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ORIGINAL ARTICLE

Differences in forest composition following two periods of settlement by pre-Columbian Native Americans

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Abstract

Temperate broadleaf forests in eastern North America are diverse ecosystems whose vegetation composition has shifted over the last several millennia in response to climatic and human drivers. Yet, detailed records of long-term changes in vegetation composition and diversity in response to known periods of human activity, particularly multiple distinct periods of human activity at the same site, are still relatively sparse. In this study, we examine a sediment record from Avery Lake, Illinois, USA, using multiple metrics derived from pollen data to infer vegetation composition and diversity over the last 3,000 years. This 3,000-year history encompasses the Baumer (300 BCE–300 CE) and Mississippian settlements (1150–1450 CE) at Kincaid Mounds (adjacent to Avery Lake), and captures differences in the impact that these groups had on vegetation composition. Both groups actively cleared the local landscape for settlement and horticultural/agricultural purposes. Given the persistence of fire-tolerant *Quercus* in conjunction with declines in other tree taxa, this clearing likely occurred through the use of fire. We also apply a self-organized mapping technique to the multivariate pollen assemblages to identify similarities and differences in vegetation composition across time. Those results suggest that the vegetation surrounding Avery Lake was compositionally similar before and after the Baumer settlement, but compositionally different after the Mississippian settlement. The end of the Mississippian settlement occurred simultaneously with a regional shift in moisture characterized by drier summers and wetter winters associated with the Little Ice Age (1250–1850 CE), which likely prevented this ecosystem from returning to its pre-Mississippian composition.

Keywords Pollen · Palaeoecology · Vegetation diversity · Environmental reconstruction · Native Americans · Anthropogenic change

Introduction

Temperate broadleaf forests have been the dominant ecosystem in eastern North America throughout most of the Holocene (Prentice et al. 1991). These forests have persisted despite fluctuations in moisture—such as those that occurred during the Medieval Climate Anomaly and the Little Ice Age (Bradley et al. 2003; Mann et al. 2009)—and clearing by humans that occurred during the pre-Columbian and Euro-American settlement phases (Whitney 1994; Abrams and Nowacki 2008). Consequently, it is often assumed that these forests, unlike those of western North America, are relatively stable and resilient to human and climate-driven disturbances. However, several studies indicate that certain key species in these forests were in fact highly sensitive to changes in moisture during the last two millennia (Campbell and McAndrews 1993; Booth et al. 2012; Minckley et al. 2012). Looking toward the future, current projections of future climate indicate an increased frequency of extreme events (Intergovernmental Panel on Climate Change 2021), while human population pressure continues to increase as development expands. To begin to predict how these forests might respond to both climate and human influence in the

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future, it is helpful to examine how they responded to these factors in the past. In addition, by examining ecosystems that experienced compound disturbance events – for example land clearing and changing climate – we can obtain a more accurate point of comparison for the future (Zscheischler et al. 2018).

It is difficult to fully characterize the extent to which humans drove eastern temperate forest vegetation composition in the past because these forests are comprised of numerous plant species – each with their own unique responses to human influence. Additionally, most studies are necessarily limited to archaeological sites where humans were known to be present. Humans constructed numerous settlements throughout this region during the late-Holocene; urban centres such as Cahokia were heavily populated and highly developed (Milner 1998; Pauketat 2004; Iseminger 2010). Yet, disagreement remains over the influence that humans had on vegetation composition and structure of eastern temperate forests (Abrams and Nowacki 2020; Oswald et al. 2020). Localized sites show significant anthropogenic influence; for example, at Fort Ancient, Ohio, approximately 2,000 years ago, Native American populations engaged in agricultural practices that notably influenced local vegetation composition (McLauchlan 2003). Around the same time, Native Americans at Cliff Palace, Kentucky, also cleared forest vegetation to cultivate native plants (Delcourt et al. 1998). However, few studies in this region contain the temporal resolution and/or duration to capture multiple, distinct periods of human settlement at the same site. This scope and resolution is important to fully evaluate how vegetation composition recovered following human disturbance, and compare the influence that different groups of humans had on vegetation in the same place over time.

Pollen assemblage data obtained from lake sediment are a robust proxy for examining how vegetation responded during and after periods of human settlement (Hicks and Birks 1996; Mazier et al. 2006; Xie et al. 2021). However, in order for the pollen to reflect human impacts to vegetation, the lake needs to be immediately adjacent to a human settlement and sufficiently small in surface area to detect a local signal (Sugita 1994). In addition, multivariate examination of the whole pollen assemblage, rather than the dominant taxa alone, is useful for assessing various aspects of vegetation diversity and turnover (Berglund et al. 2008; Matthias et al. 2015). At Kincaid Mounds in southern Illinois, humans were present for ~ 600 years and relatively absent for ~ 800 years, before they returned again for ~ 300 years and then abandoned the site (Butler and Welch 2006; Butler et al. 2011). This unique pattern of settlement, abandonment, and resettlement provides an opportunity to investigate how vegetation composition and diversity changed not only while humans were present, but also after they left. It additionally facilitates comparison of different periods of human settlement, the impacts of those groups on vegetation, and the role that changes in climate may have had on ecosystem recovery.

In this study, we present a high-resolution (decadally resolved) pollen record from Avery Lake, Illinois, which is located within the Ohio River's floodplain and immediately adjacent to Kincaid Mounds. Our two main objectives with this record are to: (1) quantitatively compare vegetation composition and diversity among periods when humans were present to assess similarities and differences in human impacts and activities; and (2) evaluate how vegetation composition and diversity responded after humans left. To achieve these objectives, we analyzed pollen composition, diversity, and turnover across the 3,000 year history of the site, and constructed a self-organizing map using each multivariate pollen assemblage to identify clusters of similar assemblages. By doing so, we provide greater insight into the impact that three distinct groups of humans (Baumer, Mississippian, and Euro-American) had on eastern temperate forest vegetation, and how that ecosystem responded to human impacts.

Study setting

Avery Lake (37.080509, – 88.485406; 102 m a.s.l.) (Fig. 1), is a swale lake located in southern Illinois on a portion of the Ohio River floodplain referred to as the Black Bottom. The Black Bottom is believed to have formed over the last 10,000–20,000 years as the Ohio River gradually meandered southward, depositing sediments on the north bank of the river (Alexander and Prior 1971). At present, the Ohio River is located 1.6 km southeast of Avery Lake. The lake has a surface area of 0.13 km^2, with approximate dimensions of 90 m × 2.1 km. At its deepest, Avery Lake has a water depth of 1 m, which is mostly uniform throughout the lake. The modern catchment of the lake is 15.8 km^2 when it is not flooded (Bird et al. 2019). However, during floods, the lake's catchment becomes the upstream catchment of the Ohio River. At present, these floods are strongly driven by a combination of spring snowmelt and excess precipitation during the early warm-season. The modern climate of Avery Lake is characterized by distinctive warm (April–October) and cold seasons (November-March), with slightly dominant warm-season precipitation. The average temperature in July (warmest month) is 26.1 °C, while average temperature in January (coldest month) is 1.3 °C. Average annual precipitation is 123 cm (PRISM Climate Group 2016). Present-day land use surrounding Avery Lake is a mix of row crop agriculture and temperate deciduous forest. This mix is mainly due to local variations in topography, with row crops dominating the flatter lowlands, and deciduous trees—especially *Carya* spp. (hickories) and *Quercus* spp. (oaks)—dominating the steeper areas.

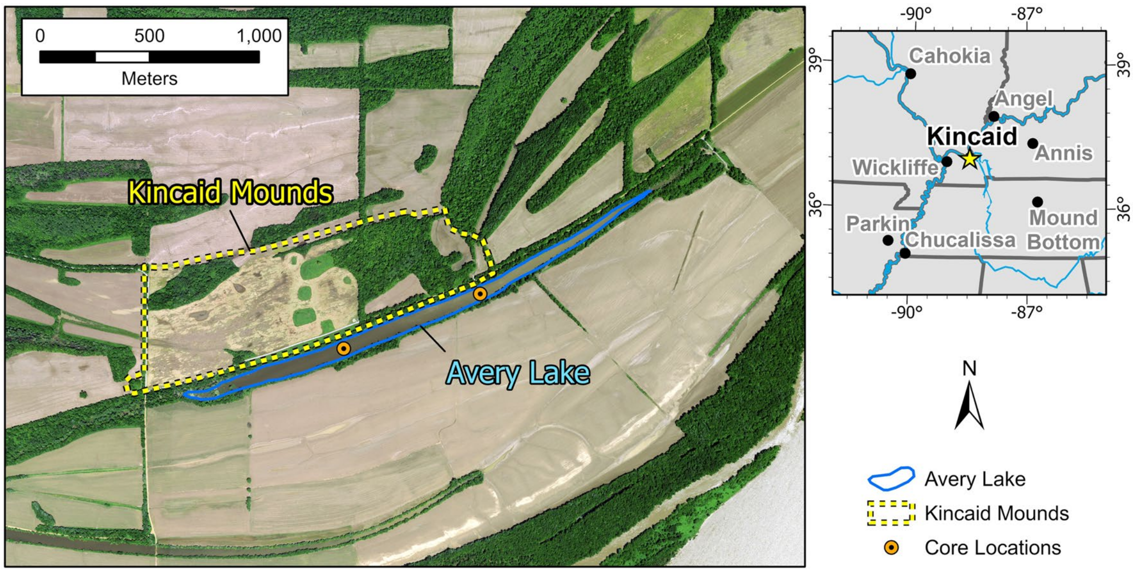

Fig. 1 Main map: Site location of Avery Lake and Kincaid Mounds. Core locations are shown as dots. Base imagery is from the United States Department of Agriculture, National Agricultural Imagery Program 2016. Locator map: Site location of Kincaid and other Mississippian sites within the region

Notably, the area immediately surrounding Avery Lake has an established record of human land use dating back almost 6,000 years (MacNeish 1948; Cole et al. 1951; Butler and Crow 2013). The most well-studied nearby archaeological site is Kincaid Mounds, which is located immediately adjacent to the lake (Fig. 1). Previous research has identified three periods of pre-European settlement at Kincaid Mounds and Avery Lake: (1) the Baumer Phase (300 BCE–300 CE), (2) the Lewis Phase (600 CE–900 CE), and (3) the Mississippian Phase (1150 CE–1450 CE) (Butler and Welch 2006; Butler et al. 2011; Pursell 2016), with the most intense settlements being the Baumer and Mississippian. The Lewis settlement is believed to have been much smaller and more dispersed, due to the comparatively limited archaeological evidence found at Kincaid for this phase (Pursell 2016). We chose Avery Lake for this study for two main reasons. First, while human activities during each of these phases have been studied through archaeological evidence discovered on land, the resulting changes to the surrounding vegetation, both while humans were present and after they left, have not been fully examined. Second, the existence of a sediment core from Avery Lake with a well-dated chronology provides an opportunity to examine changes in vegetation diversity and composition at a fine temporal resolution over the entire 3,000-year period.

Materials and methods

Sample collection, chronology and pollen processing

In June 2014, 10 m long sediment cores were collected from two locations at Avery Lake (Fig. 1). One meter long drives were collected sequentially using a modified Livingstone piston corer (Wright 1967) deployed from a floating platform and powered by an ATV winch system. An adjacent set of 1 m drives were collected at a 50 cm offset to ensure there were no gaps in the sediment archive. The undisturbed sediment water interface was collected using a modified piston corer. All cores were transported to the Indiana University – Purdue University Indianapolis (IUPUI) Paleoclimatology and Sedimentology Laboratory, where they were subsampled for pollen analysis. A total of 111 one cm^3 sub-samples were taken, with the spacing between sub-samples ranging from 1 to 40 cm, and averaging 9 cm. The core was sampled most finely (e.g. 1 to 4 cm) during the approximate Mississippian phase, and most coarsely (e.g. 20 to 40 cm) during the Euro-American settlement phase. This spacing allowed us to achieve decadal or bi-decadal resolution throughout most of the record. Results from other proxies and the first 28 pollen samples were published in Bird et al. (2019). Twelve plant macrofossil and charcoal samples were taken from the core for AMS ^{14}C dating. The uncalibrated dates were calibrated using IntCal13 (Reimer et al. 2013) and plotted against depth to produce the age-depth model (Bird et al. 2019).

Pollen was extracted from each of the 111 subsamples using standard techniques of acetolysis (Faegri and Iversen 1989). Each sample was mounted in silicone oil on a microscope slide and examined under a light compound microscope at 400× magnification. All samples were counted to a minimum of 300 terrestrial grains (with two exceptions: D2 62–63 was counted to 298 grains and D11 40–41 was counted to 297 grains). Each grain was identified to the finest taxonomic resolution possible, generally following McAndrews et al. (1973) and Kapp (2000). The raw pollen counts were converted to percentages using the sum of terrestrial pollen types and plotted in Tilia 2.6.1 (Grimm 1993).

Statistical analysis

Composition and diversity metrics

Vegetation diversity was inferred by calculating three different metrics using the pollen assemblage data: (1) taxonomic richness, (2) taxonomic evenness, and (3) compositional turnover. Taxonomic richness, as estimated by rarefaction analysis, was calculated in Past version 2.17 (Hammer et al. 2001), and plotted against age. Evenness was calculated as the ratio between rarefaction to a low count and a high count, following Matthias et al. (2015). While the Shannon Index is a typical metric for assessing evenness in many ecological studies, it is less suitable for pollen percentages due to the dependence of each taxon's percentage on the abundance of the other taxa in a sample. To infer the compositional turnover, we calculated squared-chord distance between each pollen assemblage and the next pollen assemblage above it in the core. Squared-chord distance measures dissimilarity, with values ranging from 0 to 2. Higher values indicate greater dissimilarity. Squared-chord distance has been applied widely to pollen data for identifying potential analogues and for inferring compositional turnover (Calcote 1998; Gavin et al. 2003; McLauchlan et al. 2013). We calculated this metric in R (R Core Team 2020) using the analogue package (Simpson 2015). Please see ESM 1 for specific code.

Self-organizing map

To assess and visualize similarity and dissimilarity among the pollen assemblages, we constructed a self-organizing map (SOM). A SOM is an artificial neural network that uses unsupervised machine learning to reduce dimensionality in multivariate data with a high number of variables (Kohonen 1990, 2013). It is well-suited for visualizing non-linear relationships, such as those among pollen assemblages, and produces an output that shows a lattice of nodes. Each sample is assigned to a node during the SOM process. The user begins by setting the lattice dimensions. We initially tried dimensions of 4×4 nodes, as well as 3×3 nodes. The 4×4 map was too large, as indicated by some nodes having zero assemblages assigned to them at the end of the mapping process. The 3×3 map was too small, as the mean distance (from each node's weight to the samples represented by that node) did not approach a plateau as more samples were assigned. We settled on a 4×3 lattice as the best fit for the data, given that all nodes had samples assigned at the end of the SOM process, and the mean distance approached a plateau by the 60th sample. We also plotted the distances between nodes, and average distance of samples within a node to that node's vector. All SOM analyses were conducted using the Kohonen package in R (Wehrens and Kruisselbrink 2018). Please see ESM 1 for specific code.

With each pollen assemblage (sample) assigned to a node in the 4×3 lattice, we then conducted a hierarchical cluster analysis on the nodes. We determined that five clusters were the best number for our data using the average silhouette approach. This approach measures the quality of clustering by calculating how well each node lies within its cluster group. For each node, a silhouette width was calculated (Table 1). Each silhouette width can range from -1 to 1. High values (closer to 1) indicate that the node fits the cluster well, while low values (closer to -1) indicate that the node fits the cluster poorly. When we used five clusters, the silhouette values for each node were greater than 0 (with the exception of one node that clustered alone, therefore having a value of 0). When four or six clusters were used, one or

Table 1 Silhouette widths for each node in the self-organizing map

Node	Cluster	Neighbour	Silhouette width
1	1	2	0.49
2	2	1	0.43
3	2	3	0.25
4	3	2	0.00
5	4	1	0.16
6	1	3	0.43
7	1	2	0.19
8	5	3	0.30
9	4	1	0.70
10	1	4	0.54
11	5	3	0.59
12	5	3	0.64

more nodes revealed negative silhouette values, indicating a poorer fit.

Results

Pollen composition and diversity

Six distinctive zones are visible in the pollen stratigraphy: Zone 1 (3,200–2,250 cal BP), Zone 2 (2,250–1,650 cal BP), Zone 3 (1,650–850 cal BP), Zone 4 (850–500 cal BP), Zone 5 (500–150 cal BP), and Zone 6 (150 cal BP to present) (Fig. 2). Three of these zones correspond with human activity at Kincaid Mounds: Zone 2 with the Baumer phase, Zone 4 with the Mississippian phase, and Zone 6 with the Euro-American phase. Non-arboreal pollen was highest during these three human occupations relative to other times in the record. Of these three zones when humans were present, the Euro-American phase has the highest non-arboreal pollen percentages (average of 38.5% and maximum of 80.3%), followed by the Baumer (average of 31.1% and maximum of 62.4%), and the Mississippian (average of 27.7% and maximum of 49.6%) phases. In contrast, Zones 1, 3, and 5 do not correspond with known periods of major human activity at Kincaid Mounds, and the pollen assemblages in those zones were dominated by arboreal pollen. Overall, the most common pollen types in the record are *Quercus* sp., *Carya* sp., *Ambrosia* sp., *Ulmus* sp., *Pinus* sp., Poaceae, and *Juglans* sp., comprising between 66.4 and 95.8% of the total assemblage (average 82.7%).

In Zone 1, the pollen assemblage was initially dominated by *Quercus* (66%), but *Quercus* quickly decreased and never increased above 49% for the remainder of the record. Meanwhile, *Carya* began increasing and reached its highest levels of the entire record (67%) by 2,700 cal BP. *Ambrosia* fluctuated between 0 and 25%, with the higher abundances likely indicating some type of disturbance.

Zone 2 corresponds with the Baumer occupation and contains several indicators of possible land clearing by humans. The first indicator is a dramatic spike in *Ambrosia* to 55.7%. Although *Ambrosia* decreased after the initial spike, it remained relatively high for the remainder of Zone 2. In addition, *Carya* initially decreased dramatically from 35 to 5%, but gradually increased to 20% by the end

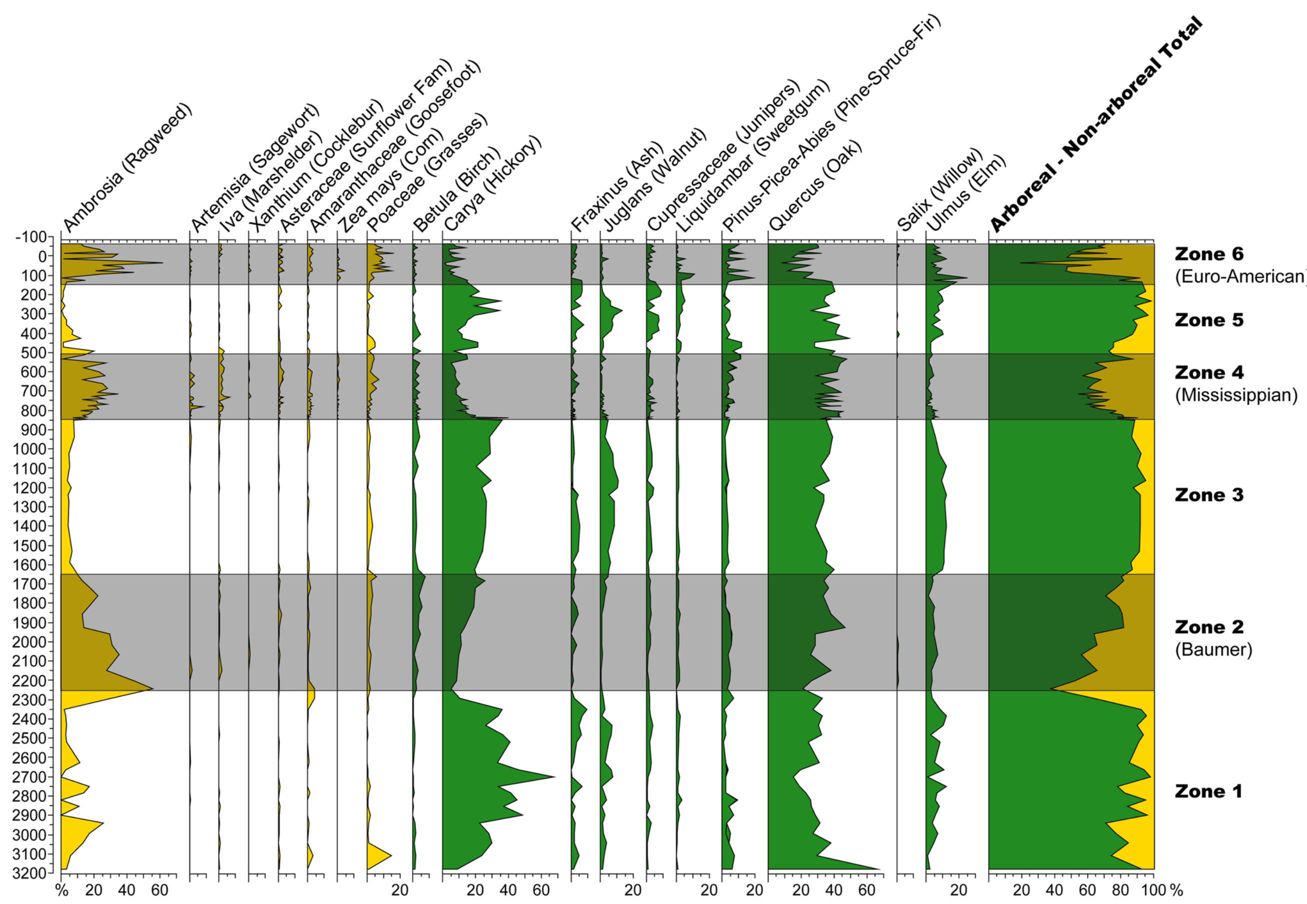

Fig. 2 Pollen percentages of dominant terrestrial pollen taxa for Avery Lake plotted against age. Non-arboreal taxa are displayed in yellow and arboreal taxa are displayed in green

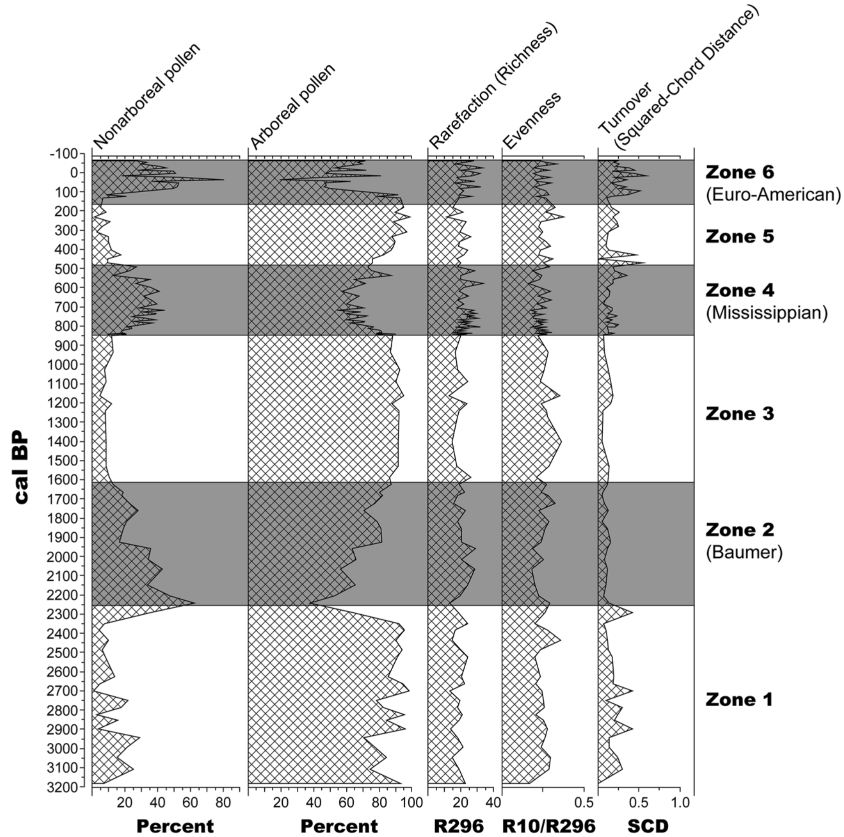

Fig. 3 Pollen summary and diversity metrics for Avery Lake plotted against age. From left: Non-arboreal pollen percentage, arboreal pollen percentage, richness (rarefaction to 296 grains), evenness (rarefaction to 10 grains/rarefaction to 296 grains), and turnover (calculated as squared-chord distance)

of Zone 2. *Ulmus* also decreased, but unlike *Carya, Ulmus* remained at low abundances throughout the zone. *Quercus* stayed relatively high between 21 and 46%. *Iva*, a type of starchy, oily seed that grows naturally or can be cultivated (Yarnell 1972), became slightly more prevalent during this zone, as did Poaceae.

Zone 3 is characterized by consistently low abundances of *Ambrosia* and other non-arboreal pollen, and consistently high arboreal pollen dominated by *Carya* and *Quercus.* Although this zone corresponds with the Lewis phase at Kincaid, the low *Ambrosia* and high *Carya* and *Quercus* suggest the Lewis had little to no impact on vegetation.

Zone 4 began with several changes in the pollen assemblage, indicating onset of disturbance by humans during the Mississippian occupation. The first of these indicators was the initial sudden decrease of *Carya* from 40 to 17%, followed by a continued decrease to 5% by 550 cal BP. However, *Quercus* abundances did not exhibit this same trend; despite numerous fluctuations of approximately 10%, *Quercus* remained at the same average abundance throughout Zone 4 (approximately 45%) as in the prior zone. *Pinus* was initially very low in abundance at the beginning of Zone 4, but increased at the end of Zone 4. *Ambrosia* initially increased from 8 to 16%, and displayed numerous fluctuations despite an overall increase to 35% by 715 cal BP. Though not a major proportion of the pollen assemblage, *Iva* increased noticeably during this zone (average 1.6%). Amaranthaceae, another group of forbs that grows wild but can also be cultivated, increased as well. In addition, *Zea mays* appeared for the first time in the record at 842 cal BP and was present in 15 total samples throughout Zone 4.

Zone 5 is characterised by a gradual increase in arboreal pollen (specifically *Carya, Ulmus,* and *Juglans*) and steady *Quercus* pollen, seeming to indicate a recovery from the disturbance of Zone 4. Non-arboreal pollen, including *Ambrosia, Iva,* Amaranthaceae, and Poaceae all decreased during this zone.

Zone 6 corresponds with the onset of Euro-American settlement in this region of North America at approximately 150 cal BP and continues until present. It is distinguished by the highest levels of *Ambrosia* pollen of the entire record (62%) at 35 cal BP and relatively high levels of Poaceae compared to the previous zones. However, after an initial decrease in arboreal pollen until 35 cal BP, some arboreal taxa such as *Quercus* recently began increasing as the vegetation surrounding Avery Lake has become a mosaic of forest and cropland.

Pollen-type richness increased at the beginning of each human-occupied zone (Zones 2, 4, and 6), but fluctuated overall throughout the entire record (Fig. 3). Richness during the human-occupied zones (average richness of 22.6) was higher than the zones without human occupation (average

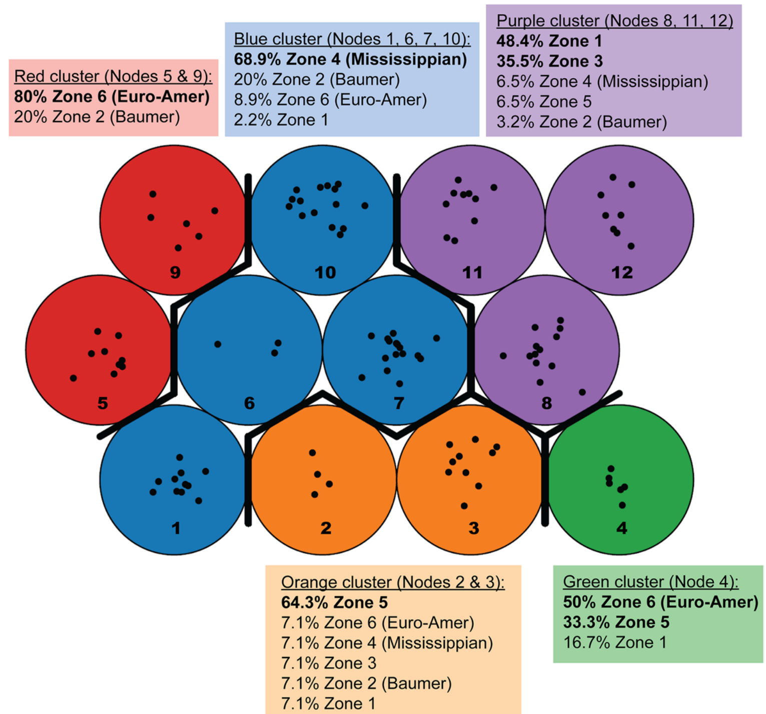

Fig. 4 Self-organizing map of the multivariate pollen data. Each dot is one pollen assemblage representing a specific point in time. Black lines separate the five clusters found through hierarchical cluster analysis

richness of 19.4). Of all six zones, richness was highest in Zone 6, with an average of 23.9. Pollen-type evenness followed a somewhat opposite pattern compared to richness throughout the record. Evenness was slightly lower during the human-occupied zones (0.24) compared to zones without human occupation (0.26).

Average turnover throughout the record was 0.184. Zones 2 and 3 had the lowest average turnover (0.12 and 0.11, respectively), which suggests that the pollen assemblage during these two zones either changed very little, or changed a lot, but very slowly. Given the slow but steady rise in arboreal pollen over Zone 2, a big slow change is most likely in Zone 2, followed by fairly stable conditions with little change in Zone 3. The highest average turnover is in Zone 6 (0.3), which corresponds with Euro-American settlement. This suggests that the pollen assemblage changed the most drastically and frequently during the most recent phase. In fact, three of the top five highest turnover events happened during the Euro-American settlement phase (Zone 6). The other two occurred toward the beginning of Zone 5, around the time of the departure of the Mississippians. In addition, another high turnover event happened at the end of Zone 1, around the beginning of the Baumer occupation. However, no large turnover events are noted at the end of the Baumer occupation or the beginning of the Mississippian occupation.

Self-organizing map (SOM)

The 111 pollen samples are represented within 12 nodes separated into 5 cluster groups (Fig. 4). Each sample and its assigned node and cluster group are provided chronologically in Table 2. The red and blue clusters are dominated by samples from times when humans occupied the site. However, most of the samples from the Mississippian phase clustered in the blue group, while the majority of the Euro-American phase samples clustered in the red group, suggesting that the vegetation composition was distinctively different during each of these two times of heavy human activity. Most of the samples from the Baumer phase clustered with either the Mississippian or the Euro-American samples. Of the samples in the red cluster, 80% are from Zone 6 (Euro-American) and 20% are from Zone 2 (Baumer). In the blue cluster, 68.9% of the samples are from Zone 4 (Mississippian), 20% from Zone 2 (Baumer), and 8.9% from Zone 6 (Euro-American). The green cluster contains only one node with six samples: three samples from Zone 6 (Euro-American), two from Zone 5, and one from Zone 1.

The purple and orange clusters are mainly comprised of samples from times when humans were not present at Avery Lake. The purple cluster mostly contains samples from Zone 1 (pre-Baumer) and Zone 3 (post-Baumer), indicating a similar pollen assemblage composition before and after the Baumer phase inhabitants. A relatively small percentage (16.2%) of the samples in the purple cluster are from other times in the record. The orange cluster is dominated by samples from Zone 5, which represents post-Mississippian and pre-Euro-American times in the record. This suggests that the vegetation composition after the Mississippians left was distinctively different than the vegetation composition after the Baumer people left (before the Mississippians arrived).

Each node in the self-organizing map is influenced by different pollen types (Table 3). The nodes in the red cluster are driven most strongly by *Ambrosia, Quercus,* and Poaceae. Most of the samples in this cluster are from the Euro-American settlement, which had some of the highest abundances of *Ambrosia* and Poaceae of the entire record. On the other hand, the nodes in the blue cluster are also mainly from a time when humans occupied the site; however, the majority are from the Mississippian phase. The blue nodes are most strongly driven by *Quercus,* followed by *Ambrosia* and *Carya*. The differences in pollen taxa weights between these two groups of samples suggests that the self-organizing map technique is capable of discerning between different intensities of human disturbance based on the pollen assemblage – particularly slight differences in the amounts of *Quercus, Ambrosia, Carya,* and Poaceae. The green cluster is the only one with *Pinus* as a top three weight, which explains why the six samples in that cluster were not placed in any of the others.

The nodes in the purple cluster are all strongly influenced by *Quercus* and *Carya*. None of the other clusters have weights as high for both of these taxa – some clusters, like the orange cluster, have a high weight for *Quercus*, but a notably lower weight for *Carya* despite *Carya* being the second highest weight. In addition, both *Ulmus* and *Juglans* also have high weights in the purple cluster. These weights suggest that a more balanced forest composition prevailed during the samples associated with the purple cluster (mostly Zones 1 and 3, pre- and post-Baumer), but a *Quercus*-dominated forest was present during the samples representing the orange cluster, which were mainly post-Mississippian.

Discussion

Landscape clearing, agricultural activities, and human impacts on vegetation composition and diversity

Humans were a major driver of the vegetation composition surrounding Avery Lake during the times when they occupied Kincaid Mounds. With regard to vegetation diversity, changes in richness (inferred through pollen rarefaction) appear to also have been largely driven by human activity. Richness increased at the onset of each period of human occupation. For the Mississippian and Euro-American occupations, the increase in richness occurred in tandem with marked decreases in most tree pollen types (Fig. 3). Given that tree pollen remained present during these times, albeit at lower abundances, this clearing provided a niche in which grasses and forbs could flourish. This landscape could be depicted as: 1) a mostly open landscape with very few trees, or 2) a mosaicked landscape with both forested and open areas. Either scenario could correspond with an increase in pollen richness. Many trees – including *Quercus,* which is a major component of the pollen assemblage at Avery Lake – produce significantly more pollen than grasses (Commerford et al. 2013; Chaput and Gajewski 2018). As such, forest cover is sometimes overestimated when interpreting pollen percentages (Fyfe et al. 2013).

Yet, the extent or intensity of tree clearing did not appear to influence richness in a linear manner. The Mississippian clearing was less pronounced than the Euro-American or the initial Baumer clearance based on the lower levels of non-arboreal pollen (maximum 45%) during the Mississippian period compared to the beginning of the Baumer. For the Baumer occupation, the increase in richness actually corresponded with a recovery of arboreal pollen (following a sharp decline). Although this decline in arboreal pollen began prior to Zone 2, our 2,250 cal BP (300 BCE) date for the beginning of the Baumer Phase (Zone 2) is based on a limited number of radiocarbon dates from an archaeological excavation at Kincaid that may or may not precisely date the onset of occupation (Parker and Butler 2017). Nonetheless, the timing of the decline in arboreal pollen in our record at 2,350 cal BP (400 BCE) is within the range of error for those dates, suggesting clearance and occupation were temporally related. Further, forest clearance almost certainly would have begun prior to construction of structures and datable features, meaning that clearance should logically predate the occurrence of structures. It is additionally possible that the onset Baumer-related disturbances at Kincaid may have begun earlier than suggested by the radiocarbon dated features given their limited number cursory archaeological investigations of the Baumer occupation that have been completed to date. In short, the temporal association between the decline in arboreal pollen and the onset of the Baumer occupation at Kincaid Mounds suggests that these were related events with clearance indicating the onset of Baumer phase occupation. It seems likely that this early Baumer phase landscape was characterised by open vegetation with fewer trees, while a mosaicked landscape with forested and open areas is more plausible for the Mississippian phase. During both times, the Kincaid Mounds area immediately adjacent to Avery Lake is thought to have been intensely developed and occupied (Butler and Welch 2006; Butler et al. 2011), so

Table 2 Self-organizing map node and cluster for each pollen sample

Zone	cal BP	Year CE	Node	Cluster
Zone 6 (Euro-American)	-63	2013	6	blue
	-53	2003	6	blue
	-43	1993	6	blue
	-33	1983	5	red
	-23	1973	5	red
	-14	1964	4	green
	-9	1959	5	red
	6	1944	5	red
	16	1934	4	green
	26	1924	9	red
	36	1914	9	red
	46	1904	5	red
	55	1895	5	red
	65	1885	9	red
	75	1875	5	red
	85	1865	9	red
	95	1855	5	red
	115	1835	4	green
	124	1826	7	blue
	134	1816	3	orange
Zone 5	182	1768	3	orange
	207	1743	3	orange
	232	1718	8	purple
	257	1693	3	orange
	283	1667	8	purple
	308	1642	3	orange
	333	1617	3	orange
	358	1592	3	orange
	384	1566	3	orange
	406	1544	3	orange
	428	1522	2	orange
	449	1501	4	green
	470	1480	4	green

Zone	cal BP	Year CE	Node	Cluster
Zone 4 (Mississippian)	492	1458	1	blue
	513	1437	7	blue
	535	1415	2	orange
	556	1394	1	blue
	578	1372	1	blue
	599	1351	1	blue
	621	1329	10	blue
	642	1308	1	blue
	664	1286	10	blue
	685	1265	1	blue
	706	1244	1	blue
	717	1233	10	blue
	726	1224	1	blue
	733	1217	10	blue
	739	1211	10	blue
	746	1204	7	blue
	753	1197	1	blue
	759	1191	10	blue
	767	1183	10	blue
	777	1173	7	blue
	779	1171	1	blue
	782	1168	10	blue
	792	1158	10	blue
	802	1148	7	blue
	806	1144	1	blue
	814	1136	7	blue
	822	1128	7	blue
	826	1124	7	blue
	834	1116	7	blue
	836	1114	7	blue
	840	1110	11	purple
	842	1108	11	purple
	844	1106	7	blue
	846	1104	7	blue

Zone	cal BP	Year CE	Node	Cluster
Zone 3	850	1100	11	purple
	938	1012	11	purple
	1026	924	8	purple
	1089	861	8	purple
	1164	786	8	purple
	1202	748	8	purple
	1240	710	8	purple
	1272	678	8	purple
	1400	550	8	purple
	1529	421	8	purple
	1587	363	8	purple
	1626	324	3	orange
Zone 2 (Baumer)	1664	286	7	blue
	1683	267	11	purple
	1722	228	7	blue
	1760	190	10	blue
	1818	132	7	blue
	1856	94	7	blue
	1926	24	2	orange
	1960	-10	10	blue
	2015	-65	10	blue
	2065	-115	5	red
	2149	-199	10	blue
	2204	-254	9	red
	2243	-293	9	red
	2293	-343	10	blue
Zone 1	2349	-399	12	purple
	2382	-432	8	purple
	2435	-485	8	purple
	2484	-534	12	purple
	2521	-571	12	purple
	2626	-676	11	purple
	2663	-713	12	purple
	2699	-749	12	purple
	2749	-799	11	purple
	2785	-835	12	purple
	2822	-872	12	purple
	2853	-903	11	purple
	2897	-947	12	purple
	2942	-992	10	blue
	2993	-1043	11	purple
	3045	-1095	11	purple
	3107	-1157	4	green
	3181	-1231	2	orange

it is possible that open vegetation extended further from the lake during the beginning of the Baumer occupation when non-arboreal pollen was higher (over 60%).

Despite the clearing that occurred during the Baumer and Mississippian occupations, *Quercus* populations remained relatively stable throughout the duration of the record until the onset of Euro-American settlement. Meanwhile, *Carya,* another dominant tree type, decreased markedly during all three human occupations. Most other tree types decreased as well. This discrepancy suggests that the Baumer and Mississippian groups were either intentionally preserving *Quercus* over other tree taxa, or, were using a method of clearing that happened to be effective on most trees except *Quercus*. It seems unlikely that *Quercus* nuts were more desirable for food than *Carya* or *Juglans* nuts, especially given abundant *Carya* nut remains found in archaeological excavations at Kincaid Mounds (Parker and Butler 2017). Therefore, the Baumer and Mississippian people probably were not sparing *Quercus* for dietary reasons, unless they were doing so to help preserve food sources for wild game, such as deer. This scenario is possible given that excavated faunal remains suggest that the Mississippians living at Kincaid Mounds consumed medium- and high-utility cuts of deer meat (Buchanan 2018), including forelimbs and hind limbs, reflecting their value as a food source. More simply though, people could have been using fire to clear the landscape for agricultural purposes and the *Quercus* trees were not as easily burned by the fire as other trees. Most mature *Quercus* in eastern North America are resilient to low-intensity fires due to their thick bark and ability to easily establish new seedlings post fire (Brose et al. 2013, 2014), while mature *Carya* have thinner bark and a lower fire tolerance (Pausas 2015; Knott et al. 2019). Additionally, the use of fire by pre-Columbian Native Americans to control vegetation composition during these times has been documented in charcoal records from Kentucky and Tennessee (Delcourt and Delcourt 1998; Delcourt et al. 1998).

While the decrease in arboreal pollen during the human occupations is the biggest indication that major land clearance occurred, there are also several non-arboreal pollen taxa that help explain how humans were utilizing the cleared land. *Iva* (commonly referred to as marsh elder or sumpweed) was present in relatively higher amounts during the Baumer and Mississippian occupations than relative to other times in the record. *Iva* is a forb that produces edible seeds, and grows well in open areas. While *Iva* can grow naturally, it was domesticated and cultivated widely by pre-Columbian Native Americans in this region (Smith 2006), and has been documented in pollen records from other pre-Columbian sites in the Ohio River Valley (McLauchlan 2003). Unfortunately, it is not possible to determine whether an *Iva* pollen grain originated from a cultivated or wild *Iva* plant, since the two have indistinguishable pollen. However, the highest levels of *Iva* occurred during the Mississippian occupation of Kincaid Mounds – much higher than during Euro-American settlement – possibly indicating that the *Iva* pollen present in Avery Lake during the Mississippian phase originated from cultivated *Iva*. If those *Iva* plants were growing wild, we would expect to see similarly high levels of *Iva* pollen during the Euro-American settlement when land clearing also occurred, but that is not the case. In addition, other pollen taxa that contain both wild and cultivated varieties, such as Asteraceae (sunflowers) and Amaranthaceae (goosefoot), were present during the Mississippian occupation and to a lesser degree during the Baumer occupation. These forbs could have been cultivated or grew wild as a result of landscape disturbance. Given the *Iva* dynamics, we believe that some of the Asteraceae and Amaranthaceae were probably cultivated rather than wild, at least during the Mississippian

Table 3 Top five codebook vector weights for each node in the self-organizing map

BLUE CLUSTER							
Node 1		Node 6		Node 7		Node 10	
Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight
Quercus	42.6	*Quercus*	30.3	*Quercus*	39.0	*Quercus*	31.3
Ambrosia	20.2	*Ambrosia*	16.2	*Carya*	17.5	*Ambrosia*	26.7
Carya	9.0	*Carya*	9.8	*Ambrosia*	15.1	*Carya*	12.4
Pinus	4.8	*Pinus*	8.0	*Ulmus*	4.6	*Pinus*	4.2
Poaceae	2.8	Poaceae	5.9	*Betula*	3.3	*Ulmus*	3.5

ORANGE CLUSTER				RED CLUSTER			
Node 2		Node 3		Node 5		Node 9	
Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight
Quercus	51.7	*Quercus*	39.5	*Ambrosia*	28.7	*Ambrosia*	47.0
Carya	12.0	*Carya*	16.3	*Quercus*	21.5	*Quercus*	18.4
Ambrosia	7.4	*Ulmus*	9.1	Poaceae	6.6	Poaceae	5.7
Pinus	6.6	Cupressaceae	6.0	*Ulmus*	6.5	*Ulmus*	5.7
Ulmus	3.3	*Fraxinus*	4.9	*Carya*	5.5	*Carya*	5.6

GREEN CLUSTER		PURPLE CLUSTER					
Node 4		Node 8		Node 11		Node 12	
Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight	Pollen taxon	Weight
Quercus	27.9	*Quercus*	33.3	*Quercus*	32.3	*Carya*	44.0
Carya	16.8	*Carya*	27.2	*Carya*	31.1	*Quercus*	24.8
Pinus	12.1	*Ulmus*	10.7	*Ambrosia*	11.8	*Ulmus*	6.5
Poaceae	9.5	*Juglans*	7.3	*Ulmus*	5.7	*Juglans*	4.9
Ulmus	8.4	*Ambrosia*	4.2	*Pinus*	3.0	*Ambrosia*	3.8

occupation at Kincaid Mounds. *Zea mays* (corn) pollen was also found in 31 samples between approximately 850 and 515 cal BP, which coincides with the entire known Mississippian occupation at Kincaid Mounds. The cultivation of corn by the Mississippians here for over 300 years is an extension from what was documented by an early examination of the first 28 pollen samples from this same sediment core (Bird et al. 2019), and aligns with well-established evidence that the Mississippians developed an agricultural society focused heavily on corn production (Bird et al. 2017; VanDerwarker et al. 2017; Emerson et al. 2020). The full pollen record presented here demonstrates that starchy, oily seeds, such as *Iva* and possibly Amaranthaceae and Asteraceae, continued to be part of the Mississippians' agricultural matrix. Further, it shows that agricultural crops were an important component of the vegetation composition surrounding Avery Lake.

Baumer impact on vegetation: similar beginnings to Euro-American

By observing the highest levels of *Ambrosia* deposited during the Baumer and Euro-American occupations, it might appear that the disturbance during the Baumer occupation was similar in intensity to the Euro-American occupation (Bird et al. 2019). However, by looking at the complete record (Fig. 2), it is apparent that the *Ambrosia* levels for the first 200 years of the Baumer occupation were similar in magnitude to the Euro-American occupation, but the remainder of the Baumer occupation was more similar in magnitude to the Mississippian occupation. Furthermore, based on the self-organizing map results that incorporated the entire pollen assemblage for each sample, it is clear that the composite pollen assemblage during the early Baumer phase was similar to Euro-American phase (Table 2). This strongly suggests that the initial Baumer impact on vegetation composition was similar in magnitude to the Euro-American impact, at least surrounding Avery Lake. The spatial extent of this intense impact is difficult to pinpoint, but was probably more localized than those of the Euro-American phase.

Pre-Columbian Native Americans in this region of North America are thought to have had an intense impact on vegetation in localized patches, with each patch serving a different purpose (Munoz et al. 2014). While the intensity of the Baumer impact on vegetation may not have matched the Euro-American impact at the same regional scale, it very likely matched it in intensity on a local scale, with test excavations at Kincaid Mounds identifying a thick midden, earth ovens, hearths, and storage pits indicating intensive re-occupation immediately north of Avery Lake for 300 + years (Parker and Butler 2017). Further, the Baumer impact may have even exceeded the Euro-American impact on a local scale if population size is taken into consideration. While the geographic extent of the Baumer impact was probably less than the Euro-American, the Baumer phase inhabitants seem to have had a larger impact on the region from a per-capita perspective than the Mississippians and Euro-Americans given that the Baumer population was not as large as the Euro-American population or even the Mississippian (Muller 1986). The Mississippians in contrast had a much larger population than the Baumer, but their disturbance was considerably less.

Mississippian impacts: gradual onset

Based on the self-organizing map, the Mississippian vegetation assemblage was distinctively different from the Euro-American and early Baumer assemblages. Two points can help explain this. First, high turnover events occurred in the pollen record around the beginning of both the Baumer and Euro-American zones, indicating a rapid vegetation change. Yet, no similarly high turnover event occurred at the onset of the Mississippian, which suggests that a more gradual change took place, and ultimately resulted in a different vegetation community. Second, by considering which pollen taxa had the strongest influence on each cluster group (Table 3), *Quercus* had the most dominant influence on the blue cluster, which contains the most Mississippian samples (the blue cluster). Meanwhile, the red cluster, comprised of Euro-American and early Baumer phase samples, was driven primarily by *Ambrosia* and secondarily by *Quercus*. Given these two points, the slower onset of human impact on vegetation, in addition to either lesser intensity or smaller extent, is a key characteristic that distinguishes the Mississippian samples from the early Baumer and Euro-American occupations. A bigger question is *why* did the Mississippians have a more gradual and/or less intense impact on vegetation? The answer may lie in the types of activities the Mississippians engaged in at Kincaid Mounds, and the timing of those activities. Archaeological data from Kincaid suggests that the Mississippians initially utilized the site as a ceremonial centre, but later transitioned to a population centre (Butler et al. 2011; Krus 2016; Pursell 2016). The early ceremonial usage associated with mound construction would match well with higher levels of arboreal pollen (less clearing) than later in the Mississippian occupation when arboreal pollen levels were noticeably lower as the site became a more heavily-utilised population and agricultural centre with an associated palisade that protected its inhabitants. The intensification of maize agriculture that would have accompanied increasing population sizes would additionally have required more land, hence leading to intensified clearance and more profound vegetation shifts.

Full vegetation recovery after Baumer … but not Mississippian

Most of the immediate pre- and post-Baumer pollen samples (Zones 1 and 3) grouped with the purple cluster, and share a similar composition (Fig. 4). This compositional similarity suggests that the temperate forest ecosystem made a fairly swift recovery following the abandonment of Kincaid Mounds by the Baumer people around 1,650 cal BP. In contrast, a similar recovery did not occur following the Mississippian occupation. Most of the post-Mississippian samples (Zone 5) grouped in the orange cluster, and are compositionally different from the Zone 3 samples. This difference in recovery is initially puzzling, especially considering that the higher arboreal pollen concentrations during the Mississippian (compared to the early Baumer) suggests that the Mississippians had less impact on the natural temperate forest vegetation than the Baumer people did. In that case, the vegetation should have been more likely to return to pre-Mississippian composition, unless another factor, or factors, drove vegetation dynamics.

One likely factor that could have been driving vegetation dynamics was a changing climate. Oxygen isotope data from other sites in this region indicate that a major shift in seasonal moisture regimes occurred from 550–480 cal BP, causing summers to become much drier while most annual precipitation became cold-season dominant (Bird et al. 2017). This timing coincided directly with the Mississippian abandonment of Kincaid based on the disappearance of *Zea mays* pollen from our record (Fig. 2), as well as archaeological evidence from the site and surrounding Black Bottom (Cobb and Butler 2002; Butler et al. 2011) and other sedimentological evidence from Avery Lake (Bird et al. 2019). Their departure also coincided with two high turnover events (Fig. 3), indicating abrupt and major shifts in vegetation composition. Similarly high turnover events did *not* occur at the end of the Baumer occupation of Kincaid Mounds. The timing of the seasonal moisture shift, combined with high turnover and resulting compositional dissimilarity between the post- and pre-Mississippian pollen assemblages strongly suggests that climate was most likely the driving force behind the inability of this temperate forest ecosystem to recover following Mississippian abandonment. Ultimately, this suggests that eastern temperate forest ecosystems in North America are fairly capable of recovering from human disturbance – even large disturbances, like that which occurred during the Baumer phase – as long as the climate regime stays consistent.

Conclusions

The vegetation composition that surrounded Avery Lake during the Mississippian settlement and latter part of the Baumer settlement was distinctively different from the vegetation composition during the Euro-American and early Baumer settlements. In addition, low turnover at the beginning of the Mississippian settlement suggests a gradual change in vegetation composition occurred as the Mississippian people slowly began exerting control over the local landscape, possibly a function of Kincaid's early usage as a ceremonial centre before transitioning to a more heavily-utilized population centre. Despite the more rapid and greater amount of clearingc—indicated by higher turnover and lower abundances of arboreal pollen—that occurred during the early Baumer settlement compared to the Mississippian, the vegetation assemblage returned to pre-disturbance composition after the Baumer settlement ended, but did not return to pre-disturbance composition after Mississippian abandonment. This suggests that another factor hindered the ability of this ecosystem to recover to its pre-disturbance composition after the Mississippian—possibly a regional shift in seasonal moisture regime. Further vegetation reconstructions coupled with climate proxies are essential in order to identify the roles of climate versus humans in shaping vegetation composition in this region. In addition, the utility of self-organized mapping techniques to discern between different levels of human disturbance based on our pollen assemblage data suggests that this technique is beneficial in disentangling slight differences in overall vegetation composition that are not readily observed through analysing only a few dominant taxa.

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Availability of data and material Original pollen data are available as ESM 2. These data will also be submitted to the Neotoma Paleoecology Database (www.neotomadb.org).

Code availability R code for squared chord distance analysis and self-organized map analysis is provided as ESM 1.

Declarations

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