mm fraction counterparts ($n = 9167$). In contrast, the shells of juveniles increased by more than an order of magnitude, from 176 to 3025. The ratio of adults to juveniles in these samples ranges from 1.42 to 5.46, and averages 3.22. As we discuss in our analysis of modern wrack samples (Supplemental File 2), adult:juvenile ratios have good potential for discriminating between autochthonous and secondary deposits.

The shells of two taxa absent in the 2-mm fractions occurred in large numbers in 1-mm fractions. The most numerous ($n = 12{,}260$) are shells of *Hawaiia sp*. Members of this taxon are distributed widely across the eastern and central US on bare ground or in leaf litter (Hubricht 1985, 29). Shells of the bottleneck snaggletooth, *Gastrocopta contracta*, are not as numerous but still abundant ($n = 2928$). The niche of this species is the leaf litter, logs, and other debris of open woodland, particularly where loose

Table 2. Absolute frequency of terrestrial snail shell >1mm by taxon and bulk sample at Clam Beach (CB) and A. B. Midden (AB), Levy County, Florida.

Sample Phase	CB-2 V	CB-3 V	CB-7 IV	CB-8 IV	CB-11 III	CB-12 III	AB-3 IV	AB-5 III	Total
Volume (L)	11.0	9.0	10.0	15.0	16.0	6.0	9.0	9.0	85.0
Truncatella Adult	3793	1473	74	174	1416	322	2497	617	10,366
Truncatella Juvenile	1020	468	52	88	530	59	627	181	3025
Hawaiia sp.	2189	2074	678	1059	2599	309	2712	640	12,260
Gastrocopta contracta	613	318	48	128	1286	265	232	38	2928
Glyphyalinia umbilicata	281	121	59	148	289	41	85	41	1065
Polygyra septemvolva	122	84	3	4	101	19	90	61	484
Lobosculum pustula	59	41	9	21	114	15	19	16	294
Oligyra orbiculata	46	17	1	4	23	7	18	4	120
Melampus bidentatus	55	13	2	6	12	6	12	5	111
Strobilops texasiana	23	18	3	11	24	11	6	14	110
Zonitoides arboreus	16	12		3	9		1	2	43
Glyphyalinia sp.	12								12
Gastrocopta pellucida/rupicola	11								11
Euglandina sp.	6	1		1					8
Total	8246	4590	929	1647	6403	1054	6299	1619	30,837
MNI/liter	749.64	510.00	92.90	109.80	400.19	175.67	699.89	179.89	362.79
MNI *Truncatella*/liter	437.55	215.67	12.60	17.47	121.63	63.50	347.11	88.67	157.54

limestone rock provides cover (Leonard 1950, 30). The stratigraphic distribution of shells of neither taxa show clear trends over time, but they have substantial presence in the organically-enriched strata of Phase III at both sites, where *Truncatella* first appear as more than a trace. As with most other taxa, standardized frequencies for these minute snails drop in the accreted shell midden of Phase IV at Clam Beach, and then rise again in Phase V, but not as high as in Phase III, in contrast to *Truncatella*.

Other taxa of the 2-mm fraction that are better represented in the 1-mm fraction include *Glyphyalinia umbilicata*, *Lobosculum pustula*, and *Strobilops texasiana*. All of these woodland species are common in Phase III contexts, decrease in adjusted frequency in Phase IV, then vary in Phase V but never rise to the level of *Truncatella* frequencies.

Relative counts for most of the remaining taxa in the 1-mm fraction mirror those of the 2-mm fraction. A noteworthy exception is the increased frequency of *Melampus bidentatus* in Phase III strata, indicative evidently of greater proximity to marsh-edge habitat following the ca. 2350 BP overstep event documented in geological cores (Wright et al. 2005).

Snail shells in wrack

In order to interpret frequency variations among archaeological *Truncatella* and other terrestrial snails as a proxy for relative sea level, we collected samples of wrack from the proximate shorelines of all three archaeological sites. Sampling methods and results of identification are reported in online Supplemental File 2. Briefly summarizing these findings, wrack contains the shells of juvenile *Truncatella* in equal proportion to those of adults owing to the fact that *Truncatella* reproduce in wrack. Moreover, modern wrack assemblages consist of higher fractions of shells of salt-marsh taxa and lower fractions of taxa associated with leaf litter than do archaeological assemblages. As

discussed below, these differences are useful for distinguishing between foreshore and storm-surge deposits.

Discussion

Variations in the proportions of snail taxa in wrack and archaeological assemblages reflect the differences between autochthonous and allochthonous deposition, respectively. For wrack assemblages, this is simply a matter of real-time observation; for archaeological assemblages, the differences enable inferences about depositional context, supported further by the premise that archaeological deposits, in their own real time, did not accumulate in close proximity to the upper foreshores of the study islands. Rather, the foreshores proximate to the test excavations of the last decade encroached upon these sites as shorelines eroded with rising sea over millennia. Simultaneously, archaeological deposits accreted vertically as sea level rose, keeping up with or even outpacing rising water. Add to these factors changes over time in the morphology of shorelines that affected the accumulation of wrack and we have a complex array of variables that conspire to mitigate any direct relationship between the occurrence of archaeological *Truncatella* and relative sea level.

Rather than bemoan the complexity of this relationship, we suggest that it opens potential for refining inferences about relative sea level not possible with geological data alone, particularly as it relates to human settlement and the use of coastal landforms. We are certain that archaeological remains of taxa people routinely collected to eat (e.g., shellfish, fish, plants, terrestrial game) can be deceiving about local ecological conditions because people traveled from places of settlement to sources of food. Assuming that food was collected only locally does not consider the need for people to settle in places safely removed from tidal water, which means back and up from the foreshore. The dune islands of the study area afforded many options for siting settlements in places less vulnerable, if not invulnerable to flooding. We know that travel by watercraft from places of settlement to patches of marine food was at times routine; the Phase I assemblages of the study area, as noted in Supplemental File 1, attest to this. Barring the collection of wrack for non-dietary purposes, these sorts of practices are not expected to have displaced the taxa of snails inhabiting wrack, notably *Truncatella*. Rather, the shells of *Truncatella* in archaeological deposits presumably arrived by water, specifically storm surges and perhaps also super tides (e.g., perigean spring tides, which occur between six and eight times a year). The question remains: can *Truncatella* shells from archaeological deposits provide a useful proxy for relative sea level?

The answer to this question, we argue, is yes, but only if data on other terrestrial snails are consulted, and only if juvenile *Truncatella* are included. As our results show, the latter requires a recovery fraction of no greater than 1 mm. The 2-mm-fraction assemblages we presented here are sufficient to benchmark the first appearance of *Truncatella* at about 2100 years ago and its general increase over time. They are not, however, sufficient to infer changes in relative sea level over the past two millennia.

In the paragraphs that follow, we collate data on terrestrial snails, archaeological stratigraphy, and shoreline morphology to infer relative sea level for surfaces evident in the profile of the test unit at Clam Beach, three of which are buried. In this exercise, the

archaeological deposits at A.B. Midden and Gardiner's Point provide independent data to assess the inferences made possible by the Clam Beach sequence.

Starting at the top of the Clam Beach profile, at the modern surface, terrestrial snails are abundant and diverse. Lacking a 1-mm sample of the modern surface, we are unable to say how closely the surface assemblage of Clam Beach compares to the wrack samples collected only a few meters away. Bulk samples immediately below the modern surface, however, provide a point of reference for the accumulation of midden during Phase V, post-1295 BP. Samples CB-1 and CB-2 have adult:juvenile *Truncatella* ratios of 3.7 and 3.1, respectively, roughly three times the ratio of nearby wrack (both 1.1). Including all *Truncatella*, the respective ratios of marsh:leaf litter taxa[2] are 1.6 and 0.8, well below the ratios of nearby wrack (3.4 and 7.5). The difference is owed in large measure to high frequencies of *Hawaiia sp*. and *Gastrocopta contracta* in the archaeological samples.

In comparing the two samples of Phase V, a trend toward increased proximity to the shoreline is evident among a few taxa, notably *Melampus bidentatus*, although the increased ratio of adult to juvenile *Truncatella* suggests the shoreline was actually closer in the earlier stages of this phase than it is today. This seeming contradiction could be explained by the effects of vertical relief between the Phase V stratum and the upper foreshore of Clam Beach (+50 cm), in which case the shells of *Truncatella* and other taxa inhabiting wrack were displaced by storm surge. Vertical displacement aside, Phase V occupation of Clam Beach elapsed during a multi-century cool and dry period known as the Vandal Minimum by archaeologists working in southwest Florida (Marquardt 2010; Wang, Surge, and Walker 2013) and as the Dark Ages Cold Period by geoscientists working in Europe (Helama, Jones, and Briffa 2017; Waltgenbach et al. 2021). The dating of this interval varies across regions and its cause is uncertain (see Helama, Jones, and Briffa 2017 for a review). What is certain is that large coastal settlements on the mainland of the study area were abandoned around 1300 years ago, when the sea level may have dropped by about 50 cm (Walker, Stapor, and Marquardt 1994), or at least stop rising (Goodbred, Hine, and Wright 1998; Jackson and Pluckhahn 2020). Local communities responded by breaking into smaller groups and dispersing across the area (Jenkins 2021), including to offshore islands, some of which have since eroded from subsequent sea-level rise. It follows that the abundance of adult *Truncatella* in the Phase V stratum may be attributed to secondary deposition due to storm surge (*sensu* Marquardt and Walker 2013, 816), an effect that no doubt increased in frequency as sea levels returned to earlier levels. It bears emphasizing that no geological coring in the region has produced evidence of a downturn in sea during this time (Goodbred, Hine, and Wright 1998; Hine et al. 1988; McFadden 2015, 2016; Wright et al. 2005), but many lines of archaeological data point to this outcome, as do the *Truncatella* shells of Clam Beach.

The snail assemblages of Phase IV at Clam Beach give mixed signals with respect to relative sea level, although they compare favorably to modern wrack assemblages in the ratio of adult to juvenile *Truncatella*. At roughly 70–80 cm below the modern surface, samples CB-7 and CB-8 have adult:juvenile *Truncatella* ratios of 1.4 and 2.0, respectively. The ratio of marsh:leaf litter taxa, however, is only about 0.2 for either sample, owing in large measure to limited counts for *Polygyra septemvolva* and *Melampus bidentatus*. We suspect that the context of deposition (i.e., accreted midden, as opposed to a buried surface) may account for the mixed signals; indeed, the overall frequency of snails in these

samples is low, save for shells of *Hawaiia sp*., a taxon adapted to wide ranging conditions. Omitting *Hawaiia sp*. from the ratio of marsh:leaf litter increases values fivefold.

The coeval sample from A.B. Midden (AB-3) provides perspective on the accumulation of snails on a relatively stable surface during Phase IV (ca. 1700 BP). The ratio of adult to juvenile *Truncatella* is the highest of all archaeological samples (4.0). The marsh:leaf litter ratio is nearly even (1.1). Again, the shells of *Hawaiia sp*. are especially abundant, strongly skewing this ratio toward the low end. In most respects, the Phase IV assemblage at A.B. Midden mirrors the Phase V assemblage of Clam Beach, especially in the large assemblages of adult *Truncatella*. Although the Phase IV surface at A.B. Midden is about 60 cm below the modern surface, its elevation is equal to the Phase V stratum at Clam Beach. We cannot infer relative sea level from this alignment alone, but suggest it shows that sea was at roughly the same level during both phases.

The Phase IV deposit at Gardiner's Point lies at the same elevation as its counterpart at Clam Beach, but it contains far fewer shells per liter than any bulk sample collected. We hasten to add that none of the 1-mm fraction of Gardiner's Point samples was analyzed, but even at the 2-mm fraction, the density of terrestrial snails (5.0/liter) is merely 7% of the values for North Key sites (both 71.4/liter). Still, shells of *Polygyra septemvolva* increase in frequency through the Phase IV sequence to become the dominant taxon in the upper-most sample (Table 1). This taxon is also dominant among translucent shells in one of two wrack samples from Gardiner's Point, the same sample with the lowest ratio of adult:juvenile *Truncatella* shell (0.2) of all wrack samples. Reflected by these numbers, we suggest, is the transgression of sea prior to Phase IV that brought salt-marsh habitat in proximity to the site but not enough to establish good habitat for *Truncatella*. In this case, the convex morphology of the shoreline likely precluded the dense accumulation of wrack, as it does today.

The Phase III surface at Clam Beach is the first surface on which abundant *Truncatella* accumulated. As with the younger surfaces at this site, the ratios of adult:juvenile *Truncatella* are high (2.7, 5.5) and the ratio of marsh:leaf litter taxa are low (0.5, 0.6). Given the strong parallels between the snail assemblages of Phase V and III surfaces at Clam Beach, the vertical differential between the two provides our first absolute estimate of former sea level, specifically 1.25 m lower during Phase III (ca. 2000 BP) than during Phase V (post-1295 BP). The Phase III assemblage from A.B. Midden corroborates this inference.

Preceding Phase III was an overstep event (Phase II) that delivered sand to the Phase I surface of A.B. Midden, but evidently not to Clam Beach, perhaps due to the difference in elevation. We do not have 1-mm fractions to consult for these oldest surfaces but note that the few *Truncatella* shells that occur are not accompanied by large numbers of shells of salt-marsh taxa. Proximity to neither salt marsh nor wrack is indicated by these assemblages, suggesting that sea level was in excess of −1.25 m before the overstep event of ca. 2350 BP, when the modern marsh system took form (Wright et al. 2005).

In sum, the shells of *Truncatella* and other terrestrial snails in stratified archaeological context are useful proxies for changes in relative sea level provided controls are in place for the effects of shoreline morphology and the accretional rate of anthropogenic deposits. Modern wrack samples provide a basis for inferring that none of the archaeological deposits were proximate to upper foreshores at the time they formed. It follows that *Truncatella* shells were displaced from wrack habitat to places up and back from foreshores by storm

surges and super tides, not all of which coincided with major transgressions as documented in geological cores. The ratio of adult:juvenile *Truncatella* has good potential to serve as a proxy for distance to wrack habitat among sample fractions no coarser than 1 mm. The appearance and growing frequency of salt-marsh taxa tracks *Truncatella* closely. It does not necessarily signal the retreat of shorelines but certainly the encroachment of brackish water conditions as the sea rose. Storm surge displacing wrack landward likely accounts for most *Truncatella* shells in archaeological deposits, where juveniles mature to adults but are incapable of reproducing successfully for lack of suitable habitat.

We do not have a good benchmark for gauging the level of the sea at the time the most recent archaeological deposits formed (post-1295 BP), but we infer it was at least 50 cm below modern elevation given the high ratio of adult:juvenile *Truncatella* it contains. Furthermore, because surfaces of Phase V at Clam Beach and Phase IV at A.B. Midden lie at the same elevation, and because they hold similar snail assemblages, we infer that sea level was similar between these two periods (−50 cm). This does not mean, however, that sea level was stable over this time. During the interim period (ca. 1550–1300 BP) sea level was evidently higher, perhaps close but not above the current level. Offshore islands were not occupied during this 250-year interval; rather, settlement was concentrated at large civic-ceremonial centers on the coastal mainland, the closest being Shell Mound (8LV42), about 12 km north (Sassaman et al. 2020). Before then, many of the *Truncatella* that accumulated on the Phase IV surface of A.B. Midden were likely delivered by storm surges associated with the transgressive event(s) accounting for this 250-year period of relatively high sea level. To the extent that sea level was down 50 cm from modern levels just prior to this transgression, the underlying Phase III surface was exposed when sea level was down another 1.25 m, or 1.75 m total. This estimate is about 50 cm greater than that provided by Wright et al. (2005) for ca. 2000 BP. This discrepancy most likely relates to the difference between mapping the facies of salt marsh, which is a direct measure of relative sea level, and benchmarking the accumulation of storm-surge deposits, which are, by definition, elevated above tidal range.

Conclusion

Many more data points are needed to refine inferences about changes in relative sea level from archaeological assemblages of terrestrial snails, but here we hope to have demonstrated the potential of *Truncatella* shell for this purpose. The specific coastal niche of this taxon lends itself to reconstructions of sea level changes, although not in the sense that archaeological *Truncatella* is a direct proxy for sea level. Our samples of modern wrack confirm that *Truncatella* inhabit the upper foreshores of sea islands in our study area along the northern Gulf Coast of Florida, where they also reproduce. Fractions of wrack no coarser than 1 mm include the shells of juvenile *Truncatella* in equal proportion to those of adults. The shells of salt-marsh species are common in wrack too, as are lesser numbers of taxa that prefer wooded habitat, which, in two of the three study sites examined here, extends up to the upper foreshore of the island. Archaeological assemblages of *Truncatella* shell with a high ratio of adults to juveniles signal distance from upper foreshores. The ratio of salt-marsh:leaf litter snail taxa is expected to covary inversely with the adult:juvenile *Truncatella* ratios, although the close proximity of mixed

hardwood and palm forest to the foreshores of offshore islands precludes such a simple relationship. Still, limited numbers of any *Truncatella* shell coincides with limited counts of salt-marsh taxa to benchmark sea levels much lower than today and, conversely, when they first appear in appreciable frequency, enable sound inferences about the transgression of sea that supported the development of the modern marsh system.

Gauging the magnitude of transgressive events from archaeological snail shell is a matter of triangulating among the rate of accretion of archaeological deposits, the differential between the upper foreshores and elevations of surface on which archaeological material accumulated, and the configuration of the shoreline, among other variables. The calculus here is admittedly complex and subject to considerable error. However, we are optimistic about the potential for terrestrial snails to inform about changing sea level that is not subject to the cultural filter of subsistence practices (*sensu* Peacock et al. 2012). Targeted food resources like oyster, clam, fish, turtle, and more were clearly transported over considerable distances from places of collecting to places of consuming and discarding, rendering the use of such resources as proxies for sea level questionable. As noted in Supplemental File 1, the faunal assemblage of Phase I occupations at North Key would lead one to infer that sea level was close to modern levels at 4000 BP, when in fact it was well over 1 m lower.

Finally, the geographic range of *Truncatella* would seem to impose limits on the relevance of our findings to coastal archaeological records elsewhere. However, we suggest that our approach can be applied to other non-dietary taxa occupying marginally terrestrial niches to refine estimates for sea level derived from the sedimentary records of geological cores. Few taxa may be as niche-specific as *Truncatella*, but terrestrial snail species adapted to salt-marsh habitats are potential non-dietary proxies for sea level, provided, that is, one can distinguish between autochthonous and allochthonous deposits. Along low-gradient shorelines like the Florida Gulf Coast, super tides and storm surges displace near-shore deposits landward, not unlike the spatial displacement attending human subsistence practices. Controlling for shoreline morphology, rates of midden accumulation, and other variables that affect depositional regimes is admittedly challenging. It may not often be possible to develop reliable proxies for sea level from terrestrial snails or other non-dietary taxa, but they are needed to circumvent the potential biases of displacing food resources from places of procurement.

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Supplemental Files

Supplement A: Stratigraphy and Chronology of Study Sites and Methods for Quantifying Terrestrial Snails.
Supplement B: Truncatella and Other Terrestrial Snails from Wrack.

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Notes

1. The wrack zone, or wrack line, is the accumulation of seagrass, shells, and other debris deposited along shorelines at high tide. Wrack zones are common to beach strands, but are also found along the edges of mangroves, salt marshes, and other coastal settings. A wrack zone forms when debris carried onshore by a rising tide is stranded in a line parallel to the shore as the tide recedes. The location of a wrack zone varies with short- and long-term changes in tidal range, and also by intermittent events like storms that carry debris farther landward than normal tides. Along sandy beaches, spring tides promote the development of erosional escarpments (i.e., wave-cut scarps) where wrack accumulates in large volume and can remain relatively stable until displaced by storms. It follows that the distribution and density of wrack is determined not only by tidal range and storm surge, but by the configuration of the foreshore (Barreiro et al. 2011).
2. Following the review of habitat for all terrestrial snails identified in this study, "marsh" species include *Polygyra septemvolva* (more specifically, marsh edge) and *Melampus bidentatus*. "Leaf litter" species refer to all taxa with wooded habitat or any niche involving leaf litter and/or fallen trees: *Oligyra orbiculata, Hawaiia Sp., Lobosculum pustula, Gastrocopta contracta, Glyphyalinia umbilicata, Strobilops texasiana, Zonitoides arboreus.* Archaeological sites on North Key are situated in wooded habitat of oaks, red cedar, and palm that extends to the shoreline and overhangs the wrack zone. The Gardiner's Point site, in contrast, is more open, consisting of coastal scrub and palms, many fallen in recent years as the shoreline has continued to erode.

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SUPPLEMENT A

Sassaman, Kenneth E., et al. Terrestrial Snails from Archaeological Sites as Proxies for Relative Sea Level on the Gulf Coast of Florida, USA.

Stratigraphy and Chronology

We have sampled three sites on two of the offshore islands of Cedar Keys with 1 x 2-m units that revealed sequences of human activity resulting in stratified accumulations of shell, vertebrate fauna, artifacts, charcoal, and other material, anthropogenic and otherwise (Figure 2 main text; see Mahar [2015a, 2015b, 2019] for technical details). All locations of testing were between 3 and 12 m landward of the modern wrack zone at the time of excavation. Two sites on North Key have stratified sequences spanning about 4,000 years, while the third site, on Seahorse Key, holds the remnant of a short-term, but stratified shell midden dating to about 1,800 years ago. A total of 14 AMS assays on wood charcoal from strata and features at these sites provide a reasonably detailed chronology. Table 1 displays these age estimates by stratigraphic context at Clam Beach (8LV66a), A.B. Midden (8LV65), and Gardiners Point (8LV68).

Table 1. AMS Age Estimates and Associated Data by Chronological Phase and Stratigraphic Context at Clam Beach, A.B. Midden, and Gardiners Point, Levy County, Florida.

Phase	Stratum	Conv. C14	cal BP (2-σ)	Context	Notes
V	CBI	1130±30	1173–962	accreted midden	
	CBII	1310±30	1295–1180	accreted midden	*Truncatella* abundant
IV	ABIII	1670±30	1685–1530	accreted midden	
	CBII	1690±30	1695–1535	accreted midden	
	GP.F2	1700±30	1697–1544	pit	
	ABIV	1790±30	1817–1620	accreted midden	
	GPIII	1820±30	1825–1635	accreted midden	*Truncatella* present
III	ABV	1940±30	1945–1825	stable surface	
	CBIII	2010±30	2035–1890	stable surface	*Truncatella* appear
II	ABVI	2090±30	2144–1991	sand deposition	*no Truncatella*
I	CBIV	2440±30	2700–2357	stable surface	
	ABVII	2400±30	2680–2350	stable surface	
	CB.F2	2730±30	2879–2761	pit	
	CB.F3	3660±30	4145–3850	pit	no *Truncatella*

Note: CB = Clam Beach (8LV66a); AB – A.B. Midden (8LV65); GP = Gardiners Point (8LV68)

Given the combination of age estimates and stratigraphic sequencing, the depositional histories of these three sites can be divided into five phases (not to be equated with cultural-historical phases). A full inventory of terrestrial snails recovered from bulk samples is provided in the main text, but we first describe the nature of deposition over these five phases with particular attention to the appearance and distribution of *Truncatella* shell (Figure 1).

Phase I. From ca. 4150–2350 B.P., sites on North Key supported intermittent but repeated human activity on relatively stable surfaces. Older age estimates come from pit features dating one millennium apart, but emanate roughly from surfaces dated as late as 2700–2350 B.P. at both A.B. Midden and Clam Beach. *Truncatella* shell is virtually absent in

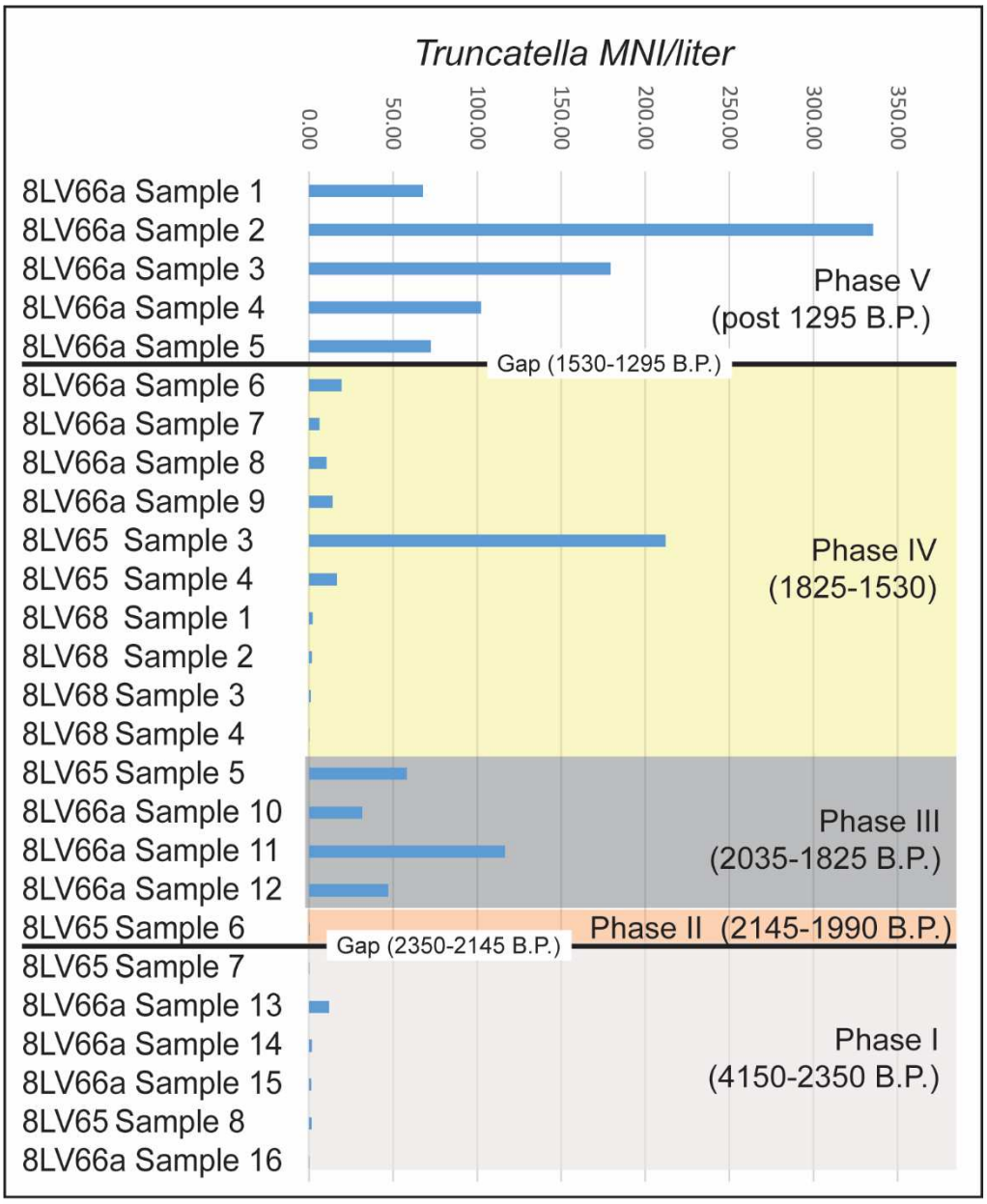

Figure 1. Composite relative frequency distribution (MNI/liter) of *Truncatella* shell (>2 mm) from archaeological bulk samples at three sites by chronological phase.

both places, suggesting that the location was not proximate to the shoreline and thus sea level was lower, as is expected from geological coring. Despite lower sea level, the high frequency of shells of high-salinity invertebrate taxa (e.g., lightning whelk [*Sinistrofulger sinistrum*, formerly *Busycon sinistrum*] and tulip shell [*Fasciolaria* spp.]) shows that people traveled by watercraft several kilometers seaward to collect preferred resources. Other sites in the study area provide supporting evidence for the inference that early land use was oriented perpendicular to the coast, with settlements sited deep on the landward side of the intertidal zone (McFadden 2015; McFadden and Palmiotto 2012).

Phase II. A stratum of largely sterile sand at A.B. Midden dated to 2144–1991 B.P. is interpreted as a storm surge deposit. The absence of this stratum at the other two sites may be due to taphonomic or pedogenetic factors, but irrespective of its pervasiveness, this deposit roughly coincides with an inferred overstep event ca. 2350 B.P. (Wright et al. 2005). This stratum contained only a trace of *Truncatella* shell. A similar sand unit at an island site 40 km to the north (Bird Island) returned a calibrated age estimate on charcoal of 2310–2120 B.P. (McFadden and Palmiotto 2012). It lacked *Truncatella* shell altogether.

Phase III. Organic midden formed on relatively stable surfaces at both A,B. Midden and Clam Beach from 2035–1825 B.P. *Truncatella* occurs on these surfaces in appreciable numbers for the first time. The appearance of this near-shore taxon supports the inference that the sand unit of Phase II indexes an overstep event that resulted in higher relative sea level. It is on this surface that thick shell midden accumulated in Phase IV.

Phase IV. Five assays date to the collective range of 1825–1530 B.P. and they come from charcoal at all three sites. This is a tight cluster of dates for what appears to be pervasive use of landforms for deposition of shellfish and other remains. Notable among the shellfish remains are large numbers of marine gastropod shells, especially those of lightning whelk but also tulip shell and pear whelk (*Fulguropsis spirata*). Unlike the earlier occurrences of high-salinity species, when sea level was down, the abundance of such taxa in these later deposits signals increased proximity to productive habitat, notably oyster bioherms and seagrass beds. *Truncatella* are present throughout but generally in low frequency. The subdued frequencies may be owed to the accretional nature of this stratum, whereby oyster shell and other material accumulated vertically to outpace rising sea and attendant storm surge.

Phase V. Following a hiatus of roughly 230 years when settlement focused on a few large sites on the mainland, activity on the offshore islands picked up again after ca. 1295 B.P. *Truncatella* are numerous in near-surface deposits at A.B. Midden and Clam Beach, suggesting that water levels were not much lower than today. Rates of sand shoal aggradation remain unknown, causing us to temper any inference about water levels based on this one proxy alone. Relatedly, diminished numbers of lightning whelk should not be taken literally as diminished habitat for this taxon because late in the history of the region, lightning whelk were delivered to places like Raleigh and Richards islands for reduction into disk beads (Barbour et al. 2019).

In sum, stratified deposits at three island sites encase many potential proxies for changing sea levels over the past 4,000 years, notably abundant shells of a marginally terrestrial snail. As shown in Figure 1, *Truncatella* shells vary wildly in frequency (standardized by volume of excavated matrix as MNI/liter) even as they tend to increase over time. If interpreted literally, the distribution of *Truncatella* shell would suggest that the shoreline was distant from these sites before about 2,350 years ago (Phase I). For the next few centuries the shoreline was proximate (Phases II and III), but evidently receded by 1800 B.P. (Phase IV). Continuing this literal reading, another pulse of water (storm surge) at ca. 1700 B.P. brought abundant *Truncatella* shells ashore, but apparently did not result in a net rise in sea. That would take place four centuries later, after 1300 B.P. (Phase V), when the modern shoreline took form proximate to these sites.

These inferred events do not fully comport with the history of sea-level change reconstructed from geological coring (Goodbred et al. 1998; Hine et al. 1988; McFadden 2015, 2016; Wright et al. 2005). The increase in *Truncatella* shell after about 2,100 years ago corroborates some of this history, but its frequency thereafter turns as much on site formation processes as it does proximity to the shoreline. At a minimum, we need to consider not only the

distance between sites of anthropogenic deposition and the shoreline, but also the relative elevation, duration, and stability of surfaces; the rate at which materials accumulated on surfaces; and how accreted surfaces affected the landward displacement of wrack and the *Truncatella* it contained. Associations between *Truncatella* shell and the shells of other terrestrial snails hold good potential for addressing these variables.

Methods of Processing, Identifying, and Quantifying Snail Shell

Available for analysis are the shells of terrestrial snails and other matter from 30 bulk samples of archaeological matrix collected from the stratified deposits described above. Sixteen of these samples came from a continuous 160-cm-long column (graduated in 10-cm increments) of the south wall of the test unit at Clam Beach; another 10 came from strata observed along various walls of the unit at A.B. Midden; the final four consist of a continuous but short, 40-cm column of the south wall of the unit at Gardiners Point. Collected for analysis was a total of 305.5 liters of matrix. Individual samples ranged from 4 to 16 liters in volume and averaged 10.2 liters. Each sample was processed with a Dausman Flote-Tech Model A system fitted with a heavy-fraction screen of 0.8 mm mesh. After drying, samples were fractionated with nested geological sieves fitted with 4.0 mm, 2.0 mm, and 1.0 mm mesh. Fully sorted and quantified were all fractions greater than 2.0 mm; in addition, the 1.0-mm fraction of a subset of eight samples was fully sorted and quantified for reasons explained in the main text.

Two of us (Steffy and Shanefield) undertook preliminary sorting and identification of shells. Refinements to identifications benefited from consultations with the Malacology Collections Manager John Slapcinsky of the Florida Museum of Natural History. Only whole or nearly whole shells were counted to estimate the minimum number of individuals (MNI) per taxon and sample. Shells of most of the taxa are minute, the vast majority of which were whole.

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SUPPLEMENT B

Sassaman, Kenneth E., et al. Terrestrial Snails from Archaeological Sites as Proxies for Relative Sea Level on the Gulf Coast of Florida, USA.

Truncatella and Other Terrestrial Snails from Wrack

To better interpret frequency variations among archaeological *Truncatella* and other terrestrial snails as a proxy for relative sea level, we collected samples of wrack from the proximate shorelines of all three archaeological sites. Shown in Figure 1 are the locations of wrack samples in topographic cross-sections of the shoreline that also include excavation unit profiles calibrated to elevation. Shown in dashed red lines is the high-high tide on April 13, 2019, the day we collected wrack samples; dashed blue lines connote the low-low tide that same day. This day was between spring tides (new moon April 5; full moon April 19), so wrack is shown above the high-high tide line of April 13. The vertical differential of about +18 cm coincides roughly with the difference between high-high tide at first quarter moon (neap tide, April 12) and at new or full moon. The exception are wrack samples at A.B. Midden, which we collected from an elevation about 50 cm above the high-high tide line.

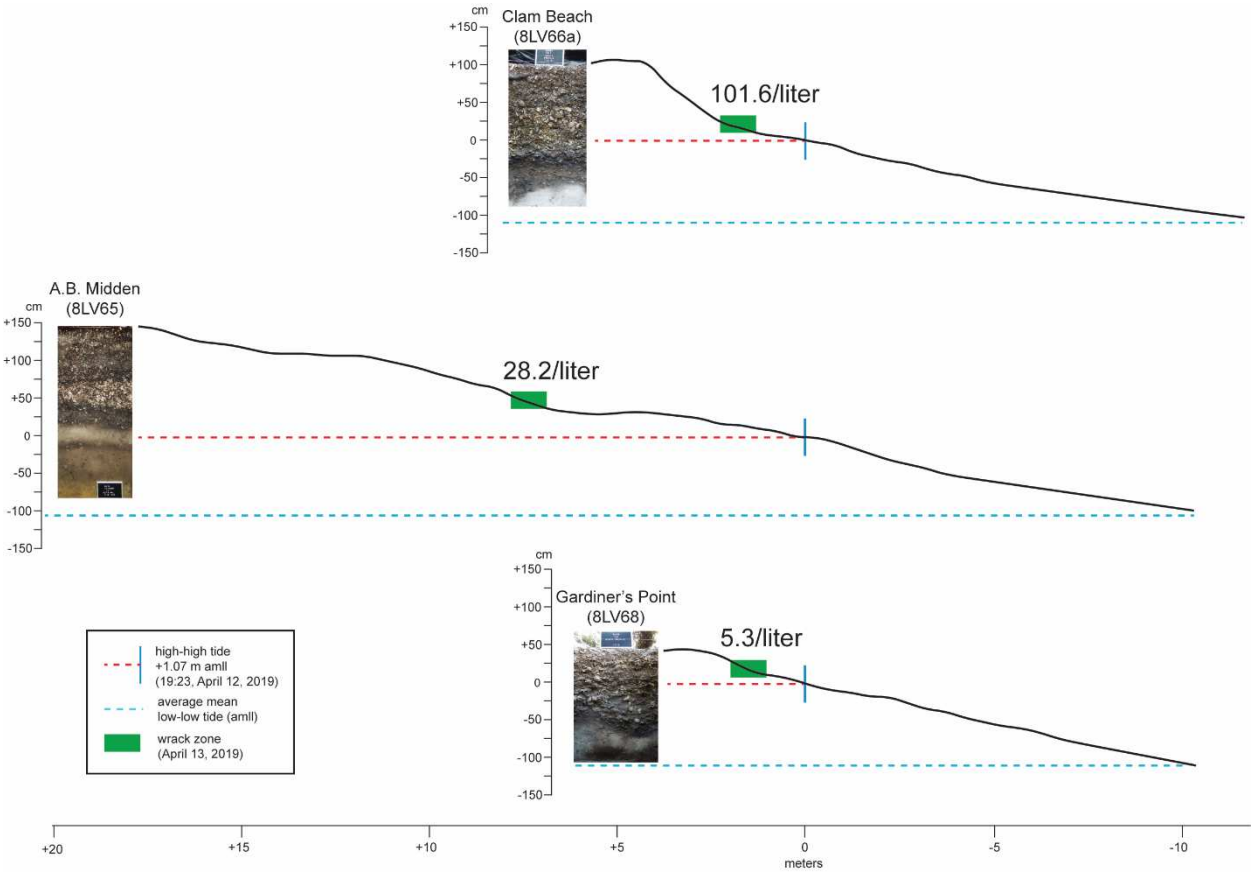

Figure 1. Profiles of shorelines at three sites of wrack sampling, showing the high-high tide line on April 12, 2019, the average low-low tide line, the calibrated positions of three test units, and the density of *Truncatella* shells per liter from samples of wrack collected on April 13, 2019.

The exceptional nature of the A.B. Midden sample points to the role of shoreline morphology and topography in wrack accumulation. For instance, the profile of Clam Beach shows a meter-high escarpment only a few meters seaward of the excavation. The escarpment exposes fully anthropogenic deposits (shell midden) that accumulated on the Phase III surface during phases IV and V. Two consequences of this configuration bear relevance to the accumulation of snail shells in wrack. First, the escarpment "traps" wrack at the high-high tide line, preventing it from accumulating farther landward, that is, short of storm surge in excess of 1 m. In contrast, the shoreline profile of A.B. Midden lacks an escarpment, enabling wrack to be displaced farther landward and at higher elevation during super tides or storms. The profile of Gardiner's Point has a slight escarpment, enough to contain wrack at the elevation of typical spring tides. Second, eroding midden contributes archaeological shell and other matter to extant wrack. This is true of all three sites, although the contribution of archaeological shell to modern wrack is expected to covary with the height and breadth of escarpments. Separating old from fresh shell is paramount to accurate characterization of modern wrack assemblages.

Besides differences in profiles, the shorelines of each of the three sample locations have their own, unique morphology: in plan, the shoreline of Clam Beach is concave (i.e., a cove); A.B. Midden is relatively straight, with a slight concavity; and Gardiner's Point is convex. Of course, these are simply modern configurations of landforms that have not only been eroded and continue to erode from tidal water and storm surge—inflected over time by changes in sea level—but also prograded at various times as the dune sands of these once-fully-terrestrial landforms were redistributed by water. These same processes account for the sand shoals seen in the stippling of subaqueous areas of Figure 2 of the main text.

With these caveats in mind, an inventory of terrestrial snail shell in modern wrack samples is provided in Table 1. We sampled wrack from the three sites in two locations each, generally a few meters both north and south of the archaeological test units. Individual samples varied from 2.5 to 3.0 liters in volume each and totaled 17.0 liters for six samples. As with archaeological matrix, we passed wrack samples through nested geological sieves. Sorted and identified was all terrestrial snail shell >1 mm.

The difference between the shells of living or recently deceased snails and those eroding from archaeological strata became obvious as wrack assemblages were sorted. Fresh shell is translucent and archaeological shell is oxidized and thus opaque (Figure 2). Shells in an intermediate condition (i.e., partially oxidized) presumably died relatively recently; none of the snail shell from autochthonous archaeological deposits was translucent. Wrack shells with intermediate translucence are included in Table 1 as "translucent" shell.

Across taxa, the fraction of translucent shells from wrack ranges from 8.6 to 51.1 percent, and averages 30.4 percent. All taxa documented in archaeological samples occur as both opaque and translucent shell in wrack samples, but not in comparable proportions in most cases. As shown in Figure 3, wrack shell (opaque and translucent) compares favorably with archaeological shell for some taxa, particularly adult *Truncatella*. Notable differences are the increased proportion of juvenile *Truncatella* and a few other taxa (*Polygyra septemvolva*, *Lobosculum pustula*, *Melampus bidentatus*) in wrack over archaeological samples, coupled with decreased fractions of *Hawaiia* sp. and *Gastrocopta contracta*. All relative differences between archaeological and wrack shell are accentuated in the subsample of translucent wrack shell except in the case of *Gastrocopta contracta,* which is virtually the same.

Table 1. Absolute Frequency of Terrestrial Snail Shell >1mm by Taxon and Wrack Sample at Clam Beach and A. B. Midden, Levy County, Florida.

		Clam Beach		AB Midden		Gardiner's Point		
		Wrack 1	Wrack 2	Wrack 1	Wrack 2	Wrack 1	Wrack 2	Total
Volume (L)		2.5	3.0	3.0	2.5	3.0	3.0	17.0
Truncatella Adult	Opaque	92	445	221	71	14	14	857
	Translucent	29	123	9	2	5	15	183
	Combined	121	568	230	73	19	29	1,040
Truncatella Juvenile	Opaque	41	183	87	10	47	7	375
	Translucent	26	112	11	1	24	7	181
	Combined	67	295	98	11	71	14	556
Hawaiia sp.	Opaque	55	414	102	84	60	44	759
	Translucent	12	4	36	5	10	4	71
	Combined	67	418	138	89	70	48	830
Polygyra septemvolva	Opaque	12	11	24	31	22	27	127
	Translucent	4	8	8	6	44	3	73
	Combined	16	19	32	37	66	30	200
Glyphyalinia umbilicata	Opaque	7	16	68	24	17	9	141
	Translucent		8	19	2	8	4	41
	Combined	7	24	87	26	25	13	182
Lobosculum pustula	Opaque	4	14	34	23	3	4	82
	Translucent	3	2	12	13	40	6	76
	Combined	7	16	46	36	43	10	158
Melampus bidentatus	Opaque	11	14	23	12	4	1	65
	Translucent	22	13	18	3	10	2	68
	Combined	33	27	41	15	14	3	133
Gastrocopta contracta	Opaque	16	27	22	9	10	1	85
	Translucent	9	14	5	1			29
	Combined	25	41	27	10	10	1	114
Oligyra orbiculata	Opaque	4	5	5	6	2	4	26
	Translucent				1	2		3
	Combined	4	5	5	7	4	4	29
Strobilops texasiana	Opaque	1	4	6	4	2		17
	Translucent		4	1	3			8
	Combined	1	8	7	7	2		25
Zonitoides arboreus	Opaque		1	2	2	1	1	7
	Translucent		2	1	3	1		7
	Combined		3	3	5	2	1	14
Total MNI	Opaque	243	1,134	594	276	182	112	2,541
	Translucent	105	290	120	40	144	41	740
	Combined	348	1,424	714	316	326	153	3,281
MNI/liter	Opaque	97.2	378.0	198.0	110.4	60.7	37.3	149.5
	Translucent	42.0	96.7	40.0	16.0	48.0	13.7	43.5
	Combined	139.2	474.7	238.0	126.4	108.7	51.0	193.0
MNI *Truncatella* /liter	Opaque	53.2	209.3	102.7	32.4	20.3	7.0	72.5
	Translucent	22.0	78.3	6.7	1.2	9.7	7.3	21.4
	Combined	188.0	863.0	328.0	84.0	90.0	43.0	1,596.0
Adult:Juvenile *Truncatella*	Opaque	2.24	2.43	2.54	7.10	0.30	2.00	2.29
	Translucent	1.12	1.10	0.82	2.00	0.21	2.14	1.01
	Combined	1.81	1.93	2.35	6.64	0.27	2.07	1.87

Figure 2. Examples of translucent (top row) and opaque (bottom row) *Truncatella* shells from one of two wrack samples proximate to test unit at Clam Beach (8LV66a).

Translucent shell from wrack—the most reliable indicator of autochthonous shell—shows roughly equal proportions of adult and juvenile *Truncatella* (Figure 3), a ratio consistent across all samples except those from Gardiner's Point and not seen in any archaeological sample, even the 1-mm fractions. Given the consistency of this ratio among the four wrack samples from sites on North Key, we accept this as the demographic profile of autochthonous populations (living and recently deceased) of *Truncatella,* at least on this island. It follows that this ratio offers a benchmark for relative displacement from reproductive habitat, the wrack of foreshores. We do not know what to expect of *Truncatella* displaced by storm surge, but assume that any juveniles surviving to maturity would not reproduce in places of displacement, if, that is, they reproduce only in wrack, which seems to be the case.

The overall trend among taxa in wrack other than *Truncatella*, which makes up about half of all shell, is for greater fractions of salt marsh species (e.g., *Polygyra septemvolva*, *Melampus bidentatus*) and smaller fractions of species associated with leaf litter (e.g., *Hawaiia sp.*, *Gastrocopta contracta*) than in archaeological assemblages. Thus, coupled with the ratio of adult to juvenile *Truncatella*, the ratio of marsh to forest taxa (mean = 2.5:1) provides a relative measure of proximity to foreshore locations and autochthonous wrack.

It is worth noting variation among wrack samples that may be attributed to shoreline morphology. As noted earlier, the escarpment at Clam Beach concentrated wrack at the high-high tide line, creating optimal conditions for *Truncatella* judging from the density of translucent shells per liter (22.0 and 78.3, the highest densities of all samples). Conversely, the foreshore of A.B. Midden lacks an escarpment and so its wrack is subject to more landward displacement from super tides and storm surge than is possible at Clam Beach. *Truncatella* densities at A.B. Midden (1.2 and 6.7) are the lowest among all samples. Differences in shoreline morphology clearly affect the accumulation and stability of wrack and thus must be factored into any inference about relative sea level rendered from archaeological shell.

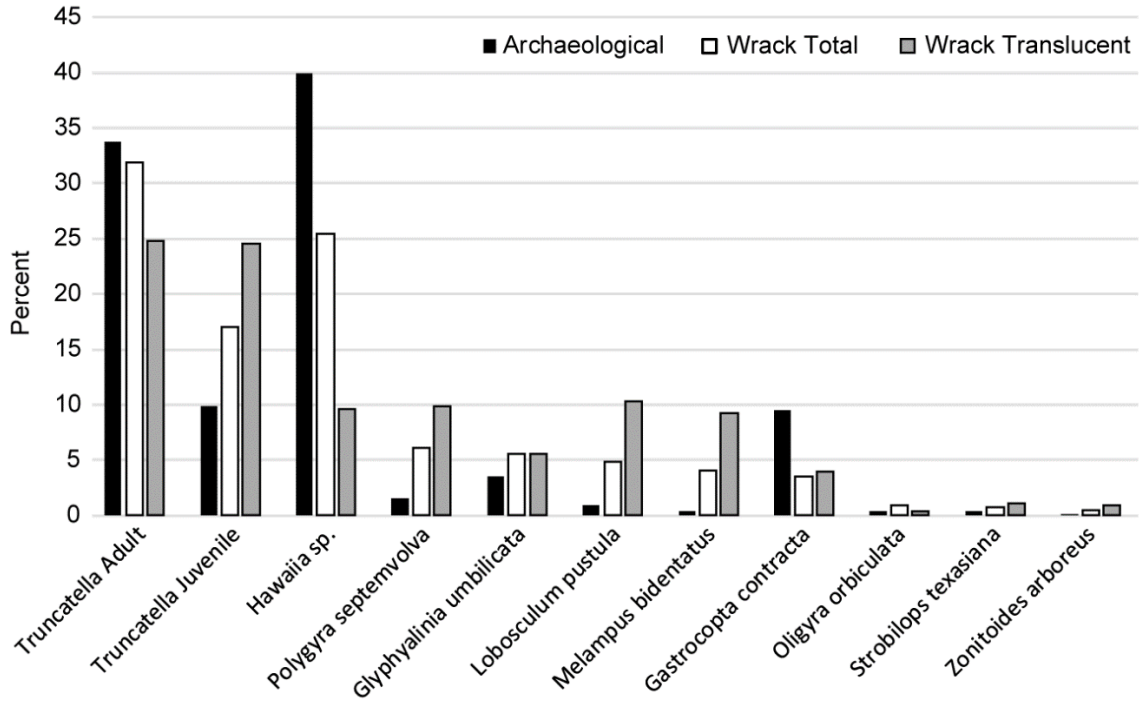

Figure 7. Comparison of the relative frequencies of shells in archaeological and wrack contexts by taxa and by condition.