

1 **A Multi-proxy assessment of the impact of climate change on Late Holocene (4500-3800 BP)**

2 **Native American villages of the Georgia coast**

3

4 Short Title: **The emergence of early villages and climate change**

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29 **Abstract**

30 Circular shell rings along the Atlantic Coast of southeastern North America are the remnants of some of
31 the earliest villages that emerged during the Late Archaic Period (5000 – 3000 BP). Many of these
32 villages, however, were abandoned during the Terminal Late Archaic Period (ca 3800 – 3000 BP). Here,
33 we combine Bayesian chronological modeling with multiple environmental proxies to understand the
34 nature and timing of environmental change associated with the emergence and abandonment of shell ring
35 villages on Sapelo Island, Georgia. Our Bayesian models indicate that Native Americans occupied the
36 three Sapelo shell rings at varying times with some generational overlap. By the end of the complex's
37 occupation, only Ring III was occupied before abandonment ca. 3845 BP. Ring III also consists of
38 statistically smaller oysters (*Crassostrea virginica*) that people harvested from less saline estuaries
39 compared to earlier occupations. These data, when integrated with recent tree ring analyses, show a
40 clear pattern of environmental instability throughout the period in which the rings were occupied. We
41 argue that as the climate became unstable around 4300 BP, aggregation at shell ring villages provided a
42 way to effectively manage fisheries that are highly sensitive to environmental change. However, with the
43 eventual collapse of oyster fisheries and subsequent rebound in environmental conditions ca. 3800 BP,
44 people dispersed from shell rings, and shifted to non-marine subsistence economies and other types of
45 settlements. This study provides the most comprehensive evidence correlations between large-scale
46 environmental change and societal transformations on the Georgia coast during the Late Archaic period.

47

48 **Introduction**

49 The emergence of village life and adaptation to coastal environments are significant transitions in human
50 history that have occurred at various times and places across the globe. Archaeologists in southeastern
51 North America, specifically, have long been interested in social, political, economic, and environmental
52 contexts surrounding the formation and abandonment of early villages along the South Atlantic Coast [1,
53 2]. Late Archaic Period (5000 – 3000 cal. BP) arcuate and circular shell rings on the Georgia and South
54 Carolina coasts represent what is left of the earliest village communities that emerged in this region.
55 Archaeological research on these circular villages, which predate the adoption of farming, has broadened
56 our understanding of hunter-gatherer economies, the nature of ceremonialism and early monumentality,

57 cooperation, as well as adaptation and resilience in the face of environmental instability [2-4]. However,
58 circular shell ring villages of the South Atlantic coast did not persist across time, and many, especially
59 those of Georgia and South Carolina, were abandoned during the Late Archaic Period. Previous research
60 has focused on the socio-ecological transformations that occurred during the time in which shell ring
61 villages were abandoned in the region, yet few researchers have examined the material record for
62 potential environmental correlations to both the emergence and abandonment of circular shell ring
63 villages. Further, much of the previous research on this topic tends to encompass coarse time scales,
64 lacking the granular resolution necessary to understand how successive generations of people
65 experienced such environmental shifts. Here, we provide a case study from Sapelo Island, Georgia, to
66 document multiple lines of evidence for types of environmental shifts experienced by several generations
67 of villagers that lead to societal transformations on the Georgia coast during the Late Archaic Period.

68 Circular shell rings along the southeastern Atlantic seaboard of North America emerged around
69 4400 cal. BP as marsh ecosystems formed in the context of rising relative sea levels, which at that time
70 had reached 1.2 m below present (mbp) [5, 6]. Climatic shifts and relative sea level changes (which may
71 have dropped by as much as 2.5 mbp by 3800 cal. BP and 3.5 mbp by 3100 cal. BP), however, are
72 thought to have led to the eventual abandonment and cessation of shell ring construction in the region [7-
73 9]. Several studies suggest that the abandonment of shell ring villages corresponded with an
74 environmentally correlated collapse in oyster fisheries at this time [7, 8]. Recent research examines the
75 extent to which the hunter-gatherer communities of the Georgia coast underwent reorganization in terms
76 of both settlement and economies to navigate shifting environmental conditions [9, 10]. Specifically, Turk
77 and Thompson [9] argue that hunter-gatherer communities of this region were resilient in the sense that
78 through cooperation and collective agency these communities were able to negotiate shifting social and
79 environmental landscapes in the face of climate change. As climatic shifts changed resource bases (e.g.,
80 reduced productivity of oyster reefs), people reorganized their social systems, resulting in changing
81 economies, settlement patterns, and spatial layouts of villages (e.g., the shift to non-shell ring sites that
82 evidence a much-reduced reliance on oysters and other shellfish).

83 Some of the more well-studied Late Archaic shell-rings villages are located on Sapelo Island,
84 Georgia. Sapelo Island, a barrier island located on the Georgia Coast some 80 km south of present-day

85 Savannah, Georgia USA, plays an important role in our understandings of change and continuity in
86 Native American coastal economies, political organization, and settlement patterns in much of the
87 published literature on the subject over the last two decades (Fig 1). In addition to its archaeological
88 significance, Sapelo Island, and other islands along the Georgia coast, were and continue to be of special
89 cultural significance to Native Americans, such as the Muscogee Nation. The Sapelo Shell Ring complex
90 is located on the northwestern side of Sapelo Island. This site along with research on nearby Ossabaw
91 and St. Catherines islands and regional surveys, has given key insight into the formation and
92 abandonment of villages during the Late Archaic Period [7, 11, 12]. The Sapelo Shell Ring Complex
93 consists of three circular shell rings (Rings I, II, and III) of varying size. Ring I is the largest, consisting of
94 some 5660 m³ of shell and covering an area of 6000 m². Previous oxygen isotope analyses ($\delta^{18}\text{O}$) of
95 mollusk shells and seasonal signatures in archaeofaunal remains from the Sapelo Shell Ring complex
96 indicate that these locales were occupied year-round, with some periods of more intensive gatherings [13,
97 14]. The Sapelo shell ring villages were likely comprised of coresidential communities characterized by
98 group cooperation and collective action, especially regarding the harvesting of estuarine resources for
99 subsistence and ceremonial purposes [4]. As argued by Thompson [4:30], these villages emerged not
100 because of individuals vying for power and prestige, but rather through the collective agency of groups
101 that worked together to manage dynamic ecosystems that are highly sensitive to human activity and
102 environmental change.

103

104 **Fig 1.** Map of the Georgia coast showing the location of Sapelo Island and shell rings.

105

106 As described above, one thing we know for certain is that environmental change played a
107 significant role in the emergence and abandonment of the Sapelo shell rings during the Late Archaic
108 Period. However, exactly what kind of environmental shifts occurred, to what degree, and on what time
109 scale early villagers experienced such shifts have remained elusive. Here, we combine Bayesian
110 chronological modeling of radiocarbon dates with multiple datasets, including oyster morphometrics,
111 stable oxygen isotopes of mollusks, and recent tree ring analyses, to understand the nature and timing of
112 environmental change associated with the emergence and abandonment of circular villages on Sapelo

113 Island, Georgia, during the Late Archaic Period. Our overarching objectives are to: (a) establish a
114 chronological relationship between the three shell rings using Bayesian statistical modeling, and (b) use
115 multiple environmental proxies to document environmental shifts across time that may have led to socio-
116 ecological changes, specifically the formation and eventual cessation of circular shell ring construction on
117 the Georgia coast.

118

119 **Materials and Methods**

120 ***Radiocarbon Analysis***

121 Establishing a chronological relationship between the three Sapelo shell rings is necessary to link the
122 formation and abandonment of the rings to one another, as well as environmental shifts over time. To
123 examine the chronological relationship of the three rings, we obtained 17 new AMS radiocarbon dates
124 across multiple proveniences from Shell Rings I, II, and III, along with 8 legacy dates. At the request of
125 our Tribal collaborators, we avoided contexts containing ancestral remains in our dating project. Most of
126 our dates come from hickory nut (*Carya* spp.), UID nut fragments, deer bone, pine (*Pinus* spp.), sooted
127 sherds, and UID carbonized wood.

128 All Accelerator Mass Spectrometry (AMS) radiocarbon measurements were carried out at the
129 Center for Applied Isotope Studies (CAIS) facility at the University of Georgia and followed procedures
130 outlined by Cherkinsky et al. [15]. The charcoal samples were treated following the acid/alkali/acid (AAA)
131 protocol involving three steps: (a) an acid treatment (1N HCl at 80°C for 1 hour) to remove secondary
132 carbonates and acid-soluble compounds; (b) an alkali (NaOH) treatment; and (c) a second acid treatment
133 (HCl) to remove atmospheric CO₂. Sample was thoroughly rinsed with deionized water between each
134 step, and the pretreated sample was dried at 105°C. The dried charcoal was combusted at 900°C in
135 evacuated/sealed Pyrex ampoule in the present CuO.

136 The deer bone samples were cleaned by wire brush and washed, using ultrasonic bath. After
137 cleaning, the dried bones were gently crushed to small fragments. The cleaned samples were then
138 reacted under vacuum with 1N HCl to dissolve the bone mineral and release carbon dioxide from
139 bioapatite. The residues were filtered, rinsed with deionized water and under slightly acid condition
140 (pH=3) heated at 80°C for 6 hours to dissolve collagen and leave humic substances in the precipitate.

141 The collagen solution is then filtered to isolate pure collagen and dried out. The dried collagens were
142 combusted at 575°C in evacuated/sealed Pyrex ampoule in the presence of CuO.

143 The resulting carbon dioxide was cryogenically purified from the other reaction products and
144 catalytically converted to graphite as described in Cherkinsky et al. [15]. Graphite $^{14}\text{C}/^{13}\text{C}$ ratios were
145 measured using the CAIS 0.5 MeV accelerator mass spectrometer. The sample ratios were compared to
146 the ratio measured from the Oxalic Acid I (NBS SRM 4990). The sample $^{13}\text{C}/^{12}\text{C}$ ratios were measured
147 separately using a stable isotope ratio mass spectrometer and expressed as $\delta^{13}\text{C}$ with respect to PDB,
148 with an error of less than 0.1‰. The quoted uncalibrated dates have been given in radiocarbon years
149 before 1950 (years BP), using the ^{14}C half-life of 5568 years. The error is quoted as one standard
150 deviation and reflects both statistical and experimental errors. The date has been corrected for isotope
151 fractionation.

152

153 ***Oyster Paleobiology***

154 Eastern oysters (*Crassostrea virginica*), hereby simply referred to as oyster(s), were an important part of
155 larger economic resources on the Georgia coast, and recent research shows that they were sustainably
156 harvested by Native American communities for thousands of years [16, 17]. Oysters were integral to other
157 aspects of life as well, including their use in mound construction and shell ring formation, which can be
158 seen at the Sapelo Shell Rings and later platform mounds along the Georgia coast, such as the
159 Mississippian Period (1150 – 370 cal. BP) Irene Mound [18]. The size of oyster shells is determined by
160 several factors including age, human predation pressures, and environmental variability, with healthier
161 reefs and climatic stability generally producing larger oyster shells [19-22]. For these reasons, temporal
162 changes in oyster size are used as a proxy for environmental change as well as human activity and
163 harvesting practices [21, 22].

164 To examine if there were any temporal changes in oyster size, we compared the size of eastern
165 oysters between Sapelo Shell Ring I, II, and III. A total of 2,130 eastern oysters were measured from
166 Sapelo Shell Rings I, II, and III. Left valve length (LVL) and left valve height (LVH) measurements (mm)
167 were taken using digital, hand-held calipers, and following a standard method outlined in Lulewicz et al.
168 [22]. All data analyses were conducted using the statistical software R. A Bartlett and Shapiro Wilk test

169 were first used to examine homogeneity of variance and normality of the data, respectively. Since the
170 data are not normally distributed or homoscedastic, a non-parametric Kruskal-Wallis test was used to
171 compare mean LVH and LVL between shell rings, and a post-hoc pairwise Mann-Whitney U test was
172 used to examine which rings are distinguishable regarding mean LVL and LVH. To reduce the possibility
173 of type-I errors associated with multiple comparisons, a Holm correction was used with the Mann-Whitney
174 U test.

175

176 ***Oyster Geochemistry: Oxygen ($\delta^{18}\text{O}$) Isotope Analysis***

177 Oxygen Isotope ($\delta^{18}\text{O}$) analysis of archaeological shell is a widely used method for reconstructing
178 paleoclimate conditions, site occupation histories, and shellfish harvesting practices. Oxygen isotope
179 values in mollusk shells ($\delta^{18}\text{O}_{\text{carbonate}}$) are dictated by multiple variables, but largely are a function of the
180 oxygen isotopes composition of ambient water ($\delta^{18}\text{O}_{\text{water}}$) [23-27]. Moreover, $\delta^{18}\text{O}_{\text{water}}$ covaries with
181 salinity in coastal estuaries [28, 29]. For these reasons, $\delta^{18}\text{O}_{\text{carbonate}}$ values in shell can be used to not
182 only trace local environmental changes in the past, but also to explore Native American shellfish
183 harvesting practices, such as season of collection and the range of habitats used for collection [30-39].
184 Here, we specifically use $\delta^{18}\text{O}_{\text{carbonate}}$ values to retrodict the salinity of the habitats where people
185 harvested shell. As with shell size, changes in estimated salinity across time may point to changes in
186 harvesting practices or environmental change. Scholars commonly use two species of mollusks in these
187 studies: hard clams (*Mercenaria* spp.) and eastern oysters, which both have a wide salinity tolerance and
188 are often found in close association. Hard clams tolerate salinity ranges between approximately 17 psu to
189 37+ psu, with optimal growth between 20 to 30 psu [40, 41]. Oysters' salinity tolerance is slightly wider,
190 from approximately 5 psu to 37+ psu, with optimal growth conditions between 14 and 28 psu [42, 43].

191 Incremental oxygen ($\delta^{18}\text{O}$) isotope analysis was conducted on both eastern oysters (n=19) and
192 hard clams (n=59) collected from all three shell rings. Twenty of these shells were recently sampled; the
193 rest are previously published data from Andrus and Thompson [30]. Laboratory protocols for $\delta^{18}\text{O}$
194 analysis were adapted from previous studies and are described elsewhere [15, 30, 36]. Briefly, only left
195 oyster valves with a complete chondrophore and clam shells with an intact edge were selected for
196 analysis. Shells with epibiont activity were excluded from analysis as they were likely dead when they

197 were collected [44, 45]. Next, oyster shells were bisected along the chondrophore and clams along their
198 axis of maximum growth. The bisected shells were then mounted onto a slide using Crystalbond™
199 adhesive and cut into approximately 0.5-inch-thick sections using a slow-speed diamond wafering saw.
200 Each shell was sampled following ontogeny using a Grizzly Benchtop micro-milling system. For oysters,
201 sampling targeted calcitic areas of each shell and avoided aragonite regions [46]. Sampling trajectories
202 followed growth increments as seen in reflected light (in the chondrophore region of oysters and the
203 middle shell layer in the clams) [15]. Generally, 12-20 samples were obtained from each shell, which
204 captured approximately one-year's worth of growth prior to capture.

205 The resultant powdered carbonate samples were weighed using tin capsules and transferred into
206 Exetainer® 12 ml borosilicate vials. All samples were analyzed for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ using a Thermo Gas
207 Bench II coupled with either a Thermo Delta V or Thermo Delta Plus isotope ratio mass spectrometer
208 in continuous flow mode at the University of Georgia's Center for Applied Isotope Analysis. The values for
209 each sample are reported in parts per mil (‰) relative to the VPDB standard by correcting to multiple
210 NBS-19 analyses (typically 14) per run. NBS-19 was also used to assess and correct for drift and sample
211 size linearity if needed. Salinity values were estimated from shell $\delta^{18}\text{O}$ values following published
212 methods established for the local environments around Sapelo Island [15, 47, 48]. Equations 1 and 2
213 were first used to estimate $\delta^{18}\text{O}_{\text{water}}$ values for each clam and oyster, respectively. The estimated $\delta^{18}\text{O}_{\text{water}}$
214 values were then used to predict salinity for each shell using equation 3. Comparisons of estimated
215 salinity were done between each shell ring for both species combined and each species separately.

216

217 **Equations**

218 **Equation 1:** Water temperature ($^{\circ}\text{C}$) = $20 - 4.42(\delta^{18}\text{O}_{\text{aragonite}} - x)$

219 whereas: 31°C is assumed to be the threshold of summer growth cessation for clams [28]; $\delta^{18}\text{O}_{\text{aragonite}}$ is
220 the most negative value in each clams' profile; and $x = \delta^{18}\text{O}_{\text{water}}$.

221 **Equation 2:** Water temperature ($^{\circ}\text{C}$) = $16.5 - 4.3(\delta^{18}\text{O}_{\text{calcite}} - x) + 0.14(\delta^{18}\text{O}_{\text{calcite}} - x)^2$

222 whereas: 28°C is assumed to be the threshold of summer growth cessation for oysters; $\delta^{18}\text{O}_{\text{aragonite}}$ is the
223 most negative value in each oyster's profile, and $x = \delta^{18}\text{O}_{\text{water}}$. Additionally, a 0.2‰ correction was applied
224 to convert VPDB to VSMOW [47].

225 **Equation 3:** $\delta^{18}\text{O}_{\text{water}} = 0.13(x) - 3.4$

226 whereas: $\delta^{18}\text{O}_{\text{water}}$ is calculated by equation 1 or 2, and x = estimated salinity (psu) [30].

227

228 **Results**

229 ***Radiocarbon Models***

230 Based on our knowledge of the types of samples, their overall contexts, and stratigraphic ordering, we
231 constructed a series of Bayesian chronological models in OxCal 4.4.4. We then constructed an overall
232 model to determine the ordering of the rings. The structure of the overall model follows closely to the
233 models for each individual ring and can be seen in Fig 2A. We calibrated and modeled all dates using the
234 IntCal20 curve [49], rounding to the nearest 5-year interval [50].

235

236 **Fig 2.** AMS models: (A) Probability distributions; (B) Posterior probability of the chronological
237 relationships for the start and end date of the Sapelo shell rings.

238

239 The results of our modeling of the dates indicate good agreement. Both the Amodel (79.2) and
240 Aoverall (79.9) for the model indicate statistical significance, exceeding the 60-threshold established for
241 Bayesian chronological analysis (49, 51). Due to the long tails in the distribution of these dates, here we
242 focus on the 68% probability range; however, we also provide the 95% ranges (Table 1). All dates
243 indicate good convergence (i.e., >95) save one date (R_Date 15084), which appears to be anomalous
244 and may be the result of bioturbation or some other factor. The model estimates a start date for Ring I of
245 4245–4175 cal. BP and an end date of 4150–4100 cal. BP; for Ring II, a modeled start date of 4290–4155
246 cal. BP and end date of 4085–3950 cal. BP; and for Ring III, a modeled start date of 4105–3985 cal. BP
247 and end date of 3965–3845 cal. BP (Fig 2A).

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252

253 **Table 1.** Modeled dates from Sapelo Shell Rings I, II, and III.

Name	Unmodelled (BP)						Modelled (BP)						Amodel 104 Aoverall 101.3 Acomb	A	C
	from	to	%	from	to	%	from	to	%	from	to	%			
Sequence															
Boundary Start: Ring I							4245	4175	68.3	4270	4160	95.4			98.5
Phase Ring															
Sequence 1															
R_Date 52191	4235	4095	68.3	4240	4090	95.4	4235	4195	68.3	4240	4165	95.4		107.7	99.3
R_Date 52190	4240	4150	68.3	4290	4095	95.4	4225	4170	68.3	4235	4160	95.4		116.2	99.5
Phase 1															
R_Date 52189	4245	4150	68.3	4295	4095	95.4	4205	4165	68.3	4220	4155	95.4		123.1	99.6
R_Date 52188	4240	4150	68.3	4290	4095	95.4	4205	4165	68.3	4220	4155	95.4		117.2	99.6
R_Date 52187	4240	4150	68.3	4290	4095	95.4	4185	4160	68.3	4205	4150	95.4		119.5	99.7
R_Date 52186	4290	4155	68.3	4400	4150	95.4	4180	4155	68.3	4195	4150	95.4		112	99.9
Phase 2															
R_Date 52185	4285	4150	68.3	4355	4145	95.4	4170	4150	68.3	4185	4145	95.4		111.9	99.9
R_Date 52184	4080	3930	68.3	4090	3920	95.4	4080	3930	68.3	4090	3920	95.4			99.8
R_Date 52183	4230	4090	68.3	4240	4085	95.4	4160	4135	68.3	4175	4100	95.4		103.5	99.9
R_Date 52182	4155	4085	68.3	4225	3990	95.4	4155	4120	68.3	4155	4085	95.4		123.7	99.4
Phase															
R_Date 15085	4220	3980	68.3	4290	3895	95.4	4215	4120	68.3	4235	4080	95.4		96.8	99.7
R_Date 15084	4065	3835	68.3	4090	3720	95.4	4160	4075	68.3	4225	4045	95.4		17.4	99.4
Boundary End: Ring I							4150	4100	68.3	4155	4020	95.4			98.2
Sequence															
Boundary Start: Ring II							4290	4155	68.3	4495	4095	95.4			97.9
Phase Ring															
Sequence 1															
R_Date 42752	4240	4150	68.3	4290	4095	95.4	4240	4145	68.3	4250	4100	95.4		102	99.4
R_Date 42751	4225	4090	68.3	4235	4010	95.4	4215	4100	68.3	4230	4095	95.4		99.6	99.5

R_Date 42750	4235	4145	68.3	4245	4090	95.4	4125	4090	68.3	4210	4085	95.4		70.9	99.9
Phase															
R_Date 52175	4085	3975	68.3	4090	3925	95.4	4090	4035	68.3	4145	3970	95.4		99.7	99.5
Boundary End: Ring II							4085	3950	68.3	4145	3745	95.4			97.9
Sequence															
Boundary Start: Ring III							4105	3985	68.3	4225	3930	95.4			96.5
Phase Ring															
Sequence 1															
R_Date 52181	3895	3835	68.3	3965	3770	95.4	3895	3835	68.3	3965	3770	95.4			99.6
R_Date 52180	4085	3980	68.3	4140	3930	95.4	4085	3980	68.3	4095	3970	95.4		104.9	99.3
R_Date 52179	4080	3925	68.3	4085	3900	95.4	4065	3965	68.3	4080	3930	95.4		101.7	99.7
R_Date 15083	4220	3980	68.3	4290	3895	95.4	4010	3925	68.3	4050	3915	95.4		80.3	99.9
R_Date 52174	4225	4090	68.3	4235	4010	95.4	4225	4090	68.3	4235	4010	95.4			99.6
R_Date 15082	3960	3725	68.3	3980	3695	95.4	3960	3725	68.3	3980	3695	95.4			99.5
R_Date 52178	3975	3895	68.3	3985	3845	95.4	3980	3910	68.3	3985	3890	95.4		109.4	99.9
R_Date 52177	3960	3845	68.3	3975	3835	95.4	3965	3880	68.3	3975	3845	95.4		93.8	99.6
Phase															
R_Date 15086	4150	3985	68.3	4240	3920	95.4	4050	3930	68.3	4130	3910	95.4		97.3	99.7
Boundary End: Ring III							3965	3845	68.3	3975	3755	95.4			97.4
Order															
Start: Ring I							4245	4175	68.3	4270	4160	95.4			98.5
End: Ring I							4150	4100	68.3	4155	4020	95.4			98.2
Start: Ring II							4290	4155	68.3	4495	4095	95.4			97.9
End: Ring II							4085	3950	68.3	4145	3745	95.4			97.9
Start: Ring III							4105	3985	68.3	4225	3930	95.4			96.5
End: Ring III							3965	3845	68.3	3975	3755	95.4			97.4

254

255

256

257 To evaluate independently the sequence of occupation of the rings, we used the Order function in
258 OxCal. This function provides probabilities for their relative order based on the dates for each ring. We
259 then used R to calculate the posterior probability for various chronological relationships for the start and
260 end date of the rings on Sapelo (Fig 2B). Based on these results, Ring II appears to be the longest
261 occupied seeing both the rise and abandonment of Ring I. The last generation to occupy Ring II likely
262 also saw the founding of Ring III, which was likely founded after Ring I ceased to be used.

263

264 ***Eastern Oyster Paleobiology***

265 Our measurements show a clear distinction in oyster size between the three shell rings (Fig 3A, Table 2).
266 Oyster shells from Ring I and Ring II are comparable in size and are generally larger than oysters from
267 Ring III (Table 2). A non-parametric Kruskal-Wallis test indicates that the rings are significantly different
268 regarding mean oyster height (LVH) and mean oyster length (LVL) (LVH: $X^2 = 49.5$, p -value < 0.01; LVL:
269 $X^2 = 39.8$, p -value < 0.01). A post-hoc pairwise Mann-Whitney U test, however, shows that only oysters
270 from Ring III are statistically smaller than Ring I and II regarding both LVH and LVL (at p -value < 0.01).
271 Tests for equality of variance show a significant difference in variation among LVH and LVL between the
272 shell rings, with Ring II exhibiting the greatest variation in oyster size (LVL: $p < 0.001$; LVH: $p < 0.001$).

273

274 **Fig 3.** Box plots comparing (A) estimated salinity and (B) mean LVH between the three shell rings,
275 showing significantly lower estimated salinity and smaller shells at Ring III. The shell rings are in
276 chronological order based on the radiocarbon model, and red diamonds show mean values for each ring.

277

278 **Table 2.** Descriptive statistics for oyster measurements and oxygen isotope analysis.

Shell Ring	N (Shell Measurements)	Mean LVL	Mean LVH	N (Shell Isotopes)	Mean $\delta^{18}\text{O}_{\text{water}}$	Mean Salinity (psu)
Ring I	65	35.3	65.3	11	0.2	28
Ring II	1057	34.1	65.3	46	0.2	28
Ring III	1008	32.1	58.4	21	-1.1	18

279

280

281 **Oyster Geochemistry: Oxygen ($\delta^{18}\text{O}$) Isotope Analysis**

282 Oxygen isotope results show a clear distinction between the shell rings regarding $\delta^{18}\text{O}_{\text{carbonate}}$, $\delta^{18}\text{O}_{\text{water}}$,
 283 and estimated salinity. Oxygen ($\delta^{18}\text{O}$) values varied among all oyster and clam shells: mean $\delta^{18}\text{O}_{\text{carbonate}}$
 284 ranged between -4.0‰ to 0.5‰ , and estimated $\delta^{18}\text{O}_{\text{water}}$ (using equations 1 and 2) ranged between -2.9‰
 285 and 1.8‰ (Table 3). Most shells also show a general sinusoidal $\delta^{18}\text{O}_{\text{carbonate}}$ profile, indicating season
 286 fluctuations in water temperature and allowing us to pinpoint summer $\delta^{18}\text{O}$ values (e.g., the most negative
 287 value within each shell profile) and predict salinity (Fig 4). Estimated salinity values ranged between 4
 288 and 40 psu, indicating that inhabitants of all three rings were targeting a wide variety of habitats (Table 2).
 289 Most estimated salinity values fell within the salinity tolerance for each species, with only three shells
 290 falling outside of the expected range. At the mean level, the shell rings are significantly different regarding
 291 both $\delta^{18}\text{O}_{\text{water}}$ and estimated salinity ($\delta^{18}\text{O}_{\text{water}}$: $X^2 = 27$, $p\text{-value} < 0.01$; salinity: $X^2 = 32$, $p\text{-value} < 0.01$). A
 292 post-hoc pairwise Mann-Whitney U test, however, indicates that Shell Ring I and II are statistically
 293 indistinguishable, and only Ring III is statistically different, with more negative $\delta^{18}\text{O}_{\text{water}}$ values and lower
 294 estimated salinity (at $p\text{-value} < 0.01$) (Fig 3B). Tests for equality of variance finds that there is no
 295 significant difference in variation among $\delta^{18}\text{O}_{\text{water}}$ and estimated salinity for each shell ring ($\delta^{18}\text{O}_{\text{water}}$: $p\text{-}$
 296 $value < 0.87$; salinity: $p\text{-value} < 0.37$). These tests remained statistically significant when comparing
 297 oysters and clams separately.

298

299 **Fig 4.** Examples of individual shell $\delta^{18}\text{O}_{\text{carbonate}}$ profiles showing seasonal fluctuations in oxygen values
 300 and estimated season of harvest. The data sequence follows ontogeny from right to left, with the first
 301 value representing time of capture. The dashed lines in each graph represent the values that divide the
 302 sample range for each profile into equal thirds (see text above).

303

304 **Table 3.** Estimated summer $\delta^{18}\text{O}$ water (‰ VSMOW) values modeled after Andrus and Thompson's
 305 (2001) oxygen isotope-temperature equations (equations 1 and 2), assuming shell growth cessation at
 306 28°C for oysters and 31°C for clams. Salinity (psu) calculated based on equation 3.

Shell Ring	Species	Sample ID	$\delta^{18}\text{O}_{\text{water}}$ (‰)	Salinity (psu)
Shell Ring I	<i>Crassostrea virginica</i>	OLTS10	-0.2	25

Shell Ring I	<i>Crassostrea virginica</i>	OLTS9	-0.3	24
Shell Ring I	<i>Crassostrea virginica</i>	OLTS12	0.4	30
Shell Ring I	<i>Crassostrea virginica</i>	OLTS15	1.2	36
Shell Ring I	<i>Crassostrea virginica</i>	OLTS11	0.0	27
Shell Ring I	<i>Crassostrea virginica</i>	OLTS3	0.3	24
Shell Ring I	<i>Crassostrea virginica</i>	OLTS14	1.2	36
Shell Ring I	<i>Mercenaria</i> spp.	CLTS7	-0.9	29
Shell Ring I	<i>Mercenaria</i> spp.	CLTS6	0.2	28
Shell Ring I	<i>Mercenaria</i> spp.	CLTS4	-0.3	24
Shell Ring I	<i>Mercenaria</i> spp.	CLTS2	0.7	32
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S1	1.0	34
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S2	0.7	32
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-4SQ1S7	0.8	33
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S6	1.8	40
Shell Ring II	<i>Crassostrea virginica</i>	9MC23A-1-4SQ1S1	0.0	26
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-5SQ1S1	0.6	31
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S5	0.9	34
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S1	1.1	35
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S4	1.5	38
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S7	0.5	30
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S3	0.6	31
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S4	-2.2	9
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-3SQ1S7	0.7	32
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S5	0.9	34
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S3	1.5	38
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-2SQ1S2	0.9	34
Shell Ring II	<i>Crassostrea virginica</i>	9MC23A-1-4SQ1S4	-0.3	24
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-5SQ1S6	0.5	30
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-5SQ1S4	1.8	40
Shell Ring II	<i>Mercenaria</i> spp.	9MC23A-1-5SQ1S5	1.3	36

Shell Ring II	<i>Mercenaria</i> spp.	C5A	-0.3	24
Shell Ring II	<i>Mercenaria</i> spp.	C6A	-1.1	18
Shell Ring II	<i>Mercenaria</i> spp.	C6A	-0.9	19
Shell Ring II	<i>Mercenaria</i> spp.	C1A	-0.3	24
Shell Ring II	<i>Mercenaria</i> spp.	C25A	0.0	27
Shell Ring II	<i>Mercenaria</i> spp.	C2A	0.3	29
Shell Ring II	<i>Mercenaria</i> spp.	C3A	-0.3	24
Shell Ring II	<i>Mercenaria</i> spp.	C12A	-0.3	24
Shell Ring II	<i>Mercenaria</i> spp.	C7A	-0.2	25
Shell Ring II	<i>Mercenaria</i> spp.	C17A	-0.5	22
Shell Ring II	<i>Mercenaria</i> spp.	C9A	-0.1	26
Shell Ring II	<i>Mercenaria</i> spp.	C4A	-0.4	24
Shell Ring II	<i>Mercenaria</i> spp.	C11A	-0.5	23
Shell Ring II	<i>Mercenaria</i> spp.	C20A	-0.8	20
Shell Ring II	<i>Mercenaria</i> spp.	C24A	0.0	27
Shell Ring II	<i>Mercenaria</i> spp.	C18A	-0.2	25
Shell Ring II	<i>Mercenaria</i> spp.	C22A	0.0	26
Shell Ring II	<i>Mercenaria</i> spp.	C14A	0.1	27
Shell Ring II	<i>Mercenaria</i> spp.	C26A	0.2	28
Shell Ring II	<i>Mercenaria</i> spp.	C16A	0.1	27
Shell Ring II	<i>Mercenaria</i> spp.	C23A	0.5	31
Shell Ring II	<i>Mercenaria</i> spp.	C21A	0.2	28
Shell Ring II	<i>Mercenaria</i> spp.	C10A	0.3	29
Shell Ring II	<i>Mercenaria</i> spp.	C19A	0.3	29
Shell Ring II	<i>Mercenaria</i> spp.	C8A	0.5	30
Shell Ring II	<i>Mercenaria</i> spp.	C15A	0.4	29
Shell Ring III	<i>Crassostrea virginica</i>	O7	-2.9	4
Shell Ring III	<i>Crassostrea virginica</i>	O15	-1.5	15
Shell Ring III	<i>Crassostrea virginica</i>	O13	-1.9	12
Shell Ring III	<i>Crassostrea virginica</i>	O14	-0.8	20

Shell Ring III	<i>Crassostrea virginica</i>	O10	-0.4	23
Shell Ring III	<i>Crassostrea virginica</i>	O4	-0.4	23
Shell Ring III	<i>Crassostrea virginica</i>	O9	-1.1	18
Shell Ring III	<i>Crassostrea virginica</i>	O8	-0.5	23
Shell Ring III	<i>Crassostrea virginica</i>	O5	-0.3	24
Shell Ring III	<i>Crassostrea virginica</i>	O3	-0.9	34
Shell Ring III	<i>Mercenaria</i> spp.	C8	-2.4	8
Shell Ring III	<i>Mercenaria</i> spp.	C1	-1.9	12
Shell Ring III	<i>Mercenaria</i> spp.	C9	-1.0	19
Shell Ring III	<i>Mercenaria</i> spp.	C4	-1.6	14
Shell Ring III	<i>Mercenaria</i> spp.	C3	-1.8	13
Shell Ring III	<i>Mercenaria</i> spp.	C5	-1.5	15
Shell Ring III	<i>Mercenaria</i> spp.	C7	-0.9	19
Shell Ring III	<i>Mercenaria</i> spp.	C11	-0.8	20
Shell Ring III	<i>Mercenaria</i> spp.	C10	-0.8	20
Shell Ring III	<i>Mercenaria</i> spp.	C13	-0.1	26
Shell Ring III	<i>Mercenaria</i> spp.	C2	-0.3	24

307

308 Discussion

309 This research provides some of the most comprehensive evidence for environmentally correlated societal
310 transformations on the Georgia coast during the Late Archaic period, specifically regarding the formation
311 and abandonment of circular shell villages on Sapelo Island. Our new chronological research indicates
312 that Native Americans occupied the Sapelo shell rings at varying times with some generational overlap.
313 Ring II had the longest occupational history, spanning from 4290 to 3950 cal. BP. Ring II also witnessed
314 the emergence and abandonment of Ring I (4245 to 4100 cal. BP), as well as the rise of Ring III ca. 4105
315 cal. BP. By the end of the complex's occupation, only Ring III was occupied before its eventual
316 abandonment around 3845 cal. BP.

317 Comparisons regarding oyster paleobiology and isotope geochemistry indicate that villagers at
318 the shell ring complex experienced significant shifts in the environment, especially during the time in

319 which Ring III was occupied. Ring III consists of significantly smaller oyster shells compared to Ring I and
320 II. This suggests a temporal decrease in oyster size given that Ring III is the youngest of the three shell
321 rings. This trend is consistent with other studies on the Georgia coast, such as the Late Archaic Ossabaw
322 Shell Ring, which had the smallest shells in its youngest deposit [22]. Furthermore, even though Rings I
323 and II had similar sized oyster shells that are significantly larger than those from Ring III, Ring II exhibits
324 the greatest variation in oyster shell size, overlapping the range in shell size at the other two rings. This is
325 likely attributed to the long occupational history of Ring II, which temporally overlaps with both Ring I and
326 III. There are two ways to interpret the temporal trend in oyster size, though these drivers are not mutually
327 exclusive and may be attributed to both. First, it is possible that oyster populations experienced
328 harvesting pressures that resulted in smaller shells across time. For example, in heavily predated oyster
329 populations, few individuals will make it to old age due to rapid turnover rates [52, 53]. This results in
330 oyster populations characterized by younger and smaller individuals. Environmental instability that
331 affected local ecosystem productivity also may explain the decrease in oyster size across time. Lower
332 salinity environments from reduced sea levels and periodic river flooding from a wetter climate have been
333 shown to led to high oyster mortality, regular intervals of growth cessation, and thus reduced oyster size
334 [54, 55]. Without other environmental proxies, however, it can be difficult to tease apart whether the
335 observed patterns in oyster paleobiology were attributed to environmental change or human activity.

336 Results from our isotope geochemistry comparisons further support an interpretation that
337 environmental instability was impacting local ecosystems during the Late Archaic period. Oxygen isotope
338 values in mollusk shells point to a shift toward lower salinity values in the estuaries in which mollusks
339 were harvested, specifically during the time in which Ring III was occupied. This temporal pattern can be
340 attributed to several factors, including previously documented changes in sea levels and local rainfall
341 amounts, which both can impact the amount of freshwater input into local estuaries [5, 6]. It is also
342 possible that villagers who lived at Ring III were targeting mollusks further up estuaries, which are
343 characterized by more freshwater input and thus lower salinity values. However, variation in estimated
344 salinity values indicate that villagers at all three rings were targeting a wide range of habitats. This is
345 corroborated by previously published data on vertebrate remains from Ring III (see supplemental
346 information), which consists of marine fishes from a variety of habitats that could be captured year-round

347 and using a range of fishing technologies [13]. Moreover, recent research shows that Native American
348 communities along the South Atlantic coast sustainably harvested oysters for thousands of years,
349 evidenced by an increase in oyster size from the Late Archaic through Mississippian periods (5000 – 370
350 cal. BP) [17]. This stands in contrast to an argument that changes in oyster sizes may reflect
351 unsustainable human management practices. Taking all the evidence into consideration, it is likely that
352 the observed patterns in oyster paleobiology and isotope geochemistry presented here were correlated
353 with environmental fluctuations occurring on decadal or generational time scales.

354 Contextualizing the observed patterns in oyster paleobiology and isotope geochemistry with new
355 climate data derived from tree ring analysis in the locale, as well as our new radiocarbon model, provides
356 a picture of how these early villagers negotiated climate change that would have ultimately been
357 observable across decades and generations. Recent dendrochronological data indicate a period of
358 environmental instability, including high interannual variability in rainfall patterns, between 4300 and 3800
359 BP, which began to ameliorate post-3800 BP (Fig 5) [56]. These data contrast with previous research
360 suggesting that environmental instability began around 3800 BP, around the time when people
361 abandoned shell ring villages along the South Atlantic coast. Furthermore, this period of instability
362 overlaps with the chronology of the entire Sapelo Shell Ring Complex, and further contextualizes the
363 changes in oyster paleobiology and estimated salinity of targeted estuaries. Ring I was constructed and
364 occupied during a period of high interannual variability in rainfalls as well as a rapid salinity intrusion
365 event that kills multiple cypress trees, which likely contributed to higher estimated salinity values from
366 oysters at both Rings I and II. Moreover, the time during which Ring III was occupied was overall wetter
367 and had fewer very dry years compared to earlier occupations. A wetter environment leading to more
368 freshwater input into local estuaries, in addition to relative sea level change, both explain the lower
369 estimated salinity seen in oyster shells from Ring III.

370

371 **Fig 5.** Temporally relevant portion of the multimillennial tree-ring chronology derived from a deposit of
372 ancient buried bald cypress trees at the mouth of the Altamaha River. The chronology is in indices
373 (standardized units representing average ring width, largely indicative in this locale of winter-spring

374 precipitation), with “1000” indicating an annual ring of average width. Enhanced interannual rainfall
375 variability and numerous very dry years are evident beginning around the earliest occupation of Ring I.

376 These new data shift our focus from not just the abandonment of shell ring villages but also their
377 emergence as an example of resilience in the face of climatic instability. Thompson (2) argues that co-
378 residential aggregation and collective action at the Sapelo shell ring villages would have provided a way
379 to effectively manage oyster and other fisheries that are highly sensitive to environmental change and
380 human activity. Our findings corroborate this argument by providing evidence of climate change and
381 environmental instability experienced by successive generation of villagers on Sapelo Island, leading to
382 societal transformations. As the climate became unstable ca. 4300 BP, Native American communities on
383 Sapelo Island underwent reorganization in both settlement and economies to navigate the shifting
384 environmental conditions. More specifically, through aggregation, cooperation, and collective agency,
385 these communities negotiated changing environmental landscapes in the face of climate change
386 documented here, specifically regarding the management of local fisheries. Given the chronological
387 overlap of the shell rings, knowledge of how to sustainably manage fisheries would have been passed
388 down across generations. Zooarchaeological data from Ring III, as well as the variability in oyster size
389 and estimated salinity values shown here, suggest a persistence of subsistence and fishing strategies
390 characterized by flexibility and use of an array of habitats - a necessity given the daily, seasonal, as well
391 as decadal and generational environmental variability experienced by villagers on Sapelo Island. With
392 continued environmental instability and sea level changes, the construction of shell ring villages ceased,
393 and oyster fisheries on Sapelo Island collapsed ca. 3800 BP. As the climate stabilized post-3800 BP,
394 people in the area shifted to relying on non-marine resources and new settlement patterns for a time (10).

395 The emergence of village life and adaptation to coastal environments are key transitions in
396 human history that occurred multiple times in a variety of geographic settings. As been the case in other
397 areas of the world (e.g., Peru) where archaeologists intensely study these phenomena, the process by
398 which people became embedded in these landscapes varied widely. Similar to other regions, the Native
399 Americans that established some of North America’s first villages also developed a complexity of ways to
400 adapt to environmental fluctuations and resource shortfalls. This study provides high resolution climate
401 and cultural datasets by which we examine how people reacted to and experienced climate change on a

402 generational level. Climate change is complex and multidimensional as is how people adapt to and
403 mediate their risk in such situations. Our example shows that the emergence of village life among Native
404 Americas created novel social and economic circumstances that revolved around certain estuarine
405 resources (e.g., mollusks). As succeeding generations that occupied the site began to experience climate
406 unpredictability and shifts in resources, occupants decided to alter these patterns to other locations and
407 possible other kinds of social relationships. What is important in this case study is that even though these
408 groups were generationally invested in a specific geographic place, they effectively adapted to changing
409 circumstances and continue to occupy these coastal regions for millennia, albeit in different ways that
410 built on the experience of generations past. This is perhaps a valuable lesson as a host of our current
411 coastal cities and landmarks experience shifting climate and seas.

412

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428

429

430 **References and Notes**

- 431 1. Birch J, Thompson, VD (eds) (2018) The archaeology of villages in eastern North America (University
432 Press of Florida, Gainesville).
- 433
- 434 2. Sanger MC, Ogden QM (2018) Determining the use of Late Archaic shell rings using lithic data:
435 “Ceremonial villages” and the importance of stone. *Southeastern Archaeology* 37(3):232-252.
- 436
437
- 438 3. Thomas DH (2008) Native American Landscapes of St Catherine’s Island, Georgia. *Anthropological*
439 *Papers of the American Museum of Natural History*, vol. 88, New York).
- 440
- 441 4. Thompson VD (2018). Collective Action and Village Life during the Late Archaic on the Georgia
442 Coast. In: The archaeology of villages in eastern North America, eds Birch J, Thompson VD
443 (University Press of Florida, Gainesville), pp 20-35.
- 444
- 445 5. Gayes PT, Scott DB, Collins ES, Nelson DD (1992) A Late Holocene sea-level fluctuation in South
446 Carolina. In: *Quaternary Coasts of the United States: Marine and Lacustrine Systems*, eds Fletcher
447 CH, Wehmler JF (SEPM Society for Sedimentary Geology, Special Publication No. 48, Tulsa), pp
448 155–160.
- 449
- 450 6. Turck JA, Alexander CR (2013) Coastal landscapes and their relationship to human settlement on the
451 Georgia coast. New York. In: *Life Among the Tides: Recent Archaeology of the Georgia Bight*, eds
452 Thompson VD, Thomas DH (*Anthropological Papers of the American Museum of Natural History*, vol.
453 98, New York), pp 169–189.
- 454
- 455 7. Sanger MC (2010) Leaving the rings: shell ring abandonment and the end of the Late Archaic. In:
456 *Trend, Tradition, and Turmoil: what Happened to the Southeastern Archaic?* eds Thomas DH, Sanger
457 MC (*American Museum of Natural History Anthropological Papers*, No. 93, New York), pp. 201–216.
- 458

- 459 8. Thompson VD, Turck JA (2009) Adaptive cycles of coastal hunter-gatherers. *American*
460 *Antiquity* 74(2):255-278.
- 461
- 462 9. Turck JA, Thompson VD (2016) Revisiting the resilience of late archaic hunter-gatherers along the
463 Georgia coast. *Journal of Anthropological Archaeology* 43:39–55.
- 464
- 465 10. Ritchison BT, Thompson VD, Lulewicz I, Tucker B, Turck JA (2021) Climate change, resilience, and
466 the Native American Fisher-hunter-gatherers of the late Holocene on the Georgia coast,
467 USA. *Quaternary International* 584:82-92.
- 468
- 469 11. Thomas DH, Sanger MC (2010) The two rings of St. Catherines Island: Some preliminary results from
470 the St. Catherines and McQueen shell rings. In: Trend, Tradition, and Turmoil: what Happened to the
471 Southeastern Archaic? eds Thomas DH, Sanger MC (American Museum of Natural History
472 Anthropological Papers, No. 93, New York), pp. 45-70
- 473
- 474 12. Thompson VD, Turck JA (2010) Island archaeology and the Native American economies (2500 B.C.
475 to A.D. 1700) of the Georgia Coast, USA. *Journal of Field Archaeology* 35:283-297.
- 476
- 477 13. Colaninno CE, Compton JM (2019) Integrating vertebrate and invertebrate seasonality data from Ring
478 III of the Sapelo Island Shell Ring Complex (9MC23). *Journal of Island and Coastal Archaeology*
479 14(4):560-583.
- 480
- 481 14. Thompson VD, Andrus CFT (2011) Evaluating mobility, monumentality, and feasting at the Sapelo
482 Shell Ring complex. *American Antiquity* 76:315–344.
- 483
- 484 15. Cherkinsky A, Culp RA, Dvoracek DK, Noakes JE (2010) Status of the AMS facility at the University
485 of Georgia. *Nuclear Instruments and Methods in Physics Research* 268:867-870.

486
487

- 488 16. Reede-Myers LA, Thompson VD, Rick TC, et al. (Under Review). Forgotten Fisheries, Indigenous
489 Communities, and the Shifting Baseline of Global Oyster Harvest. Submitted to *Nature Sustainability*
490
- 491 17. Thompson VD, Rick T, Garland CJ, Thomas DH, Smith KY, Bergh, et al. (2020) Ecosystem stability
492 and Native American oyster harvesting along the Atlantic Coast of the United States. *Science*
493 *Advances* 6(28):1-8 9652.
494
- 495 18. Thompson VD (2009) The Mississippian production of space through earthen pyramids and public
496 buildings on the Georgia coast, USA. *World Archaeology* 41(3):445-470.
497
- 498 19. Bartol IK, Mann R, Luckenbach M (1999) Growth and mortality of oysters (*Crassostrea virginica*) on
499 constructed intertidal reefs: effects of tidal height and substrate level. *Journal of Experimental Marine*
500 *Biology and Ecology* 237:157–184.
501
- 502 20. Claassen C (1998) Shells. Cambridge University Press, Cambridge.
503
- 504 21. Morrison AE, Cochrane EE (2008) Investigating shellfish deposition and landscape history at the
505 Natia Beach site, Fiji. *Journal of Archaeological Science* 35(8):2387–2399.
506
- 507 22. Lulewicz IH, Thompson VD, Cramb J, Tucker B (2017) Oyster paleoecology and native American
508 subsistence practices on Ossabaw Island, Georgia, USA. *Journal of Archaeological Science:*
509 *Reports* 15:282-289.
510
- 511 23. Jones DS, Arthur MA, Allard DJ (1989) Sclerochronological record of temperature and growth from
512 shells of *Mercenaria* from Narragansett Bay, Rhode Island. *Marine Biology* 102:225-234.
513
- 514 24. Kirby MX, Soniat TM, Spero HJ (1998) Stable isotope sclerochronology of Pleistocene and recent
515 oyster shells (*Crassostrea virginica*). *Palaios* 13:560-569.

- 516 25. Surge D, Lohmann C, Goodfriend GA (2003) Reconstructing estuarine conditions: oyster shells as
517 recorders of environmental change, Southwest Florida. *Estuarine, Coastal, and Shelf Science*
518 57:737–756.
- 519
- 520 26. Elliot M, deMenocal PD, Linsley BK, Howe SS (2003) Environmental controls on the stable isotopic
521 composition of *Mercenaria*: potential application to paleoenvironmental studies. *Geochemistry,*
522 *Geophys, Geosys* 4:1-16.
- 523
- 524 27. Andrus CFT, Crowe DE (2000) Geochemical analysis of *Crassostrea virginica* as a method to
525 determine season of capture. *Journal of Archaeological Science* 27:33–42.
- 526
- 527 28. Coplen TB, Kendall C (2000) Stable hydrogen and oxygen isotope ratios for selected sites of the U.S.
528 geological survey's NASQAN and benchmark surface water networks. *U.S. Geol. Surv. Open-File*
529 *Rept.* 0-160.
- 530
- 531 29. Andrus CFT (2011) Shell midden sclerochronology. *Quaternary Science Reviews* 30:2892–2905.
- 532
- 533 30. Andrus CFT, Thompson VD (2012) Determining the habitats of mollusk collection at the Sapelo Island
534 shell ring complex, Georgia, USA using oxygen isotope sclerochronology. *Journal of Archaeological*
535 *Science* 39:215–228.
- 536
- 537 31. Blitz JH, Andrus CFT, Downs, LE (2014) Sclerochronological measures of seasonality at a Late
538 Woodland mound on the Mississippi Gulf Coast. *American Antiquity* 79(4):697–711.
- 539
- 540 32. Burchell M, Cannon A, Hallmann, Schwarcz HP, Schöne BR (2013) Refining estimates for the season
541 of shellfish collection on the Pacific Northwest coast: Applying high-resolution stable oxygen isotope
542 analysis and schlerochronology. *Archaeometry* 55(2):258–276.
- 543

- 544 33. Hausmann N, Meredith-Williams M (2016) Seasonal patterns of coastal exploitation on the Farasan
545 Islands, Saudi Arabia. *Journal of Island and Coastal Archaeology* 00:1–20.
546
- 547 34. Lesure RG, Gagliu A, Culleton BJ, Kennett DJ (2009) Changing patterns of shellfish exploitation at El
548 Varal. In: Settlement and Subsistence in Early Formative Sonconusco: El Varal and the Problem of
549 Inter-Site Assemblage Variation, ed Lesure RG (Cotsen Institute of Archaeology, California.), pp. 75–
550 87.
551
- 552 35. Lulewicz IH, Thompson VD, Pluckhahn TJ, Andrus CFT, Das O (2018) Exploring oyster (*Crassostrea*
553 *virginica*) habitat collection via oxygen isotope geochemistry and its implications for ritual and mound
554 construction at Crystal River and Roberts Island, Florida. *The Journal of Island and Coastal*
555 *Archaeology* 13(3):388-404.
556
- 557 36. Lulewicz IH, Wallis NJ, Thompson VD (2019) Exploring the season of mound building through oxygen
558 isotope geochemistry at the Garden Patch site, Gulf Coast Florida, USA. *Southeastern Archaeology*
559 39(1):16-28.
560
- 561 37. Thompson VD, Andrus CFT (2013) Using oxygen isotope sclerochronology to evaluate the role of
562 small island among the Guale (AD 1325 to 1700) of the Georgia Coast, USA. *Journal of Island and*
563 *Coastal Archaeology* 8(2):190–209.
564
- 565 38. Twaddle RW, Ulm S, Hinton J, Wurster CM, Bird MI (2015) Sclerochronological analysis of
566 archaeological mollusk assemblages: Methods, applications, and future prospects. *Archaeological*
567 *and Anthropological Sciences* 8(2):359–379.
568
- 569 39. Walker KJ, Surge D (2006) Developing oxygen isotope proxies from archaeological sources for the
570 study of Late Holocene human climate interactions in coastal southwest Florida. *Quat. Int.* 150:3-11.
571

- 572 40. Kraeuter JN, Castagna M (2001) *Biology of the Hard Clam* (Elsevier Science, New York).
573
- 574 41. Grizzle RE, Bricelj VM, Shumway SE (2001) Physiological ecology of Mercenaria. In: *Biology of the*
575 *Hard Clam*, eds Kraeuter JN, Castagna M (Elsevier Science, New York), pp. 305-382.
576
- 577 42. Bartol IK, Mann R, Luckenbach M (1999) Growth and Mortality of Oysters (*Crassostrea virginica*) on
578 Constructed Intertidal Reefs: Effects of Tidal Height and Substrate Level. *Journal of Experimental*
579 *Marine Biology and Ecology* 237:157-184
580
- 581 43. Shumway SE (1996) Natural environmental factors. In: *The Eastern Oyster Crassostrea virginica*, eds
582 Kennedy VS, Newell RIE, Eble AF (Maryland Sea Grant College, College Park), pp. 467–513
583
- 584 44. Cobb WR (1969) Penetration of Calcium Carbonate Substrates by the Boring Sponge *Cliona*.
585 *American Zoologist* 9:783–790.
586
- 587 45. Warburton FE (1958) The Manner in which the Sponge *Cliona* Bores in Calcareous Objects.
588 *Canadian Journal of Zoology* 36:555–562.
589
- 590 46. Carriker MR, Palmer RE (1979) A new mineralized layer in the hinge of the
591 oyster. *Science* 206(4419):691-693.
592
- 593 47. Harding JM, Spero HJ, Mann R, Herbert GS, Sliko JL, Kennett JP (2010) Reconstructing early 17th
594 century estuarine drought conditions from Jamestown oysters. *Proc Natl Acad Sci USA* 107:10549–
595 10554.
596
- 597 48. Epstein S, Buchsbaum R, Lowenstam HA, Urey HC (1953) Revised carbonate-water isotopic
598 temperature scale. *Geological Society of America Bulletin* 64(11):1315–1326.
599

- 600 49. Reimer PJ, Austin WE, Bard E, Bayliss A, Blackwell PG, Ramsey CB, Talamo S (2020) The IntCal20
601 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62(4):725-757.
602
- 603 50. Hamilton WD, Krus AM (2018) The myths and realities of Bayesian chronological modeling
604 revealed. *American Antiquity* 83(2):187-203.
605
- 606 51. Bronk-Ramsey C (2009) Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51(1):337-360
607
- 608 52. Rick TC, Reeder-Myers LA, Hofman CA, Breitburg D, Lockwood R, et al. (2016) Millennial-scale
609 sustainability of the Chesapeake Bay Native American oyster fishery. *Proc Natl Acad Sci USA* 113
610 (23):6568–6573.
611
- 612 53. Wang H, Huang W, Harwell MA, Edmiston L, Johnson E, Hsieh P, Milla K, Christensen J, Stewart J,
613 Liu X (2008) Modeling oyster growth rate by coupling oyster population and hydrodynamic models for
614 Apalachicola Bay, Florida, USA. *Ecological Modelling* 211(1-2):77-89.
615
- 616 54. La Peyre MK, Gossman B, La Peyre JF (2009) Defining optimal freshwater flow for oyster production:
617 Effects of freshet rate and magnitude of change and duration on eastern oysters and *Perkinsus*
618 *marinus* infection. *Estuaries and Coasts* 32(3):522-34.
619
- 620 55. La Peyre MK, Eberline BS, Soniat TM, La Peyre JF (2013) Differences in extreme low salinity timing
621 and duration differentially affect eastern oyster (*Crassostrea virginica*) size class growth and mortality
622 in Breton Sound, LA. *Estuarine, Coastal and Shelf Science* 135:146-57.
623
- 624 56. Napora KG, Thompson VD, Cherkinsky A, Horan R, Tyler B, Jacobs C (Under review) A 5177-year
625 Tree-Ring Chronology from the Southeast Coast, USA. Submitted to *Nature Scientific Reports*
626
627

628 **Supplemental Information Captions**

629 **Table S1:** Sapelo Shell Ring Complex, Ring III, Unit 9 Species List.

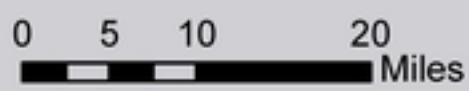
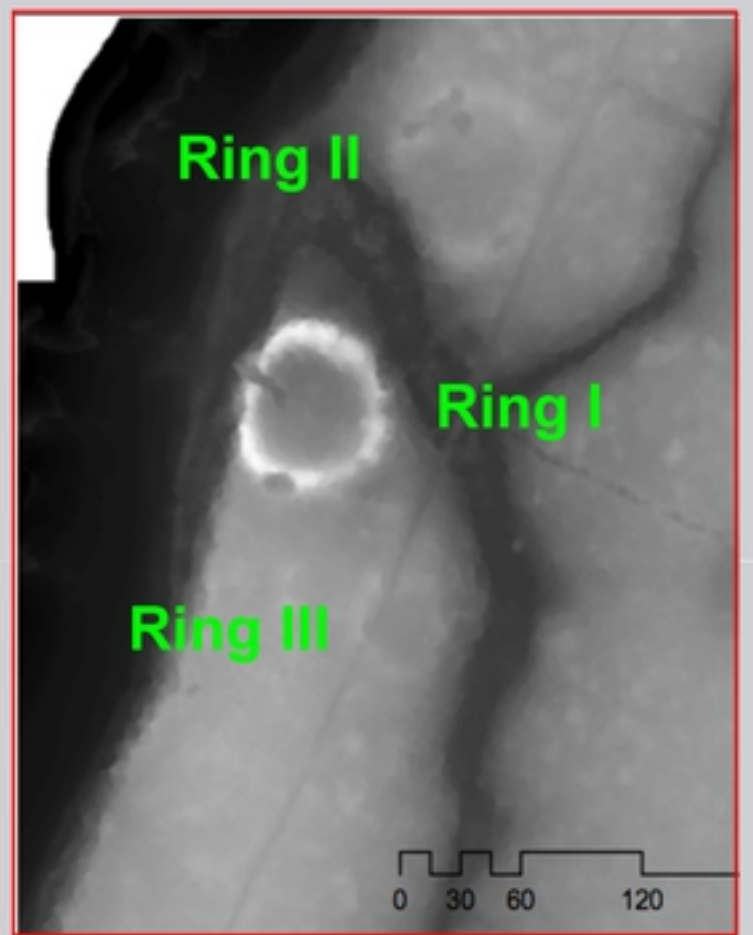
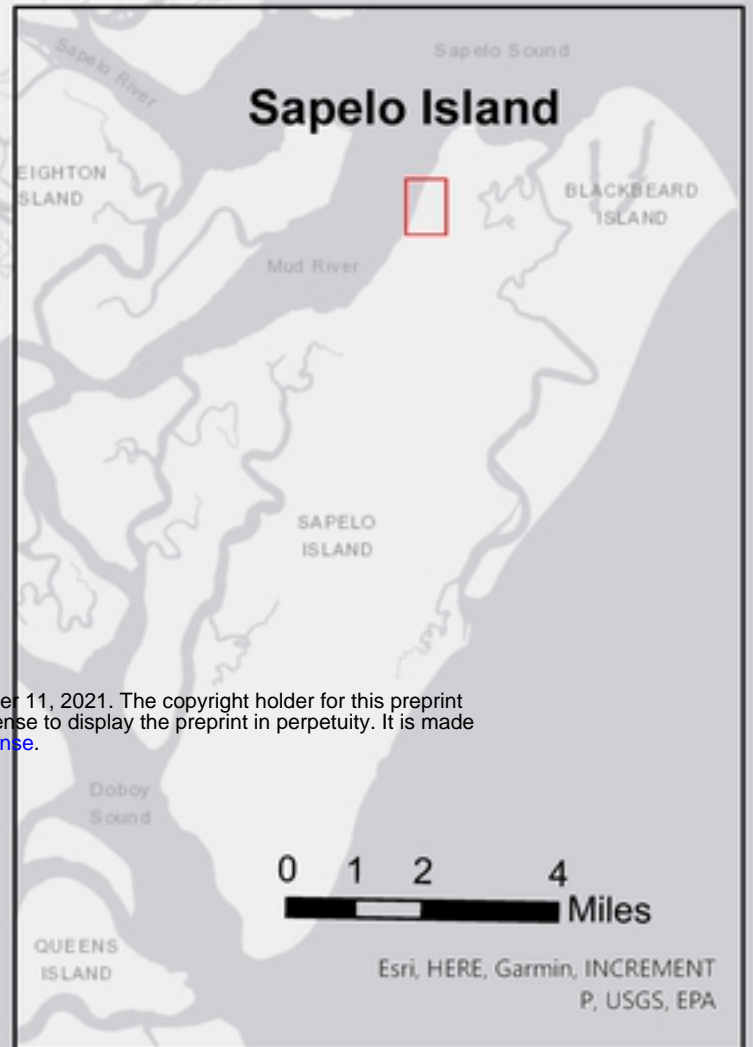
630 **Table S2:** Sapelo Shell Ring Complex, Ring III, Unit 4 Species List.

631 **Table S3:** Uncorrected AMS dates and context for each sample. See Table 1 for corrected and modeled
632 dates.

633 **Oxcal Code**

Georgia

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Esri, HERE, Garmin, USGS, EPA, NPS

Figure 1

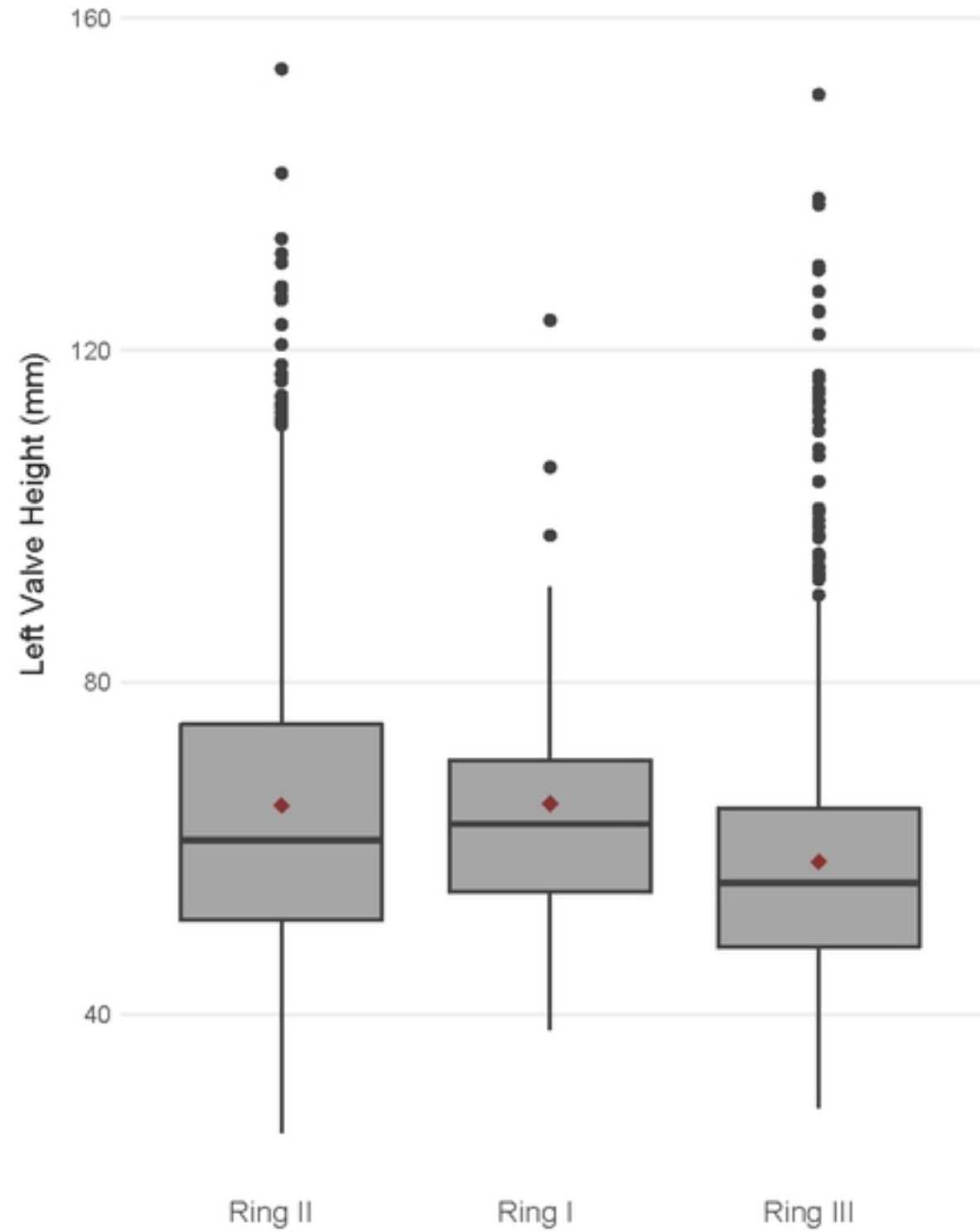
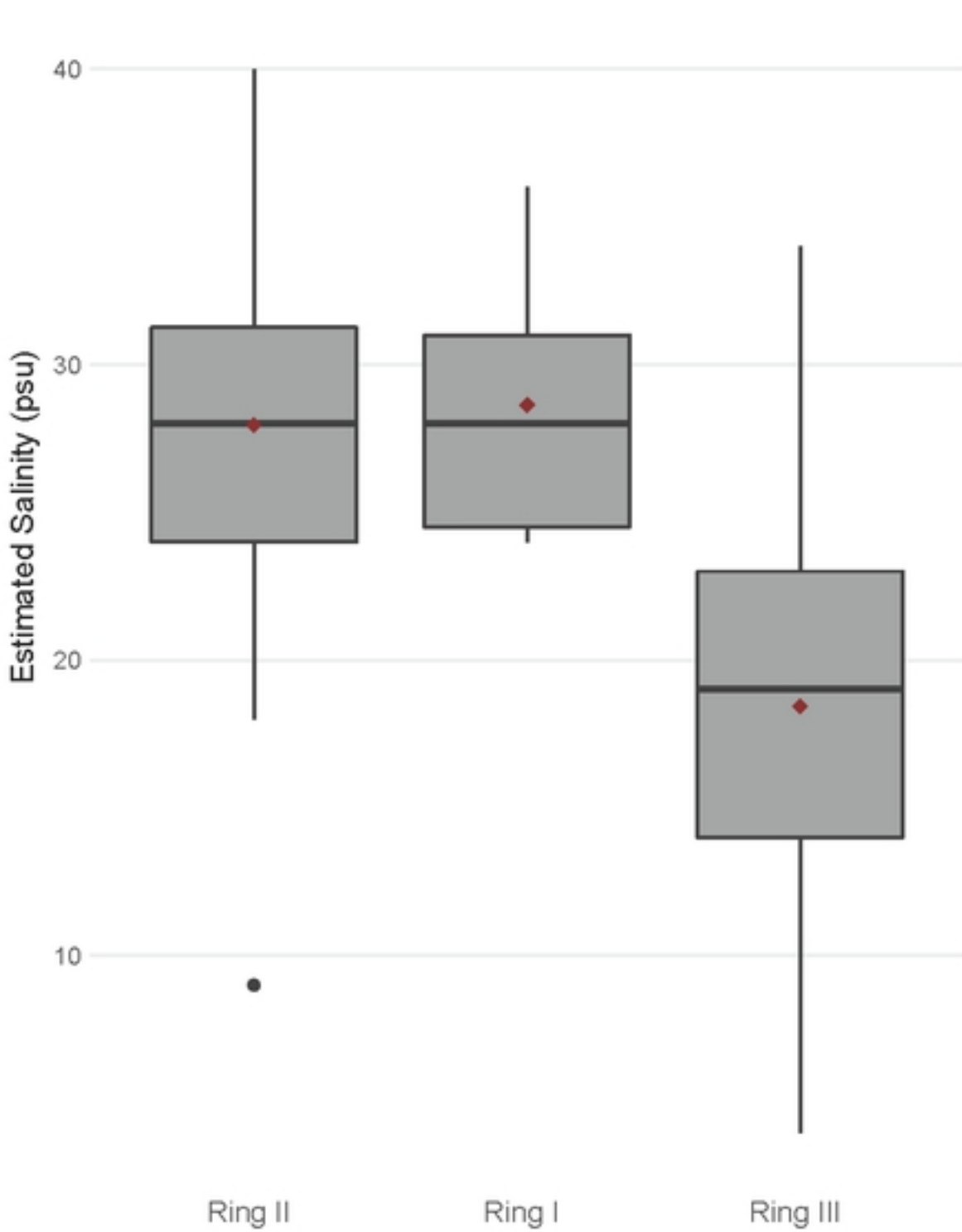


Figure 3

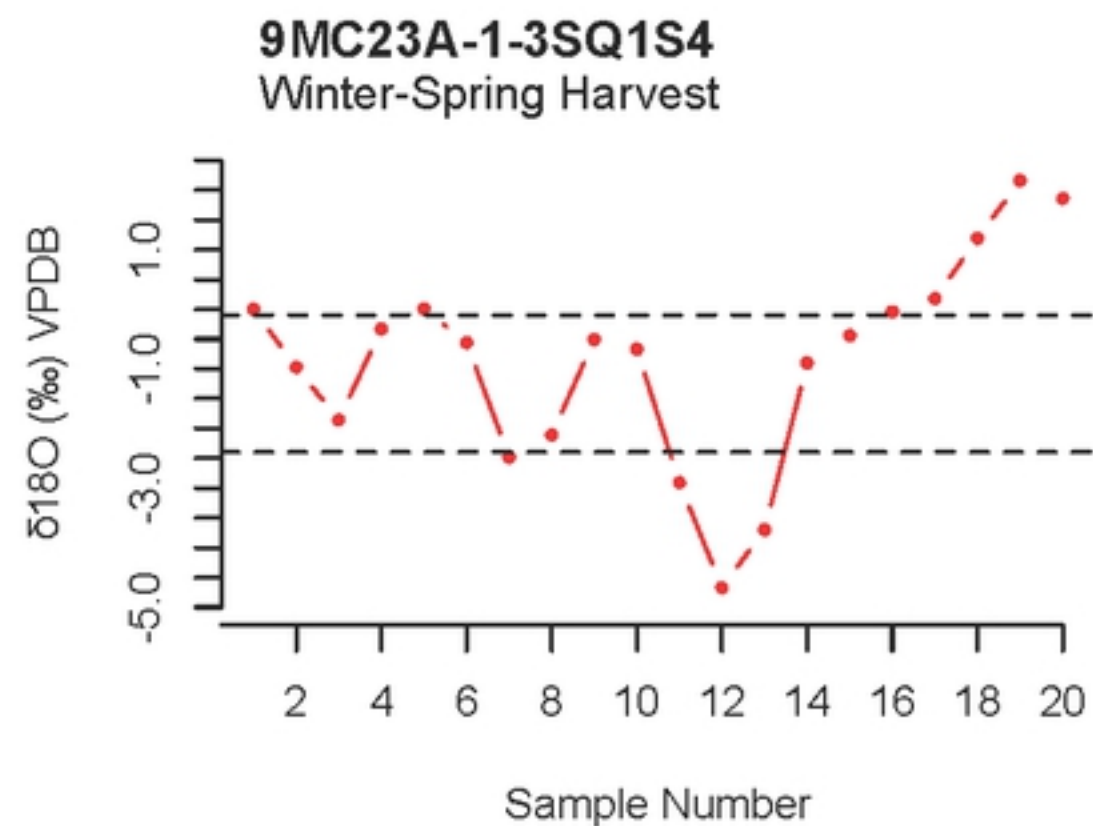
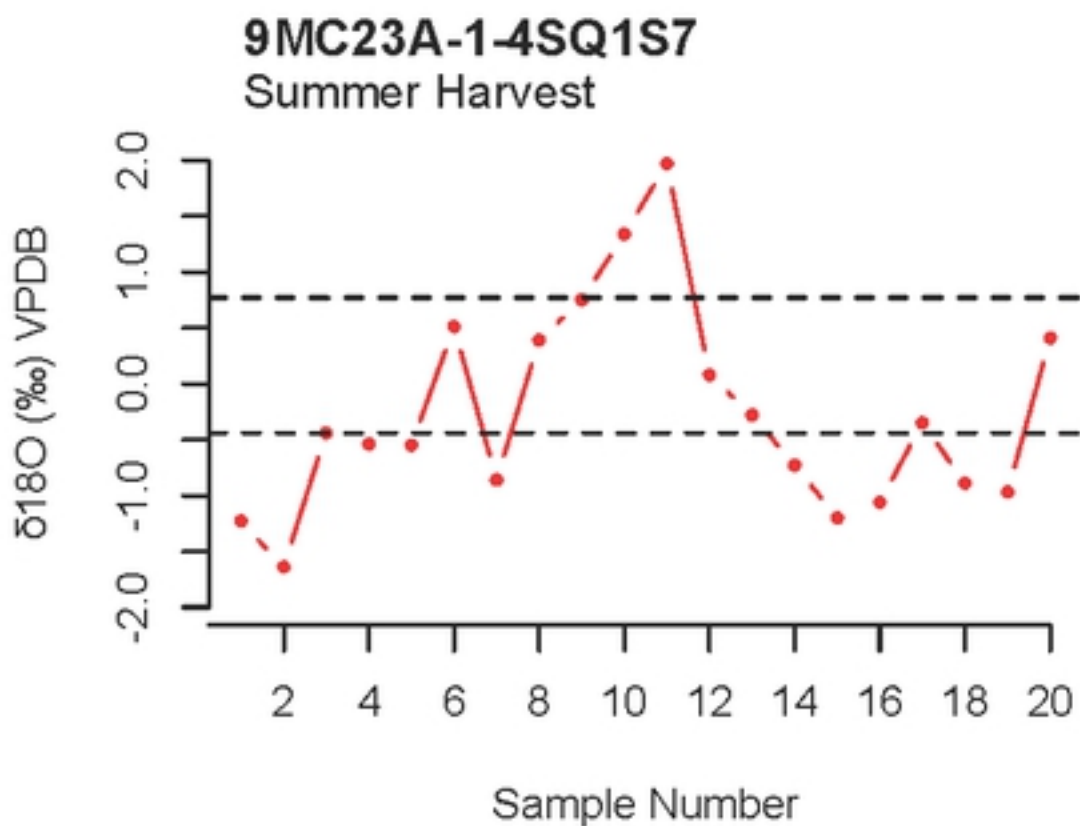
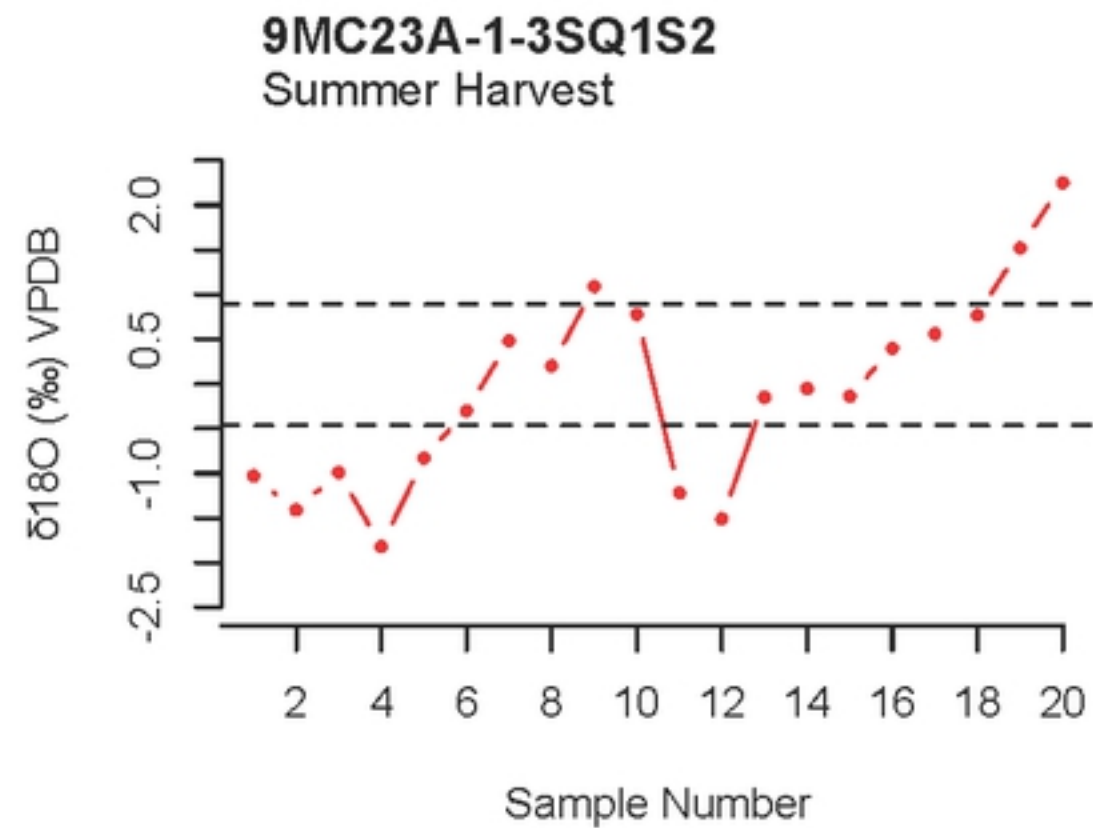
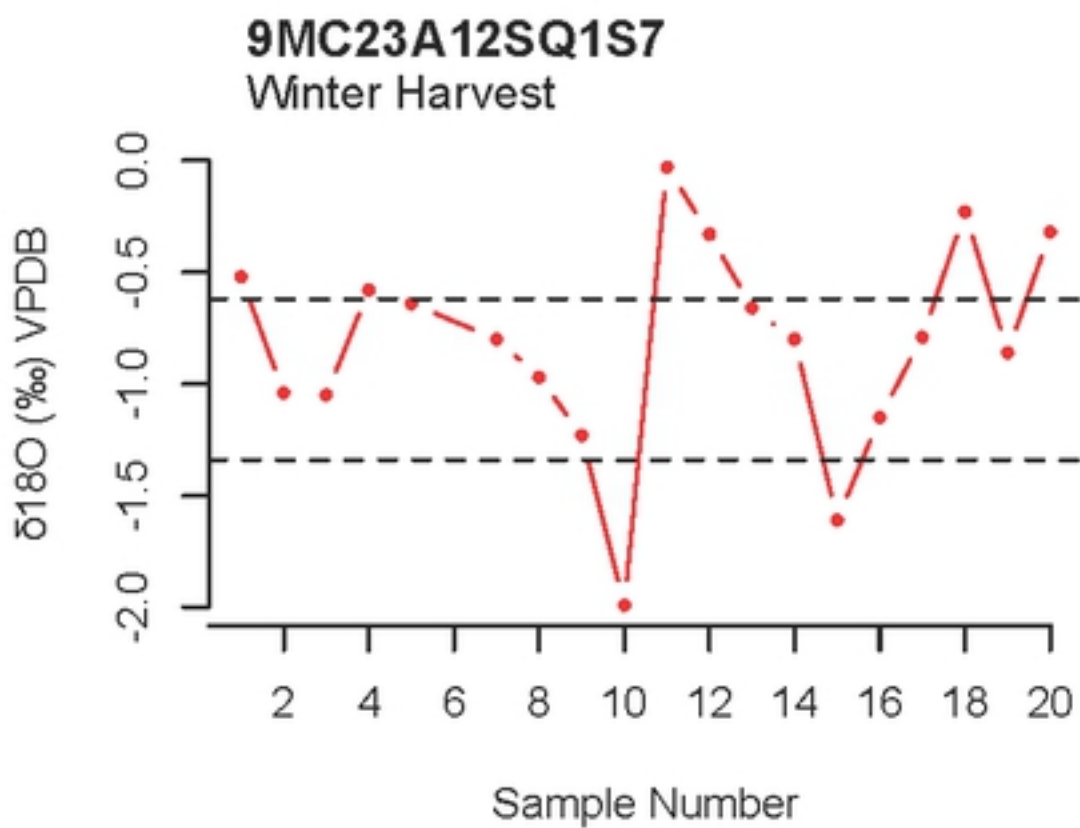


Figure 4

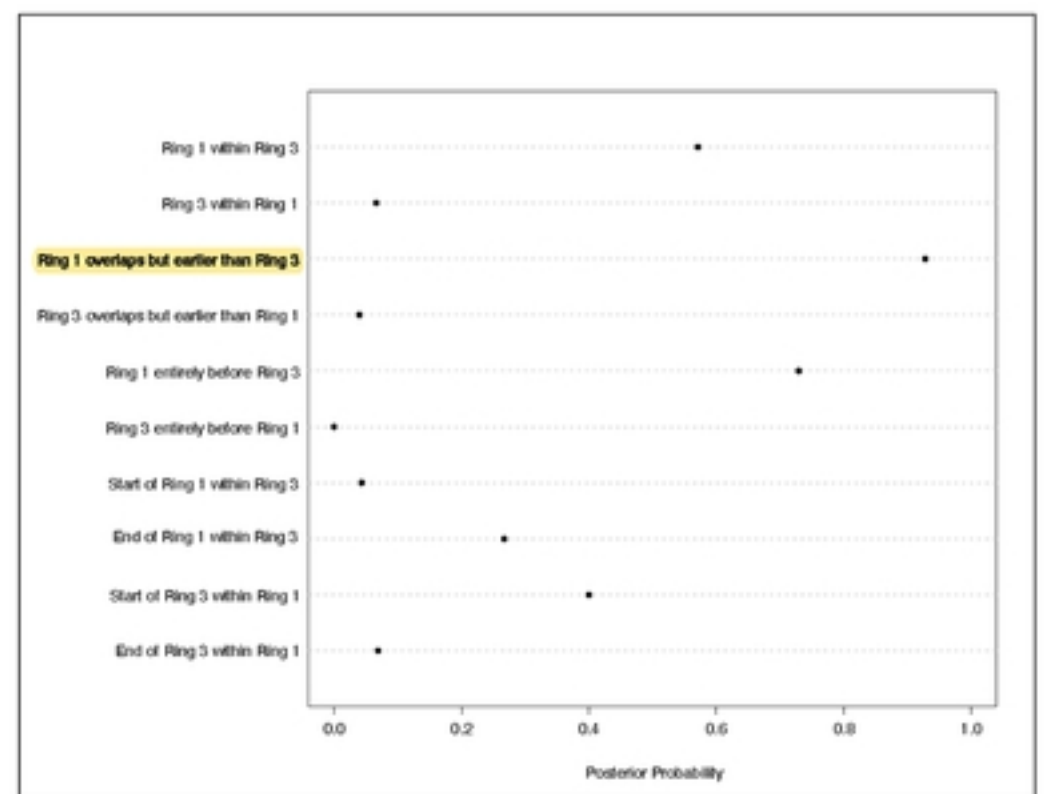
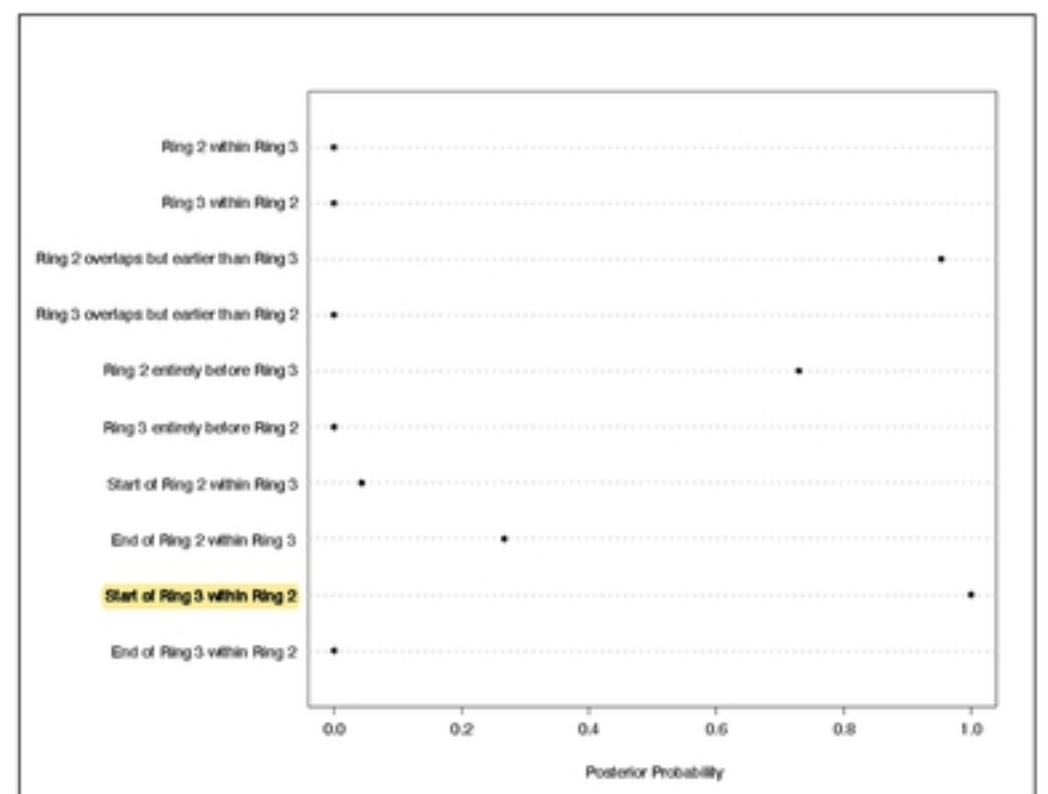
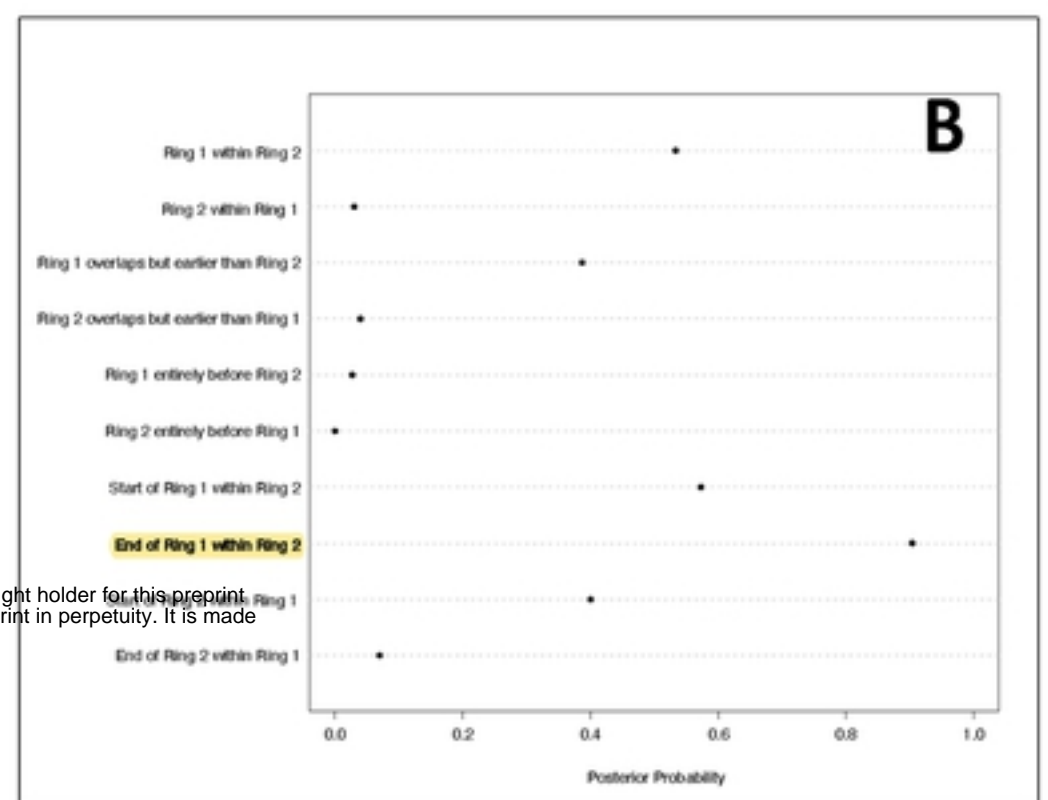
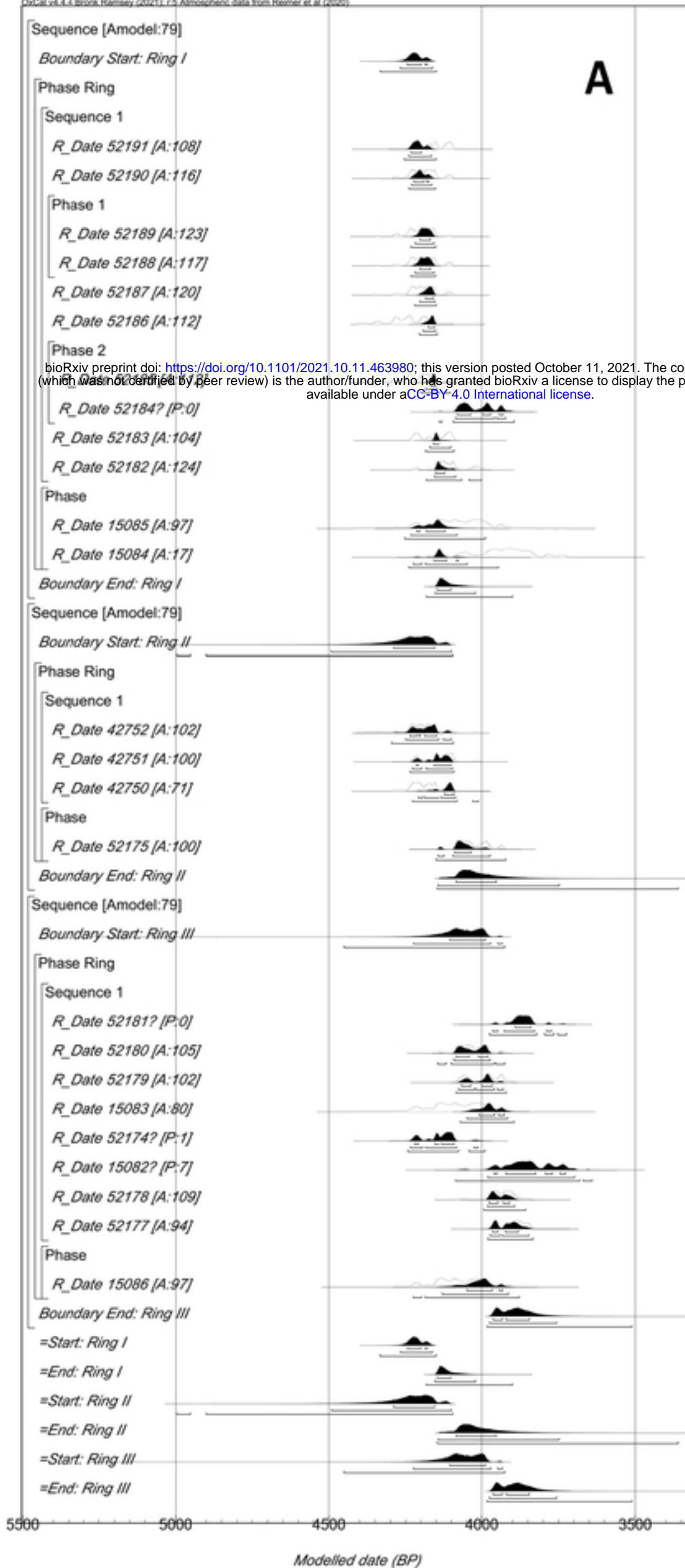


Figure 2

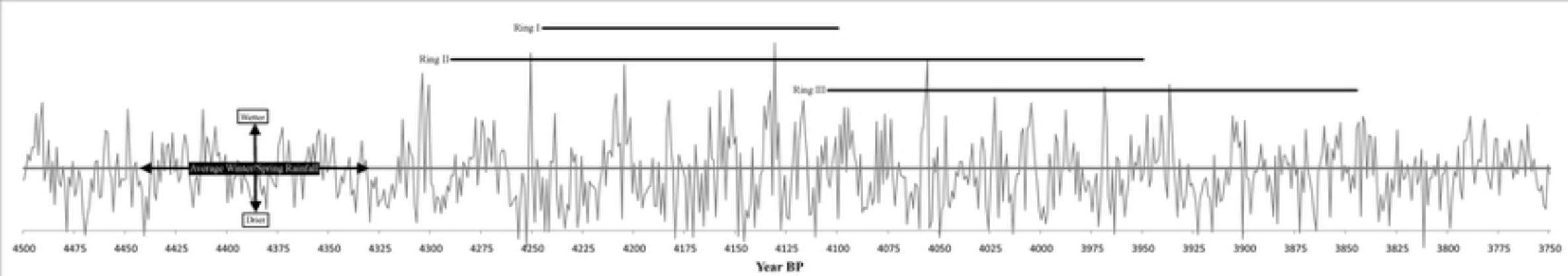


Figure 5