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ORIGINAL ARTICLE

Chapter 7. Mapping land use with integrated environmental archaeological datasets

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Abstract
Archaeologists have developed tools to reconstruct the locations of farming and animal herding using ecological and digital modeling of ancient landscapes. The determination of where on a landscape farming and herding took place, however, can remain elusive in environments with evidence for substantial geomorphological and/or ecological change since the period of occupation. Archaeobotanical and geoarchaeological evidence from the site of Gordion, in central Anatolia, indicates substantial landscape change over the last 4000 years, including deforestation, overgrazing, erosion, and alluviation. These have been inferred to be the result of past agricultural practices, but no firm evidence has pointed to specific locations (geographic and temporal) where ancient farming and herding may have caused these changes. Integrating extant archaeobotanical, zooarchaeological, and geoarchaeological evidence with new isotopic data provides a more detailed reconstruction of the sequence of agricultural practices that shaped the present landscape and ecology of the region, offering a model for future archaeological research within substantially transformed landscapes.

KEYWORDS
agriculture, archaeobotany, geoarchaeology, Gordion, stable isotopes, zooarchaeology

INTRODUCTION

Archaeological studies of agriculture, especially those that draw upon paleoethnobotanical or zooarchaeological datasets, have given considerable insight into the subsistence production at the base of large-scale political economies (e.g., Rosenzweig, 2018; Sugiyama & Somerville, 2017; Zeder, 1991), but the spatial extent of these activities often remains difficult to discern. This is a problem in the study of ancient states in particular because regional-scale political and economic networks form the core of what differentiates states from other classes of polities, rendering archaeologically under-visible hinterlands a key gap in our understanding of state-level agricultural economies. This problem has been acknowledged by scholars for decades, who have used regional settlement patterns produced by extensive survey to infer areas of agricultural production and their change over time (e.g., Adams, 1965; Casana & Glatz, 2017), as well as durable evidence of landscape modification, such as terraces or irrigation canals (Janusek & Kolata, 2004; Kirch, 2006; Wilkinson et al., 2015) or "hollow ways" formed by regular herd movement (Casana, 2013; Ur, 2003; Wilkinson et al., 2010).

Once fields have been located through survey or remote sensing, archaeological exploration of fields themselves (Gleason, 1994) can produce phytolith assemblages from which it is possible to reconstruct the plants grown in that field (e.g., Iriarte et al., 2010; Pearsall & Trimble, 1984). Such an approach, however, works only for farming, not for herding, and is constrained by the ability to detect and access ancient field surfaces. Direct archaeological evidence for the full spatial extent of cultivation and animal herding around a site, however, remains a challenge and has been rare. In light of these challenges, it remains especially critical to understand the spatial extent of agriculture around urban centers, which are key economic nodes in state economies, so that we can ask how farmers and herders adopted specific productive strategies across space in response to the demands of state finance systems, providing a more direct link between social and environmental change beyond the boundaries of a site (Arbuckle, 2012; Bogaard et al., 2009; Marston, 2015).

New integrative approaches, such as those outlined in other chapters of this volume, now provide mechanisms to identify the locations of fields. This article adopts one such approach by integrating multiple existing environmental archaeological datasets along with preliminary isotopic analyses to map the spatial extent of animal grazing and plant cultivation around the urban center of Gordion, in central Turkey, from the Late Bronze Age (ca. 1400 BCE) to the Medieval period (14th century CE). We draw on detailed zooarchaeological, paleoethnobotanical, geoarchaeological, and ecological datasets, as well as pilot data from strontium ($^{87}Sr/^{86}Sr$), carbon ($\delta^{13}C$), and nitrogen ($\delta^{15}N$) isotope analyses of both plant and animal remains, to place agricultural economies in space and time around Gordion. The approach used here illustrates the value of integrating environmental archaeological datasets and the potential of reconstructing the spatial distribution of off-site agricultural activities using on-site excavated bones and seeds.

THE ARCHAEOLOGY AND BIOGEOGRAPHY OF GORDION

Gordion is a large site: variously measured by the 13 ha flat-topped mound, the 51 ha walled inner city, or the roughly 100 ha total occupied area of the site at its maximum extent (Voigt, 2011). Its settled landscape extends further, with more than 100 burial tumuli marking (and monumentalizing) a viewshed spanning dozens of square kilometers (Stephens, 2018). The site was occupied from at least the Early Bronze Age (ca. 2000 BCE) through the Medieval period (13th to 14th centuries CE) and held the status of a large urban center from at least 900 to 300 BCE (Voigt, 2002, 2011).

Gordion occupied distinct economic roles over its long occupation history. During the Late Bronze Age (ca. 1400–1200 BCE), it was an administrative node in the Hittite kingdom, with excavations providing evidence for centralized ceramic production and grain storage (Henrickson, 1993, 2002; Voigt, 2011) and stamp seals and sealings similar to those found at Imperial Hittite sites (Dusinberre, 2005). The subsequent Early Iron Age (ca. 1100–900 BCE) saw Gordion repopulated by Phrygian-speaking immigrants from the Balkans. The small settlement of that period grew into a major city by the Middle Phrygian period (ca. 800–540 BCE) that was the capital of the Phrygian Kingdom, which controlled most of central Anatolia. Evidence for centralized economic control of this large polity from Gordion is evident in the distribution of regional pottery production (Grave et al., 2009, 2012); the wealth of the state is illustrated by extensive and elaborate textile production within the elite core of the city and the construction of massive burial tumuli (Liebhart et al., 2016; Roller, 2011; Voigt, 2011). Following the Achaemenid Persian conquest of Gordion around 540 BCE, the city remained large and prosperous as an administrative node in the Achaemenid Empire; it became somewhat smaller by the early Hellenistic period (ca. 330–260 BCE). The late Hellenistic period (ca. 260–100 BCE) saw another population change, as the mound was repopulated by Galatian Celts, mercenaries from the west who settled at Gordion and built a small kingdom in central Anatolia (Voigt, 2012). Subsequent Roman occupation lasted into the early 5th century CE; at this time Gordion was a military citadel with most civilian occupation on rural estates across the landscape (Çakırlar & Marston, 2019; Goldman, 2005; Kealhofer, 2005). The site was abandoned by the mid-5th century CE and only reinhabited in the 13th century CE as a small village within a Turkic kingdom; settlement persisted into the 14th century CE (Marston, 2017).

The landscape of the region surrounding Gordion today is varied. Central Anatolia is an orographically uplifted plateau; Gordion sits at one of its lower elevations at 680 m above sea level (masl), in the present floodplain of the Sakarya River. The river valley is surrounded by dry plateaus with gypsum-rich marl-derived soils to the west and south, and basalt-derived soils eroded from hills to the east; the highest local peaks are Çile Dağı (1440 masl) to the northeast and Dua Tepe (1100 masl) to the southeast, as well as the more distant peaks of Çal Dağı (1800 masl) and Hamam Dağı (1530 masl) to the west and north (Figure 1; Çal Dağı is off the map to the southwest). The marl-derived soils have low water retention and make poor agricultural soils, while the basalt-derived soils can be excellent for farming, depending on water availability in this semi-arid region (Marsh, 2005; Marston, 2017). Indigenous vegetation communities are strongly circumscribed to specific combinations of soil, elevation, and water availability, resulting in a regionally diverse native flora, which is further impacted by varying degrees of disturbance from human land use, especially herd animal grazing pressure (Davis, 1965–2000; Marston, 2017; Miller, 2010; Zohary, 1973).

Local vegetation communities include riparian woodlands, herbaceous communities specific to dry marl- and gypsum-derived soils, steppe grassland communities, open woodlands, and forests dominated by one of several primary tree species (see Miller, 2010, and Marston, 2017, for an extended description of the plant ecology of these communities). Woodland types are most clearly differentiated by distinct taxa that can be identified archaeologically, including riparian and open steppe woodlands, and oak, juniper, and pine-dominated forests. Each community grows under specific sets of environmental conditions and is promoted or diminished by human land-use activities (Marston, 2017;

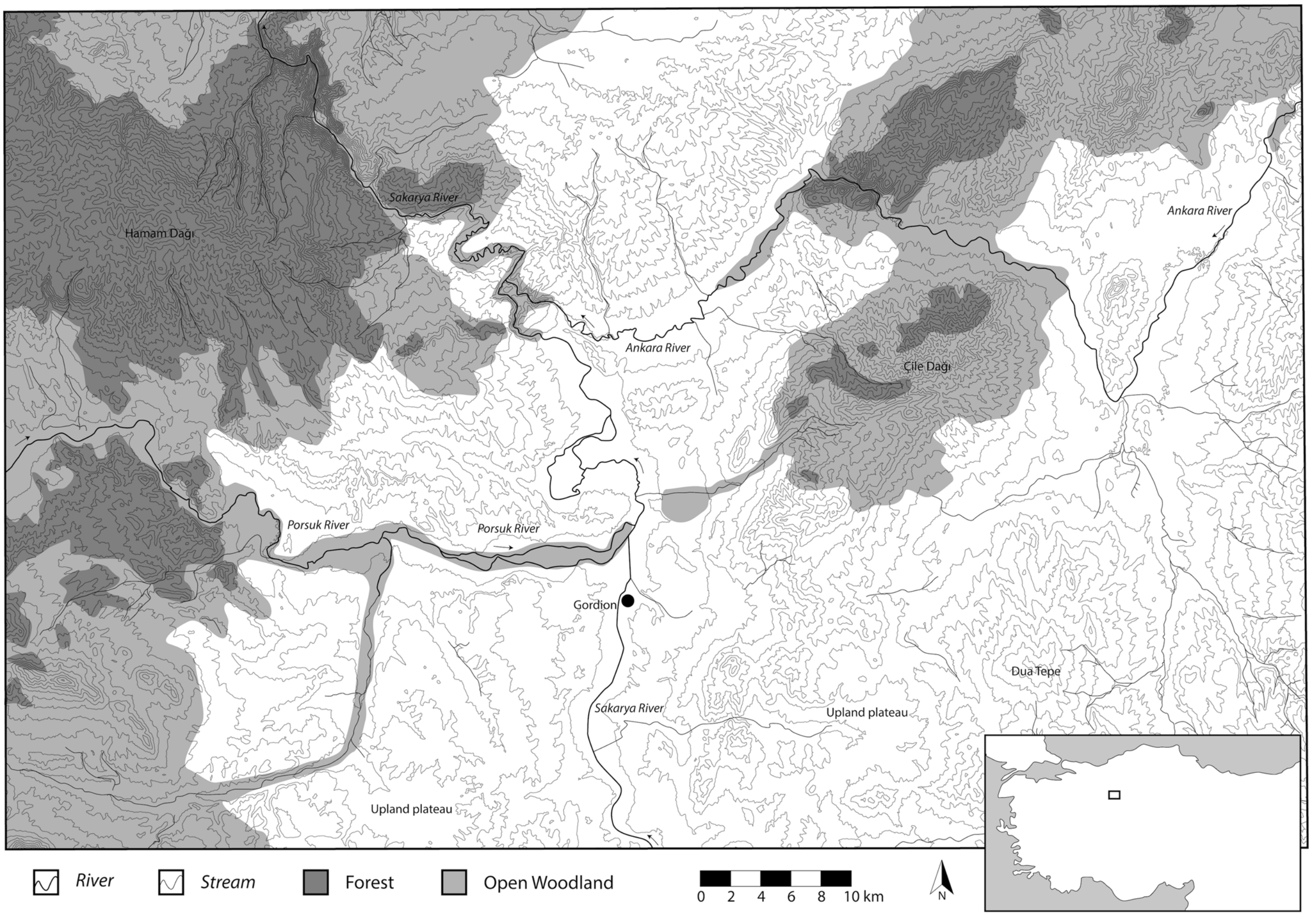

FIGURE 1 Topography of the Gordion region, with present-day forest cover and stream channels illustrated. Contours are 50 m. Approximate areas suitable for gravity-fed irrigation are defined by the 50-m contours around the Sakarya and Porsuk Rivers.

Zohary, 1973). Herbaceous and grassland communities can be distinguished less clearly within archaeobotanical assemblages, but evidence in the form of wetland indicators (species that grow in natural or human-created, i.e., irrigated, wetland soils), gypsum soils, and healthy versus overgrazed steppe have been obtained (Marston, 2011, 2015, 2017). Crop weed assemblages in contexts representing caches of stored grain or crop processing debris can also be used to locate fields in which those crops were grown (Bogaard et al., 2016; Riehl, 2014; Weiss & Kislev, 2004); this approach has been less useful at Gordion, however, as there are few contexts clearly identifiable as crop caches or pure processing debris.

RECONSTRUCTING ANCIENT LANDSCAPES

Environmental archaeology offers several toolkits for reconstructing ancient landscapes. Many of these have been applied at Gordion, with a few notable exceptions, such as phytolith analysis (Iriarte et al., 2010; Laugier et al., 2021, 2022; Ramsey & Rosen, 2016). Chief among the methods applied at Gordion are geoarchaeology and regional pedestrian survey, which together give insight into the location and intensity of extra-urban settlements and land use (Kealhofer, 2005; Kealhofer & Marsh, 2019; Marsh, 1999, 2005; Marsh & Kealhofer, 2014), as well as paleoethnobotany and zooarchaeology, which give insight into patterns of agriculture and woodland clearance, and responses of vegetation to those pressures, especially to animal grazing (Çakırlar & Marston, 2019; Marston, 2015, 2017; Miller, 2010; Miller et al., 2009).

Regional pedestrian survey combined with geological coring used to reconstruct geomorphological change over the Late Holocene has produced insights into long-term changes in population, erosion, and alluviation in the immediate region of Gordion. Drawing on these two datasets in parallel, Kealhofer and Marsh (2019; also Marsh & Kealhofer, 2014) depict a sequence of landscape change in which the first human settlements of the Gordion region in the Chalcolithic period (ca. 6000–3000 BCE), despite low population density, began a process of soil mobility in small streams located on hillslopes (Figure 2). This erosion peaked by the early Middle Bronze Age (ca. 2000 BCE), coincident with a substantial growth in regional population and the foun-

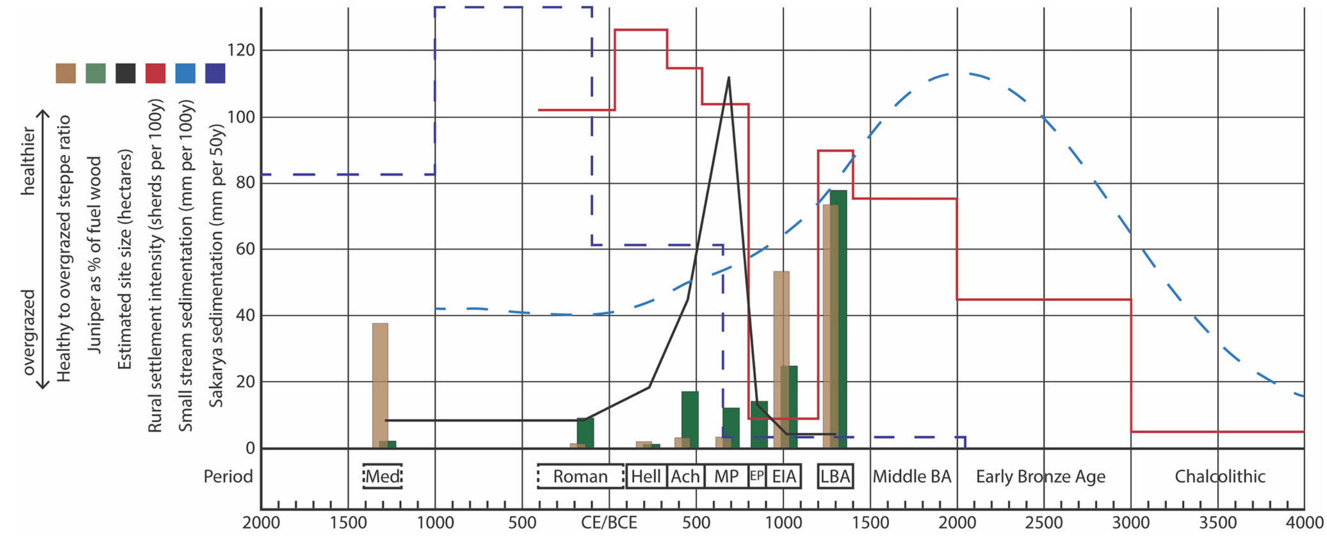

FIGURE 2 Sequences of landscape change in the Gordion region, from right to left: vegetation change as bars, settlement scale change as solid lines, sedimentation records as dashed lines. Periods in boxes correspond to Gordion strata with environmental archaeological remains; dashed box walls indicate approximate dates of period boundaries. Settlement size from Voigt (2002); small-stream sedimentation rate and sherd deposition intensity from Kealhofer and Marsh (2019, 94), with an adjustment to both Middle and Late Bronze Age values based on correcting the transition between periods to 1400 BCE; Sakarya River alluviation rate estimated from Marsh (2005, 169); juniper wood frequency from Marston (2017, 77); overgrazing proxy from Marston (2017, 129). Period abbreviations: Ach, Achaemenid; EIA, Early Iron Age; EP, Early Phrygian; Hell, Hellenistic; LBA, Late Bronze Age; Med, Medieval; MP, Middle Phrygian.

dation of Gordion as an urban center (by the Middle Bronze Age). As regional population declined into the Early Iron Age (ca. 1000 BCE), so too did rates of upland erosion and soil mobility in small streams, which declined until the beginning of the Roman period (1st century BCE) and then stabilized at moderately low levels. The period from the mid-1st millennium BCE through the Roman period, however, coincided with a population increase, reaching the peak of regional population density outside the city (Figure 2, solid red line). During this phase of population growth, however, the Sakarya River began to aggrade (Figure 2, dashed purple line), indicating substantial erosion upstream (i.e., to the south) of Gordion, reaching maximum rates of sedimentation following the Roman period (Marsh, 1999).

The paleoecology of the Gordion region has been reconstructed using two distinct datasets: assemblages of wood charcoal and carbonized seeds from animal dung burned as fuel. Both wood and dung were extensively used as fuel at Gordion (Miller, 1999; Miller & Marston, 2012) and the composition of the wood assemblage illuminates which trees were selected as fuel for inhabitants of the site (Marston, 2017; Miller, 2010). Seeds from combusted animal dung, in contrast, denote the diet of those grazers and give insight into long-term changes in grassland ecology (Marston, 2017; Miller & Smart, 1984). The major trend in the wood charcoal record is a long-term decline in the use of juniper (Figure 2, green bars), a slow-growing tree ubiquitous in some woodland formations that likely existed close to Gordion at the time of settlement, based on phytogeography and early wood use evidence (Marston, 2017; Zohary, 1973). By the Early and Middle Phrygian periods (ca. 900–540 BCE), juniper comprised less than 20% of all wood burned, but was still available for the construction of large public buildings and royal burial tumuli; by the Hellenistic period (ca. 330–100 BCE), it comprised only 1% of wood burned and was no longer used in construction (Marston, 2017; Figure 2). This decline was likely the result of selective human use of this valued construction wood and its subsequent replacement by faster-growing successional woodland communities (e.g., oak scrub; Marston, 2015, 2017). Grassland communities, in contrast, are more temporally sensitive to land use, especially grazing pressure, and showed rapid declines in steppe health near Gordion following the expansion of the city in the Middle Phrygian period (ca. 800–540 BCE) but rebounded following abandonment of the site in the mid-1st millennium CE (Marston, 2015, 2017; Figure 2, tan bars).

Bringing these lines of evidence together, we identify four major periods of land-use activity and landscape change in and around Gordion which provide a broad-scale context for considering the spatial distribution of land use.

1. Chalcolithic (ca. 6000–3000 BCE) to Late Bronze Age (ca. 1500–1200 BCE): small-scale human settlement across the landscape, likely including a significant pastoral component, results in erosion of upland soils and sedimentation of small streams (Kealhofer & Marsh, 2019; Marsh & Kealhofer, 2014).

Human populations grow and Gordion is founded by the Early Bronze Age, serving as a regional administrative hub of the Hittite Empire in the Late Bronze Age (Henrickson & Blackman, 1996; Voigt, 2013). Forests in the vicinity of Gordion still supply high-quality juniper timber in abundance; grazing pressure is low and erosion in small-stream catchments slows.

2. Early Phrygian (ca. 900–800 BCE) to Achaemenid (ca. 540–330 BCE): the city of Gordion grows massively in size and rural settlement expands; the city becomes capital of the Phrygian kingdom and later an administrative center of the Achaemenid Empire. Agriculture intensifies, increasing local agricultural production with a greater emphasis on wheat than barley and on pig and cattle than caprine husbandry (Marston, 2017; Miller et al., 2009). Steppe health declines severely, indicating a substantial increase in grazing pressure; juniper becomes a rare and valued construction resource. Land use spreads to upstream catchments of the Sakarya, resulting in increased sedimentation and aggradation of the river (Kealhofer & Marsh, 2019; Marsh, 1999, 2005).
3. Hellenistic (330–100 BCE) and Roman (ca. 100 BCE–4th century CE) periods: the site of Gordion contracts substantially to only a small settlement on the central mound, but rural settlement intensity remains high. Highly structured agricultural systems of the Roman period focus on irrigated bread wheat cultivation, an urban meat economy of beef and pork, and extensive rural wool production (Çakırlar & Marston, 2019; Marston & Miller, 2014). Juniper is scarce and unused in construction, while faster-growing riverine trees see increased use (Marston, 2017). Grazing pressure increases again, with steppe health reaching a nadir during the Roman period; increased sedimentation rates in the Sakarya drainage follow (Marsh, 2005).
4. Occupation hiatus and Medieval period: Gordion is abandoned by the early 5th century CE, with resettlement occurring in the 13th century CE as a small village; regional pollen and settlement records suggest a broader depopulation of Central Anatolia during the late 1st millennium CE (Allcock, 2017; England et al., 2008). Sakarya sedimentation rates begin to decline after 1000 CE; populations resettling Gordion find healthy grassland communities and some regrowth of regional woodlands, though juniper remains scarce. Reoccupation is short-lived, however, and the site is permanently abandoned in the 14th century CE.

RECONSTRUCTING THE SPATIAL DISTRIBUTION OF LAND USE

Within this regional diachronic context, additional environmental archaeological datasets offer information on the locations of farming and herding in the landscape. These include the presence of botanical evidence for land clearance and irrigation, and seed isotope data that indicate variability in the cultivated soils, likely the result of diverse soil management or strategic planting of crops in naturally distinct soils. Herding can be located through the ecological habits of the animals raised and their age and sex profiles, which indicate herd management strategies, as well as seeds from ruminant dung burned as fuel that indicate the ecologies in which those animals foraged (or were foddered). Stable isotope measurements of animal tooth enamel enable assessment of the scale of the animals' seasonal mobility, which can be used to infer possible locations in which the animals lived.

Locating farming

Wild plant seeds from archaeological assemblages are informative in several dimensions for locating fields. Field weeds with distinct ecological characteristics or restricted regions of growth can serve as indicators of field location, especially among caches of imported grain (Bogaard et al., 1999, 2016; Jones et al., 2005, 2010; Weiss & Kislev, 2004). Wild plant seeds introduced by other mechanisms, such as dung burning, can indicate the locations of animal grazing; these approaches are particularly useful in identifying distinct plant ecologies present at different sites (Miller, 1996; Riehl, 2014). At Gordion, two wild plant taxa with distinct ecological characteristics speak to spatial patterns in practices of land use: Cyperaceae, which indicates field locations, and *Gypsophila*, which can help to locate animal grazing.

Cyperaceae, which favors wet or inundated locations, indicates growth or contraction in water channels, whether natural, as present in a braided river, or artificial, as a network of irrigation canals. Referencing the frequency of these seeds against geomorphological changes in the river course provides a mechanism for distinguishing these two possibilities. As shown in Figure 3, Cyperaceae increase stepwise in frequency at Gordion, first in the Middle Phrygian and again in the Roman period. While there is evidence for increased meandering of the Sakarya River course by the Roman period (Marsh, 1999, 2005), the river is reconstructed as narrow and straight during the Middle Phrygian, indicating that the increase in Cyperaceae from the Early Phrygian was most plausibly the result of an expansion of irrigation canals. Water channel features at the Phrygian floodplain level are evident to the west of the Gordion mound (Kealhofer & Marsh, 2019, 97). Roman and Medieval agriculture likely made use of irrigation as well, given that both periods saw a rise in the cultivation of crops that either benefited strongly from irrigation (bread wheat, during the Roman period, and foxtail millet, in the Medieval) or required irrigation to grow at

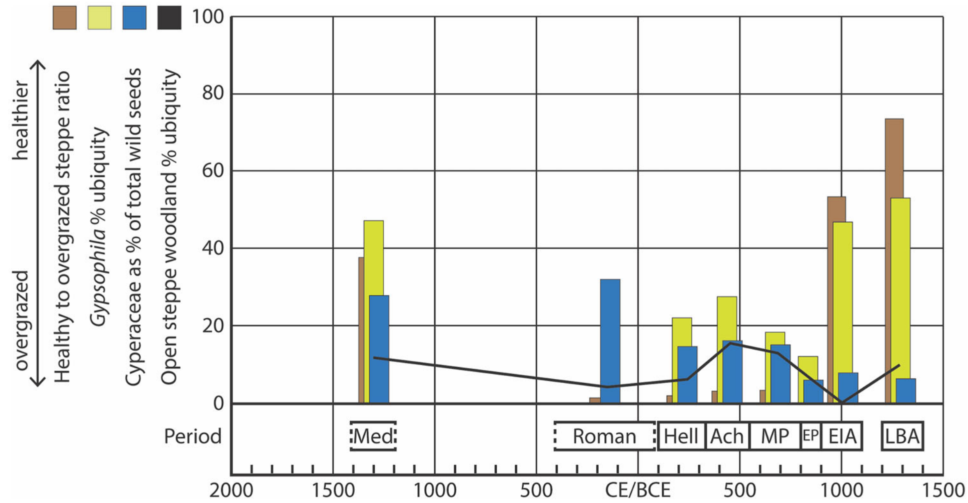

FIGURE 3 Proxy indicators of irrigation and field clearance over time from right to left: herbaceous vegetation change as bars, woodland clearance as solid line. Periods abbreviated as in Figure 2. Overgrazing proxy from Marston (2017, 129); ubiquity of *Gypsophila*, a proxy of gypsum steppe grazing, from Marston (2017, 124); frequency of Cyperaceae, a proxy of irrigation, from Marston (2017, 126); ubiquity of open steppe woodland tree charcoal, a proxy of field clearance, from Marston (2017, 79).

all in Central Anatolia (rice and cotton, in the Medieval period) (Marston, 2017; Marston & Miller, 2014). Only portions of the Sakarya and Porsuk River valleys and the drainage of the major stream to the east of Gordion (the Sülüklü Çay) are topographically suitable for gravity-fed irrigation, constraining irrigated agriculture to these areas (Figure 1).

The clearance of woodlands for agriculture is suggested by the frequency of the wood from trees that comprised the open steppe woodland community visible in the charcoal assemblage at Gordion. These trees thrive in open, sunny settings, and are only minor components or entirely absent in canopy forests, which were biogeographically restricted to higher elevations of the Gordion region (Marston, 2017). Their use as fuel wood suggests the clearance of new areas for farming. Their ubiquity in the charcoal assemblage increased as population at the site grew from the Early Iron Age to the Achaemenid period, then fell along with site size into the Roman period (Figure 3). While Hellenistic and Roman rural population densities were high (Figure 2), local open steppe woodlands had already been cleared in earlier periods. Farmers in these later periods could thus work land that had already been rendered suitable for farming, a legacy (sensu Marston, 2015, 2021) of earlier farming practices. We can infer that these former woodlands converted to fields were present where these trees prefer to grow, in low-slope basalt-derived soils with good water retention. These include the areas of the region with open woodlands today (Figure 1), as well as the lower slopes of hills to the southeast and northeast of Gordion.

A final method for inferring field locations from archaeological crop seeds is using stable carbon and nitrogen isotope analysis. Stable carbon isotope values provide an indication of crop water status, with more negative δ^{13}C values corresponding to cultivation in wetter soils (Ehleringer et al., 1993; Flohr et al., 2011; Styring et al., 2016; Wallace et al., 2013). Stable nitrogen isotope values reflect the degree of ^{15}N enrichment in soil, with factors including the application of farmyard manure and aridity causing higher soil and crop δ^{15}N values (Bogaard et al., 2007; Fiorentino et al., 2015; Wallace et al., 2013). Seeds grown within a single field in a single year are likely to be more similar isotopically to one another than seeds grown in different fields across multiple years; caches of seeds harvested in a single year thus offer the potential to distinguish the yield of a single field from those harvested from multiple fields and later combined (Diffey et al., 2020; Fiorentino et al., 2012). Secondary or tertiary deposits of carbonized seeds represent depositional mixing across both time (multiple harvest years) and space (likely multiple fields contributed to those deposits). Although mixed, these deposits provide an indication of the overall isotopic variability across space and time and enable an assessment of long-term changes in both water status and soil quality, which may correlate with changes in rainfall, irrigation use, and soil management strategies (Nitsch et al., 2017; Styring et al., 2017, 2022; Vaiglova et al., 2014, 2020).

The Gordion botanical assemblage includes crop caches dating to two periods, though most seeds come from contexts of secondary deposition: long-term accumulations of burned waste. Here, we focus only on seeds from the burned caches in order to explore the diversity of landscape locations captured within those assemblages. The seeds come from two burned structures, one dating to the Early Phrygian "destruction level" (836–802 BCE, 2σ range; Manning & Kromer, 2011, 148),

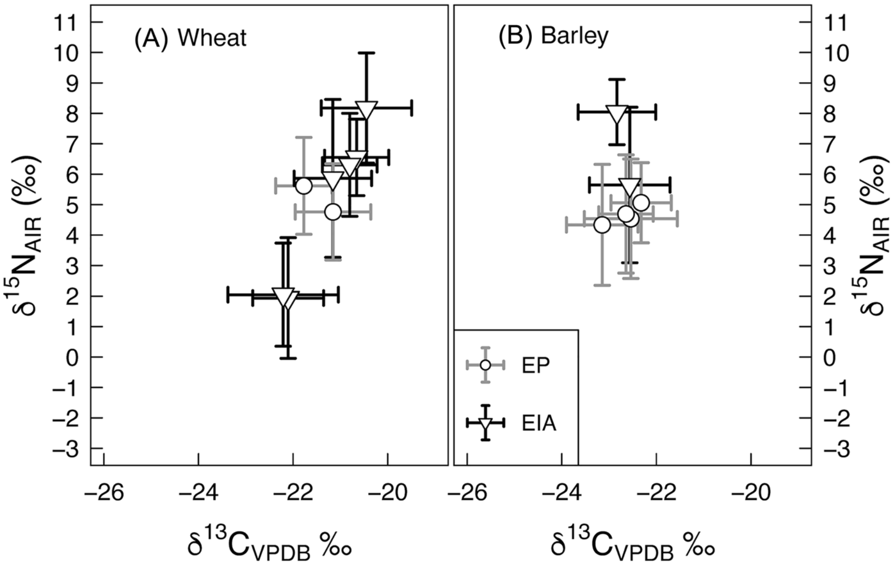

FIGURE 4 Carbon/nitrogen stable isotope biplots of wheat (A) and barley (B) grains from the Early Iron Age and Early Phrygian periods at Gordion, grouped by archaeological context. Means and one standard deviation of the sample population are shown for each context. Periods are distinguished by symbol and by color of standard deviation bars. Period abbreviations: EIA, Early Iron Age; EP, Early Phrygian.

and the other to the preceding Early Iron Age period, with a destruction date estimated around the middle of the period 1100–900 BCE (Voigt, 2011, 1077–78). The Early Phrygian building was a support building adjacent to the monumental center of the site, in which various foodstuffs were stored and attached retainers worked at tasks including food preparation (Voigt, 2011, 1081). The Early Iron Age building was a large, architecturally distinct structure, in which an oven was present and wheat, barley, and bitter vetch were stored in baskets on the floor at the time the building burned (Voigt, 2011, 1077–78). We conducted single-seed $\delta^{13}C$ and $\delta^{15}N$ measurements of seeds from two wheat caches (29 and 20 seeds analyzed) and four barley caches (n = 30, 20, 20, 20) dating to the Early Phrygian, and six wheat caches (n = 20, 15, 20, 20, 8, 30) and two barley caches (n = 20, 5) dating to the Early Iron Age.

As shown in Figure 4, stored wheat caches display considerably more variation in $\delta^{15}N$, with mean $\delta^{15}N$ values of wheat ranging from +1.9‰ to +8.2‰ (difference of 6.3‰) across both phases and the mean $\delta^{15}N$ values of barley ranging from +4.3‰ to +8.0‰ (difference of 3.7‰) across both phases. Intriguingly, wheat cache groups exhibit less overlap in $\delta^{15}N$ values than barley cache groups at the 1σ range. The mean $\delta^{13}C$ values of wheat are between −22.2‰ and −20.4‰ (difference of 1.8‰) across both phases, while the mean $\delta^{13}C$ values of barley are between −23.1‰ and −22.3‰ (difference of 0.8‰) across both phases.

These data indicate that the wheat stored in these contexts was grown in fields under a wider range of conditions than was barley, at least during the Early Iron Age. Both $\delta^{13}C$ and $\delta^{15}N$ values of samples from the Early Phrygian period structure are more similar to one another than are those of the Early Iron Age building. In fact, all of the Early Phrygian samples of the same cereal type have fully overlapping $\delta^{15}N$ and $\delta^{13}C$ values at the 1σ range. This pattern could be the result of two possible scenarios: (1) the crops of each species were cultivated under similar growing conditions (either in a single field or multiple fields), or (2) they were cultivated across a range of fields with diverse growing conditions, but the harvests of those fields were mixed prior to storage. The attached laborer context of the Early Phrygian structure suggests the possibility that this storeroom contained the centrally collected products of numerous farming households, which were mixed at the time of storage. But because the variability in the $\delta^{13}C$ and $\delta^{15}N$ values of the seed caches from the Early Phrygian (represented by standard deviation) is similar to the variability of the single-harvest caches recovered from the Early Iron Age, the first scenario seems more likely. Even if multiple harvests were combined in the Early Phrygian grain stores, they came from fields with more similar, or standardized, growing conditions.

Locating herding

The potential spatial expanse of animal herding is constrained by animal diets, ecology, sociality, and the needs of herders to restrict animals to specific locations for desired primary and secondary products. Sheep and goats offer the greatest potential for vertical transhumance, especially on a seasonal cycle, given that highland areas of Central Anatolia are accessible only in summer months, when they offer rich forage for ruminant animals. When sheep and goat herds are maintained for wool/hair or meat, their seasonal departure from population centers does not limit their economic utility. Cattle are more likely to be kept closer to human settlements, due to their use for milk and field labor. Pigs represent a more complex set of options, as they can be kept in specialized pens or range freely in the urban fabric or as semi-feral woodland populations (Halstead & Isaakidou, 2011; Marston et al., 2022; Price, 2020). Age structures of when these animals were killed can help to distinguish between alternative production aims (Reitz & Wing, 2008). At Gordion, faunal evidence indicates a large emphasis on caprines, with likely seasonal transhumance for at least a portion of these herds, with increased emphasis on cattle and pigs, likely kept close to the site, during periods of urban growth (the Middle Phrygian and Achaemenid periods) and also during the Roman period, as a specialized meat provisioning system for the Roman military (Çakırlar & Marston, 2019; Marston, 2017; Zeder & Arter, 1994).

Stable isotope measurements of animal tissues can provide additional information on the ecologies and geological locations in which animals spent their lives; analysis of tissues that grow incrementally (such as teeth) are particularly useful for gathering information on seasonal changes in diets and herding locations. The second and third molars of sheep, goats, and cattle record up to 2 years of development and isotopic analysis of a sequence of enamel samples from these teeth enables assessment of the animals' dietary and water inputs (δ^{13}C and δ^{18}O) and grazing locations (^{87}Sr/^{86}Sr) over the course of tooth formation (Makarewicz & Sealy, 2015). Stable carbon and oxygen isotope values are not yet available from Gordion fauna; only a few strontium measurements have been reported to date (DiBattista, 2014), with many more in progress. DiBattista (2014) identified one goat, dating to the Middle Phrygian period, that was raised entirely in one location, most plausibly within the alluvium of the Sakarya or Porsuk Rivers, during the timespan covered by the tooth (^{87}Sr/^{86}Sr ratios of 0.709243–0.709483). Four other animals, two sheep and two goats, have strontium isotope ratios between 0.70658 and 0.707669, consistent with hillslopes east of Gordion, based on preliminary environmental baseline data. Further analysis of more environmental and faunal samples, including sequential δ^{13}C and δ^{18}O tooth enamel carbonate values and strontium isotope ratios, will produce a more detailed picture of animal mobility in the Gordion region.

Botanical evidence of animals grazing in the form of carbonized seeds from animal dung burned as fuel provides another perspective on the plant ecologies in which animals foraged. As shown in Figure 3, the ubiquity of *Gypsophila*, a genus of plants that prefer the dry, gypsum-rich soils found on the plateaus west and south of Gordion, follows a diachronic trend similar to that of the healthy steppe indicator species. This pattern suggests that overgrazing also depressed the availability of *Gypsophila*, and thus much of the local grazing that occurred took place on these dry plateaus. That these plateaus were used for grazing makes economic sense: basalt-derived soils with higher water retention provided a far better substrate for farming and would have been preferentially reserved for that purpose when regional populations were high. Such periods, especially the peaks of urban extent in the Middle Phrygian and Achaemenid, also saw the greatest clearance of open steppe woodland, likely to expand the area under cultivation. Gravity-fed irrigation is not possible on the plateaus, rendering them unusable for cultivation before the advent of modern irrigation pumps and chemical fertilizer inputs, so additional animal husbandry in those marginal landscapes is an expected outcome of agricultural expansion.

CONCLUSIONS

The case study of Gordion illustrates how multiple environmental archaeological datasets, integrated together, can provide a uniquely nuanced perspective on diachronic changes in the spatial location, as well as intensity, of agricultural activities. Geomorphological data document the two chronologically distinct erosional events of initial human land use in the immediate Gordion region, which peaked in the Early Bronze Age, and widespread clearance of land upstream in the Sakarya watershed, beginning in the Middle Phrygian period and accelerating in the Roman period. Wood charcoal data suggest which areas were targeted for wood removal, with the clearance of open steppe woodland trees in the Middle Phrygian and Achaemenid the peak of field expansion in the Gordion fuelwood catchment. Seeds of wetland environments provide a proxy for the expansion of irrigation networks that can be putatively located based on topography, with confirmation from geological traces of now-buried irrigation canals. Seeds preserved from dung fuel combustion illustrate the timing and intensity, as well as location, of animal grazing, recording a shift in grazing location accompanying the expansion of the area under cultivation close to the site. Finally, stable isotope values offer additional insights into differences in the diversity of field locations that supplied staple cereals to Gordion in two periods, as well as the scale of landscape utilization for animal grazing. While these data are few, as analysis is still in progress, they suggest consistent farming practices for both wheat and barley between the Late Bronze Age and Middle Phrygian period, and that at least some sheep and goats lived the first 2 years of their lives within a restricted area of the landscape.

These methods offer significant potential for application to other sites, whether in semi-arid Eurasia or elsewhere, where fields themselves are not archaeologically preserved. Gathering multiple lines of evidence is critical, as they inform one another and provide additional clarification to explain patterns emerging from other lines of evidence. The conclusion that Roman Gordion enforced an intensive, irrigation-based cultivation system of bread wheat and specialized meat production for military use (Çakırlar & Marston, 2019; Marston & Miller, 2014) depended on detailed zooarchaeological and archaeobotanical analyses, interpreted within their historical context. Long-term change in both woodland and grassland ecologies can be documented, with each informing the interpretation of the other. Similar integrated studies have been used elsewhere to identify both urban provisioning economies and long-term histories of environmental change, such as at Teotihuacan (Sánchez-Pérez et al., 2013; Sugiyama & Somerville, 2017). Through careful use of botanical, faunal, geological, and isotopic datasets, the locations of agricultural activities can be reconstructed even when fields themselves are no longer visible.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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