A record of sustained prehistoric and historic land use from the Cahokia region, Illinois, USA

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ABSTRACT

In eastern North America, large prehistoric settlements were concentrated in and along the floodplains of the midcontinent, but few sedimentary records have been examined adjacent to these sites to evaluate the impacts of Native American land use on terrestrial ecosystems. Here we report a high-resolution and multiproxy paleoecological record from Horseshoe Lake, an oxbow lake in the central Mississippi River valley that is adjacent to the Cahokia site (Illinois, USA), the largest prehistoric settlement north of Mexico. Palynological and carbon isotope data document pronounced vegetation changes over the past 1700 yr driven primarily by land use, including 900 yr (450–1350 CE) of sustained prehistoric human impacts. Rapid forest clearance was followed closely by the proliferation of indigenous seed crops of the Eastern Agricultural Complex beginning ca. 450 CE, centuries before the emergence of Cahokia at 1050 CE. Agricultural intensification that included the use of maize (*Zea mays* subsp. *mays*) followed this initial clearance, with peak land use intensity between 900 and 1200 CE. A large flood event ca. 1200 CE marks the onset of agricultural contraction and Cahokia's decline. Reforestation follows the abandonment of the Cahokia region at ca. 1350 CE. The Horseshoe Lake record thus indicates that regional agricultural activity began abruptly at 450 CE and intensified over the following centuries, well before the formation of Cahokia and other large prehistoric settlements. The evidence that a major flood coincided with the onset of Cahokia's decline is noteworthy, but will require corroboration from additional records.

INTRODUCTION

Land use is a major driver of change in the Earth system (Foley et al., 2005), but preindustrial land use and its impacts on terrestrial ecosystems and atmospheric chemistry remain important sources of uncertainty in Earth system models and reconstructions of past environments (Ellis et al., 2013; Ruddiman, 2013). In eastern North America, plant domestication began in the floodplains of the central Mississippi River valley and its tributaries during the mid-Holocene (Smith and Yarnell, 2009), with major agricultural centers established centuries before Euro-American settlement (Milner, 2012). Documentation of land use patterns associated with the emergence of larger and more sociopolitically complex Mississippian societies has been limited in part by a scarcity of paleovegetation records in floodplains adjacent to large prehistoric settlements. As a result, global reconstructions of Holocene land use continue to estimate negligible cropland areas across prehistoric eastern North America (e.g., Kaplan et al., 2011).

Here we report sedimentological data, fossil pollen abundances, and organic carbon isotope data from Horseshoe Lake, Illinois (USA; Fig. 1), a large oxbow lake in the central Mississippi River valley, that describe land use patterns associated with the emergence and decline of Cahokia, the largest prehistoric settlement north of Mexico. Cahokia emerged as a major Mississippian political, cultural, and economic center ca. 1050 CE, but by the mid-12th century the cultural prominence and population size of Cahokia began to decline, and by 1350 CE Cahokia and the surrounding region were almost completely abandoned (Milner, 1998). Prior archaeological assessments of land use in the Cahokia region have focused on changes in prehistoric resource use (e.g., Simon and Parker, 2006), and do not provide continuous or comprehensive records of vegetation changes spanning Cahokia's emergence and decline. Previous paleoecological work in the Cahokia region by Ollendorf (1993) was hindered by few radiocarbon dates and low sampling resolution. We build on this previous work with high-resolution palynological sampling, physical sedimentology, a robust age model, and the inclusion of an additional paleovegetation proxy ($\delta^{13}C_{org}$) to develop a detailed reconstruction of land use and environmental change in the Cahokia region.

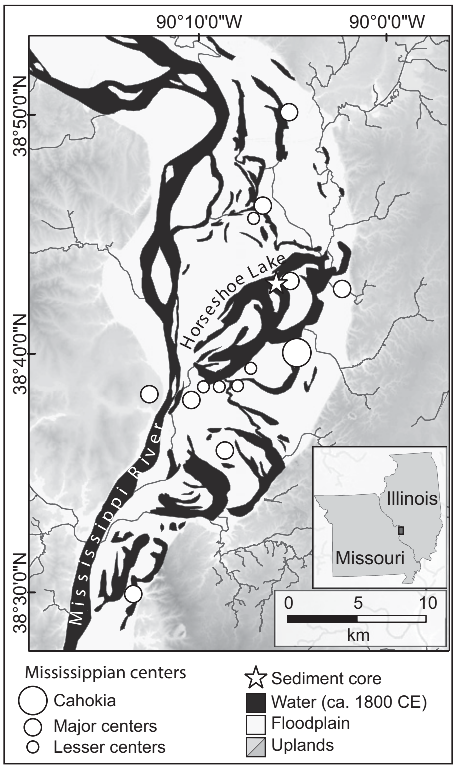

Figure 1. Map of study region in the central Mississippi River valley (central eastern United States), showing locations of Horseshoe Lake core (star) and Mississippian population centers (after Pauketat and Lopinot, 1997). Historic (ca. 1800 CE) positions of the Mississippi River, floodplain lakes, and streams modified from Milner (1998).

MATERIALS AND METHODS

Four sets of sediment cores were recovered from Horseshoe Lake in May 2012 using a modified Livingston piston corer; this paper focuses on the set of cores (4A, 4B, and 4C) recovered from the in-filled thalweg (90.081279°W, 38.704767°N, water depth 1.09 m) along the eastern channel of Horseshoe Lake (Fig. 1). The primary core sections (4A), overlapping core sections (4B), and a surface sediment section (4C) were used to create a continuous composite core based on stratigraphy and magnetic susceptibility (Fig. DR1 in the GSA Data Repository[1]). This composite core was sectioned at 1 cm intervals for geochemical and pollen analyses.

Sediment composition was determined using loss on ignition (Heiri et al., 2001) to determine organic and inorganic carbon content, respectively. Carbon isotope ratios were measured from the organic carbon fraction at 2 cm resolution by first acidifying subsamples with dilute acid (1M HCl) to remove carbonate minerals. Isotopic composition was then measured by combusting 1–10 mg of acid-insoluble residue in a Costech 4010 ECS elemental analyzer, and passing the evolved gas through a Thermo Scientific Delta V Plus mass spectrometer. Of 220

[1]GSA Data Repository item 2014178, detailed sediment core stratigraphy and radiocarbon table, is available online at www.geosociety.org/pubs/ft2014.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

GEOLOGY, June 2014; v. 42; no. 6; p. 499–502; Data Repository item 2014178 | doi:10.1130/G35541.1 | Published online10 April 2014

samples, 104 were measured at least twice, with an average reproducibility of 0.25‰ and values reported relative to the Vienna Peedee belemnite standard (VPDB). For pollen analysis, subsamples at 8 cm resolution were prepared using standard techniques described by Faegri and Iversen (1989); a minimum of 300 terrestrial pollen grains were counted in each sample. Horseshoe Lake has a surface area of 8.0 ha, implying a pollen source radius for major taxa of 10^3–10^5 m (Sugita, 1993) that encompasses Cahokia and its surrounding region.

RESULTS AND DISCUSSION

The composite sediment core from Horseshoe Lake measures 578 cm in length (Fig. 2). The basal unit of the record (440–578 cm) consists of clay interbedded with sand layers, and pollen is poorly preserved throughout this mineral-rich unit. The top 440 cm is composed primarily of silty clay (0–218 cm, 325–440 cm) and sandy silt (218–325 cm). With the exception of a mineral-rich pale brown (Munsell color chart, 10YR 6/3) silty unit from 199 to 218 cm, pollen and plant macrofossils are well preserved throughout the top 440 cm.

Our age model for the top 440 cm was developed using a modified smooth spline in Clam 2.2 (Blaauw, 2010), and is based on 9 accelerator mass spectrometry ^{14}C dates on terrestrial plant macrofossils (Table DR1 in the Data Repository) calibrated using the IntCal13 calibration curve (Reimer et al., 2013), the pollen-based *Ambrosia* rise (McAndrews, 1988) at 1825 ± 25 CE, and the year of core collection at the core top (Fig. 3). We excluded one date (UGAMS-13420) at 347 cm from the age model because it is anomalously old (1900 ± 240 BCE), most likely due to the misidentification of an aquatic macrofossil as terrestrial. The pale brown unit (199–218 cm) is sedimentologically distinct from the adjacent layers, with silty clay texture of high uniformity, low organic content, and near absence of pollen or plant macrofossils, and is inconsistent with a locally sourced mass wasting event (e.g., Woods, 2004). This layer is present in all four sets of cores across the outer channel. We thus interpret this layer to be the result of a large flood originating from the Mississippi River and treat it as an instantaneous sedimentation event in the age model. This inferred flood event has a modeled age of 1200 ± 80 CE. Additional, less pronounced, floodwater deposits are apparent as thin (<10 cm) layers with low organic content, and presumably originate from lower magnitude events that created relatively minor increases in sedimentation rate, so they are not treated as instantaneous events in the age model. The age model places the base of our pollen record (440 cm) at 270 ± 160 CE, with accumulation rates ranging from 2.5 to 7.5 yr cm^{-1}.

We divided the Horseshoe Lake record into six palynological zones based on constrained hierarchical clustering (Grimm, 1987): HORM-1 to HORM-6, interpreted to represent pre-agricultural, early agricultural, agricultural intensification, agricultural contraction, regional abandonment, and Anglo-American agricultural land use phases (Fig. 4). The earliest zone, HORM-1 (270–450 CE) is characterized by high abundances of pollen from upland trees, including *Quercus* (oak), *Carya* (hickory), and *Juglans* (walnut), as well as from the floodplain trees *Salix* (willow), *Fraxinus* (ash), *Ulmus* (elm), and *Platanus* (sycamore), and increasing abundances of *Ambrosia* (ragweed).

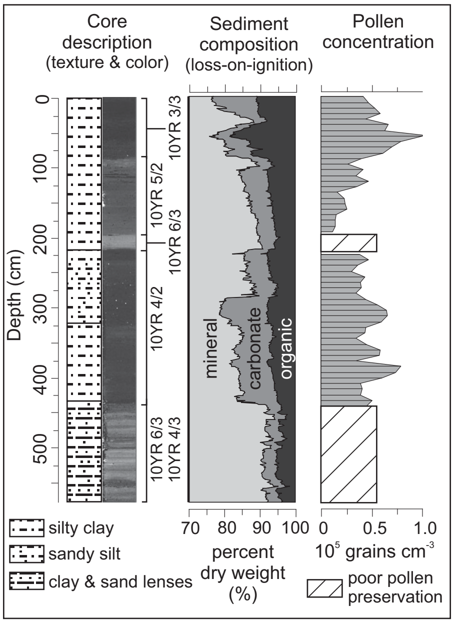

Figure 2. Core description (texture, Munsell color), loss on ignition, and pollen concentration along core axis of Horseshoe Lake (Illinois, USA) sediment core.

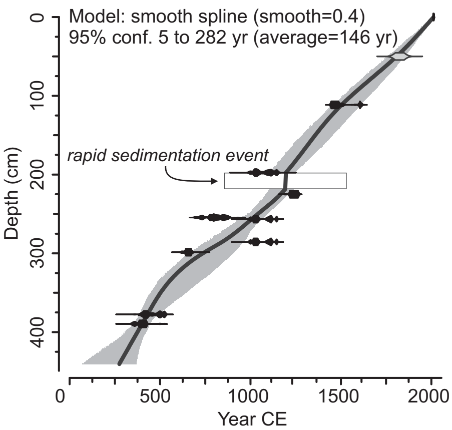

Figure 3. Age-depth model for the Horseshoe Lake (Illinois, USA) record based on smooth spline in Clam 2.2 (Blaauw, 2010), with best model (black line) bracketed by its 95% confidence (conf.) interval (gray shading). Model incorporates a rapid sedimentation event from 199 to 218 cm that is interpreted to represent a single Mississippi River flood.

Beginning in 450 CE, the early agricultural zone (HORM-2) displays a rapid reduction of most arboreal taxa alongside increases in several nonarboreal taxa. These nonarboreal pollen taxa incorporate several cultigens of the Eastern Agricultural Complex (EAC; Smith and Yarnell, 2009), namely Amaranthaceae (amaranth, includes goosefoot, *Chenopodium berlandieri*), Poaceae (grass, includes maygrass, *Phalaris caroliniana*, and little barley, *Horedum pusillum*), *Helianthus*-type (sunflower, *Helianthus annuus*), *Iva* type (sumpweed, *Iva annua*), and *Polygonum* (erect knotweed, *Polygonum erectum*). By zone HORM-3 (580–1170 CE), floodplain and most upland arboreal pollen taxa are significantly reduced and replaced by nonarboreal pollen taxa associated with the EAC. Maize (*Zea mays* subsp. *mays*) pollen first appears at 620 ± 130 CE and is present in this zone until 1050 ± 60 CE. Most arboreal taxa begin to increase during zone HORM-4 (1170–1350 CE), although several taxa associated with the EAC remain at relatively high abundances until the end of this zone. Arboreal taxa continue increasing in abundance through zone HORM-5 (1350–1850 CE), and nonarboreal taxa associated with the EAC decline and remain at low abundances. Zone HORM-6 (1850–2010 CE) is characterized by rapid reduction of *Quercus* and *Carya* and increase of *Ambrosia*, typical of historic Anglo-American settlement (McAndrews, 1988).

The organic stable carbon isotope ratios ($\delta^{13}C_{org}$) closely track changes in pollen assemblages, and provide additional information on the response of vegetation to prehistoric and historic land use (Fig. 4). During the Late Woodland (400–1050 CE) and Mississippian (1050–1350 CE) periods, $\delta^{13}C$ values gradually become more enriched, shifting from relatively depleted values (–27.5‰ to –26.0‰) to more enriched values (–24.8‰ to –23.0‰) by 900–1200 CE. After 1200 CE, $\delta^{13}C_{org}$ gradually returns to more depleted values, and remains relatively depleted (–25.8‰ to –24.7‰) until ca. 1800 CE, when a pulse of enrichment (–24.9‰ to –23.6‰) follows Anglo-American settlement, followed by a return to more depleted values during the 20th century.

The Horseshoe Lake record documents nearly two millennia of environmental change, recording geomorphic activity associated with the Mississippi River and major episodes of prehistoric and historic land use. The mineral-rich basal unit (Fig. 2) likely represents an initial stage when Horseshoe Lake was still proximal to the Mississippi River, before the main river channel migrated west to approximately its current position, 10 km away from our core site (Hajic, 1993). Following this shift in the river's position, Horseshoe Lake became more isolated from the Mississippi River, with floodwaters de-

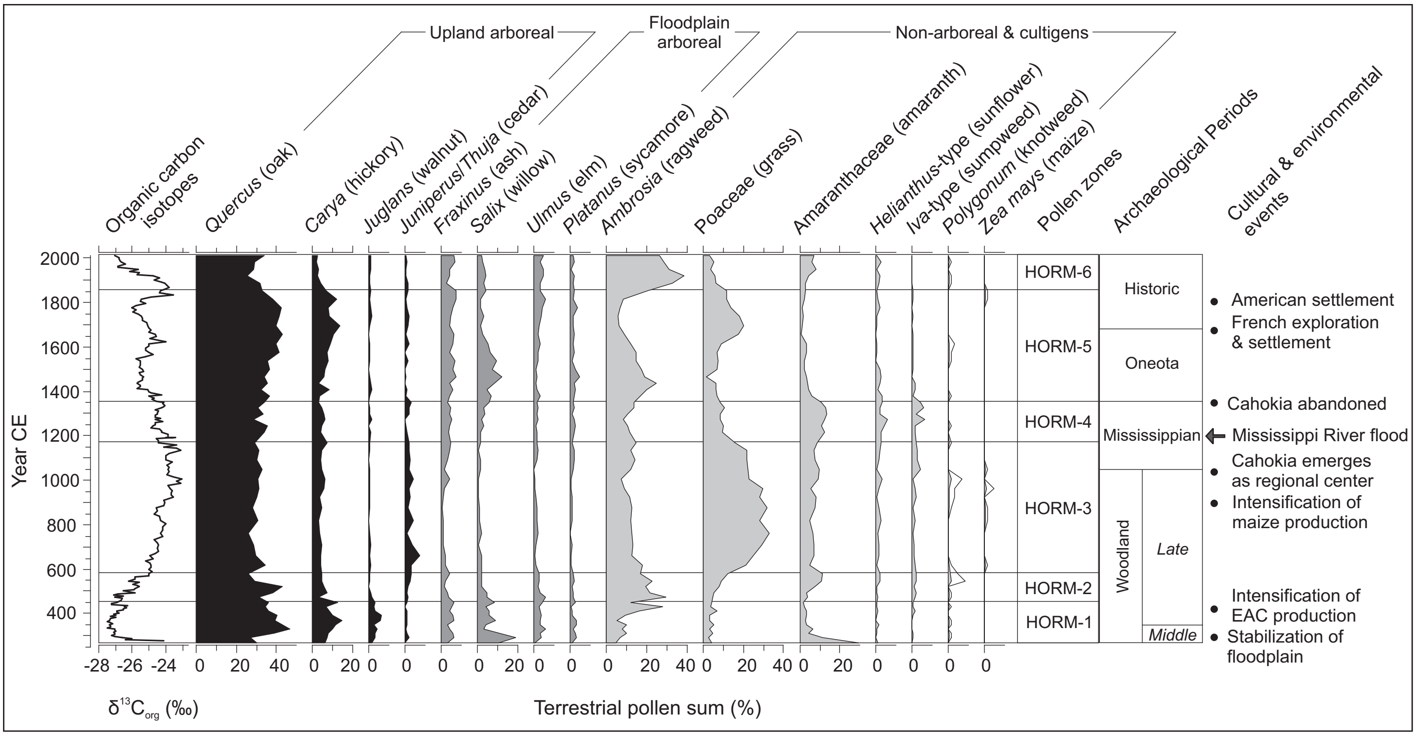

Figure 4. Organic carbon isotope ratios ($\delta^{13}C_{org}$) and relative abundances of selected pollen taxa (expressed as percent of terrestrial pollen sum), and archaeological periods and cultural and environmental events of the Cahokia region (Illinois, USA), after Fortier et al. (2006) and Simon and Parker (2006). EAC—Eastern Agricultural Complex.

positing material in the lake during high-magnitude events. The most prominent of these flood events deposited 19 cm of silty clay at 1200 ± 80 CE (Fig. 3). Sediments deposited by floodwaters contain low concentrations of poorly preserved pollen, and do not discernibly alter the relative proportions of pollen taxa.

Following lake isolation, pollen data in the Horseshoe Lake record document a rapid ecological shift from a forested region to a region dominated by agricultural activity (Fig. 4). Beginning at ca. 450 CE, the Horseshoe Lake pollen data show rapid deforestation of the floodplain and uplands followed by the proliferation of EAC cultigens. This shift toward an agricultural landscape coincides with the greater use of the EAC documented in ethnobotanical assemblages, but before the intensification of maize production ca. 900 CE and the emergence of Cahokia at 1050 CE (Simon and Parker, 2006). In these ways, the pollen data show that the formation of more open cultural landscapes predates the widespread use of maize and the emergence of large nucleated settlements typically associated with significant environmental impacts (e.g., Woods, 2004), and demonstrate that early agricultural activity based primarily on the EAC transformed regional vegetation well before the Mississippian period.

After the initial clearance of forests at 450 CE, pollen assemblages and $\delta^{13}C_{org}$ of the Horseshoe Lake record document the progressive intensification of land use over the Late Woodland and Mississippian periods (Fig. 4). The combination of low but stable arboreal pollen abundances, the sustained presence of pollen associated with cultivated taxa, and the gradual enrichment of $\delta^{13}C_{org}$ between ca. 600 and 1200 CE suggests that agricultural activity proceeded primarily from intensification on existing clearings rather than continued agricultural expansion. The enrichment of $\delta^{13}C_{org}$ reaches a stable maximum between 900 and 1200 CE, and is consistent with both the gradual intensification of maize cultivation in the Horseshoe Lake watershed (Lane et al., 2008) and/or the expansion of aquatic macrophytes stimulated by increased nutrient delivery to the lake from intensifying land use (Meyers, 2003). Together, the palynological and isotopic data indicate that agricultural land use intensified over the Late Woodland and Mississippian periods, reaching its peak intensity just prior to and during the emergence of Cahokia as a regional center.

The prominent floodwater deposit at 1200 ± 80 CE (Fig. 3) marks the onset of Cahokia's decline, and coincides with a regional sociocultural transformation characterized by decreasing population size and density, and the establishment of defensive palisades (Trubitt, 2000). The construction of levees during the 20th century isolated Horseshoe Lake from Mississippi River floodwaters (Karthic et al., 2013), so it is difficult to compare the magnitude of prehistoric flooding with historic flood events. However, the ca. 1200 CE event is the most prominent of all floodwater deposits observed over a 1700 yr period, implying that it was deposited by a flood with a high recurrence interval that likely inundated at least some Mississippian settlements in the floodplain.

Following this major flood event, pollen assemblages and the gradual depletion of $\delta^{13}C_{org}$ document diminishing agricultural activity between ca. 1200 and 1350 CE that is associated with Cahokia's declining population size and cultural prominence (Milner, 1998; Fig. 4). After 1350 CE, Cahokia was abandoned by Mississippian peoples, pollen assemblages shift back to a largely pre-agricultural state, and $\delta^{13}C_{org}$ shifts to a new stable state 1‰–2‰ above the pre-agricultural baseline. The Euro-American period begins with initial exploration of the Mississippi River in 1673 CE, with rapid clearance of upland forest and the proliferation of *Ambrosia* by Anglo-American settlers in the 19th century, followed by moderate reforestation associated with industrialization and urbanization of the St. Louis area in the 20th century (Karthic et al., 2013).

CONCLUSIONS

The sedimentary record from Horseshoe Lake, an oxbow lake in the central Mississippi River valley, provides a 1700 yr record of regional vegetation change dominated by prehistoric and historic episodes of agricultural expansion and contraction. Floodplain and upland forests were first cleared and replaced with stands of ruderals and

EAC crops starting at ca. 450 CE, well before the emergence of Cahokia as a regional center at 1050 CE. Agricultural production underwent gradual intensification following this initial period of forest clearance, reaching its peak intensity between 900 and 1200 CE. A large flood ca. 1200 CE marks the onset of declining agricultural activity, coeval with the decreasing population size and diminishing cultural prominence of Cahokia. After 1350 CE, agricultural activity becomes greatly reduced with the abandonment of Cahokia and the surrounding region by Mississippian peoples. Anglo-American settlement in the 19th century is characterized by rapid agricultural expansion. The paleoecological record from Horseshoe Lake documents nearly two millennia of regional vegetation change driven primarily by land use, and demonstrates the ability of indigenous North American land use to profoundly affect regional vegetation long before the emergence of intensive agriculture and large nucleated settlements.

Evaluating the characteristics and spatiotemporal patterns of prehistoric land use at landscape to continental scales is critical to understanding the effects of human activities on global environmental systems (Ellis et al., 2013). Beyond Cahokia, other agricultural population centers flourished in the floodplains of midcontinental North America during the late prehistoric period (Milner, 2012), and the Horseshoe Lake record demonstrates the viability of at least some floodplain lakes to track land use patterns associated with these prehistoric population centers. This study provides clear evidence for the antiquity and significance of prehistoric cultural landscapes in eastern North America that together with additional paleoecological data can be used to improve models of global land use history.

ACKNOWLEDGMENTS

We thank J. Gowen and the Illinois Department of Natural Resources for lake access and R. Brugam for early discussions, and gratefully acknowledge J. Blois, B. Rongstad, G. Schellinger, and C. Zirbel for field and laboratory assistance; K. Brady, A. Myrbo, A. Noren, and R. O'Grady of the National Lacustrine Core Facility (LacCore) for assistance with initial core processing; D. McCay of Washington University for laboratory assistance; and K. Gruley, J. Mason, S. Goring, and three anonymous reviewers for discussions and comments. This study received financial support from the National Geographic Society (YEG-9008-11), LacCore, a National Science Foundation Integrative Graduate Education and Research Traineeship (NSF-IGERT, grant DGE-1144752), and a Packard Fellowship to Fike. All data will be submitted to the Neotoma Paleoecology Database (www.neotomadb.org) and the National Oceanic and Atmospheric Administration (NOAA) Paleoclimatology Data Center upon publication.

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Manuscript received 4 February 2014
Revised manuscript received 11 March 2014
Manuscript accepted 12 March 2014

Printed in USA