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Reassessing the chronology of the Mississippian Central Illinois River Valley using Bayesian analysis

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ABSTRACT
Chronology building has long served as a major focus of archaeological interest in the Central Illinois River valley (CIRV) of west-central Illinois. Previous methods have relied primarily upon relative dating techniques (e.g., ceramic seriation) as a means of sorting out temporal relationships between sites. This study represents the first investigation into the utility of Bayesian techniques (which consider radiocarbon dates in context with archaeological information) in the CIRV. We present the results of a detailed ceramic seriation of the region, data that we use as a priori information in our Bayesian models. We then offer contiguous, overlapping, and sequential models of site occupations in the Mississippian CIRV, review the output and appropriateness of each model, and consider their implications for the pace of sociopolitical change in the region.

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Mississippian; Bayesian analysis; ceramics; seriation; Illinois

Issues of temporal control have long been of concern to Mississippian archaeologists. However, the nuts and bolts of regional chronologies often go unquestioned and unmodified for long periods of time. With advances in conceptual approaches to analyzing radiocarbon dates and the introduction of a new generation of modified accelerator mass spectrometers (AMS) that produce dates with low levels of analytical error, it is pertinent that archaeologists reevaluate existing time and space constructs. In this study, we begin the process of revising the Mississippian period chronology for the Central Illinois River valley (CIRV) of west-central Illinois. Previous chronological systems for the region relied primarily on qualitative assessments of ceramic assemblages and the analysis of a relatively small number of legacy dates calculated using a conventional radiometric (beta count) dating method. Our study advances these efforts by presenting a Bayesian analysis of previously available radiocarbon data in combination with a new suite of 24 AMS dates from the region. In each of the three resulting models (contiguous, overlapping, and sequential), radiocarbon dates are quantitatively constrained by a detailed ceramic seriation from five sequentially occupied sites in the region. We present the results of these models and then assess the suitability of each as a chronological system for the region.

The Central Illinois River valley

The Central Illinois River valley is a 209-km segment of the Illinois River running from the modern town of Meredosia in Morgan County, Illinois, northeastward to Hennepin in Putnam County (Figure 1). Within the Midwestern Taxonomic System, the Mississippian period occupation of the region is classified as the Spoon River focus based on a complex of traits including rectangular wall-trench houses, cord-marked shell-tempered pottery, and bluff-top mortuary mounds (Cole and Deuel 1937:220; Deuel 1935). Archaeologists have long observed strong stylistic similarities between Spoon River focus pottery and Mississippian assemblages from the greater Cahokia region to the south. Indeed, Cahokia archaeology often has been used to inform and supplement an understanding of the culture history of the Illinois Valley (Conrad and Harn 1972; Emerson 1991:230–231; Fowler and Hall 1975; Hall 1966). For example, salvage excavations at the Cahokia site's (11MS2) Powell Mound led to the identification of an early Mississippian period occupation dubbed the "pure village site culture" associated with thin polished pottery that contrasted with a later "Bean pot-duck effigy culture" with thicker and more coarsely made pottery (Kelly 1933; Titterington 1938). Griffin (1941), Griffin (1949), Griffin (1952) later reclassified these as the Old Village and Trappist foci. Old Village pottery was

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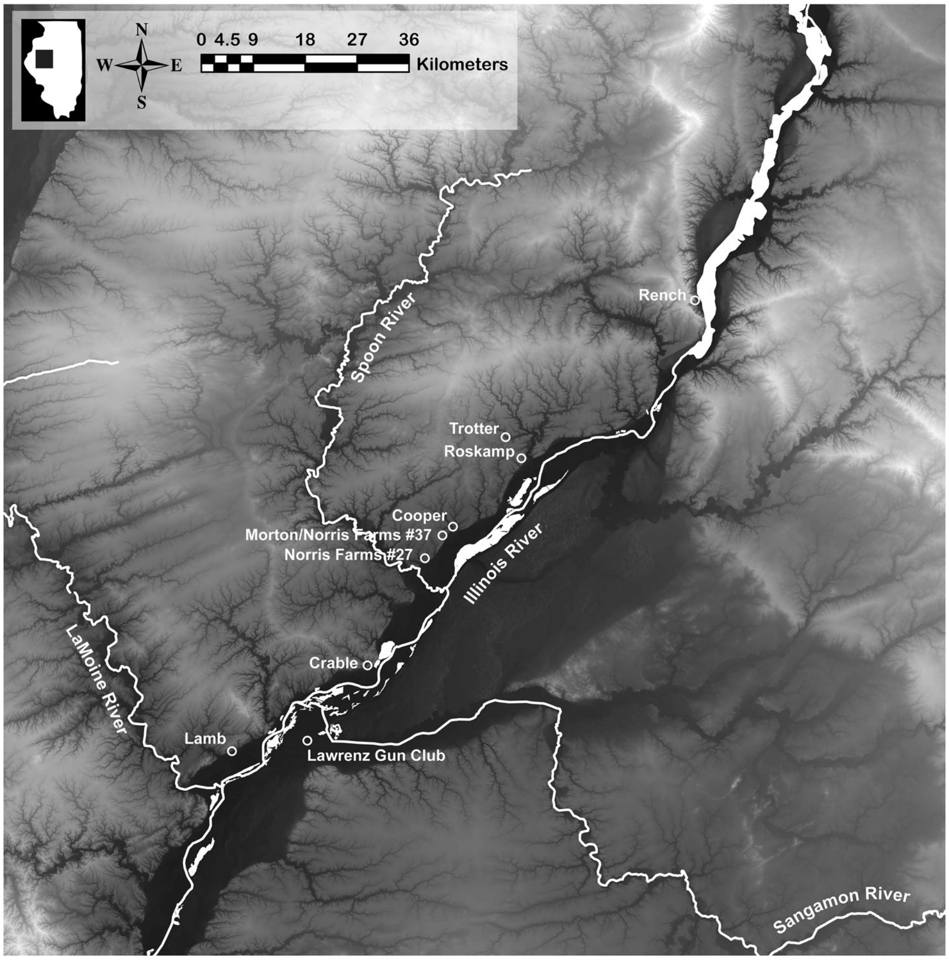

Figure 1. Map of the CIRV with study sites labeled.

observed as being present at Cahokia, the Lower and Central Illinois River valleys, the Aztalan site (47JE1) in southern Wisconsin, the Cambria focus in the Mississippi River valley, and the Mill Creek aspect of northwestern Iowa (Griffin 1949:48). Moreover, the subsequent Trappist ceramic complex was described as closely related to that of the Spoon River focus.

In a 1972 paper, Conrad and Harn further subdivided the Mississippian occupation of the CIRV into three sequential phases (Eveland, Larson, and Crable) based on the qualitative analysis of ceramic assemblages from the Cooper (11F5), Crable (11F249), Dickson Mounds (11F10), Eveland (11F353), Larson (11F3), and Sleeth (11F48) sites. The subsequent generation of a suite of radiocarbon dates from the region (Bender et al. 1975) allowed Conrad (1991) to revise further the existing chronology. Conrad created taxonomic distinctions between the northern (Spoon River) and southern (LaMoine River) portions of the valley. For the Spoon River area, he devised a three-phase sequence consisting of the Eveland (AD 1050–1150), Orendorf (AD 1150–1250), and Larson phases (AD 1250–1300), followed by a provisional Marbletown complex (AD 1300–1400). The Mississippian occupation of the LaMoine River area was divided into the Gillette phase (AD 1050–1150), a combined Orendorf and Larson horizon (AD 1150–1300), the Crabtree phase (AD 1300–1375), and the Crable phase (AD 1375–1450).

Esarey and Conrad (1998) later revised Conrad's system by calibrating the existing radiocarbon dates (Stuiver and Reimer 1993) and constructing a four-phase sequence for the entire region consisting of the Eveland (AD 1100–1200), Orendorf (AD 1200–1250), Larson (AD 1250–1300), and Crable/Bold Counselor (AD 1300–1425) phases. They defined phase boundaries by comparing calibrated intercepts, and they attempted to integrate the various broadly defined ceramic series in the region. There was also an explicit attempt to synchronize the Early Mississippian Eveland phase with the Stirling phase from the greater Cahokia region, as both phases share strong ceramic stylistic characteristics (Conrad 1991:124–130).

This long history of chronological research has allowed archaeologists to identify a series of important historical developments in the region. The transition to a Mississippian way of life appears to have begun in the eleventh century. This was directly associated with the political consolidation of the Cahokia polity located 77 river km to the south (see Conrad [1989]; Conrad [1991]; Harn [1991]). Bioarchaeological research has revealed little evidence of intergroup violence in the region during this era (Hatch 2015). This lack of violence is an important observation in that the preceding Terminal Late Woodland period was characterized by a decrease in interregional exchange networks and intensified intergroup hostilities (Milner 1999:122). This era of relative peace ended by the beginning of the thirteenth century as warfare engulfed large portions of the Midwest and Midsouth (Dye and King 2007:162; Emerson 2007:135–137; Krus 2016; Milner et al. 1991; Steadman 2008; VanDerwarker and Wilson 2016). In response, much of the CIRV's regional populace rapidly resettled into compact villages protected by wooden palisades. This resettlement was a dramatic shift from a dispersed to a nucleated settlement pattern entailing the expansion and reconfiguration of regional social groups.

Into this hornet's nest of fortified, warring settlements came a cultural group known archaeologically as the Bold Counselor Oneota. This group relocated from somewhere in the northern Midwest during the early fourteenth century (see Esarey and Conrad [1998]). Archaeological research at sites dating to this era has uncovered evidence for the cohabitation of Mississippian and Oneota individuals (Bengston and O'Gorman 2016; Esarey and Conrad 1998; Lieto and O'Gorman 2014; Santure et al. 1990). Perhaps the fighting was severe enough to merit a defensive alliance among these culturally disparate peoples. The outcome was the formation of several multiethnic towns in the region, an endeavor that would have required new or expanded practices of social negotiation at both local and regional levels. Subsequently, a population exodus from the region occurred in the early or middle fifteenth century. The reasons for this abandonment are unclear but may relate to a series of droughts that appear to have impacted extensive portions of the Midwest and Midsouth at this time (see Meeks and Anderson [2013]).

The current approach

The chronological research summarized above has facilitated considerable archaeological research in the region. However, the relationship between culture contact, migration, and warfare that structured this dynamic era of Mississippian occupation currently is understood only in a general sense. Refinement of the existing chronology would improve our archaeological ability to document the rapidly changing political, social, and economic relationships in the region. In this study, we present an examination of the Mississippian period occupation of the CIRV that relates temporal trends in ceramic design to radiocarbon dates. While such an approach is not new to the region, earlier chronological systems relied primarily on qualitative assessments of ceramic assemblages and the analysis of a relatively small number of legacy dates calculated using conventional radiometric dating methods. Our new models integrate and supplement these systems using Bayesian analysis and prior information (e.g., ceramic seriation) to constrain quantitatively the probability distributions of calibrated radiocarbon dates from Mississippian settlements in the CIRV.

As an initial step in the current analysis, Wilson conducted a detailed quantitative analysis of five Mississippian ceramic assemblages from the region. While earlier qualitative analyses were useful in identifying a general sequence of stylistic change, our quantitative assessment generated specific data by which individual assemblages could more rigorously be defined and compared. We also generated 24 new AMS dates that we combined with 12 existing radiocarbon dates from the region. This expanded set of AMS samples allowed us to date more precisely site occupations and associated ceramic series. We then used OxCal version 4.2 to conduct a Bayesian analysis of the radiocarbon dates, the results of which are presented below.

Ceramic seriation

The ceramic seriation involved examining domestic refuse assemblages from five different sites: Lamb (11SC24), Cooper (11F15), Roskamp (11F100), Norris Farms #27 (11F2646), and Trotter (see Figure 1). These assemblages were chosen because they derive from occupations that collectively span a large portion of the Mississippian period, encompassing important organizational changes in the region (Table 1). These sites were also practical choices for building a chronology because they possessed relatively short-term Mississippian occupations. Indeed, the wall-trench structures uncovered at these sites exhibit no more than a single rebuilding episode. Based on current estimates of

Table 1. Ceramic surface treatment percentages per site.

Site	Plain	Burnished	Incised	Cordmarked
Lamb	29.7%	64.4%	1.6%	4.38%
Cooper	77.9%	16.3%	3.6%	2.1%
Roskamp	84.8%	13.0%	0.6%	2.0%
VL Trotter	86.0%	1.51%	1.5%	12.0%
Norris Farms	68.0%	2.3%	1.0%	29.0%

structure longevity for wall-trench architecture, this evidence indicates that each site was occupied for no more than 10–20 years (see Milner [1998]; Pauketat [1986]; Pauketat [1998]).

The pottery series from each of these five sites has been associated previously with one of the first four phases identified in Esarey and Conrad's (1998) chronology. The Lamb site is a farmstead (or hamlet) located on a loess-mantled slackwater terrace at the base of the western bluffs of the Illinois River valley floodplains in Schuyler County, Illinois. Ceramic assemblages recovered from salvage excavations conducted at the site in 1991 have been assigned to the early Eveland phase (Bardolph 2014). The Cooper site is a small village located on the western bluff of the Illinois River near the intersection of the Sister Creek and Illinois River floodplains. Ceramics from this site that were examined in the current study were recovered from a wall-trench structure and multiple pit features thought to date to the late Eveland phase (Conrad 1991). These excavations were conducted by Western Illinois University (WIU) in 1982 and 1983. The Cooper site was later reoccupied during what is conventionally referred to as the Bold Counselor phase. We consider radiocarbon dates for plant remains associated with the Bold Counselor phase occupation of Cooper in our Bayesian analysis, but do not include materials from this occupation in our ceramic seriation. The Roskamp site is a farmstead located in northern Fulton County on the western blufftop of the Illinois River valley. WIU's excavations at this site in 1984 uncovered a wall-trench structure and multiple associated pit features yielding ceramics that were later identified as dating to the Orendorf phase (Conrad 1991). The Trotter and Norris Farms #27 sites are blufftop farmsteads located in Fulton County on the western side of the Illinois River valley. Excavations at both sites uncovered individual wall-trench structures bearing pottery that has been identified as dating to the Larson phase (Conrad 1991; Harn 1994).

The first step in our seriation of these ceramic assemblages involved calculating a series of metric ratios from jar rims for each of the five sites. This technique is commonly employed in the American Bottom to seriate Mississippian pottery (see Fishel [1995]; Holley [1989]; Milner [1984]; Pauketat [1998]). Box plots were used to compare the spread of values from different assemblages. The box portion of the graph encompasses 50% of the data. The width of the box is called the "midspread" and each edge is called a "hinge." The whiskers on either side of the box show the range of variation in the data with outliers represented by an asterisk (*) and far outliers represented by an open circle (o). The notched portion of the box displays the width of the 95% confidence interval for the median, with the center of the notch representing the median value. If the notches on two box plots do not overlap, the difference between the medians is significant at the 95% confidence level. The most successful of these measures was a lip shape ratio that quantifies diachronic changes in jar lip length and width (see Pauketat [1998:Figure 4.1]). The results from this analysis highlight a clear diachronic trend in which jar lips become statistically longer and thinner over time (Figure 2).

Next, we tabulated the sherds from each assemblage by surface treatment. This procedure generated the data necessary to conduct a Ford-style frequency seriation (see Ford [1936]). The temporal sequence presented in Figure 3 corresponds with that generated by the jar rim metrics analysis presented above. The stylistic attributes that exhibit the most temporal variability in this seriation are burnished, plain, and cord-marked surface treatments. Burnished sherds from Ramey Incised and Powell Plain jars comprise the majority of the assemblage from the Lamb site. It is important to note that grit-tempered and cord-marked Late Woodland sherds still comprise a small minority of the Lamb site assemblage. As a method of surface treatment, burnishing is far less common in the Cooper assemblage. In addition, there is a spike in the relative percentage of cord-marking present in the Norris Farms #27 and Trotter assemblages. Multidimensional scaling of the surface treatment data confirms the pattern generated by the frequency seriation (Figure 4). The relevant contribution of the multidimensional scaling is the major difference between the Lamb and Cooper site assemblages. Indeed, in terms of surface treatment, vessel wall thickness, and lip shape the Cooper assemblage is more comparable to the subsequent Roskamp assemblage than to the earlier Lamb site assemblage.

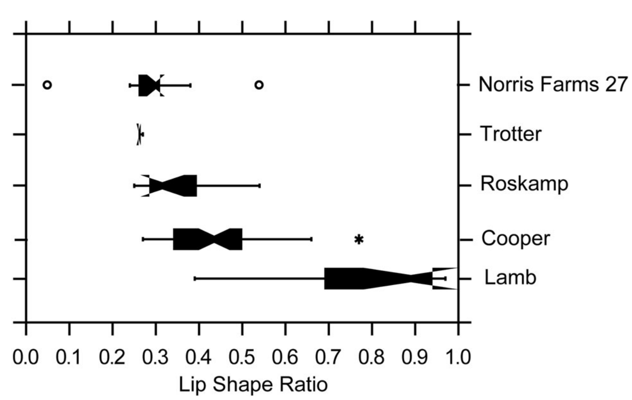

Figure 2. Lip shape ratio comparison.

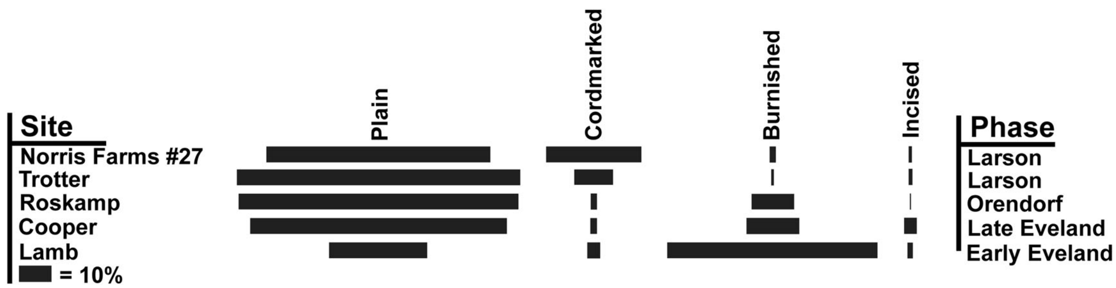

Figure 3. Seriation of surface treatment percentages using Ford's method.

Bayesian analysis

For a variety of geographic and temporal contexts, Bayesian analysis has proven to be an essential tool for generating radiocarbon chronologies that consider a priori archaeological information (e.g., Boaretto et al. 2005; Bronk Ramsey et al. 2010; Krus 2016). Prior knowledge, which may include information such as material type or stratigraphic relationships, can be inputted by the user to constrain the probability distributions of radiocarbon dates, facilitating the development of more precise chronologies (e.g., Blauuw et al. 2007; Culleton et al. 2012; Kennett et al. 2011). The computations involved in this statistical approach have been outlined in numerous publications (see Bronk Ramsey [2009a]; Steier and Rom [2000]) and are embedded into programs created for this purpose (e.g., OxCal).

Before discussing the implications of Bayesian analysis, it is first essential to explain the structure of radiocarbon data and the need for statistical modeling techniques that go beyond simple calibration. Rather than referring to an actual calendrical date, a radiocarbon date represents a probability distribution that contains a range of possible dates, some of which are more likely to represent the actual date of the original material. Even if dates are calibrated, there can be significant overlap in the probability distributions for the end of one event and the beginning of the next, obscuring interpretations of the timing of these events. Simple visual inspection of calibrated distributions can be misleading, frequently leading to an interpretation that the dated event or occupation began earlier and lasted longer than it did in reality (Bayliss 2009:131; Bayliss et al. 2009). Additionally, the type of dated material can also cause unmodeled probability distributions to be inexact, particularly for dates from old wood or redeposited charcoal (Bronk Ramsey 2009b:2; Nolan 2012; Wilmshurst et al. 2011).

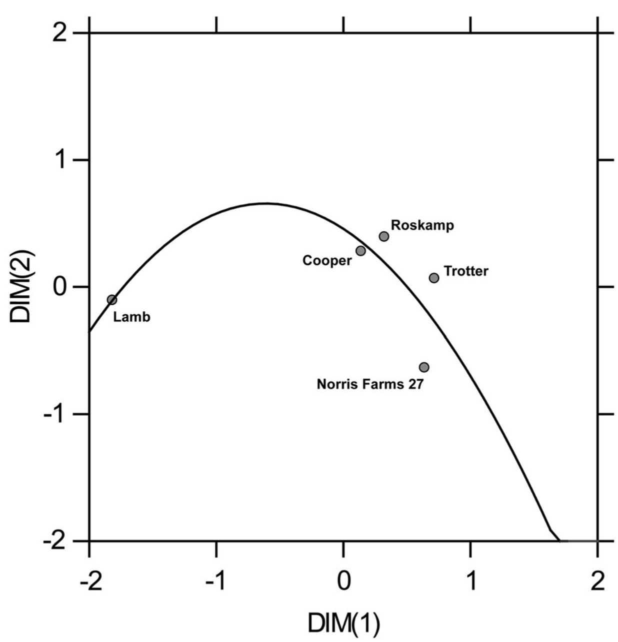

Figure 4. Multidimensional scaling seriation of surface treatment data.

Through quantitatively constraining the probability distributions of calibrated radiocarbon dates and testing the extent to which dates fit interpretive expectations, Bayesian analysis has long served Old World archaeologists as a powerful tool for reconciling archaeological information and absolute radiocarbon chronologies. More recently, this method has been adopted in the Americas to build and assess chronologies (e.g., Beramendi-Orosco et al. 2009; Culleton et al. 2012; Kennett et al. 2011; Unkel et al. 2012). In southeastern North America, Bayesian analysis recently has begun to be widely employed to refine chronologies of the construction and dismantling of palisades, mounds, middens, shell rings, and other architectural features (Kennett and Culleton 2012; Krus 2016; Krus et al. 2013; Pluckhahn et al. 2015; Randall 2013; Schilling 2013; Thompson et al. 2016; Wallis et al. 2015). It also has served as a useful means for refining the timing of site occupations in the American Bottom and the Ohio River valley (Barrier 2017; Nolan 2012). However, applications of Bayesian analysis in the Southeast have not explicitly used this method to reconcile site-based chronologies constructed using ceramic seriation with those developed using absolute dating techniques, an approach that has been used elsewhere with promising results (e.g., Finkelstein and Piasetzky 2010; McClure et al. 2014; Overholtzer 2014; Savage 2001; Zeidler et al. 1998).

Using Bayesian analysis as a tool to evaluate existing site-based regional chronologies offers several valuable contributions. For example, it could better refine approximate start and end dates as this technique yields more precise estimates for site occupations and event durations than visual inspection alone (Bayliss 2009:131; Bayliss et al. 2009). Grouping radiocarbon dates by site can also help to counter bias of preconceived chronological frameworks in modeling and interpreting radiocarbon results (Griffiths 2014:872). Experimenting with different methods of modeling chronological relationships between site occupations (e.g., contiguous, sequential, overlapping) also may aid in countering unintended bias and testing the utility of alternative frameworks, particularly in cases where these relationships are poorly understood (see Griffiths [2014]).

We employ Bayesian analysis to develop three site-based chronological models which temporally contextualize changes in vessel design in the CIRV that have long been used to sort sites into sequential phases within the Mississippian period. The models that follow are not intended to be enduring replacements for the previous taxonomic phase-based regional chronology; rather, they represent an early exploratory approach to using Bayesian techniques and more advanced methods of constraining legacy dates to build a chronology of Mississippian life in the CIRV. It is important to recognize that the results presented here represent interpretive estimates based on currently available data. We hope that our contribution will encourage others to continue developing the CIRV radiocarbon database and further refine our preliminary models as new dates are generated.

Our analysis considers 36 radiocarbon dates (27 AMS and nine conventional) from nine sites. These dates are derived from carbonized wood ($n = 8$), seeds of annual plants ($n = 14$), roof thatching materials ($n = 1$), and collagen extracted from bones of birds and mammals ($n = 13$; Tables 2–4). The W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory at the University of California Irvine and the Center for Applied Isotope

Table 2. Provenience information for radiocarbon dates in Bayesian models.

Name in models	Site	Provenience	Reference
Norris Farms 36, Burial 107	Norris Farms 36	Burial 107 (collapsed grave roof)	Santure and others (1990)
Norris Farms 36, Burial 22	Norris Farms 36	Burial 22 (collapsed grave roof)	Santure and others (1990)
Crable, F117	Crable	House F117	Bender and others (1975)
Crable, F14	Crable	House F14	Bender and others (1975)
Cooper, F30.2	Cooper	Feature 30	Bender and others (1975)
Cooper, F30.1	Cooper	Feature 30 (from clay floor)	Bender and others (1975)
Cooper, F83.2	Cooper	Feature 83	–
Cooper, F83.1	Cooper	Feature 83	–
Norris Farms 27, F17.2	Norris Farms 27	Feature 17	–
Norris Farms 27, F17.1	Norris Farms 27	Feature 17	–
Norris Farms 27, F4.4	Norris Farms 27	Feature 4	–
Norris Farms 27, F4.3	Norris Farms 27	Feature 4	–
Norris Farms 27, F4.2	Norris Farms 27	Feature 4	–
Norris Farms 27, F4.1	Norris Farms 27	Feature 4	–
Roskamp, F1002.2	Roskamp	Feature 1002	–
Roskamp, F1002.1	Roskamp	Feature 1002	–
Roskamp, F4.2	Roskamp	Feature 4	–
Roskamp, F4.1	Roskamp	Feature 4	–
Roskamp, F3.3	Roskamp	Feature 3	–
Roskamp, F3.2	Roskamp	Feature 3	–
Roskamp, F3.1	Roskamp	Feature 3	–
Cooper, F14.2	Cooper	Feature 14 (postmold of large circular building)	–
Cooper, F14.1	Cooper	Feature 14 (postmold of large circular building)	–
Cooper, F12	Cooper	Feature 12	–
Cooper, F6	Cooper	Feature 6	–
Cooper, F5	Cooper	Feature 5	–
Lamb, F5.3	Lamb	Feature 5	–
Lamb, F5.2	Lamb	Feature 5	–
Lamb, F5.1	Lamb	Feature 5	–
Lamb, F4	Lamb	Feature 4	–
Lamb, F1.2	Lamb	Feature 1	–
Lamb, F1.1	Lamb	Feature 1	–
Rench, House 1	Rench	House 1 (charred log)	McConaughy and others (1985)
Rench, House 2.2	Rench	House 2 (charred cross beam)	McConaughy and others (1985)
Rench, House 2.1	Rench	House 2 (on house floor)	McConaughy and others (1985)
Lawrenz, Unit 15–11	Lawrenz Gun Club	Unit 15–11; Bag 15–136	Jeremy Wilson (personal communication 2015)

Notes: Codes preceding sample numbers identify the lab that processed each sample (UCIAMS = University of California, Irvine; UGAMS = University of Georgia; ISGS = Illinois State Geological Survey; D-AMS = DirectAMS; WIS = University of Wisconsin, Madison). Asterisk (*) denotes conventional dates.

Table 3. Laboratory results and calibration data.

Sample no.[a]	Name in models	Context (in model)	Material	^{14}C age (yr. BP)	$\delta^{13}C$ (‰)[a]	Calibration (cal AD, 95% confidence)[b]
*ISGS-1348	Norris Farms 36, Burial 107	Bold Counselor Phase	Oak wood charcoal	690 ± 70	−25.3	1215–1410
*ISGS-1377	Norris Farms 36, Burial 22	Bold Counselor Phase	Oak wood charcoal	670 ± 70	−27.0	1224–1413
*WIS-644	Crable, F117	Bold Counselor Phase	Wood charcoal	515 ± 60	−25.8	1296–1475
*WIS-648	Crable, F14	Bold Counselor Phase	Wood charcoal	565 ± 55	−25.7	1296–1436
*WIS-645	Cooper, F30.2	Bold Counselor Phase	Wood charcoal	555 ± 55	−27.1	1297–1440
*WIS-639	Cooper, F30.1	Bold Counselor Phase	Wood charcoal	565 ± 55	−26.3	1296–1436
UCIAMS-162200	Cooper, F83.2	Bold Counselor Phase	Maize	600 ± 15	n/r	1304–1403
UCIAMS-162199	Cooper, F83.1	Bold Counselor Phase	Maize	605 ± 20	n/r	1299–1404
UCIAMS-166772	Norris Farms 27, F17.2	Norris Farms 27	Dog bone	805 ± 15	−14.5	1216–1264
UCIAMS-166770	Norris Farms 27, F17.1	Norris Farms 27	Deer bone	730 ± 15	−21.5	1263–1286
UCIAMS-181235	Norris Farms 27, F4.4	Norris Farms 27	Bird bone	810 ± 15	−22.4	1212–1263
UCIAMS-181234	Norris Farms 27, F4.3	Norris Farms 27	Bird bone	810 ± 20	−18.8	1191–1266
UCIAMS-181233	Norris Farms 27, F4.2	Norris Farms 27	Medium mammal	820 ± 20	−15.0	1181–1263
UCIAMS-166771	Norris Farms 27, F4.1	Norris Farms 27	Deer bone (juvenile)	810 ± 15	−21.7	1212–1263
UCIAMS-181232	Roskamp, F1002.2	Roskamp	Deer bone	790 ± 20	−21.3	1218–1271
UCIAMS-181231	Roskamp, F1002.1	Roskamp	Deer bone	835 ± 15	−21.8	1169–1250
UCIAMS-162207	Roskamp, F4.2	Roskamp	Maize	815 ± 15	n/r	1206–1263
UCIAMS-162206	Roskamp, F4.1	Roskamp	Maize	820 ± 15	n/r	1190–1260
UCIAMS-181253	Roskamp, F3.3	Roskamp	Deer bone	810 ± 20	−21.3	1191–1266
UCIAMS-181227	Roskamp, F3.2	Roskamp	Deer bone	820 ± 15	−22.1	1190–1260
UCIAMS-162205	Roskamp, F3.1	Roskamp	Maize	790 ± 15	n/r	1220–1268
UCIAMS-162201	Cooper, F14.2	Cooper	Maize	810 ± 20	n/r	1191–1266
UGAMS-13463	Cooper, F14.1	Cooper	Maize	840 ± 25	−8.7	1161–1257
UCIAMS-162202	Cooper, F12	Cooper	Maize	825 ± 20	n/r	1170–1260
UCIAMS-162204	Cooper, F6	Cooper	Maize	820 ± 15	n/r	1190–1260
UCIAMS-162203	Cooper, F5	Cooper	Maize	820 ± 20	n/r	1181–1263
UCIAMS-181229	Lamb, F5.3	Lamb	Deer bone	870 ± 15	−21.5	1154–1219
UCIAMS-181228	Lamb, F5.2	Lamb	Deer bone	905 ± 20	−21.1	1039–1189
D-AMS 007524	Lamb, F5.1	Lamb	Hickory	902 ± 21	−19.6	1041–1206
UCIAMS-181230	Lamb, F4	Lamb	Deer bone	905 ± 15	−22.0	1042–1183
UCIAMS-162209	Lamb, F1.2	Lamb	Maize	875 ± 15	n/r	1058–1216
D-AMS 007525	Lamb, F1.1	Lamb	Hickory	892 ± 22	−24.9	1044–1213
*ISGS-1217	Rench, House 1	Mossville Phase	Hickory wood charcoal	1000 ± 70	Unknown	891–1204
*ISGS-1216	Rench, House 2.2	Mossville Phase	Hickory wood charcoal	930 ± 70	Unknown	990–1246
*ISGS-1215	Rench, House 2.1	Mossville Phase	Butternut shells	940 ± 70	Unknown	982–1246
UCIAMS-164698	Lawrenz, Unit 15–11	Mossville Phase	Thatch	925 ± 20	n/r	1036–1160

[a]Unknown = $\delta^{13}C$ corrected, but measured value is unknown; n/r = $\delta^{13}C$ values of original material not reported. For these dates, UCI corrected all results for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with $\delta^{13}C$ values measured on prepared graphite using the AMS spectrometer. These can differ from $\delta^{13}C$ of the original material, if fractionation occurred during sample graphitization or the AMS measurement, and thus are not reported.
[b]Calibrated using OxCal version 4.2 and the IntCal13 calibration curve. Calibrated dates are not modeled.

Studies at the University of Georgia processed 27 of these samples from the Eveland, Lamb, Cooper, Roskamp, and Norris Farms #27 sites as part of the NSF-funded Living with War project, codirected by Wilson and VanDerwarker. Eight of the remaining samples represent legacy dates generated using conventional (beta count) radiometric methods that predate more precise AMS counting methods. For our analysis, we took care only to include legacy dates produced for a single wooden post (ISGS-1216, ISGS-1217), wooden structure (ISGS-1348, ISGS-1377), or annual taxon from a discrete deposit (ISGS-1215). In turn, we excluded dates derived from mixed samples that combined either multiple taxa (e.g., nutshell and wood, oak and hickory wood) or scattered charcoal

Table 4. Collagen and stable isotope data for radiocarbon dates on animal bone.

Sample no.	Name in models	Taxon	>30 kDa collagen yield (%)	$\Delta^{15}N$ (‰)	$\Delta^{13}C$ (‰)	%N	%C	C/N (wt%/wt%)	C/N (atomic)
UCIAMS-166772	Norris Farms 27, F17.2	Dog	9.4	7.2	−14.5	16.1	44.4	2.76	3.22
UCIAMS-166770	Norris Farms 27, F17.1	Deer	8.2	4.3	−21.5	16.8	46.5	2.77	3.24
UCIAMS-181235	Norris Farms 27, F4.4	Bird	11.6	3.9	−22.4	16.0	45.2	2.83	3.30
UCIAMS-181234	Norris Farms 27, F4.3	Bird	3.6	4.0	−18.8	15.4	43.5	2.82	3.29
UCIAMS-181233	Norris Farms 27, F4.2	Medium mammal	2.1	7.8	−15.0	15.3	43.9	2.87	3.35
UCIAMS-166771	Norris Farms 27, F4.1	Deer (juvenile)	7.9	4.3	−21.7	16.2	44.8	2.76	3.22
UCIAMS-181232	Roskamp, F1002.2	Deer	5.0	5.5	−21.3	16.1	45.2	2.81	3.27
UCIAMS-181231	Roskamp, F1002.1	Deer	6.6	5.8	−21.8	15.7	43.5	2.77	3.23
UCIAMS-181253	Roskamp, F3.3	Deer	3.0	3.9	−21.3	15.9	43.5	2.74	3.19
UCIAMS-181227	Roskamp, F3.2	Deer	2.2	4.4	−22.1	15.0	43.6	2.90	3.38
UCIAMS-181229	Lamb, F5.3	Deer	3.7	3.7	−21.5	15.9	44.4	2.78	3.25
UCIAMS-181228	Lamb, F5.2	Deer	10.2	4.6	−21.1	15.8	43.9	2.78	3.24
UCIAMS-181230	Lamb, F4	Deer	8.4	4.6	−22.0	15.8	43.6	2.75	3.21

not affiliated with architectural features; these types of samples include material from multiple events and thus often provide imprecise occupation estimates (see Nolan [2012]). All dates incorporated in our model derive from features with ceramic assemblages that had been ordered sequentially by our ceramic seriation.

Several of these radiocarbon dates are from sites that immediately predate (one AMS and three conventional Mossville dates) or follow (two AMS and six conventional Bold Counselor dates) the portion of the Mississippian period that we are examining. Mossville phase sites represented in this study include Rench and Lawrenz Gun Club (11CS4), while Bold Counselor phase contexts include the Crable site and a component of the Cooper site. We include dates from these sites in our analysis to both: (1) quantitatively constrain probability distributions within the portion of Mississippian period we consider; and (2) situate this segment of time within a broader regional chronology. However, as we do not include dates for surrounding taxonomic phases. Mossville and Bold Counselor date ranges are not fully constrained and should neither be considered definitive nor viewed independently of the current models.

We used OxCal version 4.2 (Bronk Ramsey 2009a) and the IntCal13 calibration curve (Reimer et al. 2013) to produce three Bayesian models. In each model, we applied the Charcoal Outlier Model to all conventional legacy dates on wood charcoal as a means of improving chronometric hygiene, or the quality of our radiocarbon data (see Nolan [2012]). The Charcoal Outlier Model uses an exponential probability function to calibrate the dates of materials susceptible to inbuilt age, specifically charcoal and wood from inner tree rings (see Bronk Ramsey [2009b]; Dee and Bronk Ramsey [2014]). In our model, we use this function to constrain the probability distributions of legacy dates (i.e., conventional radiocarbon dates) for wood samples in ways that make them more comparable to dates for annual plants, which are typically characterized by more precise probability distributions.

We used the OxCal command *Phase* to group dates from features with similar, temporally distinct ceramic assemblages. Notably, quantitative phases incorporated into our Bayesian models differ significantly from taxonomic phases (e.g., phases in previous ceramic seriations of the CIRV). The *Phase* command is a means of communicating to the program that a group of dates are related to a single period of activity and that dated materials are regularly distributed across the duration of the phase (Bayliss 2009:132). In our models, we use the *Phase* command to group dates from a single site or period (Mossville and Bold Counselor), incorporating radiocarbon dates from structures (floors and basin fills) and pit features used at different points throughout the site occupation/period. We concurrently employed the *Interval* "*Span* [Insert phase name here]" command (see Supplemental Figures 1–3) to estimate the timing of each site occupation.

OxCal allows users to choose among three different methods of assigning relationships between groups coded as phases in OxCal: contiguous, overlapping, or sequential (Bronk Ramsey 2009a). Because each relationship describes the association between two phases, different methods of relating phases (e.g., contiguous and sequential) can exist within the same Bayesian model. The contiguous method expects that phases follow one another in a continuous fashion; consequently, the program generates expected date ranges for when transitions between phases occur (i.e., transition boundaries). The overlapping method tests different ways of arranging phases and overlays them so that one phase may not end until the subsequent one begins. The sequential method operates under the expectation that the order of phases in the input corresponds to their temporal order. We explored each of these methods with respect to our data set. Below we summarize our results in terms of the interval spans estimated for each phase; refer to Supplemental Tables 1–3 for a full list of boundary ranges – start, transition (contiguous model only), and end – estimated by each model. In doing so, we discuss Agreement values for each date (A) and the entire model (A_{model}). While not a reflection of the model's accuracy, Agreement values exceeding the critical value of 60 indicate that radiocarbon dates appropriately fit the constraints of the model.

Results of our three models are presented in Figures 5–7, which present multiple plots exported from OxCal for each of the tested models. All models demonstrate sufficient agreement between the radiocarbon dates and model constraints ($A_{\text{model}} = 119$ [contiguous], 125 [overlapping], and 118 [sequential]), with no outliers (for all dates, $A \geq 71$ [contiguous], ≥ 79 [overlapping], and ≥ 61 [sequential]). As these high agreement values indicate that each of the tested models adequately fits the radiocarbon data, it is important to consider more specifically the implications of each model for understanding the timing of Mississippian site occupations in the CIRV.

Evaluating the results

Side-by-side comparisons of our output can be used to test preconceived chronological frameworks for the Mississippian CIRV. Sensitivity analysis, or the systematic assessment of multiple modeling scenarios (Bayliss et al. 2009:7; Griffiths 2014:874), is a useful approach

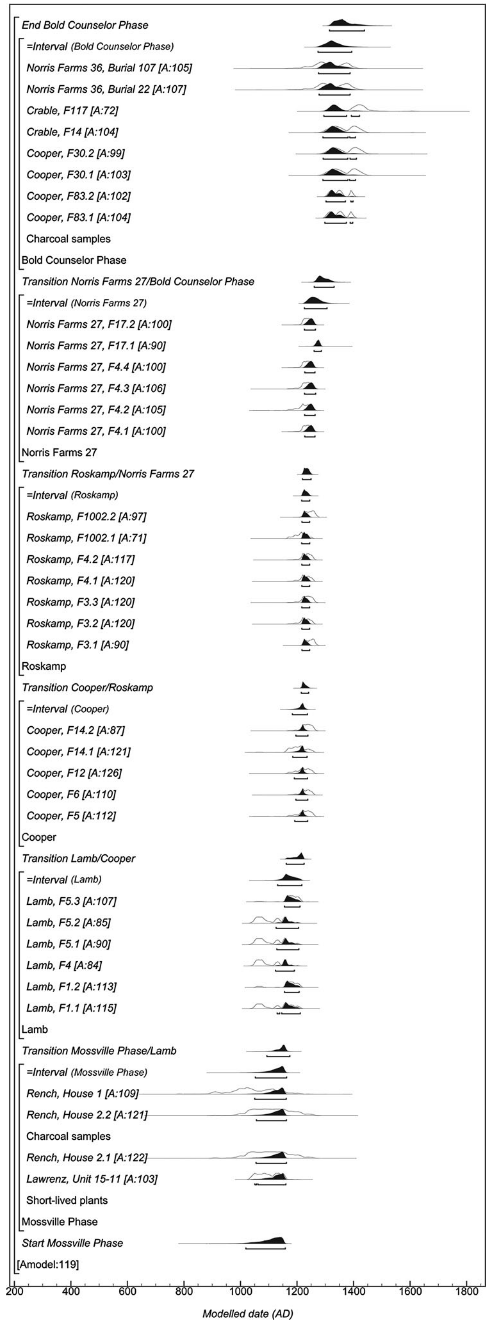

Figure 5. Contiguous Bayesian model of radiocarbon dates from Mossville, Mississippian, and Bold Counselor contexts.

for examining the degree to which data selection and/or Bayesian a priori assumptions (or priors) impact posterior probability distributions (i.e., results). For our study, calculated site occupation intervals provide a useful metric for considering the relative impact of different methods of modeling temporal relationships. Figure 8 and Table 5 summarize the probability density distributions and numerical date ranges for intervals calculated by each model, respectively.

Figure 8, which visually overlays intervals calculated for Mississippian sites in all three models, provides two

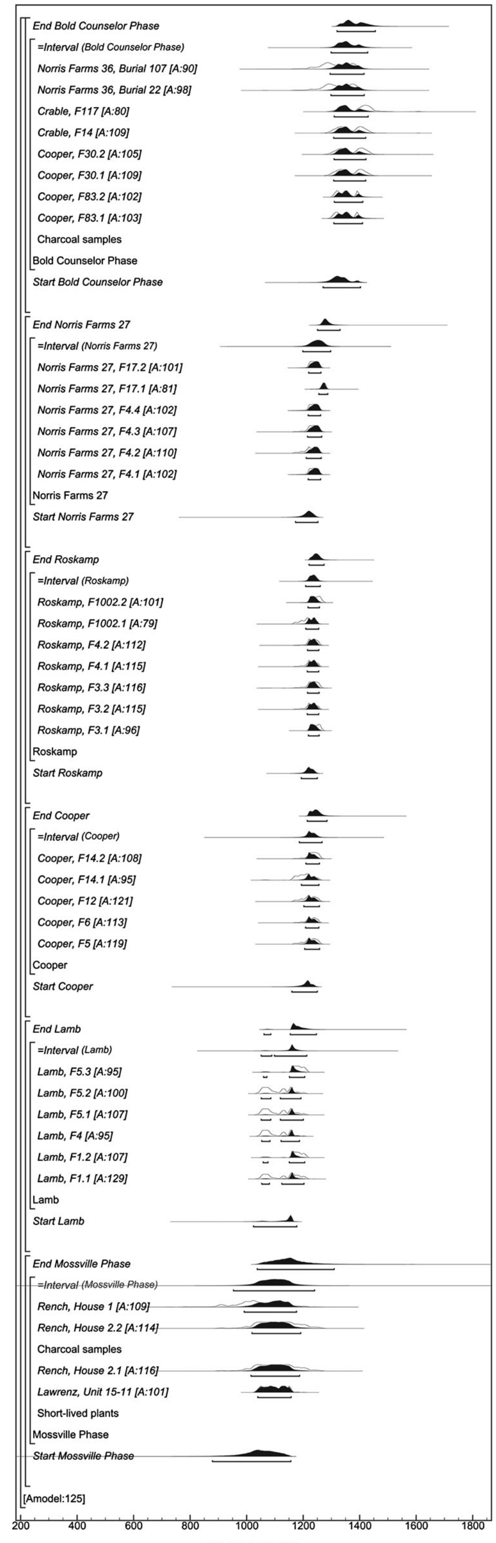

Figure 6. Overlapping Bayesian model of radiocarbon dates from Mossville, Mississippian, and Bold Counselor contexts.

valuable insights into the relative influence of phase relationships on model output. First, it illustrates that the sequential model by and large provided the highest probability densities of all tested models. Roskamp is

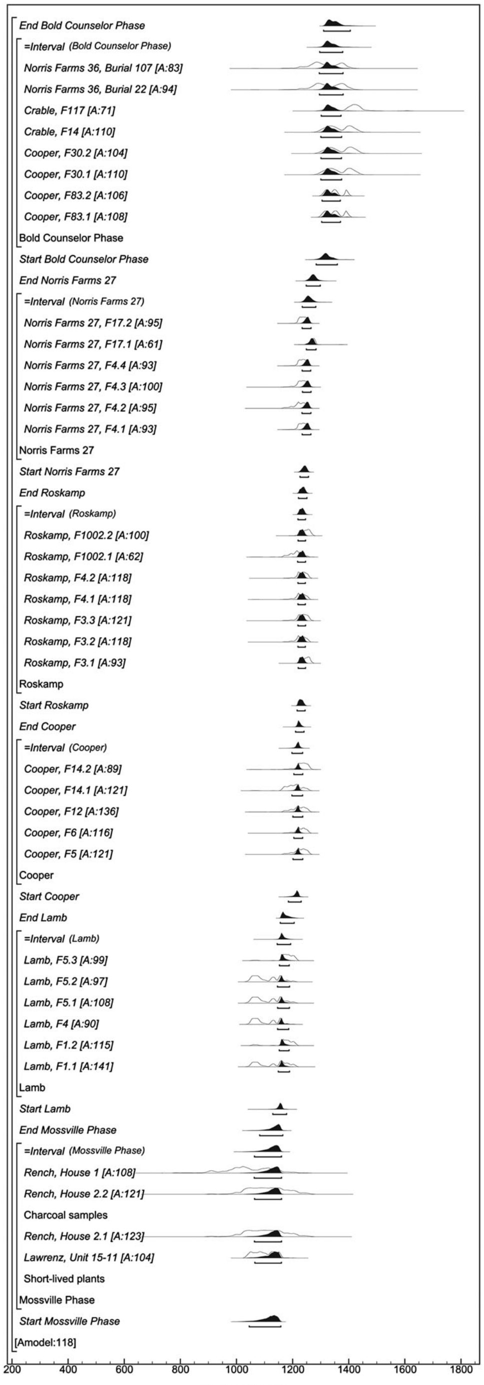

Figure 7. Sequential Bayesian model of radiocarbon dates from Mossville, Mississippian, and Bold Counselor contexts.

the only exception to this pattern, representing a context for which the contiguous model resulted in higher values; nevertheless, the sequential model demonstrated the second-highest values. Secondly, similarities between the dates corresponding to the maximum probability densities for Lamb and Cooper in all three models illustrate that the modeling of these site occupations is relatively insensitive to the assigned temporal relationship (e.g., contiguous, sequential, overlapping). When viewed in context with sufficient agreement values for all models and all dates within each model, this sensitivity testing exercise demonstrates that: (1) assigning sequential temporal relationships to the Mississippian sites considered in our analysis is a tenable solution; (2) we should not dismiss the potential validity of other temporal relationships; and (3) certain site occupation intervals are insensitive to the type of temporal relationship that is assigned. Given these general conclusions, determining which model (or models) offers the best representation of the chronology of the Mississippian CIRV requires specific consideration of each model's output in context with other lines of archaeological evidence, including the results of our ceramic seriation.

There are strong reasons to doubt the accuracy and certainly the utility of the overlapping model. Indeed, the date ranges generated by this model are too broad and overlapping to provide much assistance in parsing out the regional chronology. For example, the date ranges provided for the Mossville phase overlap with dates from four of the next five sites in the ceramic sequence (see Table 5). Not only is this impractical for chronology building purposes, it also conflicts with what is known archaeologically about site occupational histories in the CIRV. As mentioned earlier, each site included in this study was occupied for no more than about 20 years but possessed ceramic assemblages that are sequentially distinguishable through statistical analysis. These short occupational spans dramatically reduce the possibility that any two of the sites in different portions of the sequence were occupied simultaneously. However, it is important to note that there has not yet been sufficient archaeological research in the CIRV to document this ceramic sequence stratigraphically. Nevertheless, a ceramic sequence consisting of stylistically similar ceramics has been demonstrated repeatedly in the nearby American Bottom through the analysis of assemblages from superimposed houses and pit features (see Holley [1989]; Pauketat [1998]; Pauketat [2003]).

The contiguous model generated shorter date ranges than the overlapping model. However, this model does not account for the possibility that there are gaps in the sequence, a scenario made very likely by the small number of sites in the current data set. For this reason alone, we are hesitant to promote this model. Thus, we presently favor the sequential model as it estimates the narrowest temporal overlap between phases and its output provides start and end boundaries for each phase, in contrast to the contiguous model, which provides less temporal overlap and instead estimates transition boundaries between phases that are calculated based on the expectation that any site occupation directly precedes

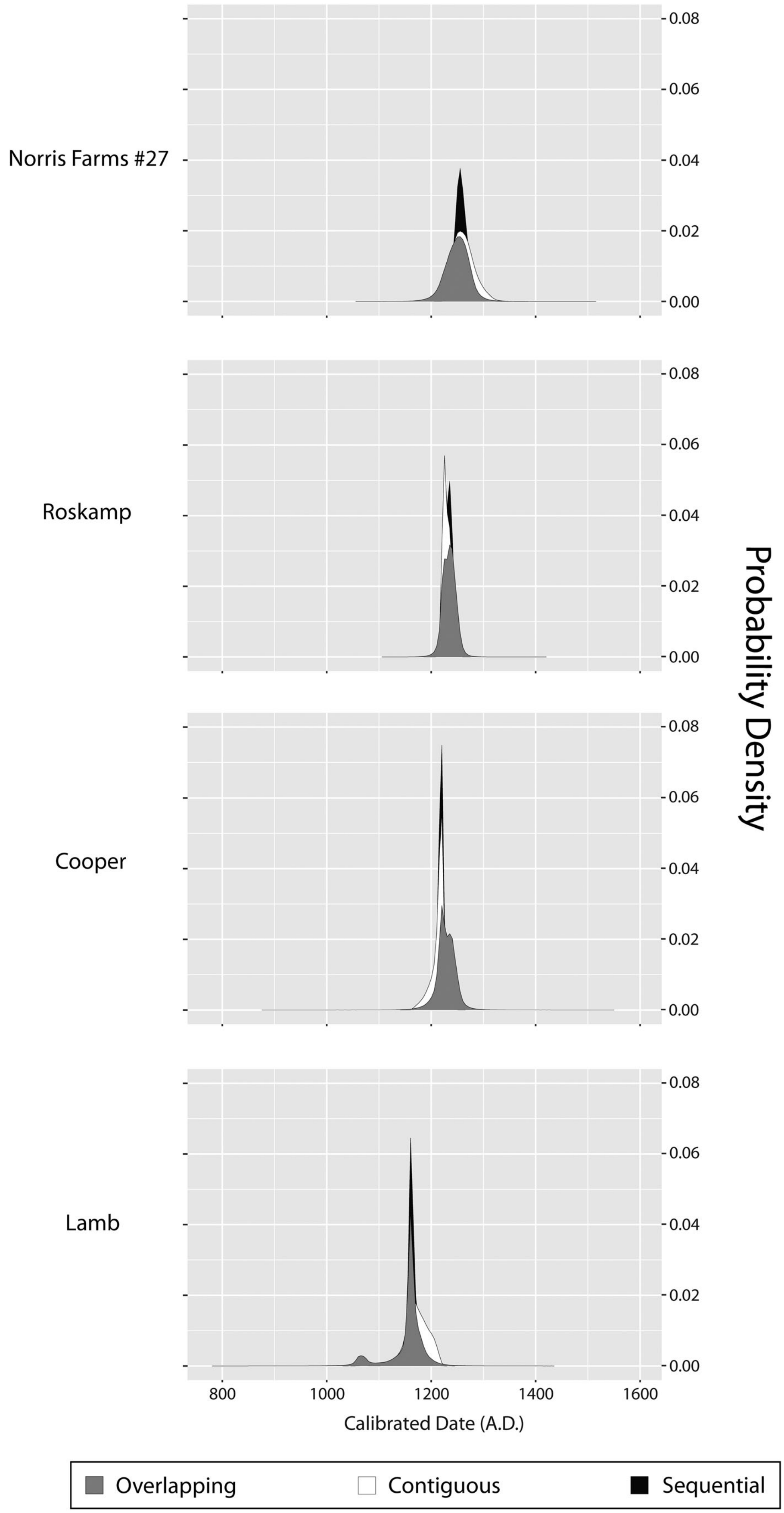

Figure 8. Intervals for Mississippian site occupations calculated by each model.

Table 5. Intervals produced by contiguous, stratigraphic, and overlapping models (all dates cal AD).

Event dated	Contiguous model (*95.4% probability*)	Sequential model (*95.4% probability*)	Overlapping model (*95.4% probability*)
Bold Counselor phase	1275–1395	1300–1380	1300–1430
Norris farms 27 occupation	1225–1305	1235–1280	1200–1300
Roskamp occupation	1220–1245	1220–1245	1210–1260
Cooper occupation	1185–1240	1200–1235	1185–1265
Lamb occupation	1130–1215	1145–1195	1050–1215
Mossville phase	1050–1160	1065–1160	950–1240

Note: Date ranges rounded to the nearest 5 years.

the next. The sequential model, however, is not without its shortcomings. It still generates overlapping date ranges between some sites that were most likely sequentially occupied. This overlap is a product, in part, of the small number of sites in the current sequence. Additional ceramic data and AMS dates from other sites are necessary to better constrain these date ranges. It is also important to note that even with Bayesian analysis it may not be possible to statistically constrain AMS dates to the degree that is otherwise specified by archaeological indications of a short occupation span (e.g., little evidence of structure rebuilding, low artifact density, lack of feature superimposition).

While our study has productively tested our understanding of the Mississippian chronology of the CIRV, it has also exposed limitations associated with the currently available radiocarbon data for the region. Irregularities in the atmospheric calibration curve corresponding with the late twelfth and early thirteenth centuries complicate occupation estimates produced by each model. Radiocarbon dates from the Lamb site fall on a specific point on the IntCal13 curve for which calibration yielded dates with multimodal probability distributions before the application of Bayesian priors (Figure 9). Thus, Lamb site occupation dates estimated by our models at *95% probability* (see Table 5; coded as = *Interval* (*Lamb*) in Figures 5–7) are potentially influenced by the constraints of the model and are subject to change if future models apply different constraints, or if date ranges of prior or subsequently occupied sites are significantly modified. To resolve these issues, it may be necessary to employ optically stimulated luminescence or some other dating method that does not rely on atmospheric fluctuations in carbon levels. Notably, probability distributions of dates belonging to subsequently occupied sites mostly plot as unimodal, bell-shaped curves (see Figures 5–7), suggesting that resulting estimates were less impacted by the problems we encountered in dating the Lamb site occupation.

Another limitation that became clear over the course of this study is that the Mossville (Terminal Late Woodland) and Bold Counselor phase occupations of the CIRV are much less thoroughly dated in comparison to those of the Mississippian period. We were only able to incorporate four dates (three of which are conventional) from two Mossville phase sites and eight dates (six of which are conventional) from three Bold Counselor phase sites into the models presented here. Expanding our archive of radiocarbon dates for these taxonomic phases would not only improve our ability to model Mississippian period events, but also help us better articulate the timing of major social changes in the CIRV. Specifically, these efforts would aid in more precisely dating the beginnings of the Mississippian period and the influx of Oneota immigrants that occurred near the end of the Mississippian period.

Discussion

The results of our ceramic seriation confirm previous chronological assessments about the sequence of site-based occupations and the general nature of ceramic stylistic change in the region (Conrad 1991; Griffin 1949). However, our quantitative approach to this issue has produced data by which these and other sites' ceramic series can be placed at particular points in that sequence. These ceramic data directly informed our Bayesian models, which generated dates for each site's occupation(s). These models, in turn, allow us to begin to revise the chronology of the region. Additionally, they illuminate the potential of using Bayesian analysis to interrogate and refine site-based chronologies rooted in diachronic changes in material culture.

Outcomes of this study impact our current understanding of the regional chronology of the CIRV, specifically the region's first 150 years of Mississippian occupation. It is important to note that we quickly encountered limitations in our ability to model the chronology, which result from irregularities in the atmospheric radiocarbon curve itself. This problem primarily corresponds to the late eleventh and early twelfth centuries. Unfortunately, this period also corresponds with the beginning of the Mississippian period in the region. Thus, while we can document the general sequence of events during this dynamic era of culture contact and change, it is currently difficult to date those changes with a high level of precision.

This study also has implications for the era previously recognized as the late Eveland phase (AD 1150–1200). Indeed, our analysis of five new AMS dates from the Mississippian occupation of the Cooper site has revealed that the ceramic assemblage originally used to define the late

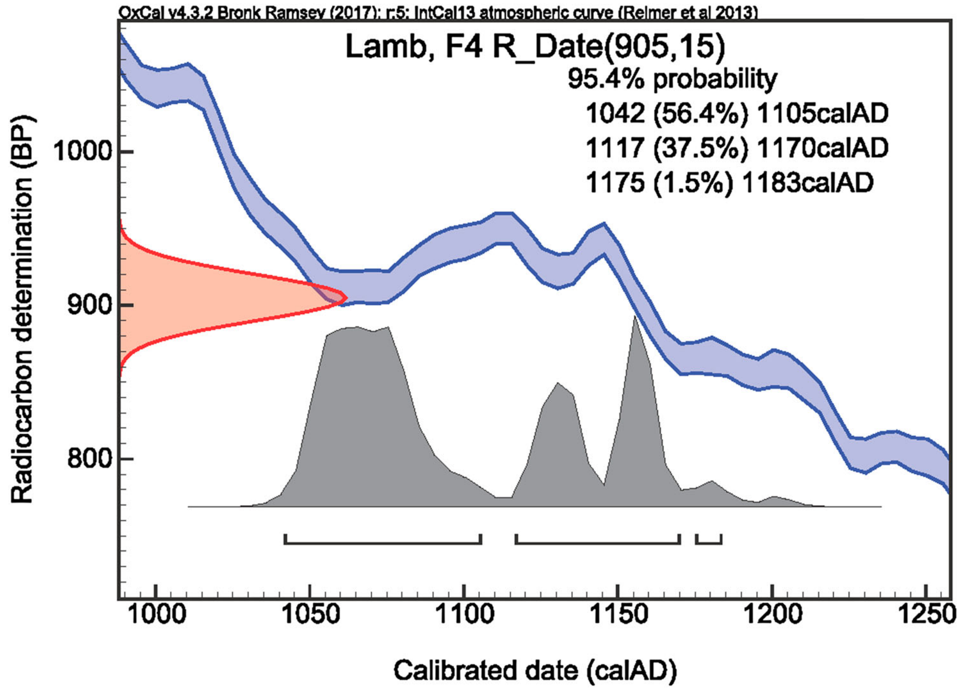

Figure 9. Probability distribution for a single calibrated radiocarbon date from the Lamb site, Feature 4 (UCIAMS-181230).

Eveland sub-phase actually dates to the early thirteenth century. Thus, the increasing regional concern with defensibility represented by the founding of the nucleated bluff-edge Mississippian village at Cooper dates later than previously thought. Based on these new dates the Cooper site's Mississippian occupation would have been roughly contemporaneous with the early portion of the Moorehead phase (AD 1200–1275) in the American Bottom, a time when palisade walls were erected around major settlements and some groups abandoned the region entirely (Pauketat and Lopinot 1997). Thus, the later occupational dates for Cooper synchronize the earliest dated evidence for escalating conflict in the CIRV with comparable evidence of intensified hostilities in the greater Cahokian area.

The new timeframe for the Cooper site also means that we are now unable to date positively any known site in the region to the late twelfth century. Excavations at the Baker-Preston (11F20), Tree Row (11F53), and Liverpool Landing (11F2713) sites have uncovered small homesteads that may date to this period (Ferguson et al. 1999; Meinkoth 1993). However, AMS dates need to be acquired from these sites and the relevant ceramic data must be added to the current seriation to evaluate this possibility.

The occupational dates generated for the Roskamp site nudges the beginning of what archaeologists have recognized ceramically as the Orendorf phase about two decades later than previously suspected (see Table 5; Conrad 1991; Esarey and Conrad 1998). However, our dates for the Norris Farms #27 site generally correspond with previous chronological assessments placing sites with stylistically Larson phase pottery in the latter half of the thirteenth century (see Table 5; Conrad 1991; Esarey and Conrad 1998).

Conclusion

Regional chronologies serve as representative frameworks for how we understand the timing and pace of social change in the past; thus, it is essential to revisit existing site-based chronologies as our analytical and interpretive tools for assessing radiocarbon age continue to improve. We conducted a detailed ceramic seriation to inform a Bayesian analysis of 36 radiocarbon dates (27 AMS and nine conventional) from nine sites in the Central Illinois River valley. We compared the statistical results from three different Bayesian models (contiguous, overlapping, and sequential) to draw attention to how different assumptions about the transitions between phases or groups within a temporal sequence can impact a regional chronological framework. In so doing, this study has laid the groundwork *to begin* to revise the chronology for the Mississippian period Central Illinois River valley. Our study confirms previous chronological assessments about the sequence of site-based occupations and the general nature of ceramic stylistic change in the region. However, our efforts also reveal limitations related to modeling the late eleventh- and early twelfth-century occupation of the region that were related to irregularities in the atmospheric radiocarbon curve itself. This investigation also exposed a previously undocumented gap in the regional occupational sequence corresponding with the late twelfth century. Much more work needs to be conducted before a robust chronological framework for the region can emerge. Future archaeological research should aim to bolster and refine our chronological models by incorporating additional AMS dates and ceramic data sets from many other sites in the region.

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Data availability statement

The ceramic assemblages analyzed for this project currently are housed in the Department of Anthropology at the University of California, Santa Barbara. The Bayesian data analyzed for this project are on file in the Department of Anthropology, University of California, Santa Barbara.

Disclosure statement

No potential conflict of interest was reported by the authors.

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