

## **<sup>14</sup>C VARIATIONS IN PRE-BOMB NEARSHORE HABITATS OF THE FLORIDA PANHANDLE, USA**

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**ABSTRACT.** This article presents radiocarbon data for known-age, pre-bomb marine gastropods, *Busycon sinistrum* and *Strombus alatus*, collected between AD 1924 and 1946 from nearshore environments of the Florida Panhandle, on the northern Gulf of Mexico.  $\Delta^{14}\text{C}$  was measured in whole crushed juvenile specimens ( $n = 7$ ) and terminal edges of adult specimens ( $n = 6$ ). A subsample of adult specimens ( $n = 3$ ) was subjected to additional, intrashell sampling to observe short-term variability in  $^{14}\text{C}$  conditions.  $\Delta^{14}\text{C}$  values were consistent within and among *B. sinistrum* specimens, and we propose a reservoir age offset ( $\Delta\text{R}$ ) of  $-9 \pm 25$   $^{14}\text{C}$  yr for *B. sinistrum* from the northwest coast of Florida. *S. alatus* shells exhibited significant variability from one individual to another, and also within individual specimens.  $\Delta\text{R}$  values for *S. alatus* range from  $-3 \pm 30$  to  $659 \pm 30$   $^{14}\text{C}$  yr. These differences may result from a combination of factors, including subregional variability in inputs of  $^{14}\text{C}$ -depleted waters and life-history factors including mobility, mode of feeding, and ontogenetic niche shifts.

## **INTRODUCTION**

Radiocarbon dating of marine shell is complicated by a variety of factors. Because ocean waters are depleted in  $^{14}\text{C}$  relative to the atmosphere, the  $^{14}\text{C}$  ages of marine samples appear older than those of contemporary terrestrial materials. Variations in coastal geomorphology, ocean circulation, and upwelling create localized, time-dependent deviations from the global-averaged marine reservoir age. Methods for estimating corrections for local offsets, designated  $\Delta\text{R}$ , are described by Ascough et al. (2005b) and involve measuring the  $^{14}\text{C}$  concentration of known-age marine materials (e.g. museum specimens, tephra isochrones, and pairs of terrestrial and marine samples from archaeological contexts).

In coastal areas where there are no carboniferous rocks and minimal freshwater inputs,  $^{14}\text{C}$  activity does not differ significantly among different species of mollusks; therefore, a single  $\Delta\text{R}$  value can be used to correct  $^{14}\text{C}$  ages from different species (Higham and Hogg 1995; Ascough et al. 2005a). Researchers working in coastal areas use an online database of published  $\Delta\text{R}$  values, accessed via mapping software by Reimer and Reimer (2001), to calibrate and correct measured marine  $^{14}\text{C}$  ages. However, data are absent for the nearshore environments of the northern Gulf of Mexico. Therefore, this paper presents measurements of  $^{14}\text{C}$  for known-age pre-bomb marine gastropods, *Busycon sinistrum* and *Strombus alatus*, which are recovered frequently from archaeological sites on the northern Gulf of Mexico (Figure 1).

*B. sinistrum* and *S. alatus* shells record  $^{14}\text{C}$  conditions of nearshore environments throughout their lives, which is about 10 yr for the genus *Strombus* (Berg 1976; Appeldoorn 1988) and up to 20 yr or more for the genus *Busycon* (Eversole et al. 2008; Power et al. 2009). Shell growth follows an ontological pattern such that, in absolute terms, the oldest portion of a gastropod shell is the apex, and the terminal edge of the lip is the youngest (Figure 2). Intrashell  $^{14}\text{C}$  dating, as described by Culleton et al. (2006), therefore provides a time-series record of local  $^{14}\text{C}$  conditions.

We observed significant variability in  $^{14}\text{C}$  concentrations (1) between species; (2) among *S. alatus* shells; and (3) throughout the lives of individual *S. alatus*. These variations likely reflect a combination of environmental and life-history factors including source and volume of freshwater inputs,

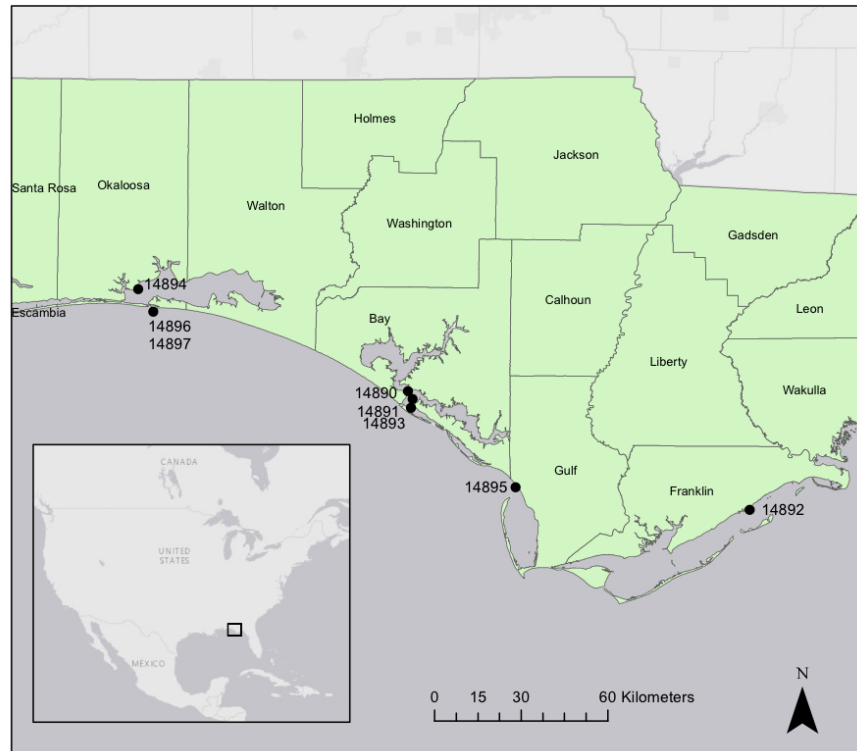


Figure 1 Map of study area showing approximate collection locations of known-age, pre-bomb gastropods from the Florida Panhandle included in this study.

terrestrial runoff, and the diet, range, and extent of mobility of the animals. These potential sources of variability are not unique to the nearshore environments of the northern Gulf of Mexico.

## MATERIALS AND METHODS

We selected four *B. sinistrum* and nine *S. alatus* shells for accelerator mass spectrometry (AMS) analysis, and obtained a total of 30  $^{14}\text{C}$  dates (Table 1). Shell specimens were loaned to the Georgia Museum of Natural History (GMNH) and the Center for Applied Isotope Studies (CAIS) from the malacology collections at the Florida Museum of Natural History (FLMNH) and the Academy of Natural Sciences of Drexel University (ANSP). The specimens were collected between AD 1924 and 1946 from Okaloosa, Bay, Gulf, and Franklin counties, in the “panhandle” region of northwestern Florida, USA (Figure 1). Museum records rarely indicated whether the shells were collected live or dead, but care was taken by the museum curators and the authors to select specimens that likely had died no more than a few years prior to collection (e.g. periostracum intact; glossy, unbleached appearance; presence of operculum; lack of epibionts on shell interior).

Preparation and sampling methods were determined by the size and ontogenetic age of the shell specimen (Table 1). Very small shells (~1 cm in length) likely represent no more than a year or two of growth. Small shells (UGAMS-14896 and -14897) were cleaned in an ultrasonic bath of deionized water, and the whole shells were crushed to obtain 20-mg bulk samples of carbonate powder. Larger shells represent multiple years of growth. Large shells (UGAMS-14890 through UGAMS-14895) were physically cleaned with a wire bristle brush, and a hand-held drill was used to collect ~20 mg of carbonate powder from the interior lip region of the shell. The collection year

was assumed to be a reasonable approximation for the year the organism died (but see Yoneda et al. 2000) and ceased incorporating <sup>14</sup>C into new shell growth. For large specimens, which lived for many years, the collection year is an approximation for the year that the lip region grew; for small specimens, the collection year was assumed to be a reasonable approximation for the entire shell.

To calculate  $\Delta R$  (Table 2), we relied on the following equation:

$$\Delta R = P - Q$$

where  $P$  is the measured <sup>14</sup>C age of a sample of known age, and  $Q$  is the marine model age, obtained from the Marine13 calibration curve (Reimer et al. 2013). Uncertainty in  $\Delta R$  was calculated as  $\sigma_R = \sqrt{\sigma_P^2 + \sigma_Q^2}$  (Stuiver et al. 1986).

We used chi-squared ( $\chi^2$ ) tests to determine whether groups of <sup>14</sup>C dates and  $\Delta R$  values were homogeneous and could be combined into a weighted average following the method of Ward and Wilson (1978). If dates were not homogeneous, we used the method described by Wilson and Ward (1981) to identify clusters of dates. Weighted average errors were calculated using the greater value of the weighted uncertainty or the standard deviation (Rick and Henkes 2014).

Three large shells (UGAMS-14890, -14891, and -14894) were selected for additional, sequential sampling to examine intrashell variability (Table 3). For each of those three shells, we sampled five positions on the shell: one sample from the exterior edge of the shell lip, and one from each of four adjacent whorls of the spire (Figure 2). This sampling strategy results in a time-ordered sequence of data points, but because the growth rates of these particular species are understood poorly we do not know the time interval between sample points and it is not possible to associate precise calendar ages with individual samples.



Figure 2 Sequential sampling points on *Busycon sinistrum* (UGAMS-14891). The lip (sample point 1) is the most recent growth, and the apex (sample point 5) is the earliest growth.

Carbonate samples were reacted with 100% phosphoric acid in evacuated vessels. The resulting carbon dioxide was cryogenically purified from the other reaction products and catalytically converted to graphite using the method of Vogel et al. (1984). Graphite <sup>14</sup>C/<sup>13</sup>C ratios were measured using the 0.5MeV accelerator mass spectrometer at the CAIS, University of Georgia, USA. The sample ratios were compared to the ratio measured from the oxalic acid I (NBS SRM 4990). Carrara marble

(IAEA C1) was used as a background, and travertine (IAEA C2) was used as a secondary standard. The sample  $^{13}\text{C}/^{12}\text{C}$  and  $^{18}\text{O}/^{16}\text{O}$  ratios were measured separately using a stable isotope ratio mass spectrometer and expressed as  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  with respect to PDB, with an error of less than 0.1‰. The error is quoted as one standard deviation and reflects both statistical and experimental errors. All  $^{14}\text{C}$  dates have been corrected for natural isotope fractionation using the isotope ratio mass spectrometer value.

## RESULTS

The results of the interior-lip and whole-shell samples, which represent the  $^{14}\text{C}$  conditions of near-shore environments at the time the shells died, are presented in Table 1. The weighted average *B. sinistrum* age is  $437 \pm 29$   $^{14}\text{C}$  yr ( $T = 2.67$ ,  $\chi^2_{0.05} = 5.99$ ), with good agreement among samples. The weighted mean *S. alatus* age is  $814 \pm 275$   $^{14}\text{C}$  yr ( $T = 1706.6$ ,  $\chi^2_{0.05} = 16.92$ ), with a wide dispersal of ages and poor agreement among samples.

Table 1  $\Delta^{14}\text{C}$  measurements from lip and whole-shell samples of known-age pre-bomb shells from the Florida Panhandle.

UGAMS nr	Museum lot nr	County	Year col- lected	Sample position	$\delta^{18}\text{C}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\Delta^{14}\text{C} \pm 1\sigma$ (‰)	$^{14}\text{C}$ age $\pm 1\sigma$ , BP
<i>Busycon sinistrum</i>								
14891	ANSP 181844	Bay	1945	interior lip	0.0	0.4	$-54.2 \pm 2.6$	$450 \pm 20$
14893	FLMNH 8652	Bay	1924	interior lip	-0.3	0.0	$-55.0 \pm 2.6$	$450 \pm 20$
14896A <sup>a</sup>	FLMNH 153206	Okaloosa	1941	whole shell	1.4	-0.5	$-49.6 \pm 2.6$	$410 \pm 20$
14896B <sup>a</sup>	FLMNH 153206	Okaloosa	1941	whole shell	2.0	-0.5	$-49.1 \pm 2.6$	$400 \pm 20$
				Average	0.8	-0.2	$-52.0 \pm 2.6$	$437 \pm 29$
				Range	2.3	0.9	5.9	50
<i>Strombus alatus</i>								
14890	ANSP 181769	Bay	1946	interior lip	1.3	-0.9	$-62.1 \pm 2.6$	$510 \pm 20$
14892A <sup>b</sup>	FLMNH 10900	Franklin	1929	interior lip	-1.0	-2.2	$-77.8 \pm 2.5$	$650 \pm 20$
14892B <sup>b</sup>	FLMNH 10900	Franklin	1929	interior lip	—	—	$-79.4 \pm 2.5$	$670 \pm 20$
14894	FLMNH 10899	Okaloosa	1929	interior lip	1.7	-1.1	$-54.2 \pm 2.6$	$450 \pm 20$
14895	FLMNH 2272	Gulf	1945	interior lip	-0.2	-1.4	$-63.7 \pm 2.5$	$530 \pm 20$
14897A <sup>c</sup>	FLMNH 151409	Okaloosa	1941	whole shell	-0.5	-2.1	$-117.9 \pm 2.4$	$1010 \pm 20$
14897B <sup>c</sup>	FLMNH 151409	Okaloosa	1941	whole shell	—	—	$-119.2 \pm 2.5$	$1020 \pm 20$
14897B2 <sup>c</sup>	FLMNH 151409	Okaloosa	1941	whole shell	—	—	$-127.4 \pm 2.5$	$1100 \pm 20$
14897C <sup>c</sup>	FLMNH 151409	Okaloosa	1941	whole shell	—	—	$-122.9 \pm 2.5$	$1060 \pm 20$
14897C2 <sup>c</sup>	FLMNH 151409	Okaloosa	1941	whole shell	—	—	$-131.7 \pm 2.5$	$1140 \pm 20$
				Average	0.3	-1.5	$-96.4 \pm 30.8$	$814 \pm 275$
				Range	2.7	1.3	77.5	690

<sup>a</sup>Different shells from same museum lot; <sup>b</sup>Replicate samples from same shell; <sup>c</sup>Different shells from same museum lot.

Table 2 presents  $\Delta R$  estimates from the lip and whole-shell samples, calculated from the  $\Delta^{14}\text{C}$  values in Table 1. In these calculations,  $^{14}\text{C}$  ages from the same museum lots (i.e. same species, date, and collection locale) were clustered and combined following the methods of Ward and Wilson (1978; Wilson and Ward 1981). The  $\Delta R$  values for *B. sinistrum* from the lip-only and whole-shell samples are in good agreement, with a weighted average of  $-23 \pm 29$   $^{14}\text{C}$  yr ( $T = 1.89$ ,  $\chi^2_{0.05} = 5.99$ ). The *S. alatus* dates were not homogeneous, and several clusters of dates were identified (Wilson and Ward 1981; see Table 2 notes). The weighted average  $\Delta R$  for the species,  $257 \pm 287$   $^{14}\text{C}$  yr, is more dispersed than expected ( $T = 456.08$ ,  $\chi^2_{0.05} = 11.07$ ).

Table 2 <sup>14</sup>C ages and ΔR offsets of known-age pre-bomb shells from the Florida Panhandle.

UGAMS nr	Museum lot nr	Year collected	<sup>14</sup> C age ±1σ, BP	Marine model <sup>14</sup> C age ±1σ, BP	ΔR ±1σ
<i>Busycon sinistrum</i>					
14891	ANSP 181844	1945	450 ± 20	464 ± 23	-14 ± 30
14893	FLMNH 8652	1924	450 ± 20	450 ± 23	0 ± 30
14896A,B <sup>a</sup>	FLMNH 153206	1941	405 ± 20	461 ± 23	-56 ± 30
				Average ΔR	-23 ± 29
				Range	56
<i>Strombus alatus</i>					
14890	ANSP 181769	1946	510 ± 20	465 ± 23	45 ± 30
14892A,B <sup>b</sup>	FLMNH 10900	1929	660 ± 20	453 ± 23	207 ± 30
14894	FLMNH 10899	1929	450 ± 20	453 ± 23	-3 ± 30
14895	FLMNH 2272	1945	530 ± 20	464 ± 23	66 ± 30
14897A,B,C <sup>c</sup>	FLMNH 151409	1941	1030 ± 20	461 ± 23	569 ± 30
14897B2,C2 <sup>d</sup>	FLMNH 151409	1941	1120 ± 20	461 ± 23	659 ± 30
				Average ΔR	257 ± 287
				Range	662

<sup>a</sup>Weighted average of two different shells from same museum lot ( $T = 0.13$ ,  $\chi^2_{0.05} = 3.84$ ).

<sup>b</sup>Weighted average of two replicate samples from same shell ( $T = 0.01$ ,  $\chi^2_{0.05} = 3.84$ ).

<sup>c</sup>Weighted average of three different shells from same museum lot ( $T = 3.50$ ,  $\chi^2_{0.05} = 5.99$ ).

<sup>d</sup>Weighted average of two different shells from same museum lot ( $T = 2.00$ ,  $\chi^2_{0.05} = 3.84$ ).

Results of the sequential samples from shells UGAMS-14890, -14891, and -14894 are shown in Table 3. These data demonstrate the variability in <sup>14</sup>C conditions during the lives of individual shells. The *B. sinistrum* specimen (UGAMS-14891) exhibited little variability in Δ<sup>14</sup>C activity within its shell. The average age is  $477 \pm 35$  <sup>14</sup>C yr ( $T = 5.69$ ,  $\chi^2_{0.05} = 9.49$ ), with a weighted average ΔR value of  $13 \pm 36$  <sup>14</sup>C yr ( $T = 3.55$ ,  $\chi^2_{0.05} = 9.49$ ). A comparison of *B. sinistrum* ΔR estimates from Tables 2 and 3 suggests they can be combined to a weighted average value of  $-9 \pm 25$  <sup>14</sup>C yr ( $T = 0.61$ ,  $\chi^2_{0.05} = 3.84$ ).

Both *S. alatus* shells (UGAMS-14890 and -14894) exhibited considerable intrashell variability. Shell UGAMS-14890 had a weighted average age of  $790 \pm 135$  <sup>14</sup>C yr ( $T = 81.55$ ,  $\chi^2_{0.05} = 9.49$ ), with an average ΔR value of  $325 \pm 135$  <sup>14</sup>C yr ( $T = 50.83$ ,  $\chi^2_{0.05} = 9.49$ ). Shell UGAMS-14894 had a weighted average age of  $674 \pm 229$  <sup>14</sup>C yr ( $T = 352.96$ ,  $\chi^2_{0.05} = 11.07$ ), with an average ΔR value of  $241 \pm 229$  <sup>14</sup>C yr ( $T = 202.34$ ,  $\chi^2_{0.05} = 11.07$ ). The  $T$  statistics indicate poor agreement within *S. alatus* shells; both have greater dispersions of <sup>14</sup>C and ΔR values than expected.

## DISCUSSION

The current study included samples of two species of marine mollusks collected from four coastal counties of the Florida Panhandle, spanning over 150 km of coastline. The results suggest that there are significant differences in the <sup>14</sup>C compositions of *S. alatus* and *B. sinistrum* shells in this region. Based on data from four pre-bomb specimens collected from Okaloosa and Bay counties, Florida, we suggest a regional ΔR correction of  $-9 \pm 25$  <sup>14</sup>C yr for *B. sinistrum*. <sup>14</sup>C data from nine pre-bomb *S. alatus* specimens collected from Okaloosa, Bay, Gulf, and Franklin counties did not produce a reliable, statistically significant ΔR correction value.

A preliminary study of three paired marine and terrestrial archaeological samples from northwestern



Florida resulted in  $\Delta R$  estimates of  $255 \pm 61$   $^{14}\text{C}$  yr for *S. alatus* and  $52 \pm 32$   $^{14}\text{C}$  yr for *B. sinistrum* (Shanks and Byrd 2012). Shanks and Byrd's estimate for *B. sinistrum* is statistically identical to our own estimate of  $-9 \pm 25$   $^{14}\text{C}$  yr ( $T = 2.26$ ,  $\chi^2_{0.05} = 3.84$ ). While their estimate for *S. alatus* is statistically identical to our weighted average of  $255 \pm 287$   $^{14}\text{C}$  yr ( $T < 0.00$ ,  $\chi^2_{0.05} = 3.84$ ), we note that the error term in our estimate, calculated from the standard deviation of  $\Delta R$  values, reflects considerable uncertainty for this particular species. Previous studies of other marine and estuarine mollusks document substantial variability in  $\Delta R$  values across the Atlantic coast of North America (e.g. Little 1993; McNeely et al. 2006; Rick et al. 2012), ranging from  $-134$   $^{14}\text{C}$  yr at St. Catherines Island, Georgia (Thomas 2008) to  $230$   $^{14}\text{C}$  yr at Casco Bay, Maine (McNeely et al. 2006). In comparison, we observed  $\Delta R$  values ranging from  $-3$  to  $659$   $^{14}\text{C}$  yr among *S. alatus* shells from the Florida Panhandle, a greater range than is observed across the entire Atlantic seaboard.

Aquatic mollusks build their calcium carbonate shells largely, though not exclusively, from ambient dissolved inorganic carbon (DIC) (McConnaughey and Gillikin 2008). Variability in  $\Delta^{14}\text{C}$  and  $\Delta R$  in mollusk shells is typically attributed to variability in the  $^{14}\text{C}$  content of DIC, due to environmental factors such as upwelling, freshwater inputs, or carbon recycling, or life-history factors such as mobility or mode of feeding (e.g. Forman and Polyak 1997; Hogg et al. 1998; Ulm 2002; Yoneda et al. 2004, 2007; Culleton et al. 2006; Jones et al. 2007; Rick et al. 2012). Although DIC is the dominant source of carbon in mollusk shells, experiments have shown that substantial amounts of shell carbon may be obtained metabolically (Tanaka et al. 1986; McConnaughey and Gillikin 2008).  $\Delta^{14}\text{C}$  in dissolved organic carbon (DOC) and particulate organic carbon (POC) vary in riverine, estuarine, and coastal habitats due to different sources and transport mechanisms for DOC and POC (Raymond and Bauer 2001), further complicating  $\Delta R$  corrections.

Determining precisely which factors are responsible for the variability in *S. alatus*  $\Delta R$  is difficult with our small data set. Though a fully marine species, *S. alatus* could be influenced by freshwater inputs in nearshore marine systems. The coastline in the study area includes a mix of high-energy beaches, hypersaline bays, and brackish bays fed by rivers and streams. In Okaloosa County, at the western edge of the study area, the Choctawhatchee River system discharges into the Gulf of Mexico via Choctawhatchee Bay. The river and bay system collectively drains  $13,900$   $\text{km}^2$  of the Alabama and Florida coastal plain. At the eastern edge of the study area, in Franklin County, the Apalachicola–Chatahoochee–Flint (ACF) river system meets the Gulf of Mexico. The ACF system drains  $50,000$   $\text{km}^2$  in Florida, Alabama, and Georgia, with its headwaters in the mountains of northern Georgia. Portions of these rivers pass through limestone deposits on their way to the coast, and are potential sources of  $^{14}\text{C}$ -depleted DIC. Large inputs of freshwater runoff also can introduce both dissolved atmospheric  $\text{CO}_2$  and terrigenous sources of carbon. These effects are amplified in areas of enclosed coastal topography (Ulm 2002; Ascough et al. 2005a), such as the bays and estuaries of the northern Gulf of Mexico.

*S. alatus* specimens from Okaloosa and Franklin counties, where major river systems drain into the gulf, are generally more depleted in  $^{14}\text{C}$  than are specimens of the same species from Bay and Gulf counties (Table 1), which lack major freshwater inputs. This lends support to the hypothesis that environmental factors, particularly freshwater inputs, are a major source of the  $^{14}\text{C}$  variability observed in *S. alatus*. *S. alatus* specimens from Okaloosa County (UGAMS-14894 and -14897A-C) exhibited a wide range of  $\Delta R$  values, from  $-3$  to  $659$   $^{14}\text{C}$  yr. It may be that super-local variation in  $\Delta R$  reflects microenvironmental variation in  $^{14}\text{C}$  within the nearshore coastal system, influenced by variables such as distance from freshwater inputs, water circulation, or carbon recycling. Museum records do not provide precise collection locations for the specimens studied, so it is difficult to determine whether this represents patterned, subregional spatial variability within and around Choctawhatchee Bay.

Table 3 Sequential  $\Delta^{14}\text{C}$  measurements of known-age pre-bomb shells from the Florida Panhandle.

UGAMS nr	Sample position	$\Delta^{14}\text{C} \pm 1\sigma$ (‰)	$^{14}\text{C}$ age $\pm 1\sigma$ (BP)	Marine model $^{14}\text{C}$ age $\pm 1\sigma$ (BP)	$\Delta R \pm 1\sigma$	$\delta^{13}\text{C}$ (‰)	$\delta^{18}\text{O}$ (‰)
ANSP181769 <i>Strombus alatus</i> (Bay County, 1946)							
14890.01	exterior edge of lip (1)	$-73.2 \pm 3.1$	$610 \pm 30$	$465 \pm 23$	$145 \pm 38$	1.5	1.0
14890.02	spire (2)	$-83.4 \pm 3.0$	$700 \pm 30$	$465 \pm 23$	$235 \pm 38$	0.6	-0.2
14890.03b	spire (3)	$-104.8 \pm 3.0$	$890 \pm 30$	$465 \pm 23$	$425 \pm 38$	0.7	1.2
14890.04	spire (4)	$-111.0 \pm 2.9$	$940 \pm 30$	$465 \pm 23$	$475 \pm 38$	0.1	-0.1
14890.05	near apex (5)	$-95.8 \pm 3.0$	$810 \pm 30$	$465 \pm 23$	$345 \pm 38$	-0.4	-0.4
				Average	$325 \pm 135$	0.5	0.3
				Range	330	1.9	1.6
ANSP181844 <i>Busycon sinistrum</i> (Bay County, 1945)							
14891.01	exterior edge of lip (1)	$-58.6 \pm 2.8$	$480 \pm 20$	$464 \pm 23$	$16 \pm 30$	-0.3	-0.4
14891.02	spire (2)	$-64.0 \pm 3.1$	$530 \pm 30$	$464 \pm 23$	$66 \pm 38$	0.6	-0.6
14891.03	spire (3)	$-56.5 \pm 2.9$	$470 \pm 20$	$464 \pm 23$	$6 \pm 30$	-0.8	1.4
14891.04	spire (4)	$-58.4 \pm 3.3$	$480 \pm 30$	$464 \pm 23$	$16 \pm 38$	-0.5	1.0
14891.05	near apex (5)	$-52.6 \pm 3.1$	$430 \pm 30$	$464 \pm 23$	$-34 \pm 38$	0.1	0.2
				Average	$13 \pm 36$	-0.2	0.3
				Range	100	1.4	2.0
FLMNH10899 <i>Strombus alatus</i> (Okaloosa County, 1929)							
14894.01	exterior edge of lip (1)	$-59.7 \pm 3.0$	$490 \pm 20$	$453 \pm 23$	$37 \pm 30$	2.3	0.1
14894.01b	exterior edge of lip (1)	$-58.4 \pm 3.3$	$480 \pm 30$	$453 \pm 23$	$27 \pm 38$	2.1	0.6
14894.02	spire (2)	$-77.0 \pm 2.9$	$640 \pm 20$	$453 \pm 23$	$187 \pm 30$	0.9	0.5
14894.03	spire (3)	$-101.0 \pm 3.0$	$850 \pm 30$	$453 \pm 23$	$397 \pm 38$	0.1	0.6
14894.04	spire (4)	$-124.8 \pm 2.8$	$1070 \pm 30$	$453 \pm 23$	$617 \pm 38$	0.5	1.4
14894.05	near apex (5)	$-93.7 \pm 3.0$	$790 \pm 30$	$453 \pm 23$	$337 \pm 38$	-0.1	0.8
				Average	$241 \pm 229$	1.0	0.7
				Range	590	2.4	1.3

As discussed, *S. alatus* from counties with major freshwater inputs were significantly more depleted in  $^{14}\text{C}$  than were specimens from counties lacking major rivers. In contrast, *B. sinistrum* shells from Okaloosa and Bay counties produced statistically indistinguishable  $^{14}\text{C}$  ages (Table 1), despite differences in freshwater inputs. The variability observed among *S. alatus* shells, and the lack of variability among *B. sinistrum* shells, possibly reflects a combination of factors, including micro-environmental variation and sampling bias. A much larger sample of *S. alatus* shells ( $n = 9$ ) was available for study than for *B. sinistrum* ( $n = 4$ ). The larger sample of *S. alatus* shells may represent a greater range of  $^{14}\text{C}$  microenvironments, resulting in a larger range of  $\Delta R$  values. Larger samples of both species, with precisely known collection locations, would clarify whether the apparent variability observed among *S. alatus*, but not *B. sinistrum*, is a natural or statistical phenomenon.

The intrashell  $^{14}\text{C}$  data, though limited, suggests that *S. alatus* have “noisier”  $^{14}\text{C}$  records than do *B. sinistrum* (Table 3). Similar studies have reported intrashell variability in  $\Delta R$  as high as 100  $^{14}\text{C}$  yr on the Atlantic coast (Rick and Henkes 2014), and as high as 240  $^{14}\text{C}$  yr on the Pacific coast (Culleton et al. 2006). The range of  $\Delta R$  values in the *B. sinistrum* specimen is 100  $^{14}\text{C}$  yr, consistent with what others have reported. In comparison, the two *S. alatus* specimens exhibited much greater intrashell variability, with  $\Delta R$  ranges of 330 and 590  $^{14}\text{C}$  yr, respectively (Table 3). Changes in oceanic circulation and deep-water upwelling often are connected with temporal fluctuations in marine  $^{14}\text{C}$ , and may produce seasonal or annual fluctuations in  $^{14}\text{C}$  (Kennett et al. 1997; Deo et al. 2004;

Andrus et al. 2005; Culleton et al. 2006; Jones et al. 2007, 2010). Coastal upwelling is not a typical characteristic of the mostly shallow Gulf of Mexico, although episodes of upwelling related to El Niño–Southern Oscillation (ENSO) and hurricane events have been documented (e.g. Collard and Lugo-Fernández 1999; Walker et al. 2005). The current study lacks the resolution needed to evaluate seasonal or subannual fluctuations.

The intrashell variability observed among *S. alatus* likely reflects factors related to their life history, habitats, and habits. Gastropods are generally mobile, and are more likely to “scrape up” older sources of carbon from the sea floor than are bivalves, which are generally sessile (Angulo et al. 2005). Also, because they are mobile, gastropod shells record  $^{14}\text{C}$  conditions from a spatial range or territory, rather than a single, stationary locale. Little is known about the mobility of *S. alatus*; however, the commercially important queen conch, *S. gigas*, is well studied. Its complex lifecycle includes ontogenetic habitat and niche shifts, with a pelagic larval stage, infaunal and epibenthic juvenile stages, and an epibenthic adult stage (Peel and Aranda 2012). In addition to juvenile migrations (Stoner et al. 1988; Danylchuck et al. 2003; De Jesús-Navarrete and Valencia-Beltrán 2003), adult queen conchs also have seasonal migrations (Hesse 1979; Stoner and Sandt 1992). Thus, the variability in  $^{14}\text{C}$  of *S. alatus* may reflect these ontogenetic and seasonal shifts. In contrast, the mobility of *B. sinistrum* and other busyconine whelks tends to be limited (Menzel and Nichy 1958; Anderson et al. 1985; Walker 1988; Walker et al. 2008). In recapture studies, the majority of *B. sinistrum* are recaptured at their release sites. Seasonal migrations have not been reported, although they may bury themselves or move from intertidal flats to subtidal areas during summer and winter months (Walker et al. 2008).

Although problematic for  $^{14}\text{C}$  dating, the variability in  $^{14}\text{C}$  observed in *S. alatus* shells may provide a proxy record for studying environmental fluctuations or ontogenetic shifts during its lifecycle. The possibility of ontogenetic variability in  $^{14}\text{C}$  within mollusk shells merits further research because portions of the shell may not be representative of the marine environment in which the organism died (Culleton et al. 2006). For example, the spire region of *S. alatus* may appear centuries older than the lip region (Table 3), although these animals live for only ~10 yr. This has important implications for sampling shells of unknown age, which often are recovered in fragmented condition.

Mode of feeding may also influence the variability in  $^{14}\text{C}$  observed between species. Filter feeders, including most bivalves, derive carbonate from seawater or suspended phytoplankton, and are typically preferred for estimating marine reservoir corrections (Reimer et al. 2002). Many archaeological coastal shell midden sites in northwestern Florida are dominated by large marine gastropods, especially *B. sinistrum* and *S. alatus* (White 2014). Grazers scrape microflora from the substrate, and may incorporate “old” carbonates from the substrate into their shells (Reimer et al. 2002). Strombid snails, including *S. alatus*, are unselective herbivorous grazers, and have been observed swallowing large amounts of substrate (Robertson 1961). Thus, the  $^{14}\text{C}$  content of *S. alatus* may be more sensitive to particulate sources of carbonate than are *B. sinistrum*, which are predators.

In middens dominated by marine gastropods, filter-feeding bivalves are less common, and eastern oysters (*Crassostrea virginica*), which have been studied for marine reservoir effects in eastern North America (e.g. Thomas 2008; Rick et al. 2012; Thomas et al. 2013; Rick and Henkes 2014), are rare. The most common bivalve taxa in these contexts are bay scallop (*Argopecten irradians*) and sunray venus (*Macrocallista nimbosa*). Although less abundant than *B. sinistrum* or *S. alatus*, determining  $\Delta\text{R}$  corrections for these taxa should prove fruitful for building  $^{14}\text{C}$  chronologies in this region.



## CONCLUSIONS

This research has demonstrated significant variability in pre-bomb shells from the Florida Panhandle region of the Gulf of Mexico. We propose a  $\Delta R$  correction of  $-9 \pm 25$  <sup>14</sup>C yr for *B. sinistrum* from the Florida Panhandle, and caution against the use of *S. alatus* for <sup>14</sup>C dating due to significant intra- and intershell variability in  $\Delta^{14}\text{C}$ . In the case of *S. alatus*, the spire and lip regions of the same shell may differ in apparent age by hundreds of <sup>14</sup>C yr. Intrashell variability likely reflects a combination of factors, including environmental and life-history factors, such as ontogenetic niche and habitat shifts. When preparing samples for AMS dating, archaeologists and <sup>14</sup>C laboratory personnel should be aware of the possibility of ontogenetic variability in <sup>14</sup>C within mollusk shells, in addition to seasonal and annual variability as described by Culleton et al. (2006) and Jones et al. (2007).

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