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The earliest occurrence of a newly described domesticate in Eastern North America: Adena/Hopewell communities and agricultural innovation

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ABSTRACT

Archaic and Woodland period communities in eastern North America domesticated a suite of annual seed crops referred to the Eastern Agricultural Complex (EAC), some of which subsequently fell out of cultivation and were lost. Recently, a domesticated sub-species of one of these lost crops, erect knotweed (*Polygonum erectum*) has been described. This paper reports the earliest example of this domesticated sub-species, which was recovered from a sub-mound context at an Adena/Hopewell site in central Kentucky (Walker-Noe, 15Gd56) dating to c. 1 AD. Contemporary Middle Woodland erect knotweed assemblages from habitation sites in western Illinois are not domesticated. A review of the paleoethnobotanical record suggests that farmers on the western front of the Appalachian Mountains developed several innovative agricultural practices, beginning around 1000 BC, that subsequently were adopted across the core area of EAC cultivation. The ethnography and sociology of 20th and 21st century farmer networks suggests that Adena/Hopewell exchange and community integration at mounds and earthworks may have been instrumental to this process. Additional analyses of botanical assemblages from mounds and earthworks, especially morphometric analyses of crop seeds, are necessary to test this hypothesis. The dynamics of social learning involved in this process may also be implicated in the spread of crop varieties and agricultural techniques in other regions.

1. Introduction

Ancient farmers in eastern North America domesticated several annual seed crops beginning around 1800 BC (Fig. 1; Smith and Yarnell, 2009), including sunflowers (*Helianthus annuus* var. *macrocarpus* (DC. Ckll.) and native squashes (*Cucurbita pepo* ssp. *ovifera* D.S. Decker) (Cowan and Smith, 1993; Heiser, 1954; Kistler et al., 2015; Smith, 2014). Extinct domesticated sub-species have also been described for several *lost crops* – species that are no longer cultivated. These include goosefoot (*Chenopodium berlandieri* ssp. *jonesianum* Smith and Funk) (Gremillion, 1993a; Fritz and Smith, 1988), sumpweed (*Iva annua* var. *macrocarpa* Blake) (Yarnell, 1972), little barley (*Hordeum pusillum* Nutt.) (Hunter, 1992; Graham et al., 2017) and, most recently, erect knotweed (*Polygonum erectum* ssp. *watsoniae* N.G. Muell.) (Mueller, 2017d). Maygrass (*Phalaris caroliniana* Walt.) was also widely cultivated but does not appear to have been domesticated (Fritz, 2014). These crops pre-date maize agriculture by centuries or millennia and are referred to as the Eastern Agricultural Complex (EAC). This paper reports the earliest evidence for erect knotweed domestication, from the Middle Woodland Walker-Noe site (15Gd56), in central Kentucky, and the results of morphometric analyses from two contemporary Middle Woodland sites in western Illinois, then addresses the significance of these assemblages for understanding the development and spread of agricultural knowledge and practice in eastern North America.

As in other centers of domestication where there is a high resolution archaeobotanical record (Fuller et al., 2011; Zhao, 2011), all evidence indicates that the EAC changed in species composition, geographical extent, and intensity over the course of thousands of years, as farmers improved this diverse suite of crops and encountered neighbors with different seed stock and methods. Hundreds of years after the domestication of squash, goosefoot, sunflower, and sumpweed, changing agricultural practices led to the addition of erect knotweed to the crop complex, and its eventual domestication (Fig. 1). When innovative agricultural practices or improved crop varieties are developed by one community, what social conditions tend to favor their adoption by neighboring groups? The sociology and anthropology of modern farmers can provide some insight into why certain periods, such as the Middle Woodland period in eastern North America, seem to have been particularly conducive to the expansion and consolidation of agricultural systems.

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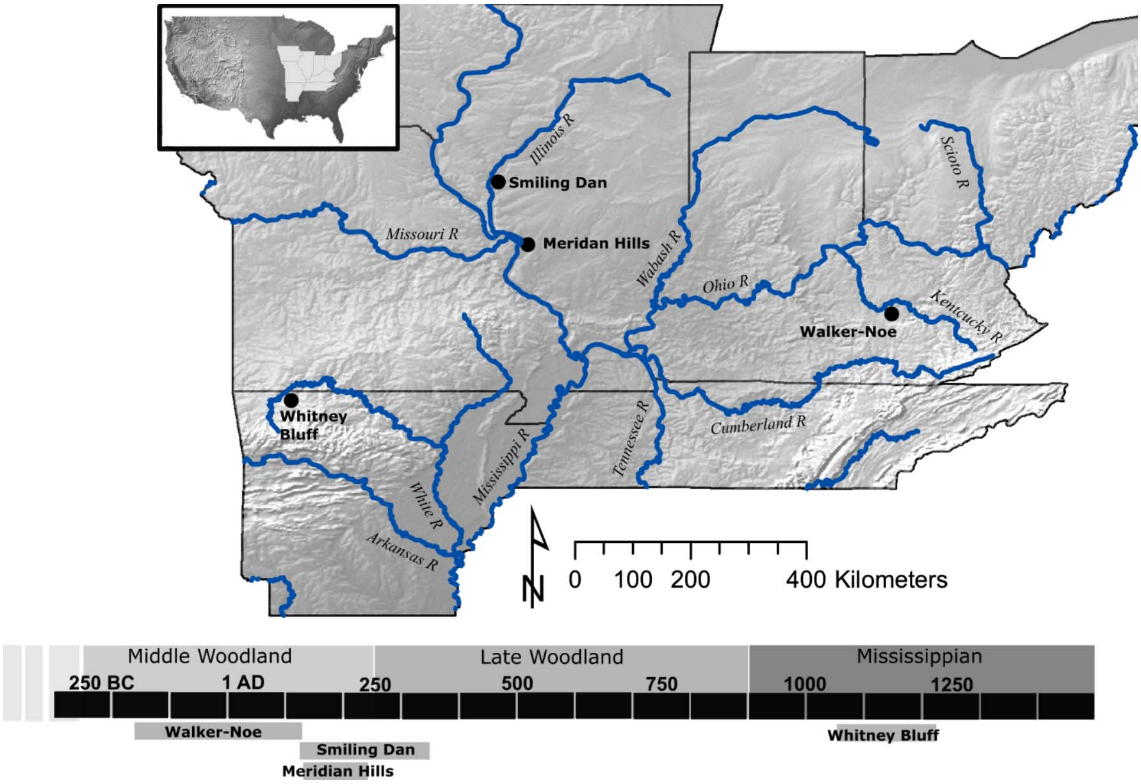

Fig. 1. Map of the core area of Eastern Agricultural Complex (EAC) cultivation. The three Middle Woodland sites included in this analysis are shown (Smiling Dan, Meridian Hills, and Walker-Noe). Regions mentioned in the text: The Adena/Hopewell core areas extends both north and south of the Ohio River valley. Smiling Dan is located in the Lower Illinois valley (LIV) and Meridian Hills is located in the American Bottom floodplain. The Whitney Bluff site erect knotweed has been described as the type specimen for the domesticated sub-species, and is included in the analysis of Middle Woodland sites as a point of comparison. A timeline of eastern North American periods mentioned in the text is included below the map. Ninety-five percent confidence intervals for the radiocarbon dates obtained directly from analyzed erect knotweed achenes are represented as bars below the timeline.

Erect knotweed first entered the crop system of eastern North America at the end of the Late Archaic period, c. 3500 years ago. The earliest evidence comes from rockshelters in eastern Kentucky (Gremillion 1993b). A diachronic series of assemblages from the Lower Illinois valley (LIV) and American Bottom floodplain, in western Illinois, were analyzed (Mueller, 2017e). Previous research has shown that erect knotweed cultivation had great time depth and was consistently intense in this region during the Middle and Late Woodland periods (Asch and Asch, 1985c, Simon and Parker, 2006; Fig. 1), so I expected to find the earliest evidence for a domesticated subspecies there. As expected, erect knotweed was locally domesticated in western Illinois between ~700 and 1000 AD (Mueller, 2017e). Domesticated erect knotweed was widely grown by Mississippian times (1000–1400 AD): it has been documented at Mississippian sites in Arkansas, Illinois, and Missouri (Mueller, 2017e). These data suggest that domesticated erect knotweed evolved in western Illinois during the Late Woodland period, then spread south as far as the Ozarks and perhaps elsewhere by late Mississippian times.

But complicating this neat narrative of domestication and spread, the earliest occurrence of domesticated erect knotweed is almost a millennium older than those from western Illinois, and comes from hundreds of miles to the east. It was recovered from Walker-Noe, a large multicomponent site in central Kentucky (Pollack et al., 2005; Fig. 1). The assemblage comes from beneath a small burial mound that dates to ~1 AD (Table 3; Reimer et al., 2013). Contemporary Middle Woodland assemblages from western Illinois do not show any signs of domestication, indicating that the Walker-Noe assemblage likely represents a separate domestication process from the one documented in Illinois during the Late Woodland–Mississippian. This precocious domesticated population of erect knotweed can be used to reconstruct some elements of Early–Middle Woodland agricultural practice before and during the florescence of the Adena/Hopewell[1] phenomenon in the Middle Ohio Valley and its tributaries.

I characterize the morphology of this assemblage in comparison to other archaeological and modern populations of erect knotweed and show that it represents a (so-far) isolated occurrence of the domesticated sub-species in the Ohio Valley, and is unlike contemporary assemblages from western Illinois. The results of experimental studies of erect knotweed provide a bridge between observed signs of domestication and the practices of Early and Middle Woodland farmers in central Kentucky. I integrate these insights into what is already known about the trajectory of agricultural innovation in eastern North America. This study demonstrates the utility of data from cultivation experiments with crop progenitors for reconstructing ancient agricultural practice and land use patterns. Finally, I use ethnographic descriptions of contemporary farmer seed networks and the theory of diffusion of innovations, borrowed from 20th century rural sociology, to suggest some directions for future research into the connection between Adena/Hopewell networks and rituals, and the development of agriculture in eastern North America. While this connection remains hypothetical, the vast body of research documenting how modern farmers adopt new crops and techniques should be more widely applied to the study of the origins of agriculture. The seeds of domesticated

[1] The affiliation of Walker-Noe with "Adena" traits is discussed by Pollack et al. (2005). To summarize, Walker-Noe is a Middle Woodland site and is contemporary with "Hopewell" sites in Ohio (where Adena is generally considered an Early Woodland phenomenon). Diagnostic Adena Plain pottery and Adena stemmed points were recovered during the excavations. On the other hand, the mound itself is not typically "Adena." By using Adena/Hopewell, I am referring to the general Early-Middle Woodland trend in the Middle Ohio valley and its tributaries towards increasingly large exchange networks and elaborate monumental constructions (see also Henry 2017).

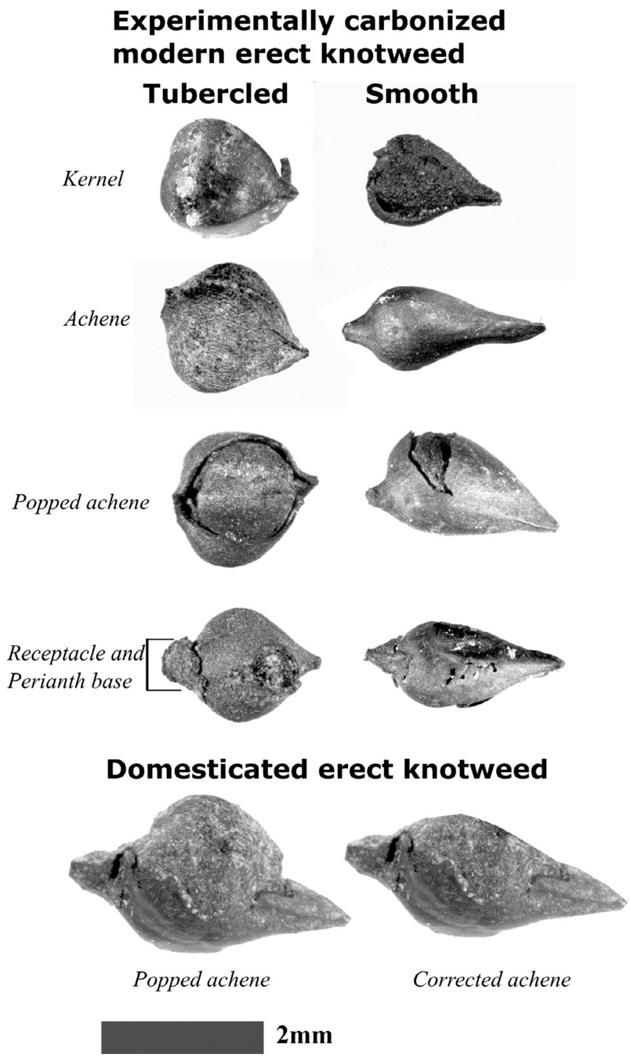

Fig. 2. This figure provides a visual comparison of different carbonized morphotypes found in the archaeological record, as well as of the size difference between typical wild erect knotweed and typical domesticated erect knotweed. Kernels (seeds), and achenes (fruits) are both commonly recovered, but only achenes were used in this analysis. Popped achenes were not used in the morphometric analysis (Analysis 1), unless they could be easily corrected (an example of a corrected achene is shown at the bottom of the figure). Otherwise, the pericarp texture of popped achenes was recorded for Analysis 2. Achenes often have their receptacle and perianth (flower) base adhering. Correction factors for missing receptacle/perianth base were developed experimentally and are reported in Table 2. These correction factors were applied to all achenes that lacked these parts. The top four rows show typical wild sized achenes/kernels, with tubercled morphs on the left and smooth morphs on the right. A typical domesticated achene is pictured in the final row: domesticated assemblage have larger achenes and are predominately made up of smooth morphs like the one pictured. This is an image of popped carbonized achene from the Mississippian Gypsy Joint site, MO, that was manually corrected.

plants are an archaeological proxy for the agricultural knowledge of communities: they cannot be created or maintained in a consistent form without an equally consistent set of management practices. Using the occurrence of domesticates in the archaeological record, it is possible to see the contours of exchange networks and communities of practice, and boundaries across which knowledge and material do not spread.

1.1. Domesticated erect knotweed (Polygonum erectum ssp. watsoniae) background

Erect knotweed is commonly recovered from storage pits, hearths, and middens at archaeological sites in the core area of EAC cultivation dating between c. 1000 BC and 1400 AD (see Fig. 1 for core area; Fritz, 1993). Erect knotweed was cultivated for its edible seeds. It produces seeds that are encased in a hard pericarp, or fruit coat. This type of fruit is called an achene. Both achenes (fruits) and kernels (seeds) are commonly recovered from archaeological sites, although the latter are usually more abundant in carbonized assemblages (Fig. 2). Erect knotweed exhibits seasonally controlled achene dimorphism, which means that individual plants produce two distinct fruit types in ratios that vary over the course of the growing season (Costea et al., 2005; Mueller, 2017c). The two morphs are called *smooth* and *tubercled* with reference to the surface texture of their fruit coat. During the summer and early fall, plants produce only tubercled morphs. Beginning in mid-September, plants begin to produce both tubercled and smooth morphs. The functional difference between them is that smooth morphs have thinner, less water resistant fruit coats and will germinate immediately the spring after they are produced, whereas tubercled morphs can survive in the seedbank for at least 18 months (Yurtseva, 2001; Mueller, 2017c). Thus erect knotweed naturally produces a fruit type (smooth morphs) that already has one key characteristic of a domesticated seed crop: reduced germination inhibitors. Human selection was brought to bear on this natural variation during the process of domestication (Mueller, 2017b, 2017c; Table 1).

Speculation about a domesticated subspecies of erect knotweed began when two curious assemblages were reported in the mid-1980s. First, Asch and Asch (1985b; 1985c) reported a carbonized assemblage from the Late Mississippian Hill Creek site, IL that was composed exclusively of abnormally large smooth morphs. Fritz (1986) reported a similar, but desiccated, assemblage of large smooth morphs from the Mississippian Whitney Bluff site, in northwestern Arkansas. A taxonomic analysis of these assemblages and all native species of *Polygonum* resulted in the naming of a new sub-species: *Polygonum erectum* ssp. *watsoniae* (Mueller, 2017d). Domesticated erect knotweed differs from its wild progenitor in two ways: its achenes are larger, and tubercled morphs are reduced or eliminated in favor of smooth morphs. The selective pressures that may have led to these changes under cultivation, informed by three years of observations of wild populations and cultivation under controlled conditions, are described in detail elsewhere (Mueller, 2017b). To summarize, domesticated erect knotweed is probably the results of both active human selection and the relaxation of certain selective pressures in human-mediated ecosystems. The inherent developmental plasticity of erect knotweed plants likely also played an important role in this process. These forces and their effects are summarized in Table 1, and discussed with reference to the Walker-Noe site and the Adena/Hopewell phenomenon below.

2. Materials and methods

I sought out well-defined contexts that contained > 20 measureable erect knotweed achenes because homogenous masses of seeds in well-defined contexts are more likely to represent living populations than many small samples. In instances where the assemblage I analyzed had been dated by previous researchers and where I also obtained a second date, these two dates were in close accordance (Mueller, 2017e). I first recorded the initial weight of all identifiable *Polygonum* (kernels, achenes, and pericarp fragments) from a given context. Next, I sorted the entire sample, counting all achenes that had sufficient observable pericarp to classify them as either smooth or tubercled. I did not count fragments of pericarp smaller than 50% of a complete pericarp to avoid double counting. Of these, I separated achenes that had well-preserved pericarps and had not grossly changed shaped during carbonization. Many achenes were popped: they had perisperm extruding from cracks in the pericarp (Fig. 2). These were excluded from the morphometric analysis unless they could be easily corrected by manually removing the extruding tissue from the photograph. Achenes both with and without adhering receptacles/perianth bases were included (Fig. 2). Correction factors for missing receptacles/perianth bases were developed experimentally (Mueller, 2017a) and are given in Table 2. I sampled one

Table 1
Summary of hypothesized effects of cultivation on erect knotweed achene morphology.

Agricultural practice	Rationale for agricultural practice	Evolutionary effects
Seed saving Seed exchange	Farmers maintain seed security – they have seeds to plant if crops are wiped out before they reproduce Landraces with desirable characteristics are shared	(1) Farmers replace the bet-hedging function of tubercled morphs by acting as seed dispersers and by providing an alternative to storage in the seed bank
Habitat expansion by land clearance	Erect knotweed crops can be destroyed by early summer floods, so farmers move plants to more predictable environments on terraces and in uplands	(2) Farmers move a disturbance adapted plant to a predictable, protected environment • Selective pressures maintaining achene dimorphism are relaxed. Plants producing mostly smooth pericarp achenes become predominate in cultivated populations
Thinning seedlings	Farmers notice that thinning stands produces plants with more branches, and more seeds. Farmers realize they will get a bigger harvest by growing fewer plants per area	Relatively large smooth morphs germinate and grow more quickly than small smooth morphs or tubercled morphs. Farmers eliminate the smaller seedlings year after year, giving a selective advantage to plants producing seeds that germinate as soon as they are planted and produce robust seedlings • Active selection for plants producing mostly large smooth pericarp achenes

Summary of hypothesized effects of cultivation on erect knotweed based on observations of populations of erect knotweed in their natural habitat and on experimental cultivation. See Mueller (2017c) for detailed discussion.

achene per 0.01 g of *Polygonum* remains in order not to bias the photosample against poorly preserved (usually older) assemblages – or if there were fewer measureable achenes than one per 0.01 g, then I sampled all of them. The modern comparative sample used in this morphometric analysis is comprised of measurements from 275 individual achenes derived from 21 herbarium specimens and collections over the course of two years from two populations of erect knotweed plants in Illinois and Missouri (Table 3).

I took grayscale photographs of each achene in the same orientation with the widest of their three sides down using a Zeiss SV11 microscope fitted with a manual stage, z-stepping motor, and an AxioCam MRC5 digital camera. I recorded the texture of each pericarp as "Smooth" or "Tubercled." Using ImageJ open source software, then measured several shape factors and area, length, and width. In order to take area measurements, the object to be measured must be thresholded (differentiated from the background on the basis of color or shade). With solid objects such as seeds on a white or black background it is usually easy to select all non-white or non-black pixels, but it is sometimes necessary to manually trace the outline of fruits that are similar in color to background shadows. Length and width are the two longest perpendicular straight line distances across the image of the achene. I applied correction factors for change in size due to carbonization, which were developed experimentally (Mueller, 2017a), and are reported in Table 2.

Domesticated erect knotweed differs from its wild progenitor in two ways: an increase in fruit size and a decrease in fruit dimorphism. The Walker-Noe assemblage is evaluated for these two differences by comparing it to the modern comparative sample and to the Mississippian Whitney Bluff assemblage, which is the type specimen for domesticated *P. erectum* ssp. *watsoniae*. Two other Middle Woodland assemblages from western Illinois, Smiling Dan and Meridian Hills, are also included in these comparisons to investigate regional variation during this time period.

(1) Analysis 1: Comparison of fruit size. The size of tubercled and smooth morphs, respectively, are considered in terms of *area*. Area is a more accurate measure of size than length or width because it more closely reflects volume (Mueller, 2017b). Length X width is also reported to facilitate comparison with other studies. Where variances are not significantly different, the means of each sample are compared to the two reference populations (modern and Whitney Bluff) using Tukey's Honestly Significant Differences test. Where variances differ significantly, pairwise Welch's t-tests were used instead. For significant differences, p-values are stated in the text.
(2) Analysis 2: Comparison of the proportion of smooth morphs. This is a more difficult variable to assess, especially in carbonized assemblages, because of preservation and sampling biases (Mueller, 2017a). Population proportions in modern populations range between ~25 and 75% smooth morphs by the time the plant is ready to harvest in late October or early November, so the proportion of smooth morphs must significantly exceed 75% in order to constitute evidence of domestication syndrome. There are two complicating factors. First, smooth morphs are more easily destroyed by carbonization and are thus systematically underrepresented in the archaeological record (Mueller, 2017a). Second, estimating population proportion accurately enough to recognize such a shift requires an adequately large sample, which cannot always be obtained from archaeological collections. There is an established probabilistic relationship between the true population proportion and the expected accuracy of a sub-sample: the closer the true population proportion is to 50–50, the larger the sample required to accurately estimate it (Fig. 3). In archaeology, we cannot always dictate sample size, and must instead be explicit about the error inherent in our estimates

Table 2
Measurements and correction factors.

Measurements	Description	Correction factors	
		Smooth	Tubercled
Area	# of pixels within the margins of object	$A_{no\ receptacle} * 1.10 = A_1$ $A_2 * 1.18 = A_1$	$A_{no\ receptacle} * 1.13 = A_1$ $A_2 * 1.22 = A_1$
Length	#of pixels along major axis of selected object	$L_{no\ receptacle} * 1.12 = L_1$	$L_{no\ receptacle} * 1.17 = L_1$
Width	Number of pixels along minor axis of selected object	$LXW_2 * 1.17 = LXW_1$	$LXW_2 * 1.23 = LXW_1$

Correction factors for missing receptacle (see Fig. 2) and for change in size due to carbonization were developed experimentally (see Mueller, 2017a). When correcting a carbonized achene that is also missing its receptacle, the correction factors were applied in the order they are listed: first, the achene measurement was corrected for the missing receptacle, then that measurement was corrected for changes due to carbonization.

Table 3
Contexts, sample summary, and results.

Site	Context	Date	Sample weight (g)	N Analysis 1 Photo sample	Mean area (mm^2)		Mean LXW (mm)		N Analysis 2 All achenes	% Smooth
					Smooth	Tubercled	Smooth	Tubercled		
Walker-Noe 15GD56	Unit 9, Z2 L2	2000 ± 60[a] 167 BCE – CE 125	0.22	3	4.64	–	7.23	–	24	100
	Feature 2	1950 ± 25 21 BCE – CE 125	0.17	7	4.42	4.04	7.11	6.48	16	94
Site total			0.39	10	4.49	4.04	7.15	6.48	40	98
Smiling Dan 11ST123	F242		1.62	21	3.69	3.35	4.95	5.36	43	23
	F194 Structure B	1840 ± 20 CE 125–238	0.19	2	–	4.03	–	6.20	14	0
	F110 Structure C	1750 ± 20 CE 236–347	0.14	10	2.90	2.38	4.61	3.71	40	28
	F164		0.86	27	4.08	3.54	6.84	5.84	79	37
	F205		0.22	12	2.51	3.11	3.85	4.92	35	34
	F92 Structure C		0.15	11	3.36	3.24	5.53	5.24	30	43
Site total			3.18	83	3.43	3.29	5.57	5.30	241	31
Meridian Hills 11MS1258	55	1830 ± 20 CE 130–237	2.37	28	4.26	3.46	6.85	5.58	31	6
Whitney Bluff 3BE20	32-57-5	885 ± 20 CE 1046–1217	0.88	81	5.66	4.73	9.54	8.42	706	100[b]
	32-57-3		1.2	120	5.67	—	9.62	—	601	100
Site total			2.08	201	5.67	4.73	9.59	8.42	1307	100
Modern	Bellews Creek	2014–2015	N/A	140	2.77	3.16	4.70	5.05	140	29
	Crawford Creek	2014–2015	N/A	87	3.69	3.03	6.30	4.75	87	24
	Herbarium specimens	1950–present	N/A	48	3.90	3.51	6.16	5.71	48	27
Modern total			N/A	275	3.23	3.18	5.41	5.06	275	27

Sites included in this analysis are listed, along with contexts sampled, and results of both analyses. All but one of the dates listed were obtained by the author from the National Ocean Sciences Accelerated Mass Spectrometer (NOSAMS; Mueller, 2017e). Size and shape measurements were taken only from well-preserved complete achenes (Analysis 1). Pericarp texture was noted from all achene fragments greater than one half of a complete achene (Analysis 2).

[a] Pollack et al. (2005:67-8).

[b] Two out of 1307 achenes were tubercled, which rounds to 100%.

given the sample available. The relationship between sample size and the accuracy of a population proportion estimate at 95% confidence is modeled in Fig. 3, and Table 3 reports samples size and sample proportion of smooth morphs for the assemblages discussed.

For all carbonized assemblages, the number of achenes with observable pericarp texture (Analysis 2) was greater than the number that were well-preserved enough to include in the photosample for morphometric analysis (Analysis 1), so both sample sizes are reported in Table 3.

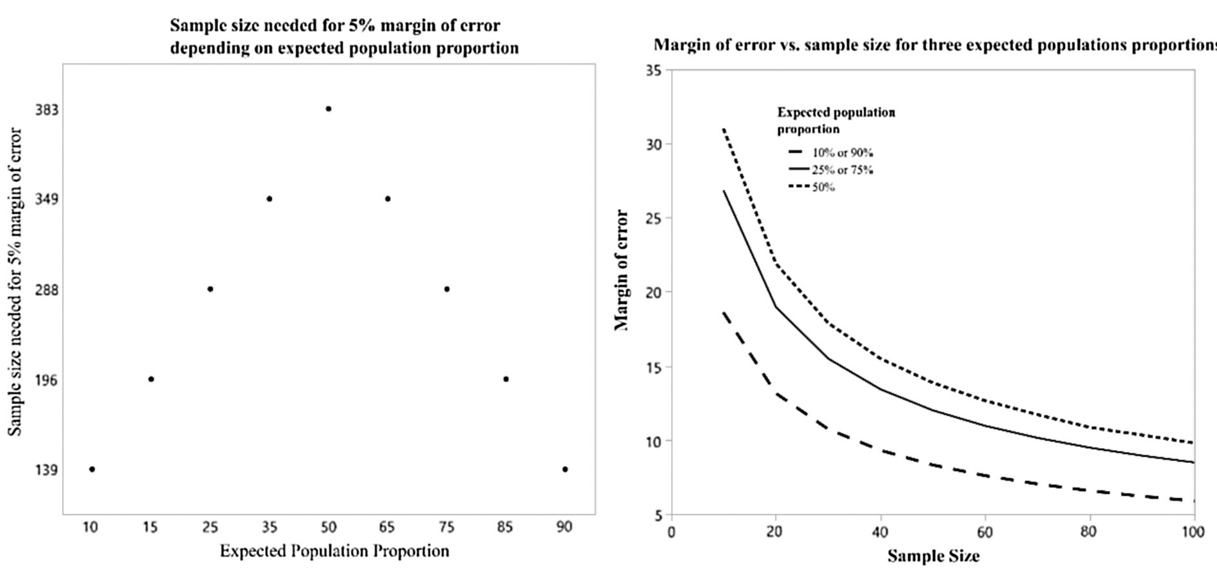

Fig. 3. These two charts are visualizations of the probabilistic relationship between population proportion and sample size. For both graphs, confidence is set at 95%. Left: It is more difficult to estimate population proportion accurately from a sample the closer the population proportion is to 50/50. If the true population proportion is skewed towards one or the other type (90% or 10% in this chart), it is relatively easy to estimate. Right: Since the ideal sampling conditions cannot always be met, the graph on the right shows the margins of error for different sample sizes given different true population proportions (which are unknown for archaeological assemblages) again with 95% confidence. The maximum population proportion of smooth morphs observed in modern wild populations is 72%, so the 75% line represents a hypothetical ancient population that is only slightly outside of the norm. *Example:* The Walker-Noe assemblage had 40 achenes with observable pericarp texture (Table 3). Since the true population proportion is unknown, the margin of error is also unknown. Could the Walker-Noe sample have been drawn from a population with a normal proportion of smooth morphs, ~75%? Fig. 3 shows that the margin of error for such a population at a sample size of 40 is ~15%, meaning that the highest proportion of smooth morphs expected for a sample of that size from a normal population is 90%. Thus we can be confident that the Walker-Noe sample is drawn from a population that is outside the range of natural variation for erect knotweed. It is important to reiterate, too, that smooth morphs are systematically under-represented in carbonized assemblages, so this conclusion is conservative.

3. The sites and sample contexts

3.1. Walker-Noe

Walker-Noe is located in central Kentucky on a tributary of Paint Lick Creek, which flows into the Kentucky River some 23 km north of the site. It is a large site complex (~50 hectares) that, on the basis of artifact scatters, was repeatedly occupied from the Paleoindian period through the Fort Ancient period and is likely made up of several discrete sites. The entire complex is characterized by a high density of debitage scatter. Its size and the longevity of occupation can probably be attributed to its importance as a quarry and lithic production site: both Boyle and Crab Orchard chert outcrop on-site. In addition to quarrying, production may have occurred at Walker-Noe. At the nearby Peter Village site, a lack of debitage suggests that the finished Boyle chert points recovered there were produced elsewhere – perhaps at Walker-Noe (Clay, 1987).

The Kentucky Archaeology Survey carried out a 42 m^2 excavation at Walker-Noe in 2000, after the landowner unearthed a concentration of calcined bone while plowing part of the site (Pollack et al., 2005). The excavation focused on a small mound with a diameter of about 10 m and a height of 30–40 cm. Characteristic Adena Plain pottery and Adena points were recovered, but unlike the typical Adena mound in the Kentucky Bluegrass region, Walker-Noe is not accretionary, lacks a log crypt or any extended burials, and does not cap any discernable submound structure. Instead, this mound covered between 17 and 40 human cremations, including infants, adolescents, and adults (Herrmann et al., 2014). Both fleshed and defleshed individuals were cremated, indicating a mixture of primary and secondary interments. These remains are associated with a large area of burned red clay loam and fire-cracked dolostone (a sedimentary rock that outcrops on site). The only other feature beneath the mound was an anomalous pit, also filled with densely packed burned dolostone. The pit contained very little wood charcoal and trace amounts of hickory nut shell, indicating that it was probably not used for preparing plant foods (Rossen, 2002). The three dates from these deposits indicate that the burning episode occurred between 50 BC and 70 AD, and their concordance suggests that the cremations and the mound could represent a single event (Table 3, Pollack et al., 2005). Because the contexts of the two samples from Walker-Noe are continuous and both have been directly dated to the same period, I treat them as a single sample for both analyses. The burials were accompanied by abundant plant food remains. Recovered seeds include goosefoot (n = 161), sunflower (n = 15), sumpweed (n = 3), and erect knotweed (n = 225, this total includes both achenes and kernels), as well as the seeds of fruits, and nutshell fragments, all of which were recovered from the central feature or other cremation burials beneath the mound (Pollack et al., 2005:71-72; Rossen, 2002).

3.2. Smiling Dan

Smiling Dan presents a unique opportunity to examine the development (or lack thereof) of one household's cultivated erect knotweed over a period of a few hundred years during the Middle Woodland period in western Illinois – a region that was already becoming the heartland of erect knotweed cultivation by that time (Asch and Asch, 1985c; Simon and Parker, 2006). Smiling Dan is located on the floodplain of Campbell Creek, a small stream that drains the uplands east of the Illinois River. The site is bisected by what was during the Middle Woodland an even smaller intermittent stream, and sprawls onto the floodplain of Campbell Creek and the adjacent bluff slopes (Stafford and Sant, 1985:87). Middle Woodland deposits range in thickness from a 30 to 60 cm layer over most of the site, to a 2 m deep midden within the old stream channel. Six dates were obtained by the excavators of the site from well-defined Middle Woodland contexts. These suggest a Middle Woodland occupation of ~200 years, from 125 to 400 AD (Hajic, 1985:49). I obtained new dates for the two analyzed assemblages that were most clearly associated with structures (Table 3). The calibrated 95% confidence spreads from the two structures overlap very slightly, supporting the excavators' impression that they represent sequentially occupied houses (Stafford and Sant, 1985:449). The Middle Woodland Smiling Dan homestead consists of three small houses and their associated pits and middens. It was subject to a very thorough botanical analysis for such a small site, with 12,000 l of sediment floated and analyzed (Asch and Asch 1985a:344). This sampling effort yielded a richly detailed portrait of Middle Woodland agriculture in the Lower Illinois Valley. Not surprisingly given the richness of the assemblage, Smiling Dan also provides the largest assemblage of Middle Woodland erect knotweed in this analysis by far, with a total of 103 achenes in the photosample. But these come from six distinct contexts (Table 3). I consider these both as a single sample and as individual samples below.

3.3. Meridian Hills

Meridian Hills was a Middle Woodland site 1.3 km east of the bluff edge of the northern American Bottom at the headwaters of an intermittent stream running west into Cahokia Creek. It was destroyed by development in 1984. A salvage excavation was carried out by a local amateur archaeologist, Robert A. Williams, who documented 72 features – mostly pits, with remnants of midden and three post holes. It is likely that many more features, including the remains of any Middle Woodland structures, were destroyed by grading before excavations began (Williams, 1993). Feature 55 yielded the analyzed erect knotweed assemblage: it was an 80 cm diameter pit that was 40 cm deep when excavated (Williams et al., 1988). The site was dated using diagnostic ceramics to the American Bottom Holding Phase, named for the nearby floodplain village of the same name. This is consistent with the date I obtained for the analyzed erect knotweed, 130–237 AD, which also indicates that the occupation of Meridian Hills was contemporaneous with at least the earlier part of the occupation of Smiling Dan, some 100 km to the north. Both western Illinois assemblages were deposited somewhat later than the Walker-Noe assemblage (Table 3). The botanical remains recovered from the Meridian Hills site were typical of Middle Woodland farming communities in the region in terms of their diversity and abundance.

4. Results

4.1. Walker-Noe

The morphology of the Walker-Noe erect knotweed is as extraordinary as its context. Fig. 4 illustrates that while the Walker-Noe smooth morphs are not as large on average as those from the type population for *P. erectum* ssp. *watsoniae* (Whitney Bluff), they are significantly larger than modern erect knotweed. The Walker-Noe assemblage falls squarely in between these two reference populations, and the differences are highly significant ($p = < 0.0001$ for both comparisons). The Walker-Noe assemblage also displays the second aspect of the domestication syndrome: reduction in achene dimorphism. A total of 40 achenes had enough pericarp preserved to observe texture. Of these, 98%, were smooth morphs (this total includes the photosample, of which 9 out of 10 were smooth morphs). Assuming that all of the submound achenes come from the same population, this sample proportion is distinguishable from the observed modern erect knotweed harvest proportion maximum of 72% (see Fig. 3). The Walker-Noe assemblage exhibits intermediate forms of both aspects of the domestication syndrome that characterizes later Mississippian assemblages, such as Whitney Bluff.

4.2. Smiling Dan

The Smiling Dan erect knotweed is very similar to the modern

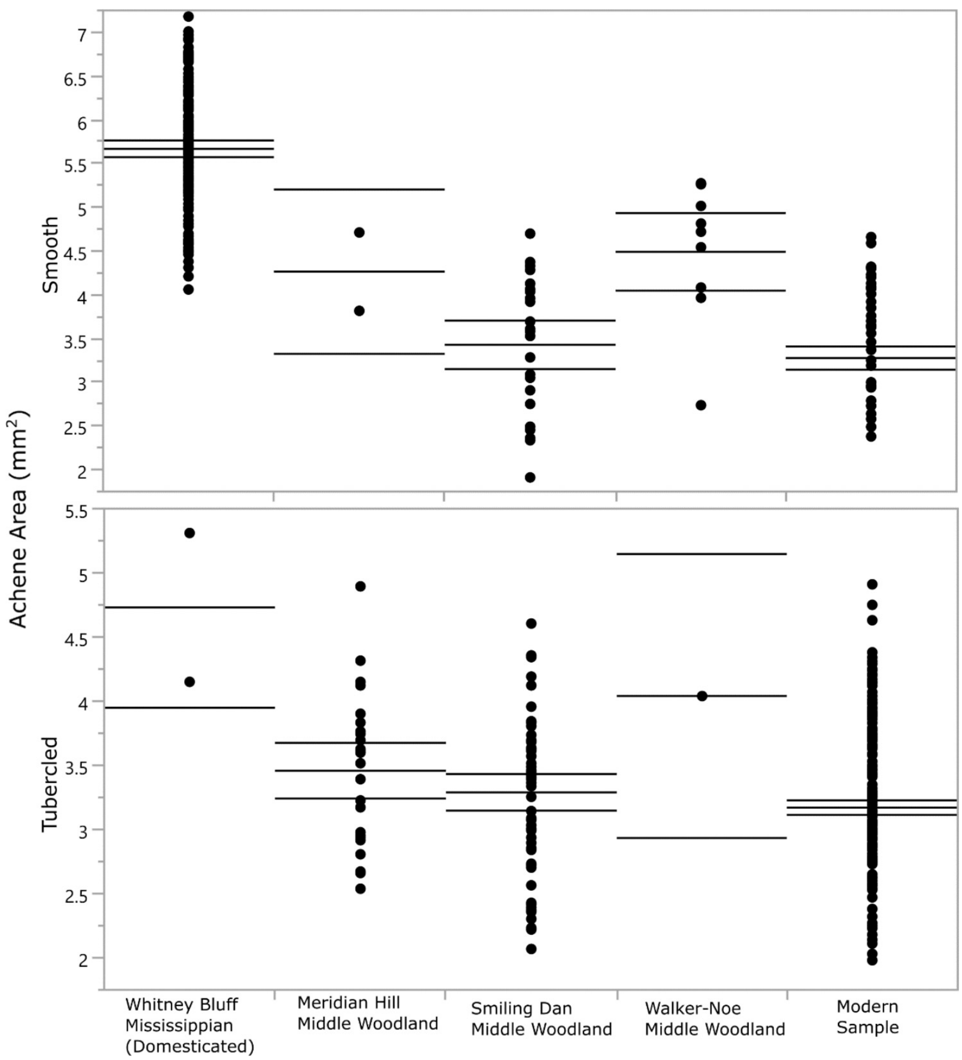

Fig. 4. This chart shows the distribution of size measurements for the assemblages included in this analysis. Each dot represented the area (mm^2) of a photograph of an achene taken in a standard orientation (see Section 2). The lines represent the mean and confidence interval of the mean for each sample.

comparative sample (Table 3, Fig. 4). While Smiling Dan smooth and tubercled morphs are on average slightly larger than those of modern populations, they are statistically indistinguishable, and none of the individual samples has a percentage of smooth morphs higher than 50%.

Smiling Dan is the only site in this study for which I have analyzed more than one large concentration of erect knotweed, and it provides an opportunity for intra-site comparison. There are slight differences in terms of fruit size between the individual photosamples from Smiling Dan. While the assemblage as a whole is statistically indistinguishable in terms of achene size from the modern comparative population, the sample from F164 has significantly larger achenes than the modern population and the other Smiling Dan samples ($p < 0.0001$). With no direct date it is impossible to say if this assemblage is later than the others, but it may represent the first small effects of human mediated selection on erect knotweed in the Lower Illinois Valley. Further morphometric analysis and more extensive dating will be necessary to test this hypothesis.

4.3. Meridian Hills

Twenty-nine out of 31 achenes with observable pericarps were tubercled morphs – a very high proportion of tubercled morphs even for a wild population. Given the small sample size and the fact that carbonization biases against the preservation of smooth morphs, this population proportion may be partially attributed to sampling error and preservation bias, but it may also represent early plastic responses to a sunnier, less crowded growth environment (Mueller, 2017b; 2017c). Although most are tubercled morphs, the Meridian Hills achenes *are* significantly larger than the modern sample ($p < 0.0001$), thus exhibiting the beginnings of one part of the domestication syndrome.

5. Discussion

5.1. The location, timing, and dynamics of erect knotweed domestication

Erect knotweed cultivation may have begun in western Illinois during the Late Archaic, although the small numbers of seeds recovered from this era may also represent incidental burning of a plant that tends to colonize the trampled earth of camps and pathways (Asch and Asch, 1985c; Simon and Parker, 2006). There is a much stronger case for cultivation in the Early Woodland era, especially on the eastern margin of the core area. Assemblages from rockshelters on the Cumberland Plateau (Gremillion, 1993b; 1998; 2004) are unlikely to be the result of accidental burning of a weedy camp followers, because erect knotweed does not naturally occur in such high and dry locations (Murray and Sheehan, 1984; Asch and Asch, 1985c; Mueller, 2017c). It is also clear from paleofecal specimens that Early Woodland people on the eastern margin of the core area were consuming erect knotweed (Faulkner, 1991). On the southwestern margin of the core area, the Ozark Escarpment, people were evidently experimenting with one or more members of the closely related genus *Periscaria*, the smartweeds, based on the assemblage from Marble Bluff, AR (Mueller, 2017e), but there is no evidence from those rockshelters that they were also harvesting erect knotweed at this time.

If casual gathering of erect knotweed began in the major river valleys of the core area during the Terminal Archaic, and moved into the highlands when populations abandoned the major floodplains during the Early Woodland (Kidder, 2006), this may have been a significant moment in the evolution of domesticated erect knotweed. The fruit dimorphism exhibited by wild erect knotweed is a form of evolutionary bet-hedging (Mueller, 2017b; 2017c). Organisms that are evolutionary bet-hedgers exhibit strategies that do not maximize the survival of their offspring within a single generation, but which instead tend to reduce variation in survival rates over many generations. In the case of erect knotweed, most of its tubercled morphs do not germinate the spring after they are produced, which means that they are subject to an entire year of potential predation and pathogen risks before they germinate. Once they do germinate, they also grow more slowly than seedlings sprung from smooth morphs, meaning that they are less competitive in the dog-eat-dog world of a seasonally scoured river bank, where dozens of different weedy species compete for light and space. Smooth morph germination rates are much higher, sometimes 100% (Mueller, 2017c). In short, a mother plant that uses resources producing tubercled morphs that could otherwise be used to produce smooth morphs is not maximizing its fitness for the next generation – so why has the production of tubercled morphs evolved, and how is it maintained?

The specific source of strong selective pressure suggested by my observations is the unpredictability of flooding from year to year. When floods occur in the early spring, they are probably beneficial to populations of erect knotweed because they clear the riverbank and deposit soil nutrients (Smith, 1992). Robust erect knotweed plants can also survive fall floods – although they probably lose some of their immature seeds to such events. But floods that occur in the early summer can eliminate an entire generation of erect knotweed plants (Mueller, 2017c). When this occurs, the near-100% germination rate of smooth morphs is a liability that could lead to localized extinctions. Tubercled morphs allow the population to regenerate the following year, because they are able to weather bad years, remaining in the soil seedbank when conditions improve. In order for this protective fruit dimorphism to be eliminated under cultivation, I have hypothesized that farmers were protecting populations of erect knotweed from the effects of unpredictable flooding, both by creating clearings for erect knotweed seedlings in micro-topographic zones that rarely or never flood and by storing seed stock, which provided an alternative to the soil seed bank (Table 1).

A combination of several lines of evidence suggests that this process began during the Early Woodland period. First, many communities evidently abandoned the floodplains in several regions of eastern North America to escape the effects of unpredictable and/or severe floods (Kidder, 2006). It is clear that they took their floodplain adapted crops, including erect knotweed, with them, because we find the cached seeds of these plants in upland rockshelters both in the Ozarks and western Appalachia (Fritz, 1986; Gremillion, 1993b), and they have recently also been recovered from a Late Archaic site in the mixed Appalachian forest zone of southeastern Ohio (Patton and Curran, 2016). There are floodplains in the uplands, albeit narrower ones, and people may have used a variety of micro-topographic zones to grow their crops. Uplands is also a relative term – there are uplands near the major river valleys: zones that are protected from flooding by relatively small differences in altitude. But during the Early Woodland, there is also evidence for the clearance of forests (Delcourt et al., 1998), and naturally forested terraces offer low slopes and fertile soils that could have been turned into productive gardens (Gremillion et al., 2008). Perhaps these Early Woodland refugees of severe flooding in the major river valleys were the first EAC farmers to recognize the importance of altitudinal diversity in field placement. It was probably more work to clear terrace forests for cultivation than to it was to grow crops along the annually scoured riverbanks (Smith, 1992), but it may also have been critical for maintaining food security during a period of climate change. By cultivating erect knotweed in newly cleared gardens where flooding never occurred, as well as by saving seeds in rockshelters, Early Woodland farmers would have relaxed the selective pressures that maintain fruit dimorphism as a bet-hedging strategy in wild erect knotweed.

Direct evidence in support of this scenario comes from the comparison of erect knotweed assemblages presented here. Walker-Noe, the earliest Middle Woodland assemblage analyzed, and the closest to western Appalachia, is also the earliest assemblage to exhibit the full domestication syndrome of erect knotweed – increase in fruit size and decrease in fruit dimorphism – hundreds of years before such a landrace was developed in the major river valleys of western Illinois.

5.2. The spread of agricultural knowledge and practice

Beginning around 3000 year ago, and intensifying throughout the last millennium BC, several lines of evidence indicate that communities along the western Appalachian front developed novel agricultural techniques. First, there is dramatically increased evidence for the storage of crop seeds in caves and rockshelters at this time. At Cold Oak rockshelter, KY, both the percentage of crop seeds in the assemblage and their overall abundance increase markedly around 3000 years ago (Gremillion, 1993b; 1998; 2004). Concurrently, there is direct evidence that people were consuming the seeds of EAC lost crops from human paleofeces recovered from dry caves, such as Mammoth Cave, KY (Gremillion and Sobolik, 1996; Yarnell, 1969), and Big Bone Cave, TN (Faulkner, 1991). Analyses of pollen and charcoal from Patton Bog, OH, Cliff Palace Pond, KY, and the Little Tennessee River, TN all agree that there was a clear change in forest composition along the western Appalachian edge of the core area from 1000 to 800 BC. Forests were cleared, and fire tolerant species became better represented in pollen cores, while the pollen of fire intolerant species became rare (Abrams et al., 2014; Delcourt et al., 1986; Delcourt et al., 1998; Delcourt and Delcourt, 2004). By the end of the Early Woodland period, a shift to a greater reliance on cultivated annual grains is also evident at open sites on the western Appalachian front (Rossen, 1999).

All of these developments were directly followed by the appearance of a distinct Middle Woodland botanical assemblage in the two regions compared in this analysis (western Illinois and the Middle Ohio valley). Fire-loving hazelnuts are one hallmark of this diverse emerging Woodland agroecosystem. People were still growing all of the crops that were domesticated during the Late Archaic (sunflower, sumpweed, squashes, and goosefoot), but the starchy seed complex (erect knotweed, little barley, goosefoot, and maygrass) had become much more abundant. Caches or large concentrations of EAC seeds in pits that were rarely seen at earlier open sites, and a diverse array of nutshells, fruit seeds, and sometimes even the elusive remains of root crops are recovered from Middle Woodland sites in both regions (Asch and Asch, 1985c; Johannessen, 1988; Simon and Parker, 2006; Wymer, 1993, 1996, 2009, 2017; Wymer and Abrams, 2003).

The Smiling Dan and Meridian Hills assemblages are both at least a century later than the assemblage from Walker-Noe, and they come from a region where erect knotweed cultivation was the most intense and of the greatest duration. Contrary to expectations, then, these two assemblages show only the beginnings of a domesticated morphology, whereas the Walker-Noe assemblage is fully domesticated. There is another important difference to consider between the western Illinois populations and the Walker-Noe population. The Smiling Dan and Meridian Hills assemblages come from pits at habitation sites, and likely represent the accidental burning of erect knotweed fruits as they were processed or cooked. If so, they are a random subset of all erect knotweed achenes harvested by the community. But the Walker-Noe assemblage was deliberately interred with human burials and then capped with a mound, just like the various other classes of artifacts that inform archaeological theories about Adena/Hopewell interaction spheres. Perhaps it is time to consider the possibility that *high quality seed stock* was a prestige good and exchange item on par with exotic materials or iconographically rich pottery and pipes used to infer social roles and organization (Carr, 2008). Such an investigation might also make more space to imagine the role of women in Adena/Hopewell ceremonialism and exchange, since it is likely that women were the keepers of seeds (Watson and Kennedy, 1991; Mueller and Fritz, 2016).

5.2.1. Previous research on botanical assemblages from Adena/Hopewell ritual contexts

Many Adena/Hopewell habitation botanical assemblages have been analyzed from the LIV (Asch and Asch, 1985a; Calentine, 2005; Mueller, 2013), the American Bottom (Johannessen (1988); Simon and Parker, 2006), the Middle Ohio River's northern tributaries in Ohio (Wymer, 1993; 1996, 2017; Wymer and Abrams, 2003), and southern tributaries in Kentucky (Bonzani, 2005; Lopinot, 1988; Rossen, 2006). Analysis of assemblages from clearly ritual contexts has been rarer, but that is beginning to change.

One of the earliest analyses comes from the Edwin Harness mound excavations within the Liberty earthworks in Ross County, OH (Smart and Ford, 1983). Two maize kernels recovered there have long been considered among the earliest evidence of maize cultivation in eastern North America. Simon (2017) has recently called into question early dates on maize macroremains by showing that all of the Middle and early Late Woodland maize from the American Bottom is either not maize or not accurately dated. Both maize kernels from Edwin Harness were directly dated to c. AD 300 (Crawford et al., 1997), but their identification as maize was not corroborated by isotope analysis. If they were correctly identified, the early presence of this exotic crop at a site of Adena/Hopewell ritual gathering lends support to the hypothesis that these networks were implicated in the spread of new agricultural techniques and materials. Along with these enigmatic kernels, a total of at least 31 goosefoot seeds and 29 "knotweed" seeds (probably erect knotweed) were recovered from an unknown volume of flotation samples. Some came from the floor and a pit associated with the sub-mound "Big House." The bundled burial of a 19–22 year woman (Feature 60) was associated with a great variety of different kinds of wood charcoal, one of the two maize kernels from the site, at least four goosefoot seeds, and at least 16 "knotweed" seeds (Belovich, 1983; Smart and Ford, 1983).

Another point of comparison comes from an analysis of archived samples collected at Seip Earthworks (Wymer, 2009). Most of the recovered seeds, including goosefoot and single erect knotweed and little barley seeds, come from the fill of a large post mold located within the earthwork, but of uncertain association. Flotation samples were also taken from a large pit containing fire-cracked rock, similar to the sub-mound pit at Walker-Noe. Like the Walker-Noe pit, this one did not contain any seeds, but did contain abundant wood charcoal. Wymer (2017) has also recently analyzed 143 l of flotation samples from the Datum H "ceremonial encampment" area of the Hopewell Mound group. These come from a diverse range of contexts including pits, earthovens, post molds, and a possible midden. The contextual diversity of this assemblage is unprecedented for a Hopewell mound or earthwork in Ohio, and has likewise yielded an uncommonly rich botanical assemblage, with a density of seeds similar to that of habitation sites. These assemblages, along with her analyses of assemblages from Hopeton, Liberty, and Capitolium, contribute to Wymer's (2009) general impression of botanical assemblages from mounds and earthworks in Ohio: "Unlike Hopewell habitation sites, there appears to be less consistency in what plant materials have been found in ceremonial/ritual contexts… unusual plants, or caches of specific species, have been noteworthy in a number of well-documented ceremonial contexts."

In Kentucky, there are also several points of comparison. My own recent analysis of 94 l taken from an interior sheet midden, post molds, and the encircling ditch of the Winchester Farms earthwork in Fayette County, KY (Jefferies et al., 2013) yielded only three seeds – a remarkably low seed density compared to either habitation or mound/earthwork assemblages in general. At the Evans site in Montgomery County, 270 l of soil yielded a substantially richer assemblage. The seeds of maygrass, goosefoot, and sunflower were recovered, a few of which were associated with human cremations (Rossen, 2016). At Amburgey, also in Montgomery County, Feature 2 contained a tetrapodal vessel, two copper ear spools, debitage, and the seeds of goosefoot, squash and several other plants. This unusual assemblage of artifacts was interpreted as a ritual cache (Richmond and Kerr, 2005).

Walker-Noe, Edwin Harness, and Evans provide evidence that seeds were sometimes among the objects included in burials and mortuary rituals. It is intriguing that the person buried with crop seeds at Edwin Harness was a woman, given the likely leadership of women in all matters agricultural. However, it is impossible to say how common this practice was because the vast majority of mortuary excavations were carried out before it was commonplace to take flotation samples from such contexts. In general, the idiosyncrasy in the mound/earthwork assemblages from the Middle Ohio Valley, contrasting with relative uniformity in habitation site assemblages, is also found in the LIV during this period (Mueller, 2013).

The same communities who lived in Middle Woodland houses also built and visited Adena/Hopewell mounds and earthworks, but they clearly weren't doing the same things with plants at these sites as they were at their houses. This is hardly surprising, given the complex acts of ritual, remembering, and negotiation that occurred at these sites (Henry, 2017). Most Adena/Hopewell researchers work from the premise that mounds and earthworks were places on the landscape where people from different households and communities periodically came together, making the integration of societies at multiple scales one key component of the Adena/Hopewell phenomenon (Abrams, 2009; Buikstra and Charles, 1999; Carr 2008; Ruby et al., 2005; Seeman and Branch, 2006). How might this phenomenon be related to the adoption and spread of new crops and agricultural techniques during the same era? The following discussion is not meant to present conclusions, but rather to generate hypotheses and further research on plant remains from Adena/Hopewell ritual contexts and similar sites in other regions.

5.2.2. Insights from ethnography and sociology

Contemporary farmers are dealing with the pressures and the opportunities of global exchange networks and capitalism very different from those faced by early food producing communities, but studies of contemporary farmer networks can still provide some basic insights into how seeds and information flow between farmers. Seeds are *the* fundamental agricultural input, along with the farmers themselves. Small scale farmers rely on various kinds of networks to make sure that they always have access to seeds. Informal seed networks often map onto other exchange networks and institutions that exist to facilitate communal labor (Stromberg et al., 2010) – such as those needed to build mounds and earthworks and obtain the exotic materials interred there. Another consistent factor that falls out of many different ethnographies is that people procure seed from individuals who they trust, and who are members of their own perceived community or social network (Badstue et al., 2006; Kiptot et al., 2006; McGuire, 2008; Misiko, 2010). For example, Perales et al. (2005) investigated the relationship between landraces and ethnolinguistic groups in Chiapas, Mexico. The authors found that distinct maize landraces were maintained by neighboring ethnolinguistic groups, even though one variety had consistently higher yields. The lower yielding landrace was maintained partly because it was a marker of social identity, but more importantly because farmers obtained both and seed an information about how to grow it *only* from trusted members of their own social group. Both information and seeds flow unevenly between members of a multiethnic society.

It is also possible to draw on the theory of diffusion of innovations (Rogers, 2003) to understand how the spread of seeds and knowledge may have been related to ritualized exchange networks. The theory of the diffusion of innovations is rooted in rural sociology, and its progenitors developed the key tenets of this theory working among American farmers in the 1940s and 1950s. Diffusion studies have since branched out into many different settings and kinds of innovations, and generally have shown that:

(1) The rate of adoption of a new technology or idea is S-shaped, with innovators and early adopters being key individuals in the successful adoption of a new practice or idea.
(2) People seldom adopt a new innovation unless they are able to discuss it with individuals within their social network.
(3) Innovators and early adopters tend to be cosmopolitan and are often economic elites.

There were almost certainly *cosmopolitan people* in Early and Middle Woodland eastern North America: those who traveled widely to create the continent wide trade networks that provided people with copper, marine shell, obsidian, and mica, among other materials (DeBoer, 2004; Emerson et al., 2005; Lepper, 2006; Wright and Loveland, 2015), and, at least between western Illinois and the Scioto valley, the movement of people is also supported by ancient mtDNA analysis (Bolnick and Smith, 2007). These cosmopolitan individuals in general may have been both men and women, but we know that historically women were responsible for skilled agricultural labor and seed selection among Indigenous eastern North Americans, so for this scenario it is more plausible to imagine a woman. She may have been the person who first told distant communities about the agricultural innovations of her community – new techniques that had emerged on the western Appalachian front around 1000 BC. Diffusion studies indicate that, even if her crop varieties and methods were consistently more productive or less risky, she is only likely to have convinced a small percentage of any given community to adopt them – these people are called early adopters.

When new technologies or practices are adopted by an entire community, the process often starts with the biased cultural transmission of knowledge from high status early adopters to the rest of society through social emulation (Henrich, 2001). When people chose which members of society to emulate, their choices may reflect their perception of the model's skill or success in a given domain, not high status *per se* (Henrich and Gil-White, 2001; Henrich and Broesch, 2011). High status in Adena/Hopewell societies in some places may have been ascribed (from birth) (Cook, 1981), but most lines of bioarchaeological evidence do not support this scenario (Bolnick and Smith, 2007; Buikstra, 1976). Situational leadership and a fluid tribal organization are suggested by the variability of the ritual landscape in the Kentucky Bluegrass region (Henry, 2013). The unique features of the Walker-Noe mound and artifact assemblage, on the southern edge of this region, are an apt example. In the Scioto Valley, Carr (2008) has used mortuary analysis to identify clans and sodalities that were present from the beginning of the Middle Woodland period, and grew in size and complexity throughout the period. All of these lines of evidence paint a picture of a society in which there were differences in rank, but also a malleable social structure that responded to displays of skill, wisdom, or worldliness from individuals.

High status in these societies was almost certainly connected to another general characteristic of early adopters and influencers: they have larger social networks and a greater frequency of social interaction than do late adopters. As Henrich points out, "Large social networks and high status may have nothing to do with an individual's chances of innovating, but they may be critical to the subsequent transmission of these traits. When poor, low-status individuals innovate, no one copies them…"(2001:1010). The words poor and rich are likely not appropriate descriptors for any members of Middle Woodland society, but there were differences in social status and (even more so) in the size of social networks, which allowed some individuals to influence more people than others. Early adopters have more frequent and predicable exposure to "change agents," a cosmopolitan traveler in the Adena/Hopewell case (Rogers, 2003). The cyclical rituals that Adena/Hopewell sites represent would have provided stability for networks of innovators and early adopters. Henry and Barrier (2016:103), after a close reading of the Wright Mound burials, argue that they represent a society "in which interaction – and evaluation – was based upon regular face-to-face interactions in and apart from ritual settings…those buried in the mound were individuals who were valued within their networks…" With reference to neither the ethnography of seed networks nor the theory of diffusion of innovations, they have nonetheless perfectly described the individuals and circumstances that most readily facilitate the adoption of new agricultural practices: individuals with large and varied social networks who can demonstrate their innovative practices via regular face-to-face interactions. The multi-scalar nature of Adena/Hopewell interaction would have allowed early adopters to receive information and material from cosmopolitan change agents, and then to repeatedly model new techniques and crops to the more recalcitrant, isolated, or conservative members of their network. How might we see this in the archaeological record? One possibility is that new domesticated varieties would appear first in association with the innovators and early adopters themselves – that is, in burials and other contexts at mounds and earthworks.

6. Conclusions

Several lines of evidence indicate that communities on the eastern margin of the core area began to make more use of uplands during the last millennium BC, that they burned forests in order to move their gardens and fields out of naturally disturbed environments into what would otherwise have been stable forest ecosystems, and that many communities either adopted new crops or intensified their cultivation of old ones, ultimately culminating in the distinctive botanical assemblages recovered from Middle Woodland houses in western Illinois and the Middle Ohio valley. Using the ethnography of seed networks and the theory of diffusion of innovations, I have argued that Adena/Hopewell networks facilitated the adoption of new practices and crops and the consolidation of agricultural knowledge during this period. To determine how widespread the early domesticated landrace of erect knotweed from Walker-Noe was, more morphometric analyses of other Middle Woodland assemblages from the Ohio valley are needed. This assemblage provides preliminary evidence for a scenario in which multi-scalar Adena/Hopewell exchange networks, anchored as they were to monumental landscapes and various kinds of performance and negotiation by prestigious individuals, facilitated the exchange of superior seed stock and agricultural knowledge between communities. The ethnography and sociology of farmers in the modern era suggest that similar networks and institutions in other times and places would also have facilitated the rapid spread of new crops and techniques between communities.

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Conflict of interest

The author declares that she has no conflict of interest.

References

Abrams, Elliot M., 2009. Hopewell archaeology: a view from the northern woodlands. J. Archaeol. Res. 17 (2), 169–204.

Abrams, Elliot M., Freter, AnnCorinne, Stefanova, Vania, 2014. Environmental change since the Woodland period in the mid-Ohio valley: results from Patton bog sediment core palynological analyses. Midcontinental J. Archaeol. 39 (2), 163–178.

Asch, David L., Asch, Nancy B., 1985a. Archaeobotany. In: Stafford, Barbara D., Sant, Mark B. (Eds.), Smiling Dan: Structure and Function at a Middle Woodland Settlement in the Lower Illinois River Valley. Center for American Archaeology, Kampsville, IL, pp. 327–400.

Asch, David L., Asch, Nancy B., 1985b. Archaeobotany. In: Conner, Michael D., (Ed.), The Hill Creek Homestead and the Late Mississippian Settlement in the Lower Illinois River Valley. Kampsville Archaeological Center. vol. 1. The Center for American Archaeology, Kampsville, IL. pp. 115–170.

Asch, David L., Asch, Nancy B., 1985c. Prehistoric plant cultivation in west central Illinois. In: Ford, Richard I., (Ed.), Prehistoric Food Production in North America. Anthropological Papers. vol. 75. Museum of Anthropology, University of Michigan, Ann Arbor, MI. pp. 149–203.

Badstue, Lone B., Bellon, Mauricio R., Berthaud, Julien, Juàrez, Xóchitl, Rosas, Irma Manuel, Solano, Ana María, Ramírez, Alejandro, 2006. Examining the role of collective action in an informal seed system: a case study from the central valleys of Oaxaca Mexico. Human Ecol. 34 (2), 249–273.

Belovich, Stephanie J., 1983. Analysis of human skeletal material: Cleveland museum of natural history collections. In: Greber, N'omi, (Ed.), Recent Excavations at the Edwin Harness Mound, Liberty Works, Ross County, Ohio. MCJA Special Paper No. 5. The Cleveland Museum of Natural History, Cleveland, IL. p. 62.

Bolnick, Deborah A., Smith, David Glenn, 2007. Migration and social structure among the Hopewell: evidence from ancient DNA. Am. Antiq. 72 (4), 627–644.

Bonzani, Rene, 2005. Recovered economic remains: botanical analysis. In: Hall, Christopher T. (Ed.), Phase III Archaeological Investigations at the Hayes Site (15Cl67), Carroll County, Kentucky. Cultural Resource Analysts Inc, Lexington, KY.

Buikstra, Jane E., 1976. Hopewell in the Lower Illinois Valley: A Regional Study of Human Biological Variability and Prehistoric Mortuary Behavior. Northwestern University Archaeological Program Scientific Papers No. 2, Evanston, IL.

Buikstra, Jane E., Charles, Douglas K., 1999. Centering the ancestors: cemeteries, mounds, and sacred landscapes of the ancient North American Midcontinent. In: Ashmore, Wendy, Bernard Knapp, A., (Eds.), Archaeologies of Landscape Contemporary Perspectives. Blackwell Publishers, London. pp. 201–228.

Calentine, Leighann, 2005. The Spoon Toe Site (11MG179): Middle Woodland Gardening in the Lower Illinois River Valley. Masters Thesis, Department of Anthropology, University of Missouri, Columbia, MO.

Carr, Christopher, 2008. Social and ritual organization. In: The Scioto Hopewell and Their Neighbors: Bioarchaeological Documentation and Cultural Understanding. Springer, New York, pp. 151–288.

Clay, R. Berle, 1987. Circles and ovals: two types of Adena space. Southeastern Archaeol. 6 (1), 46–56.

Cook, Della C., 1981. Mortality, age-structure and status in the interpretation of stress indicators in prehistoric skeletons: a dental example. In: Chapman, Robert, Kinnes, Ian, Randsborg, Klavs (Eds.), The Archaeology of Death. Cambridge University Press, London, pp. 133–144.

Costea, Mihai, Tardif, François J., Hinds, Harold H., 2005. Polygonum L. In: Flora of North America Editorial Committee (Ed.), Flora of North America North of Mexico, vol. 5. eFloras.org, New York and Oxford.

Cowan, C. Wesley, Smith, Bruce D., 1993. New Perspectives on a Wild Gourd in Eastern North America. J. Ethnobiol. 13, 17–54.

Crawford, Gary W., Smith, David G., Bowyer, Vandy E., 1997. Dating the entry of corn (*Zea mays*) into the lower great lakes region. Am. Antiq. 62 (1), 112–119.

DeBoer, Warren R., 2004. Little Bighorn on the Scioto: the Rocky Mountain connection to Ohio Hopewell. Am. Antiq. 69 (1), 85–108.

Delcourt, Paul A., Delcourt, Hazel R., 2004. Prehistoric Native Americans and Ecological Change: Human Ecosystems in Eastern North America since the Pleistocene. Cambridge University Press, Cambridge.

Delcourt, Paul A., Delcourt, Hazel R., Cridlebaugh, Patricia A., Chapman, Jefferson, 1986. Holocene ethnobotanical and paleoecological record of human impact on vegetation in the little Tennessee River valley, Tennessee. Quaternary Res. 25 (3), 330–349.

Delcourt, Paul A., Delcourt, Hazel R., Ison, Cecil R., Sharp, William E., Gremillion, Kristen J., 1998. Prehistoric human use of fire, the eastern agricultural complex, and Appalachian oak-chestnut forests: paleoecology of cliff palace pond Kentucky. Am. Antiquity 63 (2), 263–278.

Emerson, Thomas E., Hughes, Randall E., Farnsworth, Kenneth B., Wisseman, Sarah U., Hynes, Mary R., 2005. Tremper Mound, Hopewell catlinite, and PIMA technology. Midcontinental J. Archaeol. 30 (2), 189–216.

Faulkner, Charles T., 1991. Prehistoric diet and parasitic infection in Tennessee: evidence from the analysis of desiccated human paleofeces. Am. Antiq. 56 (4), 687–700.

Fritz, Gayle J., 1986. Prehistoric Ozark Agriculture: The University of Arkansas Rockshelter Collections. Dissertation, Anthropology, University of North Carolina, Chapel Hill.

Fritz, Gayle J., 1993. Early and middle woodland period paleoethnobotany. In: Margaret Scarry, C. (Ed.), Foraging and Farming in the Eastern Woodlands. University Press of Florida, Gainesville, pp. 39–56.

Fritz, Gayle J., 2014. Maygrass: its role and significance in native eastern North American. In: Minnis, Paul E. (Ed.), New Lives for Ancient and Extinct Crops. Universtiy of Arizona Press, Tuscon, AZ, pp. 12–43.

Fritz, Gayle J., Smith, Bruce D., 1988. Old collections and new technology: documenting the domestication of *Chenopodium* in Eastern North America. Midcontinental J. Archaeol. 13 (1), 3–27.

Fuller, Dorian Q., Willcox, George, Allaby, Robin G., 2011. Cultivation and domestication had multiple origins: arguments against the core area hypothesis for the origins of agriculture in the Near East. World Archaeol. 43 (4), 628–652.

Graham, Anna F., Adams, Karen R., Smith, Susan J., Murphy, Terrance M., 2017. A new record of domesticated little barley (*Hordeum pusillum* Nutt.) in Colorado: travel, trade, or independent domestication. Kiva: J. Southwestern Archaeol. 1–29.

Gremillion, Kristen J., 1993a. The evolution of seed morphology in domesticated *Chenopodium*: an archaeological case study. J. Ethnobiol. 13, 149–169.

Gremillion, Kristen J., 1993b. Plant husbandry at the archaic/woodland transition: evidence from the Cold Oak shelter, Kentucky. Midcontinental J. Archaeol.gy 18, 161–189.

Gremillion, Kristen J., 1998. Changing roles of wild and cultivated plant resources among early farmers of eastern Kentucky. Southeastern Archaeol. 17 (2), 140–157.

Gremillion, Kristen J., 2004. Seed processing and the origins of food production in eastern North America. Am. Antiq. 69 (2), 215–233.

Gremillion, Kristen J., Sobolik, Kristin D., 1996. Dietary variability among prehistoric forager-farmers of eastern North America. Curr. Anthropol. 37 (3), 529–539.

Gremillion, Kristen J., Windingstad, Jason, Sherwood, Sarah C., 2008. Forest opening, habitat use and food production on the Cumberland plateau, Kentucky: adaptive flexibility in marginal settings. Am. Antiq. 73 (3), 387–411.

Herrmann, Nicholas P., Devlin, Joanne L., Stanton, Jessica C., 2014. Bioarchaeological spatial analysis of the Walker-Noe crematory (15GD56). In: Osterholtz, Anna J., Baustian, Kathryn M., Martin, Debra L. (Eds.), Commingled and Disarticulated Human Remains: Working Toward Improved Theory, Method, and Data. Springer, New York, pp. 51–66.

Hajic, Edwin R., 1985. Geomorphological and stratigraphic investigations. In: Stafford, Barbara D., Sant, Mark B. (Eds.), Smiling Dan: Structure and Function at a Middle Woodlands Settlement in the Lower Illinois River Valley. Center for American Archaeology, Kampsville, IL, pp. 41–82.

Heiser, Charles B., 1954. Variation and subspeciation in the common sunflower. Helianthus Annuus. Am. Midland Naturalist 51 (1), 287–305.

Henrich, Joseph, 2001. Cultural transmission and the diffusion of innovations: adoption dynamics indicate that biased cultural transmission is the predominate force in behavioral change. Am. Anthropologist 103 (4), 992–1013.

Henrich, Joseph, Broesch, James, 2011. On the nature of cultural transmission networks: evidence from Fijian villages for adaptive learning biases. Philos. Trans. Roy. Soc. London B: Biol. Sci. 366 (1567), 1139–1148.

Henrich, Joseph, Gil-White, Francisco J., 2001. The evolution of prestige: freely conferred deference as a mechanism for enhancing the benefits of cultural transmission. Evol. Human Behavior 22 (3), 165–196.

Henry, Edward R., 2013. Working out Adena political organization and variation from the ritual landscape in the Kentucky Bluegrass. In: Early and Middle Woodland Landscapes of the Southeast. University Press of Florida, Gainseville, FL, pp. 219–236.

Henry, Edward R., 2017. Building bundles, building memories: processes of remembering in Adena-Hopewell societies of Eastern North America. J. Archaeol. Method Theory 24 (1), 188–228.

Henry, Edward R., Barrier, Casey R., 2016. The organization of dissonance in Adena-Hopewell societies of eastern North America. World Archaeol. 48 (1), 87–109.

Hunter, Andrea A., 1992. Utilization of *Hordeum pusillum* (Little Barley) in the Midwest United States: Applying Rindos' Co-evolutionary Model of Domestication. Dissertation, Anthropology, University of Missouri-Columbia, Columbia, MO.

Jefferies, Richard W., Milner, George R., Henry, Edward R., 2013. Winchester Farm: a small Adena enclosure in central Kentucky. In: Henry, E.R., Wright, A.P. (Eds.), Early and Middle Woodland Lanscapes of the Southeast. University Press of Florida, Gainesville, FL, pp. 91–107.

Johannessen, Sissel, 1988. Plant remains and culture change: are paleoethnobotanical data better than we think? In: Hastorf, C.A., Popper, V.S. (Eds.), Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Achaeological Plant Remains. University of Chicago Press, Chicago, pp. 145–166.

Kidder, Tristram R., 2006. Climate change and the Archaic to Woodland transition (3000–2500 cal BP) in the Mississippi River Basin. Am. Antiq. 71 (2), 195–231.

Kiptot, Evelyne, Franzel, Steven, Hebinck, Paul, Richards, Paul, 2006. Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. Agroforest. Syst. 68 (3), 167–179.

Kistler, Logan, Newsom, Lee A., Ryan, Timothy M., Clarke, Andrew C., Smith, Bruce D., Perry, George H., 2015. Gourds and squashes (*Cucurbita* spp.) adapted to megafaunal extinction and ecological anachronism through domestication. Proc. Natl. Acad. Sci. 112 (49), 15107–15112.

Lepper, Bradley T., 2006. The great Hopewell road and the role of the pilgrimage in the Hopewell interaction sphere. In: Charles, Douglas K., Buiksra, Jane E. (Eds.), Recreating Hopewell. University of Florida Press, Gainesville, pp. 122–133.

Lopinot, Neal H., 1988. Hansen site archaeobotany. In: Ahler, Steven R. (Ed.), Excavations at the Hansen Site (15Gp14) in Northeastern Kentucky. Program for Cultural Resource Assessment, University of Kentucky, Lexington, KY.

McGuire, Shawn J., 2008. Securing access to seed: social relations and sorghum seed exchange in Eastern Ethiopia. Human Ecol. 36 (2), 217–229.
Misiko, Michael, 2010. Indigenous Seed Institutions in Fragile Communities. Paper presented at the Innovations and Partnerships to Realize Africa's Rice Potential, Bamako, Mali.
Mueller, Natalie G., 2013. Mound Centers and Seed Security: A Comparative Analysis of Botanical Assemblages from Middle Woodland Sites in the Lower Illinois Valley. Springer Briefs in Plant Science, Springer, New York.
Mueller, Natalie G., 2017a. Carbonization, differential preservation, and sampling bias in domestication studies: an erect knotweed (*Polygonum erectum* L.) case study. J. Archaeolog. Sci.: Rep. 13, 303–311.
Mueller, Natalie G., 2017b. Documenting domestication in a lost crop (*Polygonum erectum* L.): evolutionary bet-hedgers under cultivation. Vegetation History Archaeobotany 26 (3), 313–327.
Mueller, Natalie G., 2017c. Evolutionary "Bet-Hedgers" under cultivation: investigating the domestication of erect knotweed (Polygonum erectum L.) using growth experiments. *Human Ecol.* 45(2) 189–203.
Mueller, Natalie G., 2017d. An extinct domesticated subspecies of erect knotweed in Eastern North America: *Polygonum erectum* L. ssp. *watsoniae* (POLYGONACEAE). *Novon* 25(2).
Mueller, Natalie G., 2017e, Seeds as artifacts of communities of practice: the domestication of erect knotweed in eastern North America. Dissertation, Anthropology, Washington Universtiy in St. Louis, Saint Louis, MO.
Mueller, Natalie G., Fritz, Gayle J., 2016. Women as symbols and actors in the Mississippi valley: evidence from female flint-clay statues and effigy vessels. In: Claassen, Cheryl (Ed.), Gendered Perceptions of Native American Landscapes. University of Tenessee Press, Knoxville, TN.
Murray, Priscilla M., Sheehan, Mark C., 1984. Pehistoric *Polygonum* use in the midwestern United States. In: Munson, Patrick J., (Ed.), Experiments and Observations on Aboriginal Wild Plant Food Utilization in Eastern North America. Prehistory Research Series. vol. VI. Indiana Historical Society, Indianapolis.
Patton, Paul E., Curran, Sabrina, 2016. Archaic period domesticated plants in the mid-Ohio valley: archaeobotanical remains from the County Home site (33at40), Southeastern Ohio. Midcontinental J. Archaeol. 41 (2), 127–158.
Perales, Hugo R., Benz, Bruce F., Brush, Stephen B., 2005. Maize diversity and ethnolinguistic diversity in Chiapas, Mexico. PNAS 102 (3), 949–954.
Pollack, David, Sclarb, Eric J., Sharp, William E., Tune, Teresa W., 2005. Walker-Noe: an early Middle Wooldand Adena mound in central Kentucky. In: Applegate, Darlene, Mainfort, Robert C. (Eds.), Woodland Period Systematics in the Middle Ohio Valley. The University of Alabama Press, Tuscaloosa, pp. 64–75.
Reimer, Paula J, Bard, Edouard, Alex Bayliss, J., Beck, Warren, Blackwell, Paul G, Ramsey, Christopher Bronk, Buck, Caitlin E, Hai Cheng, R., Edwards, Lawrence, Friedrich, Michael, 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55 (4), 1869–1887.
Richmond, Michael D., Kerr, Jonathan P., 2005. Middle Woodland ritualism in the Central Bluegrass: evidence from the Amburgey site, Montgomery county, Kentucky. In: Applegate, Darlene, Mainfort, Robert C., Jr. (Eds.), Woodland Period Systematics in the Middle Ohio Valley. University of Alabama Press, Tuscaloosa, AL. pp. 76–93.
Rogers, Everett, 2003. Diffusion of Innovation. Free Press, New York.
Rossen, Jack, 1999. Archaeobotanical remains. In: Stokes, Jo, Shields, Carl R. (Eds.), Woodland Occupations along Clear Creek in Southeastern Kentucky. Kentucky Archaeological Survey, Lexington, KY, pp. 73–85.
Rossen, Jack, 2002. Botanical remains from Walker-Noe, site 15GD56. Kentcuky Archaeological Survey Report. Submitted to the Kentucky Archaeological Survey. Available at the William S. Webb Museum, Lexington, KY.
Rossen, Jack, 2006. Archaeobotanical remains. In: Burdin, S. Rick, Pollack, David (Eds.), The Early Late Woodland Wiley Creek site (15JO74) and Early Fort Ancient Curtis Site (15JO75), Johnson County, KY, Kentucky Archaeological Survey, Lexington, KY. pp.89–104.
Rossen, Jack, 2016. Archaeobotanical remains. In: Schlarb, Eric J., Pollack, David (Eds.), Archaeological Investigation of the Evans Site, Montgomery County, Kentucky. Kentucky Archaeological Survey, Lexington, KY, pp. 41–50.
Ruby, Bret J., Carr, Christopher, Charles, Douglas K., 2005. Community organizations in the Scioto, Mann, and Havana Hopewellian regions: a comparative perspective. In: Carr, Christopher, Case, D. Troy, (Eds.), Gathering Hopewell: Society, Ritual and Interaction. Springer, New York. pp. 199–176.
Seeman, Mark F., Branch, James, 2006. The mounded landscapes of Ohio: Hopewell patterns and placements. In: Charles, Douglas K., Buiksra, Jane E. (Eds.), Recreating Hopewell. University Press of Florida, Gainesville, pp. 106–121.
Simon, Mary L., 2017. Reevaluating the evidence for Middle Woodland maize from the Holding Site. Am. Antiq. 82 (1), 140150.
Simon, Mary L., Parker, Kathryn E., 2006. Prehistoric plant use in the American Bottom: new thoughts and interpretations. Southeastern Archaeol. 25 (2), 212–257.
Smart, Tristine L., Ford, Richard A., 1983. Plant remains. In: Greber, N'omi, (Ed.), Recent Excavations at the Edwin Harness Mound, Liberty Works, Ohio, MCJA Special Papers No. 5. The Cleveland Museum of Natural History, Cleveland, OH. pp. 54–58.
Smith, Bruce D., 1992. Rivers of Change: Essays on Early Agriculture in Eastern North America. Smithsonian Institution Press, Washington.
Smith, Bruce D., 2014. The Domestication of *Helianthus annuus* L. (Sunflower). Vegetation History Archaeobotany 23 (1), 57–74.
Smith, Bruce D., Yarnell, Richard A., 2009. Initial formation of an indigenous crop complex in eastern North America at 3800 B.P. Proc. Natl. Acad. Sci. 106 (16), 6561–6566.
Stafford, Barbara D., Sant, Mark B., (Eds.), 1985, Smiling Dan: Structure and Function at a Middle Woodland Settlement in the Illinois Valley. 2. Center for American Archaeology, Kampsville, IL.
Stromberg, Per M., Pascual, Unai, Bellon, Mauricio R., 2010. Seed systems and farmers' seed choices: the case of maize in the Peruvian amazon. Human Ecol. 38, 539–553.
Watson, Patty Jo, Kennedy, Mary C., 1991. The development of horticulture in the Eastern Woodlands of North America: Women's Role. In: Gero, Joan, Conkey, Margaret W. (Eds.), Engendering Archaeology. Blackwell Publishing, Oxford, pp. 255–275.
Williams, Joyce A., 1993. Meridian Hills: an upland Holding phase Middle Woodland habitation site. Illinois Archaeol. 5(1 and 2) 193–199.
Williams, Joyce A., Maher, T.O., Parker, Katherine E., 1988. The Meridian Hills site (11-Ms01258). Illinois Antiquity 2, 8–12.
Wright, Alice P., Loveland, Erika, 2015. Ritualised craft production at the Hopewell periphery: new evidence from the Appalachian Summit. Antiquity 89 (343), 137–153.
Wymer, DeeAnne, 1993. Cultural change and subsistence: the Middle Woodland and Late Woodland transition in the mid-Ohio valley. In: Scarry, C. Margaret (Ed.), Foraging and Farming in the Eastern Woodlands. University Press of Florida, Gainesville, pp. 138–156.
Wymer, DeeAnne, 1996. The Ohio Hopewell econiche: human-land interaction in the core area. In: Pacheco, Paul J. (Ed.), A View from the Core: A Synthesis of Ohio Hopewell Archaeology. The Ohio Archaeological Council Inc, Columbus, OH, pp. 36–53.
Wymer, DeeAnne, 2009. The paleoethnobotanical assemblage from the 1971–1977 Excavations at the Seip Earthworks. Midcontinental J. Archaeol. 34 (1), 123–142.
Wymer, DeeAnne, 2017. The Paleoethnobotanical Recod of the Datum H. Site – on the Edge of the Vision Place of Souls. Manuscript accessed at academia.edu, May 2017.
Wymer, DeeAnne, Abrams, Elliot, 2003. Early woodland plant use and gardening: evidence from an Adena hamlet in Southeastern Ohio. Midcontinental J. Archaeol. 28 (2), 175–194.
Yarnell, Richard A., 1969. Contents of human paleofeces. In:Watson, Patty Jo, (Ed.), The Prehistory of Salts Cave, Kentucky. Reports of Investigations. vol. 16. Illinois State Museum, Springfield, IL. 1972, Iva annua var. macrocarpa: Extinct American Cultigen? American Anthropologist 74:335-341. pp. 41–54.
Yarnell, Richard A., 1972. *Iva annua* var. *macrocarpa*: extinct American cultigen? Am. Anth. 74, 335–341.
Yurtseva, O.V., 2001. Ultrasculpture of achene surface in *Polygonum* section *Polygonum* (Polygonaceae) in Russia. Nordic J. Botany 21 (4), 513–528.
Zhao, Zhijun, 2011. New Archaeobotanic data for the study of the origins of agriculture in China. Curr. Anthropol. 52 (S4), S295–S306.