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MODELING RESILIENCE AND SUSTAINABILITY IN ANCIENT AGRICULTURAL SYSTEMS

John M. Marston¹

The reasons why people adopt unsustainable agricultural practices, and the ultimate environmental implications of those practices, remain incompletely understood in the present world. Archaeology, however, offers unique datasets on coincident cultural and ecological change, and their social and environmental effects. This article applies concepts derived from ecological resilience thinking to assess the sustainability of agricultural practices as a result of long-term interactions between political, economic, and environmental systems. Using the urban center of Gordion, in central Turkey, as a case study, it is possible to identify mismatched social and ecological processes on temporal, spatial, and organizational scales, which help to resolve thresholds of resilience. Results of this analysis implicate temporal and spatial mismatches as a cause for local environmental degradation, and increasing extralocal economic pressures as an ultimate cause for the adoption of unsustainable land-use practices. This analysis suggests that a research approach that integrates environmental archaeology with a resilience perspective has considerable potential for explicating regional patterns of agricultural change and environmental degradation in the past.

Keywords: agriculture, resilience, sustainability, climate change, environmental archaeology

Introduction

The sustainability of agricultural systems is a key issue for contemporary societies, especially in the context of ongoing anthropogenic climate change. Food security and equity depend ultimately on agricultural production and reliable harvests worldwide. While the sustainability of many human relationships with natural environments has come to the forefront of scientific inquiry in recent years (Barnosky et al. 2012; Jackson et al. 2001; Liu et al. 2007b; Westley et al. 2011), the field of ethnobiology has addressed such topics for the past century (Hunn 2007). Concern for agricultural sustainability extends into the study of the human past as well, with historians (Gallant 1991; Garnsey 1999) and archaeologists (Butzer 1982; Childe 1934; Cooke 1931) looking to ecological explanations for the rise, and potential collapse, of societies (Fisher et al. 2009; McAnany and Yoffee 2010a; Smith 2006; Tainter 1988).

Resilience thinking, also termed resilience theory or the theory of adaptive change, is a body of heuristic theory that originated in ecology. Resilience thinking attempts to understand how and why change occurs in complex adaptive systems, whether they be ecological, social, or linked social-ecological systems (Gunderson and Holling 2002; Holling 1973; Miller et al. 2010; Walker and Salt 2006). Archaeologists have applied this theoretical approach only sparingly, focusing mainly on the durability and collapse of societies (Butzer and

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Endfield 2012; Hegmon et al. 2008; Redman 2005; Redman and Kinzig 2003; Redman et al. 2009) but recently also on foraging and agricultural systems (Anderies and Hegmon 2011; Peeples et al. 2006; Rosen and Rivera-Collazo 2012). The value of resilience thinking for the study of agricultural sustainability lies in its flexible application to both social and ecological systems over multiple scales and its emphasis on processes of cause and effect.

In this article, I argue that a resilience approach to agricultural sustainability shifts our focus to concepts of spatial, temporal, and organizational scale that underlie social and environmental change and the causal relationships between the two. In studying the material past, it can be difficult to identify the causal relationships among social and economic change, herding and agricultural strategies, and environmental change. While social change clearly influences agricultural practices, the *processes* by which changes in the social realm lead to specific agricultural choices rather than others are generally not clear. Using the ancient city of Gordion in central Turkey as a case study for 2000 years of linked social and environmental change, I illustrate how resilience thinking offers a framework for exploring the processes by which incompatible scales of interaction (mismatches) and particular moments (thresholds) lead to unsustainable outcomes that affect future populations (legacy effects): such processes may not be evident using other modes of archaeological inquiry. I conclude that thresholds deserve particular attention from archaeologists, who have access to unique data that identify when abrupt transformations occurred and who can explore the factors that contributed to those thresholds being crossed.

Agricultural Sustainability and Resilience

The archaeological investigation of agriculture has a long history, including the analysis of both plant (Ford 1979; Helbaek 1969; Hillman 1981; Renfrew 1973; van Zeist and Casparie 1984; van Zeist et al. 1991) and animal (Bar-Yosef and Meadow 1995; Clutton-Brock 1989; Ucko and Dimbleby 1969; Zeder 1991) components of subsistence systems. Archaeology is especially well suited to explore the sustainability of agriculture due to several distinct advantages over other methods of inquiry. The first is the time depth of archaeology, which allows scholars to ascertain both the short-term (years to decades) and long-term (centuries to millennia) impacts of specific agricultural practices on environments and economies (e.g., Hastorf 1990; Miller 2010; Piperno and Pearsall 1998; van der Veen 1992). Second, archaeology is inherently interdisciplinary and uses multiple lines of evidence to reconstruct diet, agricultural strategies, and human impacts on environments, producing stronger interpretive arguments than those based solely on a single type of evidence (Fisher et al. 2009; Flannery 1986; Redman 1999; Tainter 1977, 1988). Third, archaeology is a discipline of materiality: archaeological methods investigate the material remnants of agricultural systems directly within their contemporary cultural contexts so that the study of coincident cultural and environmental change is the default approach, in contrast to the divorce between ecological and sociological data and attendant analytical methods used to study this question in the present day (cf. Folke et al. 2004; Folke et al. 2005; Holling et al. 2002a; Liu et al. 2007b). Finally, archaeology

operates across multiple spatial and organizational scales (Redman 2005), using methods ranging from within-site excavation to regional survey, remote sensing, and synthesis of these various results (e.g., Casana 2014; Colledge et al. 2004; Menze and Ur 2012; Riehl 2009; Riehl et al. 2014).

A critical limitation, however, of the archaeological study of agricultural sustainability lies in the difficulty in establishing causal relationships among observed patterns of cultural, economic, climatic, and landscape change. While finely resolved chronological sequences of environmental and agricultural change can suggest directions of causality (i.e., if one event occurs prior to the other it is more likely to be a cause than an effect), archaeologists often face essentially synchronic datasets due to the error inherent in absolute dating and ambiguities of ceramic chronologies. Debates about the reasons behind social and ecological collapse focus on divergent narratives regarding cause and effect (e.g., Diamond 2005; Hunt and Lipo 2010; McAnany and Yoffee 2010a; Tainter 1988, 2006), as do arguments about the role of climate change in demographic, political, and economic transitions (e.g., Jones et al. 1999; Rosen 2007; Weiss et al. 1993; Zhang et al. 2008).

Resilience thinking offers a theoretical approach to disentangle cause and effect between the social and ecological realms and across temporal, spatial, and organizational scales, and thus to clarify why sustainable or unsustainable agricultural systems may have been adopted. Resilience thinking can help explain how and why social change happens within an environmental setting and provides a framework for cross-cultural comparison of case studies from different times and places, going beyond simple narratives of political (Tainter 1988) and environmental collapse (Diamond 2005) to explore deep histories of human occupation across time and space (Hegmon et al. 2008; McAnany and Yoffee 2010b; Nelson et al. 2012; Redman and Kinzig 2003). Several volumes (e.g., Gunderson and Holling 2002; Gunderson et al. 2009; Walker and Salt 2006) and multiple case studies (see especially the journal *Ecology and Society*, formerly *Conservation Ecology*) have defined the core tenets of resilience thinking and applied them to a variety of ecological and human case studies, and I refer the reader there for further inquiry.

The applications of resilience thinking in archaeology to date have focused primarily on the concept of the adaptive cycle, a general model for cycles of growth and decline (Holling and Gunderson 2002). However, the adaptive cycle has found only limited use by archaeologists to model change in linked cultural and ecological systems (see Peeples et al. 2006; Redman and Kinzig 2003; Rosen and Rivera-Collazo 2012). I argue that a broader application of resilience thinking in archaeology is possible by focusing instead on a core concern of resilience thinking that for decades has been a focus of archaeologists from many theoretical perspectives: temporal, spatial, and organizational scale.

Scale and its Effects in Adaptive Systems

The study of agricultural systems and their sustainability can benefit from a resilience perspective on the role of scale and of interactions across scales and between human societies and their surrounding environments. Cross-scalar

effects arising from interactions across temporal, spatial, and organizational scales are among the most revealing of how social and ecological systems interact (Cumming et al. 2006; Liu et al. 2007a; Liu et al. 2007b; Walker et al. 2012). In particular, three classes of scalar effects warrant investigation for the study of human-mediated environmental change in the past: mismatches, thresholds, and legacy effects.

Mismatches include a subset of interactions between variables operating on different scales, either within or between social and ecological systems, e.g., fast and slow processes within a system, such as the relationship between predation rate on a species and the birth rate of that species, or organizational hierarchies misaligned with the spatial distribution of a managed resource. In particular, mismatches occur when variables “are aligned in such a way that one or more functions of the social-ecological system are disrupted, inefficiencies occur, and/or important components of the system are lost” (Cumming et al. 2006:3). Such mismatches may lead to systemic changes of varying degrees, from species extinctions to deforestation (Liu et al. 2007b). In agropastoral systems, mismatches between water supply and crop growth, or between herd animal grazing intensity and grass regrowth, may result in significant limitations on agricultural productivity.

Thresholds are tipping points in a system where a small change that crosses a threshold value leads to a substantial subsequent change, perhaps to an alternative stable state or potentially from one phase of an adaptive cycle to the next (Scheffer 2009). One example much discussed today is the impact on global temperature of an ice-free Arctic Sea. Such tipping points are rarely obvious when approached or even when first crossed, but they are often evident in retrospect and frequently arise from mismatches or cross-scalar interactions between variables (Barnosky et al. 2012; Rockstrom et al. 2009; Scheffer and Carpenter 2003; Walker and Meyers 2004), although perhaps not at a global scale (Brook et al. 2013).

In contrast, legacy effects, the results of past human-environmental interaction on the current state of a region, are often readily evident. Legacy effects, such as soil salinization, deforestation, or massive overfishing, are slow to change and potentially irreversible, and pose constraints on future ecosystems and societies (Butzer 1982:258; Jackson et al. 2001; Liu et al. 2007a; Scheffer and Carpenter 2003). Such constraints may even create “poverty traps,” in which the impoverished state departs from the adaptive cycle entirely and leads to complete, and likely irreversible, social or ecological change; desertification and soil loss in periglacial regions are ready examples (Holling 2001:400-401; Holling et al. 2002b:95-96). Poverty traps are thankfully rare, but legacy effects can persist for centuries or millennia and have a major impact on decision making for subsequent inhabitants of a region, rendering an understanding of the past of great value in addressing present-day environmental concerns.

In the case study of Gordion that follows, I focus on the identification of mismatches and thresholds that led to the adoption of unsustainable agricultural strategies, and on the legacy effects resulting from those practices. This resilience perspective highlights causal forces that have not been evident using other analytical approaches, resulting in a better understanding of processes of social

and environmental change in the region and providing data that are more useful for cross-cultural comparison.

History, Biogeography, and Climate of Gordion

The ancient city of Gordion in central Anatolia, modern Turkey, represents a long-lived urban center that lies between the Mediterranean and Near Eastern worlds and engaged with many cultural and economic influences throughout its history. Years of interdisciplinary investigation into agricultural systems and environmental change at Gordion, using botanical (Marston 2012; Miller 2010) and faunal (Miller et al. 2009; Zeder and Arter 1994) remains from the site, as well as regional geomorphological and archaeological survey (Kealhofer 2005; Marsh 1999, 2005; Marsh and Kealhofer 2014), provide rich datasets on human-environmental interaction to explore from a resilience perspective.

Deposits and structures at Gordion were dated using the Yassıhöyük Stratigraphic Sequence (YHSS), which is based on ceramic chronology from well-stratified deposits and targeted radiocarbon and dendrochronological dating (Rose and Darbyshire 2011; Voigt 1994; Table 1). Gordion was occupied from at least the Early Bronze Age (before 2000 BCE) through the Medieval period (thirteenth to fourteenth centuries CE), with only limited periods of intermittent abandonment prior to the Roman period, followed by a longer hiatus prior to Medieval resettlement (Voigt 2011). The site grew tremendously in size, population, and wealth as the capital of the Phrygian kingdom from 900-550 BCE. During this period, rulers at Gordion controlled the entirety of the Anatolian plateau, including areas of the highlands 400 km to the east (Roller 2011).

Gordion lies along the Sakarya River, with access within a 20 km radius to broad alluvial floodplains, dry upland plateaus to the south and west, and forested hills and mountains to the north and west (Figure 1). The vegetation of this region is characterized as “steppe woodland,” with elevations below 1000 meters above sea level (masl) that are characterized by perennial grasses and highly diverse herbaceous vegetation communities. Increasing densities of trees appear at higher elevations, with open woodlands around 1000 masl and canopy forest above 1200-1400 masl (Miller 2010; Zohary 1973; Figure 1). Geological sections and a reconstruction of the alluvial history of the Sakarya indicate that significant erosion postdates substantial human settlement of Gordion and suggest deforestation and overgrazing as probable causes for this erosion (Marsh 1999, 2005; Marsh and Kealhofer 2014).

The region of Gordion today is characterized by a continental, semiarid climate with rainfall mainly restricted to spring rains and winter snow (Atalay 1997; T.C. Meteoroloji Genel Müdürlüğü 2013). Annual rainfall over the past 80 years averages less than 350 mm; dry years are marginal for non-irrigated cereal agriculture (Marston 2010). Regional paleoclimatic reconstructions for central Anatolia indicate changes in temperature and precipitation during the occupation period of the site (Figure 2a). A significant period of aridity beginning perhaps as early as 1300 BCE (Eastwood et al. 2007; Kuzucuoğlu et al. 2011) and certainly by 1100 BCE (Roberts et al. 2011a; Roberts et al. 2011b) may have contributed to the dissolution of the Hittite Empire during the Late Bronze Age,

Table 1. The chronology of Gordion. Samples are grouped by periods for analytical convenience, although some can be dated more precisely to subphases within periods; a few deposits were precisely dated by radiocarbon analysis. Dates follow Marston 2012, after Voigt 2011.

YHSS phase	Period name	Approximate dates
1	Medieval	13 th -14 th cent. CE
-	Abandonment	4 th -13 th cent. CE
2	Roman	1 st cent. BCE -4 th cent. CE
3	Hellenistic	330-100 BCE
4	Achaemenid Persian	540-330 BCE
5	Middle Phrygian	800-540 BCE
6	Early Phrygian	900-800 BCE
7	Early Iron Age	1100-900 BCE
8/9	Late Bronze Age	1400-1200 BCE
10	Middle Bronze Age	1600-1400 BCE

affecting Hittite control of Gordion. The first millennium BCE appears to have been a period of fluctuating wet and dry periods, but such changes are not well correlated temporally within or between regions. Available data indicate relative aridity during the Iron Age and Hellenistic periods across the eastern Mediterranean, albeit with substantial local climatic variation in the intensity and timing of climatic shifts (Allcock 2013; Kuzucuoğlu et al. 2011; Wick et al. 2003). Humid conditions began in the Roman period and appear to have continued through roughly 1400 CE, after occupation had ended at Gordion

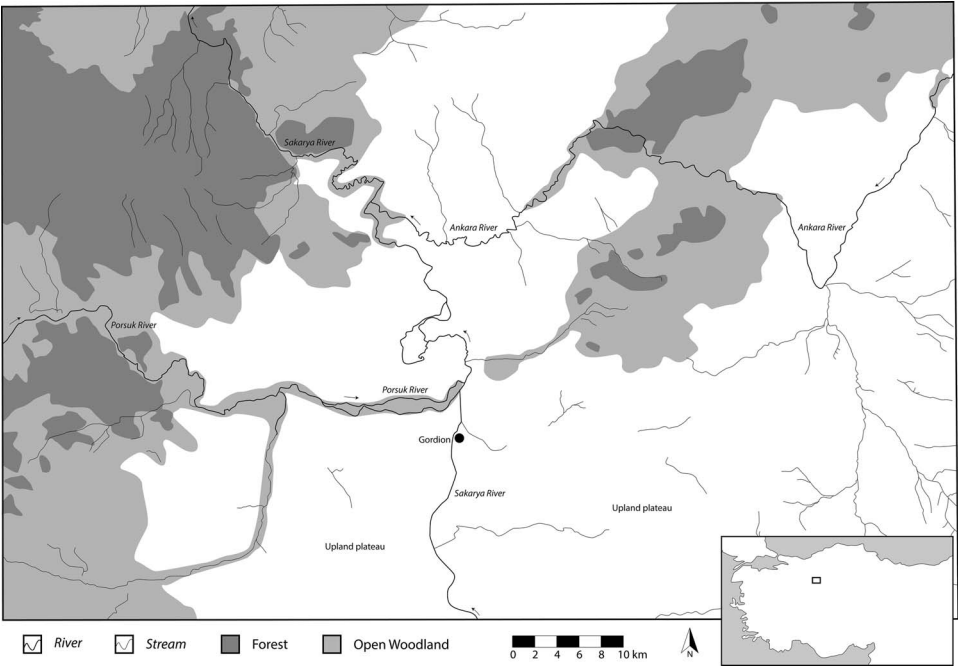


Figure 1. Map of the Gordion region depicting modern woodland distribution. Non-forested areas are steppe/grazing lands or under cultivation.

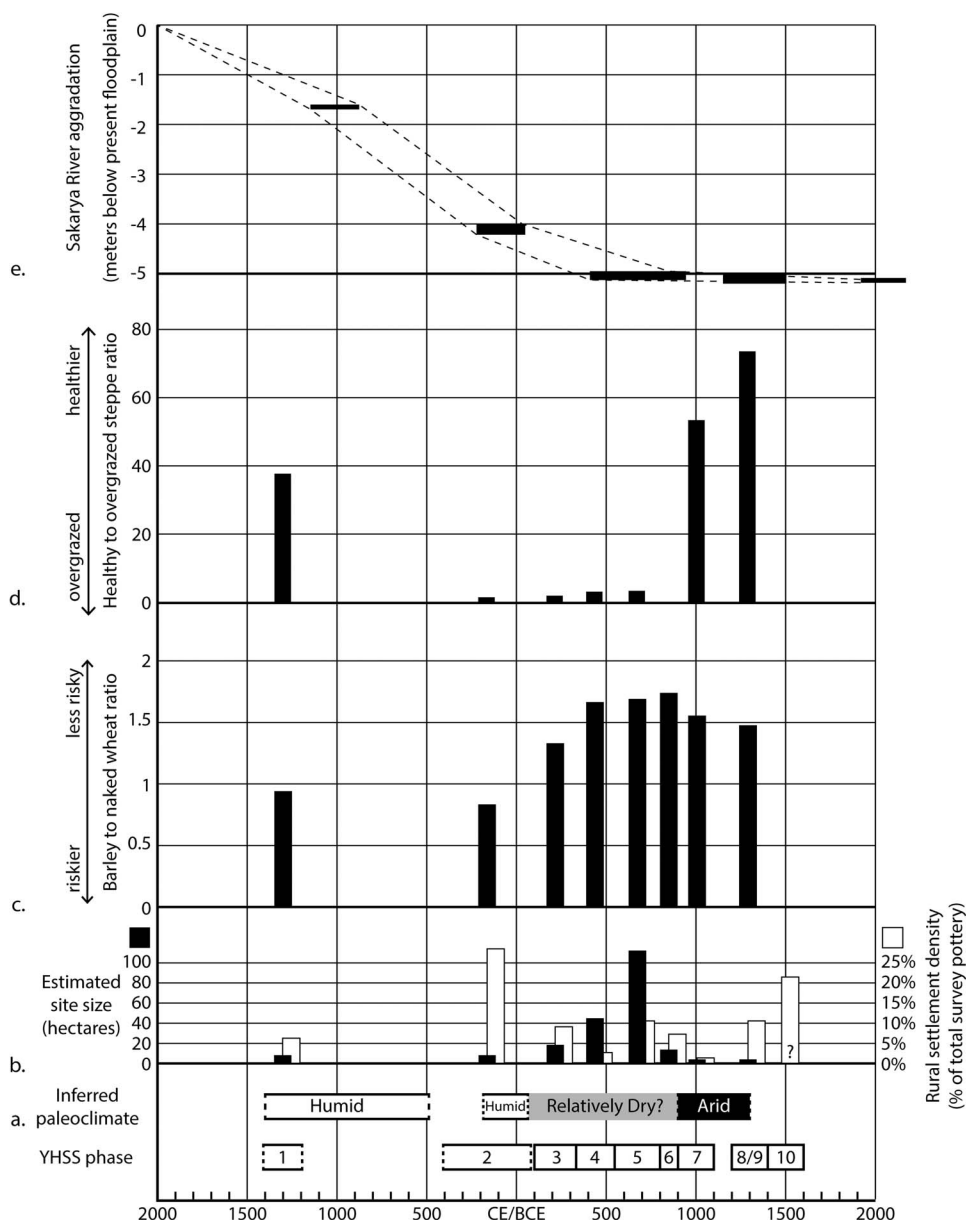


Figure 2. The environmental, agricultural, and settlement histories of Gordion. Samples are grouped by periods for analytical convenience and are placed at the midpoint of their period, except for erosion data where bars represent radiocarbon date error ranges. Nothing is known about agriculture or urban site size during the Middle Bronze Age from excavations to date. Site chronology follows Table 1; paleoclimate reconstruction (a) based on the consensus of multiple sources (described further in text); urban site size data (b, black bars) estimated from Voigt 2002; rural settlement density (b, white bars) from Kealhofer 2005:141; agricultural data (c, d) from Marston and Miller 2014:767; erosion data (e) for the alluviation of the Sakarya River from Marsh 2005:169.

(Bakker et al. 2012; Dean et al. 2013; Jones et al. 2006; Kuzucuoğlu et al. 2011; Woodbridge and Roberts 2011).

Agricultural and Environmental Change at Gordion

Prior research at Gordion includes the analysis of 452 flotation samples, averaging roughly 10 L of soil each, which yielded more than 90,000 carbonized seeds (Marston 2010; Miller 2010) and nearly 115,000 animal bones that were recovered by hand and from screened soils during excavation (Zeder and Arter 1994). These data demonstrate continuity in diet over time, with the cereals bread wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) as the primary crops and sheep (*Ovis aries* L.) and goats (*Capra hircus* L.) as the most common sources of meat in the diet throughout Gordion's history, although hard wheat (*Triticum turgidum* subsp. *durum* [Desf.] Husn.), lentils (*Lens culinaris* Medik.), bitter vetch (*Vicia ervilia* [L.] Willd.), cattle (*Bos taurus* L.), and pigs (*Sus scrofa* L.) also were significant foods (Miller 2010; Miller et al. 2009; Zeder and Arter 1994). What changes over time, however, are agricultural strategies and the balance between farming and herding. Agricultural strategies can be reconstructed through the recovery and analysis of charred botanical remains that are the product of repeated actions of daily practice related to crop processing and food preparation (Jones et al. 1999; van der Veen 2007). Simple statistics and integrated analysis of plant and animal remains allow for interpretation of entire agropastoral systems (Marston 2014; Smith and Miller 2009; VanDerwarker 2010; VanDerwarker and Peres 2010).

I have suggested that changes in cereal and pulse choice over time have implications for agricultural risk (Marston 2011). In particular, an emphasis on free-threshing bread and hard wheat, which require relatively more water than hulled barley, is a risky agricultural strategy in the drier regions of the Near East (Riehl 2009:98). This analysis suggests that the population that occupied this region during the Roman (YHSS 2) period adopted the riskiest agricultural practices (Figure 2c). Perhaps not coincidentally, this period represents the regional population maximum for the Gordion region (Kealhofer 2005; Figure 2b).

Pastoral practice can be reconstructed from animal bones, which can indicate herd structure and management strategies as well as butchery and meat consumption patterns (Arbuckle 2012; Arbuckle et al. 2009; Reitz and Wing 2008; Zeder 1991). Unfortunately, while preliminary species identifications are complete from all periods of occupation at Gordion except for the Roman period (Zeder and Arter 1994), more detailed data on age and sex structure of herds and the change in herd structure over time are not yet available. The ecological impacts of animal grazing, however, are evident in seeds derived from animal dung burned as fuel. A ratio, derived from more than a decade of comparative plant survey in the Gordion region (Marston 2012:393-394), that compares the seeds of plants characteristic of healthy, ungrazed steppe to those plants that persist in overgrazed indicates that local steppe landscapes were more overgrazed during the Roman period (YHSS 2) than during other periods of occupation (Figure 2d).

The ultimate result of human settlement and land use in the Gordion region was erosion on a regional scale. Two distinct periods of erosion are evident. Initial human occupation of the region resulted in changes in regional forest structure resulting from wood procurement (Marston 2009; Miller 2010) and rapid sedimentation of upland streams, which was likely the result of agricultural practices and animal husbandry in a previously unsettled landscape (Marsh 2005; Marsh and Kealhofer 2014). The Sakarya River, however, shows aggradation during a much later period, with most of its sedimentation dating to the Middle Phrygian (YHSS 5) and later periods (Marsh 1999, 2005; Figure 2e). Marsh and Kealhofer (2014:698) argue that this is likely due to the expansion of Phrygian and Roman agricultural practices upstream, suggesting a much broader landscape impact during these later periods of occupation.

Questions remain, however, concerning chains of cause and effect between these variables. Why did farmers change agricultural strategies when they did? What was the role of climate change versus human activity in causing regional erosion? To what extent were population growth and changes in cultural affiliation and economic networks causal forces in agricultural and environmental change? A resilience perspective offers new insights into cross-scalar processes and suggests a mechanism for environmental change at Gordion resulting from a complex set of historically contingent social-ecological interactions.

Scale, Mismatches, and Thresholds

A resilience approach to this case study shifts our focus from simple inferred causality based on chronological sequences of data to sustained attention on scalar processes that underlie both social and environmental change. In particular, varying scales of change between social pressures on landscapes and environmental responses appear to be significant factors in determining the resilience of agricultural landscapes and the economic systems built upon them (Cumming et al. 2006; Redman and Kinzig 2003). When such variances in scale have demonstrable negative effects on resilience in a system, they become scalar mismatches (Cumming et al. 2006).

I illustrate two examples of mismatches from Gordion. The first is a mismatch across temporal and spatial scales of population growth, herd mobility, grazing intensity, grassland growth, and soil formation. The second is a spatial and organizational mismatch between economic pressures imposed from without and the decision-making processes of individual farmers. Ultimately, I argue that both examples reveal thresholds (*sensu* Holling et al. 2002b) of environmental and social resilience: moments at which small changes trigger large-scale implications for people and landscapes, creating legacy effects for future generations (Groffman et al. 2006; Walker and Meyers 2004).

Temporal and Spatial Mismatches in Grazing Systems

A temporal mismatch results from interactions between cycles of change operating at different speeds. Whether these interactions result in significant change and the formulation of new system attributes depends in part on the degree to which the cycles of change are temporally disconnected and in part on

the intensity of the interactions between these cycles. Evidence for scalar mismatches has to date been identified much more often in contemporary case studies than in archaeological cases, despite the attested importance of this concept to understanding environmental and social change (Cumming et al. 2006; Redman 2005:71; Redman and Kinzig 2003:14).

Drawing on data from Figure 2, the Middle Phrygian period (YHSS 5) sees a rapid and substantial increase in site size and, presumably, urban population. There is contemporary evidence for overgrazing (Figure 2d) and the beginning of regional erosion leading to alluviation of the Sakarya (Figure 2e). Conventional archaeological analysis allows us to deduce that population pressure is the likely cause of overgrazing, which can lead to erosion (as I have argued in prior work; Marston 2012), but that does not explain the *process* by which this occurred and why this particular phase of site growth led to substantial environmental change.

A focus on temporal and spatial scale illustrates the important mismatches that ultimately led to regional erosion. I argue that it was not population growth itself, but the speed of that growth, that was the ultimate causal agent. As the city expanded rapidly, and rural populations remained large, there was both a rapid need for more agricultural products to feed the city and less space in which to produce that food. We see several indicators that herding strategies changed in response. The relative frequency of cow and pig bones at Gordion, versus sheep and goats, more than doubles from the Early to the Middle Phrygian period, perhaps because those animals can be kept penned within the urban setting and pigs are often fed on urban detritus (Miller et al. 2009). Sheep and goat herds would have been pushed farther from the city and its adjacent agricultural hinterland. We see evidence for less use of animal dung as fuel, suggesting it was less available to city residents, along with an increase in the presence of agricultural products and markers of overgrazed grassland in that dung, indicating that nutritious grasses were less available close to the city (Figure 2d; Miller and Marston 2012). The rapid increase in population and resulting increase in local agriculture would have led to increased grazing pressure in the remaining pasture lands close to the city, overwhelming local grassland resources, and pushed mobile sheep and goat herds away from the city into new areas, likely including hillslopes less suitable for agriculture. Preliminary strontium isotope ratio data indicate that Middle Phrygian sheep and goats came from geological regions more distinct than during the subsequent Persian period when Gordion was a smaller city, suggesting greater spatial mobility (DiBattista 2014).

The mismatch between the speed of population expansion and changes in herding strategies to become more spatially diversified had two effects. First, local overgrazing significantly transformed the structure of local grassland ecosystems, leaving grasslands in an impoverished state and diminishing their adaptive capacity to provide effective forage for herds, forcing some animals further afield and requiring the foddering of others with agricultural products. Herd management strategies changed to increase the mix of locally kept cattle and pigs over sheep and goats. But the ultimate, and presumably unforeseen, outcome of this adaptation was that the sheep and goats pushed out of the alluvial plains of the Sakarya and Porsuk Rivers moved into less stable soils on

gypsum upland plateaus south and west of the city and wooded hillslopes to the west and north, the areas least suitable for agriculture in the region. The presence of large herds, which both remove ground cover and displace loose soil, in these landscapes is the most likely cause for widespread regional erosion leading to the alluviation of the Sakarya (Figure 2e), which explains the patterns of increased geological variation seen in strontium signatures from Middle Phrygian sheep and goat remains. The environmental effects of this unprecedentedly large spatial scale of food production were distinct from the impact of earlier herding systems, leading to regional environmental change.

Spatial and Organizational Mismatches in Agricultural Production

In the case above, a temporal mismatch expanded across a broad spatial scale due to population pressures. Thus the ultimate causes for a suite of environmental changes lay in the social realm: both in the factors that led to rapid population growth and the lag in implementing effective adaptive strategies before local grasslands were significantly altered. An example from the subsequent Roman period at Gordion, however, illustrates a mechanism by which political and economic forces produced spatial and organizational mismatches, leading to the adoption of unsustainable agricultural practices that diminished the resilience of local agricultural systems and increased social and environmental vulnerability.

Regional surveys at Gordion indicate an increase in rural population during the Roman period (Figure 2a), perhaps due to the protection of a Roman military unit stationed at Gordion itself (Goldman 2007), which would have made living outside the city walls a safer proposition. Coincident changes include a focus on the cultivation of bread wheat, a relatively risky crop requiring good rainfall, at the expense of a broader suite of agricultural products as seen during all earlier periods (Marston and Miller 2014; Figure 2b). Measures of steppe health indicate severe overgrazing during this period (Figure 2d), suggesting large sheep and/or goat herds (although faunal data have not yet been published from Roman levels). Crop specialization is risky (Marston 2011), as is keeping large herds that primarily rely on pasture land (seen in a low proportion of agricultural products in dung burned as fuel) (Marston and Miller 2014). Increased chances for crop failure and accelerated erosion are likely outcomes; it is difficult to imagine that farmers with generations of experience in the region would have been unaware of these risks. So why would farmers and herders at Gordion adopt risky and potentially unsustainable agricultural practices that might permanently alter their landscape?

The answer appears to lie in spatial and organizational mismatches between external economic pressures and local agricultural decision making. Extractive taxation policies imposed by provincial governors during the Roman period encouraged intensive farming of bread wheat, which was valued more highly by tax collectors (Marston 2012:395; Mitchell 1993:149-158, 232-234). Wool, or woollen goods, may have been another form of tax payment levied on local populations (Mitchell 1993:146). The decision makers who dictated these taxes were spatially divorced from the location of production, as they resided in the provincial capital of Ankara or ultimately in Rome itself, as well as organizationally uninvolved in

agricultural production. As a result, adaptive feedbacks between land-use strategies and their environmental impacts that we observe operating in earlier periods no longer informed production decisions. Such outcomes are predicted by resilience thinking: when fixed rules for resource management take the place of adaptive response to changing resource availability, and emphasize *efficiency* of function rather than long-term *existence* of function, rapid changes in both economy and environment are expected (Holling and Gunderson 2002:27-28). Both fixed rules and an emphasis on efficiency are evident within Roman taxation practices, and both are associated with nonlocal or extractive decision making in general (cf. Ostrom 1990; Ramankutty 2001; Tainter 1995). When external forces override local decision making that are based on accumulated local environmental knowledge, traditional conservation practices may cease to be implemented, exacerbating the degree of environmental change resulting from agriculture (Berkes and Turner 2006; Cumming et al. 2013; Lepofsky and Kahn 2011; Turner and Berkes 2006).

Such a regimented economy, which demands specific products despite local conditions, may lead to a “rigidity trap” in which static overconnectedness within a system (here, within the regional economy) reduces adaptation and innovation, and thus increases the probability that a subsequent change in the system is catastrophic (Hegmon et al. 2008; Holling et al. 2002b). In this rigid, externally controlled state, the agropastoral system of Gordion was increasingly vulnerable to shocks from within and without the system, including natural hazards (Berkes 2007; Nelson et al. 2012; Turner II 2010). In this vulnerable state, it was easier to cross a stability threshold leading to local economic transformation, perhaps the cause of the subsequent abandonment of Gordion in the fourth century CE, during the height of Byzantine prosperity in Anatolia.

Thresholds of Stability

The mismatches identified above during both the growth of the Phrygian city and the static extractive economy of the Roman period highlight stability thresholds that have not been readily apparent in prior investigations at Gordion. A threshold of soil stability was breached by Middle Phrygian agricultural practices, as recorded in the alluvial history of the Sakarya River (Marsh 1999; Figure 2e). This threshold is ecological in nature, as sufficient plant cover is needed to retain soil on hillslopes and on dry upland plateaus, but its crossing is the effect of the speed of change within a social system, that of the agropastoral economy. A similarly rapid increase in land devoted to pasture without the corresponding reduction of herd sizes in recent years has led to significant environmental degradation in central Anatolia (Fırıncioğlu et al. 2007), and we can envision a parallel regional process having occurred during the expansion of the population and urban footprint of Phrygian Gordion. While the ecological nature of this threshold has been discussed previously (Marsh 1999; Marsh and Kealhofer 2014; Marston 2012), attention to the process of crossing that threshold yields new insights into the linked social and environmental factors that led to upland erosion at Gordion. In addition, climate change leading to increased rainfall in Anatolia during the Roman period (Figure 2a), coupled with ongoing regional deforestation (Marston and Miller 2014; Miller 2010), may have then

exacerbated the erosion that began in the Middle Phrygian period, resulting in increased aggradation of the Sakarya river from the first century BCE (Figure 2e).

A second threshold highlighted in considering Roman Gordion relates to the impact of economic and political processes that limit the autonomy of farmers and their ability to respond to changing local conditions. Within the social and economic framework of the Phrygian kingdom, the increased population did not trigger apparent social instability — we see an intensification and expansion of agricultural practices, but one regulated at a local level, with farmers continuing to use traditional agropastoral strategies. During the Roman period, however, externally imposed parameters limited the ability of farmers to adapt to local environmental conditions, resulting in a specialized and risky agricultural system focusing on bread wheat (Figure 2c) and extensive animal grazing (Marston and Miller 2014; Figure 2d). This mismatch in decision making reveals thresholds of both environmental and socioeconomic stability. Taxes within the Roman Empire were evidently sufficient to alter agricultural strategies significantly, leading farmers to adopt rigid and ultimately unsustainable practices, as evidenced by severe overgrazing and economic vulnerability that may potentially have contributed to the abandonment of Gordion in the fourth century CE.

Awareness of thresholds also brings attention to the management of resilience and the points of intervention at which stress can be reduced and resilience increased (Walker et al. 2002). The causal processes that lead to thresholds being crossed are not the only processes of interest; rather, those that serve to maintain system resilience and prevent thresholds from being reached are equally worthy of attention. Contemporary studies of system resilience often focus on quantifiable indicators of sustainability that can be made more resilient to loss of system function, e.g., in urban water distribution (Milman and Short 2008). From an archaeological perspective, however, abrupt systemic change (often termed “collapse”) is often easier to identify than continuity and adaptation.

Legacy Effects

Legacy effects provide a middle ground for consideration; less abrupt or far reaching than a collapse, legacy effects are the long-term results of interactions between social and environmental processes that result in altered conditions for subsequent populations. At Gordion, two legacy effects are evident. The first is the result of human wood procurement for both construction and fuel, which is tied directly to agropastoral practices and the availability of dung fuel. Transformation of local woodlands is evident in charcoal remains from the site; the reduction in slow-growing juniper and its replacement with pine and oak occurs early in the occupation history of the site prior to the large population increases of the Phrygian period (Miller 2010). These results are suggestive of broader changes in woodland cover that appear to have endured through the present day. Today, large junipers are found only at a distance of 20 km from the site (Marston 2009).

A second legacy effect is soil erosion, which takes place in two phases. First, during early human settlement of the Gordion region (the Chalcolithic through Middle Bronze Age, prior to 1600 BCE), anthropogenic landscape disturbance led to highland erosion and stream aggradation (Marsh 2005; Marsh and Kealhofer

2014). A second phase of erosion upstream of Gordion began in the Middle Phrygian period, possibly exacerbated by increased rainfall during the Roman period, and resulted in the aggradation of the Sakarya River (Marsh 1999; Marsh and Kealhofer 2014). Both phases of erosion constrained the future choices of the inhabitants of Gordion. Marsh and Kealhofer (2014) argue that early erosion was of more fragile and easily transported hillslope sediments, constraining subsequent agriculture to more durable plains sediments. The increased sedimentation rate of the Sakarya River during later periods created significant problems for inhabitants of the site, as the river began to erode city walls and swamped much of the lower town, rendering that area uninhabitable following the Roman period (Marsh 1999). Medieval residents and contemporary farmers in the area have engaged with a landscape significantly transformed from that encountered by the first inhabitants some 5000 years ago.

Conclusions and Future Directions

Through the well-documented case study of Gordion, I attempted to demonstrate the utility of resilience thinking for elaborating how social and environmental change affect the sustainability of agricultural systems. The concepts of mismatches and thresholds provide an effective heuristic model to explain processes of interaction between human actions and environmental change that are not the result of simple cause and effect. Mismatches in temporal scale have helped to explain cycles of deforestation and population movement in the American Southwest (Peeples et al. 2006) and may prove useful for resolving high-profile debates about the role of humans in environmental degradation and social collapse, such as the ongoing argument regarding deforestation and population decline on Easter Island (e.g., Diamond 2005; Hunt and Lipo 2010; Mieth and Bork 2010). In particular, as temporal mismatches between population growth, agriculture, and cycles of landscape renewal (e.g., grassland growth, soil formation, forest succession) were the primary cause of human-induced landscape change at Gordion, I suggest that closer study of rates of change both in agricultural systems and local ecosystems can help us identify why certain agricultural practices may have been sustainable in certain times and places but not in others.

Spatial and organizational mismatches should prove to be useful concepts in building causal explanations to assess the differential impacts of imperial and colonial expansions on local agricultural practices, and to situate those case studies in a diachronic, worldwide perspective (cf. Cumming 2011a). At Gordion, periods of local autonomy and foreign imperial domination are evident. The least sustainable agricultural system was adopted during the period of Roman foreign control, but other periods of external political control resulted in sustainable agricultural outcomes (e.g., Achaemenid Persian). This case highlights the wide range of potential outcomes of imperial control due to the diverse array of complex factors that play a role in agricultural decision making. Resilience thinking suggests that the degree of environmental degradation resulting from extralocal decision making will be influenced by the resilience of the local ecosystem to agricultural practices, the nature of any taxation or tribute imposed, and the degree

to which external control restricts local adaptive decision making. Exploring these processes at different locations and scales throughout an empire should yield important insights into imperial policies and the role of local ecosystems in modulating the environmental and economic outcomes of those policies.

I believe that in addition to benefiting from the application of resilience thinking, archaeologists can offer important new insights to resilience scholars (cf. Redman et al. 2004; van der Leeuw and Redman 2002). Thresholds deserve particular attention. Archaeologists have access to data that provide a uniquely powerful ability to detect thresholds of social or ecological resilience in the past because we can identify when abrupt transformations occurred and then explore what factors contributed to those thresholds being crossed (van der Leeuw and Aschan-Leygonie 2005). We also have the ability to work across spatial scales, from the household to the hemisphere, and thus the ability to examine how resilience concepts explain social and environmental change from the micro- to the macro-scale (Cumming 2011b; Redman 2005). Resilience is employed to explain global patterns of environmental and social change today, and archaeologists should consider it on similarly broad scales in the past, despite its limited application at regional scales to date (Redman and Kinzig 2003). Geographically and culturally connected zones, such as central Anatolia or the Basin of Mexico, would be particularly fruitful scales at which to work. A resilience perspective on agricultural sustainability provides a framework within which to integrate the past, present, and putative future of such regions, and thus to draw on the past to help make more sustainable decisions for the future.

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