Contemplating the history and future of radiocarbon dating in the American Southeast

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ABSTRACT
We consider the history, present, and future of radiocarbon dating in the American Southeast. We point out some of the past and present flaws related to archaeological research and dating. Our approach to this review is rooted in the perspective that each radiocarbon date collectively adds to our knowledge of the region and not just a particular site. Based on our observations, we suggest some "good" practices with respect to certain aspects of radiocarbon dating. Our concluding discussion considers Bayesian chronological analysis and the growing contribution of chronological modeling to the Southeast.

KEYWORDS: Chronology; Radiocarbon dating; Digital databases; Bayesian philosophy; Archaeological theory

We are at war with the odds. There are so many things going against our grasp and understanding of chronology and its relation to the temporality of events that it is hard to maintain equanimity amidst all the pitfalls that can work against us as archaeologists. When we reflect on the history of radiocarbon dating in the American Southeast, we observe a landscape fraught with obstacles, some of which are entrenched from past practices, but it would seem new ones continue to emerge. What is clear to us is that for southeastern archaeologists to begin to turn the tide on uncertainty, we must collectively acknowledge our shortcomings in past and present practices when it comes to radiocarbon dating and to define a path forward. We are not the first to offer such observations either on regional practices or with issues regarding radiocarbon as a whole (Bayliss 2009; Taylor 2000a; Wood 2015). In fact, we suggest that, in addition to this paper, readers should consult the following papers, as these are critical readings pertaining to the radiocarbon literature: Aitken (1990), Bayliss (2015), Bowman (1990), Buck and Meson (2015), Cook et al. (2015), Guilderson et al. (2005), Taylor and Bar-Yosef (2014).

In this paper, we consider some of the impediments to clarity in the radiocarbon record for the American Southeast. Our intent here is not to provide a how-to-guide for radiocarbon dating, or a step-by-step guide for Bayesian analysis (see for example Aitken [1990]; Bayliss and Bronk Ramsey [2004]; Hamilton and Krus [2017]), but rather to point out some of the larger issues regarding radiocarbon dating for the southeastern United States. Specifically, we approach this review from the perspective that each time a radiocarbon date is run it collectively adds to our knowledge of the region and not just to our knowledge of a particular site. We take this perspective given that many archaeologists use summed probability distributions to examine demographic changes in a region (e.g., Kelly et al. 2013; Thomas 2008). There are clear issues with using such methods (see Contreras and Meadows [2014]; Williams [2012]) that are directly related to the individual practices of archaeologists. Yet individual radiocarbon dates, and databases of dates, continue to be used, often uncritically, for summed probability distributions. This is not to say that they should not be used for these purposes; however, our intent is to provide some guidance so that the quality of the collective record of radiocarbon dates is enhanced both at the site level and for the region. Such a perspective is not revolutionary; however, framing our thinking in such a way can lead us to identify some past problems in the record and suggest "good" if not "best" practices when it comes to some aspects of radiocarbon dating (e.g., sample selection, legacy data, etc.). Following this discussion, we turn our attention to Bayesian chronological analysis and the growing contribution of chronological modeling to archaeological knowledge. Finally, we consider the broader implications of radiocarbon dating in the American Southeast.

Accelerator Mass Spectrometry and conventional radiocarbon dating [first level heading]

There are two major benefits to using radiocarbon dating with accelerator mass spectrometry (AMS) over conventional radiocarbon methods (see Aitken 1990; Ashmore 1999; Bayliss et al. 2011; Hedges 1987; Litherland 1987; Taylor 1995). The first is that very small samples (< 0.5 mg of carbon) can be analyzed by AMS dating (Aitken 1990:85), whereas conventional radiocarbon dating requires drastically larger sample sizes, ones much more susceptible to contamination from small residual organics. The other great advantage is that modern AMS dates, in general, have precisions of ± 24 – 35 radiocarbon years as opposed to about two decades ago when precisions of ± 50 – 70 radiocarbon years were common. This makes a significant difference in the probability distributions for calibrated dates, as well as Bayesian modeling of these data. This is especially true for sections of the calibration curve that produce multiple intercepts, such as the period between 800 – 400 BC (2400 – 2700 BP) known as the Hallstatt plateau (Baillie 1991; Guilderson et al. 2005; Hamilton et al. 2015). Additionally, AMS dates are prone to less error because the process involves directly measuring the amount of radioactive carbon in the sample, and can be further refined by conducting longer counting times (Bronk Ramsey et al. 2004; Walker 2005).

Given the advantages discussed above it is curious that southeastern archaeologists continue to run conventional dates. We understand the appeal. The average cost of running a conventional radiocarbon date is about US $250 less than running an AMS date at most radiocarbon laboratories in the United States. Therefore, the logic is that the researcher is sacrificing precision for more dated contexts to learn something more about the site. Unless the research question deals with broad-scale changes over an extended time frame, however, conventional dates usually only provide a general basis for interpreting behavioral practices. This is not to say that all previous conventional dates are bad or useless for archaeological analysis. In fact, some of the issues that we identify above can be mediated via a Bayesian analysis of such legacy data (see the Bayesian section below). In sum, however, we strongly advocate for using AMS over conventional dates by all archaeologists.

Material and sample selection [first level heading]

One of the first things that archaeologists should consider when they want to date an event is the material itself. A good cautionary example of how this can go wrong is the recent re-dating of leather attached to a bronze buckle from the Seward Peninsula in Alaska (Cooper et al. 2016). The initial reported date assumed a terrestrial origin for the leather; however, measurement of isotopic fractionation at the University of Georgia Center for Applied Isotope Studies (UGA CAIS) produced a more accurate $\delta^{13}C$ value consistent with a marine origin as well as a $\delta^{15}N$ value (which was not measured during the original analysis) that conclusively demonstrated a marine origin for the leather. This more complete understanding of the sample prompted the use of the marine calibration curve (Reimer et al. 2013) and a local ΔR correction for the Marine Reservoir Effect (MRE) to calibrate the date, which was dramatically different by hundreds of years from the date first reported for the leather (Cooper et al. 2016). On average, the MRE radiocarbon offsets are 400 years for the global surface oceans in the Northern Hemisphere (Stuiver and Braziunas 1993) but MRE radiocarbon offsets vary locally and are corrected through using appropriate local values. Along many areas of the southeastern coasts, we currently do not understand the exact geographic variability of MRE, which we see as a substantive issue. If one does not apply the appropriate calibration curve for a sample and corresponding local ΔR correction, then the resulting date(s) can be off by hundreds and sometime thousands of years.

People have spent thousands of dollars on dates that are problematic and it is entirely possible that many dates offset from marine carbon are undetected. We advocate that readers review the ^{14}CHRONO Centre's global database for local ΔR corrections (http://calib.org/marine/) to find the most appropriate local ΔR corrections. Unfortunately, this is an understudied topic in the southeastern United States, made evident by the extensive spatial gaps in local ΔR corrections. It is worth noting that dates from migratory birds (such as ducks) that consume marine organisms may contain marine carbon, as might dates from pottery residues that may contain remains of birds, fish, or other animals containing marine carbon or a local freshwater reservoir effect (e.g., Cumming et al. 2017). Readers should be aware that marine carbon can make its way into local food webs and diets, thereby prompting the need for stable isotope analysis and the use of mixed calibration curves to accurately calibrate dates from omnivores and carnivores (Cook et al. 2015). It is important that readers note that both maize and marine carbon have enriched δ^{13}C values (δ^{13}C average for maize is ca. -12.5 ± 1.1%, Cerling et al. [1998:Figure 3]), prompting the need for δ^{15}N measurements on radiocarbon samples of bone and pottery residues to determine the fractions of marine carbon and C_4 carbon from maize in these samples (Petchey and Green 2005). We strongly advocate that readers request δ^{13}C and δ^{15}N measurements on their radiocarbon samples (which is provided as a complimentary service at many radiocarbon laboratories), because these isotopic values can provide extremely useful data for statistically estimating the percentage of marine and freshwater carbon in samples. Likewise, a mixed calibration curve that combines the internationally agreed curves of Reimer et al. (2013) should be explored in cases where a single sample derives its estimated carbon from multiple reservoirs (Cook et al. 2015; Sayle et al. 2016).

A salient example of issues with MRE offsets in southeastern archaeology comes from the use of shellfish for dating. There are advantages to dating shellfish including their ubiquity across a given site and the correlation with a specific behavioral activity (i.e., collection, consumption, and disposal of shellfish). Factors that affect the dating of shell, however, extend beyond the local MRE correction.

Some of the main issues with the radiocarbon dating of marine shellfish are highlighted by examining the potential problems associated with dating eastern oysters (*Crassostrea virginica*) from the Crystal River area of Florida. Cherkinsky et al. (2014) found a hardwater effect on oysters in the area. The difference between the oyster shell dates and the carbonized wood was on the order of 560 to 1140 years, which cannot be attributed exclusively to factors pertaining to the marine reservoir effect. In other cases, the offset varies within an individual mollusk because mobile species change habitats and incorporate different local marine and freshwater carbon into their shells over their lifetimes. Hadden and Cherkinsky (2017) noted that there was high intra-shell variability in Florida fighting conch (*Strombus alatus*) and they suggest that this may be the case for other species of conchs. Additionally, robust shellfish remains are susceptible to multiple anthropogenic repositions for decades (if not centuries) after their death due to their high durability, adding another reason why dates from fighting conch samples might not securely date their corresponding archaeological context. Therefore, such species are poor candidates for dating events in the archaeological record (see also Luer and Loger 2014).

The case studies presented above suggest a need for basic science (meaning how these taxa incorporate radiocarbon during ontogeny) and background research on both mobile species and their diverse habitats before they are used in radiocarbon dating (see Hadden and Cherkinsky 2017 for methods). This may seem like an overly simple point to make, but if we consider the history of dating in the American Southeast it seems there has been a "date first, ask questions later" mentality, with only a qualitative evaluation of whether the dates conform to expectations. As Luer and Loger (2014:65) note it was only through the suspicion that fighting conch samples were yielding dates that were "too old" that led them to evaluate the issue in a quantitative manner. This, however, is changing with Thomas and colleague's (2013) evaluation of the local MRE for certain areas of the Georgia Coast and other researchers' work on species-specific problems (Hadden and Cherkinsky 2017; see also Rick et al. 2005).

Most radiocarbon dates submitted by southeastern archaeologists are derived from carbonized wood, but this material category is not, without its own pitfalls. As smaller samples of carbonized wood are required for AMS dating, we must be sure that the carbonized wood is associated with the event we would like to date (e.g., layer, feature, etc.). Sometimes, there is little choice in the matter as suitable materials for dating in a specific context are often limited; however, it pays to evaluate carefully taphonomic interpretations during the selection process and when interpreting the results. For example, in Thompson, Marquardt, and colleagues' work (2016) at Mound Key, the project archaeobotanist, Lee Newsom, identified all wood taxa recovered from post molds before AMS dating. The posts were made of pine (*Pinus* sp.) but smaller amounts of other taxa were present in each post mold sample. These other taxa likely were introduced from the surrounding midden-mound. If we had not known that pine was the primary taxon used for posts, we could have dated a species that did not represent the event we wanted to evaluate (i.e., the construction of structures on the summit). Likewise, Krus (2016) interpreted dated pieces of charred wood deep within Mississippian palisade trenches as *termini post quos* for the timing of palisade construction and architectural modification, because these samples may have been redeposited from the adjacent ground surface or from older, nearby archaeological features.

When possible, we believe that thorough botanical and faunal identifications of radiocarbon samples are critical to the success of dating programs. We sympathize that this is often expensive and sometimes delays the process; however, this can be a critical step in dating events that are key to site and region-wide interpretations. Further, the archaeobotanist will be able to indicate if this is heartwood or new growth (or roundwood, which is commonly identified in Britain) and if there is a need to be concerned about the so-called "old wood" effect (Schiffer 1986). The "old wood" effect has prompted the use of statistical corrections for "old wood" effects (Bronk Ramsey 2009b; Dee and Bronk Ramsey 2014) and the use of chi-square tests on paired samples of different species from single contexts to statistically verify the dates (Ward and Wilson 1978). Samples from short-lived plant often offer a very attractive alternative to wood for dating (Ashmore 1999), but we recommend that readers date the samples that most strongly relate to the formation and use of the corresponding archaeological context. For example, a large charred wood sample from a discrete burnt layer may have a much more secure association with the event the archaeologist wishes to date than might a single un-burnt nutshell at the top of the layer. Likewise, it is important to note that the carbon in ancient soot samples adhering to pottery and within cremated material is always at risk of coming from "old wood" thereby potentially offsetting all radiocarbon dates from these samples (Bonsall et al. 2002:54; Olsen et al. 2013; Snoeck et al. 2014).

Following best practice approaches in the submission and interpretation of dates (see Bayliss [2015]; Cook et al. [2015]) is not only critical for interpretations by archaeologists, but also for developing a better "big data" legacy for archaeological interpretations. As we have come to realize, some archaeologists contributing to large compilations of radiocarbon data in the region have failed to record pertinent information needed to understand the dates in them, limiting the usefulness of such data even under ideal circumstances. Establishing standards for reporting and conforming to those standards are critical steps if we are to be able to move beyond our own sites, river valleys, and regions. Each one of us when we run dates contributes, for better or worse, to this collective record. By holding ourselves, and our colleagues, to higher standards regarding "good" practices in reporting and sample selection, we move contribute to a larger record that can answer questions heretofore not thought of by contemporary and past archaeologists.

Radiocarbon databases [first level heading]

Compiling radiocarbon databases to examine human population dynamics using summed probabilities (Anderson et al. 2011, 2015; Bamforth and Grund 2012; Kelly et al. 2013; Miller and Gingerich 2013a, 2013b; Thomas 2008; Zahid et al. 2016) and Bayesian modeling of cultural practices (e.g., shellfishing and monument construction [Randall 2013; Turck and Thompson 2016]) is increasingly common among North American archaeologists, generally, and southeasterners specifically. And, these regional databases are being incorporated into continent-wide ones that will allow archaeologists to ask a host of new question of these data. For example, Robert Kelly and colleagues (2013) are, with National Science Foundation support, compiling datasets from all over North America and this database should soon be available publically.

We both have created large radiocarbon databases from legacy data and applied them to various projects (e.g., Krus 2016; Turck and Thompson 2014, 2016). The process of creating these databases relies on cleaning up and evaluating each date, often referred to as radiometric or chronometric hygiene (Bayliss 1999; Faught 2008; Fitzpatrick 2006; Nolan 2011, 2012; Pettitt et al. 2003; Spriggs 1989; Spriggs and Anderson 1993; Taché and Hart 2013). Truly useful radiocarbon databases need to include numerous pieces of information, such as a description of the archaeological context of the dated sample (with reference to published sources for this archaeological information), the radiocarbon measurement data (lab code, uncalibrated 1σ date, corresponding isotopic information (when available), reference to original publication or laboratory report), and specialist identifications of the dated sample (archaeobotanical, zooarchaeological, osteological, etc.). Including information about the calibration of radiocarbon measurements is of no use in these databases unless the calibration methods and curve used are described. We have used some of the protocols outlined by Graf (2009) to evaluate dates for the Georgia Coast (Turck and Thompson 2014), and in doing so we have learned that information about each radiocarbon date must be closely evaluated (e.g., context, laboratory protocols, original reporting etc.) to create a useful database. Doing this correctly is incredibly arduous, but necessary, work. The process almost always involves tracking down and examining the original sample forms from radiocarbon laboratories and/or contacting radiocarbon laboratories and the original submitters for more information.

Why is the creation of databases so difficult? There are many reasons for this, and perhaps the main one is underreporting or incomplete reporting of dates by archaeologists.

Archaeologists often do not provide all the pertinent information about dates when they publish them. We strongly support the best practice approach advocated by Bayliss (2015) for publishing and reporting radiocarbon data. We further encourage archaeologists to provide as much information as possible for all dated samples, including $\delta^{13}C$ values, $\delta^{15}N$ values (especially for samples of fauna, humans, and food residues), and specific sample identifications by archaeobotanists, zooarchaeologists, and/or human osteologists. Other problems exist as well, such as misreporting radiocarbon data, or only reporting calibrations (sometimes without referencing calibration methods or the calibration curve used).

Before moving on to the future of radiocarbon dating, we would like to sum up our thoughts on compiling and contributing to radiocarbon databases. We advocate the point of view that every time an archaeologist submits a radiocarbon date, they are not just doing it for a particular site or their own purposes, but also to add to the collective radiocarbon legacy for the region. This, of course, is true for all archaeological data; however, published radiocarbon measurements are, theoretically, more easily accessible to archaeologists across the region and will continue to become much more accessible in the future due to their compilation on publically accessible digital databases. We would do well to remember that our published radiocarbon data are now more likely to be evaluated and used by our peers. If this is the case, then we need to do more to make sure dates are published following best practice guidelines and eventually become freely and publicly accessible. In general, we believe that the southeastern United States is a bit behind in this respect in terms of hosting and creating digital databases, but also in following global standards for radiocarbon publication and interpretation (for example see Bayliss [2015] for a European perspective). This, again, goes for all archaeological data; however, we argue that radiocarbon dates are a good place to start, leading to broader discussions about standardization of data and publication practices. Imagine the questions we could ask and answer if our data quality standards were higher and the data themselves were standardized into formats easily accessible to a large audience of researchers.

The final frontier? Bayesian approaches in the American Southeast [first level heading]

The basis for Bayesian statistics derives from Bayes' rule (Bayes 1763; Kruschke 2014), a statistical equation for calculating probabilities that is totally different from null-hypothesis testing statistics. Due to the complex calculations needed for Bayesian probability estimations, it was not until the widespread use of computers that Bayesian methods began to be used routinely, leading to Bayesian revolutions in numerous scientific fields (Kruschke 2010, 2014). Over the past decade there has been a rapid growth in the use of Bayesian statistics in most academic fields, as Bayesian probability estimates are intuitively friendlier and more powerful than null hypothesis statistics (Kruschke 2010, 2014). Notably, Bayes has begun to enter mainstream popular culture from the FiveThirtyEight's (https://fivethirtyeight.com) Bayesian estimates for sports, awards, and politics; all of which have recently received much publicity.

In the United Kingdom, the Bayesian approach has been used for archaeological chronological modeling since the 1990s (Bayliss 2015; Buck and Meson 2015). This has allowed for tremendous advances in the obtainable level of precision and accuracy for archaeological chronologies in Britain, supporting scientific interpretations that go drastically beyond previous culture-historic approaches based on loose interpretations of radiocarbon data (Bayliss 2009). OxCal (Bronk Ramsey 1995, 2009a) is used for most of these applications, serving as both the most flexible and user-friendly software for Bayesian chronological modeling.

Archaeologists in the southeastern United States (and other regions of North America [see Bayliss 2015; Hamilton and Krus 2017]) have been slow to adapt Bayesian chronological modeling methods (although there are some slightly earlier uses [Buck and Bard 2007; Kennett and Culleton 2012; Kennett et al. 2011; Kidder 2006; Kidder et al. 2009, 2010; McNutt et al. 2012]). Instead, they have chosen to use legacy culture-historic chronologies and often statistically ill-informed interpretations of chronological data. The marked increase in Bayesian chronological modeling in American archaeology over the past several years, has brought about the propagation of myths about the process (Lekson 2015:191) and use of uncritically reviewed plug-and-play pieces by archaeologists who do not understand the fundamentals of the process. This is covered in a much longer forthcoming review about the use of Bayesian chronological modeling in American archaeology (Hamilton and Krus 2017). We hope that readers will understand that attaining high-level proficiency in Bayesian chronological modeling not only requires expert understanding in archaeology, statistics, and radiocarbon dating science, but also specialized mentorship and training (Buck and Meson 2015) well beyond what can be learned in a 2- or 3-day workshop or seminar.

That is not to say that only archaeologists with expertise in statistics and radiocarbon dating science should be creating and publishing models, but those who do not have this expertise should closely follow the best practice approaches for publishing Bayesian chronological models provided in Bayliss (2015) and do what they can to ensure that the practices of world-class experts (such as specialists in chronological modeling at Historic England, the Oxford Radiocarbon Accelerator Unit, Pennsylvania State's Human Paleoecology and Isotope Geochemistry Lab, and the Scottish Universities Environmental Research Centre) are followed. The future success of Bayesian chronological modeling in southeastern archaeology depends largely upon the creation of studies with the highest-quality control at the peer-review level (Killick 2015).

We encourage southeastern archaeologists and others working in North America to embrace Bayesian chronological applications given its potential for facilitating a greater understanding of southeastern archaeology, as highlighted by the exponentially growing body of scholarship from the last four years (Anderson et al. 2013; Barrier 2017; Cobb et al. 2015; Halligan et al. 2016; Krus 2016; Krus et al. 2015; Moore et al. 2017; Munoz et al. 2015; Ortmann and Kidder 2013; Pluckhahn et al. 2015, 2016; Randall 2013; Schilling 2013; Thompson et al. 2016; Thulman 2017; Turck and Thompson 2016; Wallis et al. 2015; Wright 2014). We especially hope that students will understand the long-term potential that these methods have for transforming our current understandings of chronology in the Southeast. This ultimately should orient our field to depend less on legacy (and in many cases chronologically outdated) culture-historic artifact chronologies, and more on decadal-scale probabilistic chronologies from high-quality Bayesian modeling (for example, see Bayliss et al. [2007]; Bayliss [2009]; Hamilton et al. [2015]; Kennett et al. [2013, 2014]; Whittle et al. [2011]). We hope that eventually all major southeastern culture-historic chronologies will undergo the rigorous, robust re-dating and Bayesian re-thinking that is currently being done for key European chronologies (Conneller et al. 2016; Garrow et al. 2009; Macsween et al. 2015; Sheridan and Bayliss 2008; Whittle et al. 2011, 2016).

Unfortunately, formal training opportunities for Bayesian chronological modeling in the southeastern United States are rarely available. For most students of southeastern archaeology, the only viable path towards learning Bayesian chronological modelling is through college and university courses on Bayesian statistics (offered in statistic departments at most universities) and from self-teaching through closely studying and recreating the modeling presented in seminal European archaeological studies. The OxCal Google Groups (https://groups.google.com/forum/#!forum/oxcal) and the online OxCal manual (http://c14.arch.ox.ac.uk/oxcalhelp/hlp_contents.html) are excellent resources for learning more about Bayesian chronological modeling practices. Additionally, McNutt (2013) serves as an accessible introduction to OxCal. While perhaps wishful thinking, our hope is that anthropology departments in the Southeast will do more in the future to hire archaeological scientists with expertise in statistical and chronological training into tenure track positions, providing necessary training for the next generation of southeastern archaeologists to ensure that they become more than just casual users of modern chronological (and other) modeling methods and also to ensure that southeastern archaeology projects once again become a source for global innovation in the archaeological sciences (Crane and Griffin 1959; Taylor 1985, 2000b).

Writing ancient histories [first level heading]

Thus far, most applications of Bayesian chronological modeling in southeastern archaeology have been relatively small-scale and often undertaken by individuals who are self-taught in OxCal. Although this research has been mostly path-breaking, it stands in stark contrast to carefully coordinated European high-quality chronological projects that have carefully used Bayesian radiocarbon simulations (Bayliss et al. 2007; Griffiths 2014; Kennett et al. 2017; Steier and Rom 2000) and the iterative submission of several hundred to more than a thousand radiocarbon dates to carefully and critically model ancient histories at individual sites and regions. Projects such as “Gathering Time” (Whittle et al. 2011), “Times of Their Lives” (Bánffy et al. 2016; Bayliss et al. 2016; Czerniak et al. 2016; Denaire et al. 2017; Jakucs et al. 2016; Oross et al. 2016; Osztás et al. 2016; Richards et al. 2016; Tasić et al. 2015, 2016), and others are providing the groundwork to trace Neolithic settlement histories and societal practices at regional and generational levels with extremely high accuracy and precision. While there has yet to be a chronology program undertaken in the Southeast (or other parts of North America) that rival these well-funded British-based projects, our hope is that continued publication and interest in smaller chronological modeling applications will eventually lead to larger-scale Bayesian applications that will address important multi-scalar questions of interest to the *Southeastern Archaeology* readership at a much higher level of resolution than ever before.

Acknowledgments

We would like to thank Jeff Speakman, David Thulman, and three anonymous reviewers for their comments and critique on an earlier version of this document. This manuscript was initially prepared as a discussion piece for a series of papers based on a symposium organized by Jake Lulewicz, Brandon Ritchison, and Matt Colvin at the Southeastern Archaeological Conference held in Athens, Georgia. We thank them for their invitation to comment on their papers and for providing an impetus for this work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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