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Archaeology for Sustainable Agriculture

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Abstract
How will archaeology contribute to agricultural sustainability? To address that question, this overview reflects on the diverse and complementary ways that archaeology has advanced our understanding of sustainable agriculture. Here, I assess recent archaeological research through the lens of the five principles of sustainable agriculture used by the Food and Agriculture Organization of the United Nations. These principles—efficiency, conservation, rural livelihoods, resilience, and governance—highlight the social and environmental dimensions of agricultural sustainability. By drawing on case studies from around the world, I show how archaeology is uniquely situated to examine the interactions of these social and environmental dimensions over long periods of time. Archaeology's strongest conceptual contributions to sustainable agriculture are (1) its capacity to demonstrate that sustainability is historically contingent and (2) its attention to outcomes. If transformed into meaningful action, these contributions have the potential to advance modern agricultural sustainability and environmental justice initiatives. This overview is an invitation to clarify a plan for future research and outreach. It is an invitation to imagine what an archaeology for sustainable agriculture will look like and what it will accomplish.

Keywords Agriculture · Sustainability · Food systems · Climate change

Introduction

We have just about 30 years, as I write this, to figure out a way to produce the 13.5 billion metric tons of food every year needed to feed the 9.3 billion people who will be alive in 2050 (FAO 2014a). We produce about 8.4 billion metric tons now, mostly in ways that have depleted and continue to deplete the health of our ecosystems. If our agriculture does not change, soon and in major ways, there is simply no way that humankind will be able to meet its food needs three decades from now.

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These kinds of figures and language are grim. They raise feelings most of us would rather avoid. But at the same time, their urgency has compelled the optimists among us to seek creative and meaningful action to meet the challenges of the coming decades head on. The movement to make our food and agroecosystems more sustainable, to ensure hope for future generations, has drawn farmers, politicians, activists, chefs, and community and spiritual leaders into the effort. It has also drawn scientists from diverse fields. These scientists realize a common conviction that their work can contribute, in some way, to a more sustainable food system. Among them are archaeologists.

This paper is an overview of how archaeology has participated in the sustainable agriculture movement. Though saturated with the urgency of the present moment, this overview is an invitation to collect our thoughts as a field and pause to consider how we will continue to advance archaeology's contribution to agricultural sustainability. From my reading of the literature, I see two areas where archaeology has particularly great potential to contribute to agricultural sustainability initiatives. The potential contributions, I should emphasize, are largely *conceptual*. Figuring out ways to transform these conceptual contributions into meaningful action is its own challenge. While I offer my own preliminary ideas as to what those actions might look like in the concluding section, most of this overview deals with archaeology's conceptual contributions to sustainable agriculture.

The first potential contribution is archaeology's capacity to demonstrate that agricultural sustainability is *historically contingent*. Even agricultural techniques considered inherently sustainable rise and fall in dynamic relationship with social, political, economic, and environmental factors. When agricultural sustainability is "achieved"—itself a slippery word that mistakenly suggests we can freeze a society and its agriculture in time—it always comes at a cost. For whom is it sustainable? What is it, exactly, that is being sustained? What is and is not being valued when we say something is sustainable? Emphasizing the historical contingency of agricultural sustainability allows us to explore these questions and the tensions they hold. Importantly, archaeology's ability to document and explain long-term processes of complex change counters narratives that would cast agricultural sustainability as ahistorical or apolitical. This contribution invites critical discussion of the social factors of sustainability. It challenges the typecasting of ancient (or really any preindustrial) agriculture as inherently sustainable and in harmony with nature. Archaeology can enhance the sustainability discourse by showing the complex ways in which sustainability itself is a historically contingent construct.

The second potential contribution is archaeology's *attention to outcomes*. This is closely related to historical contingency. Not only can archaeology show that sustainability is historically contingent, it also can investigate specific instances of long-term agricultural success and failure. We have the ability to show under what conditions—social, political, economic, and environmental—a particular agricultural system is sustainable. We can document how and how well that agricultural system responds to unexpected change. Just as importantly, we can identify and explain what has to happen to render that same agricultural system unsustainable. In this way the agricultural past offers us, as the poet and environmental activist Wendell Berry (2015, p. 184) puts it, "a lexicon of proven possibilities and understood mistakes" that we can compare against our still unfolding modern agricultural systems. This attention to outcomes offers a fuller understanding of the collective human record of past successes and failures. What lessons might be waiting for us?

I return to these two contributions in the sections that follow as I develop an overview of the archaeology of sustainable agriculture. I chose to frame this discussion using the principles of sustainable agriculture defined by the Food and Agriculture Organization (FAO) of the United Nations (UN). The FAO is a leader in promoting global agricultural sustainability and, critically, marshals a range of programs that span the spectrum of top-down (e.g., policy decision analysis) and bottom-up (e.g., education for smallholder farming families) initiatives. I chose to structure this overview around FAO's principles because they showcase archaeology's potential contributions to a broader sustainability discourse. In the paper's conclusion I discuss possible strategies for advancing archaeology's role in agricultural sustainability initiatives. I begin by tracing how archaeologists have developed approaches for understanding sustainable agriculture.

Understanding Sustainable Agriculture in the Past

Since modern archaeology's beginnings, archaeologists have studied the agriculture of past societies (e.g., Curwen 1927). The materials of farming are many—tools, seeds, canals, storage and processing facilities, the land itself— and lend themselves to the most basic kinds of archaeological investigation. Over the last century, archaeologists have transformed our understanding of the origins of agriculture and domestication (e.g., Flannery 1986; Piperno and Pearsall 1998; Watson 1995; Zeder 2011), the dynamic relationship between political complexity and subsistence (e.g., Hastorf 1990; Kirch 1994; Marcus and Flannery 1996), and the lived experiences of farmers in the past (e.g., Bender 1978; Hegmon 2016; Warner 2015), among other lines of inquiry.

To provide a general summary of archaeology's deep and ongoing attention to agriculture would be a formidable task—and not necessarily useful for the specific considerations of this paper, which deals not with agriculture in isolation but with the intersections of *archaeology and agricultural sustainability*. I step into the conversation in the later decades of the 20th century, at the point when "sustainability" entered the international imagination as something worth caring about.

The Origins of "Sustainability"

Farmers understood "sustainability" long before a mid-20th century mix of anxiety and optimism gave rise to the term itself (du Pisani 2006; Kidd 1992). With the advent of environmental crises, and public awareness of those crises, the word was coined. Western ideas of limitless human progress, forged in the Enlightenment and tempered during the Industrial Revolution, met the post-World War years with enthusiastic commercial development. Wartime technologies were adapted for agricultural production. The resulting chemical fertilizers, heavy mechanization, and other innovations fundamentally changed farmers' relationship with the land.

Yet by the late 1960s and early 1970s, the confluence of population growth, increased consumption, and the dawning realization that we *could* deplete the planet's natural resources served as harbingers of a coming environmental crisis (du Pisani 2006). The Green Movement and its keystone writers and activists pointed to an alternative to unchecked economic growth (e.g., Abbey 1968; Berry 2015; Carson 1962). They borrowed the term and language of "sustainability" from ecology to describe a set of compromises between development and environmental conservation that could be maintained indefinitely (Goldsmith and Allen 1972).

Sustainability emerged as a new paradigm of development in the 1980s, but it crystallized as an international movement when the United Nations coordinated efforts to develop long-term environmental strategies at a global scale. It is from this collaboration, called the Brundtland Commission (WCED 1987), that emerged the basic definition of sustainable agriculture used by many people and organizations today: agriculture "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 43). Though facing its share of critiques (e.g., Mitcham 1995) and evolving through shifting moral arguments (du Pisani 2015), the concept of sustainability has persisted.

From this work, we define *sustainable agriculture* as the production of food and other agricultural products, like fiber and fuel, in ways that ensure that future generations will be able to continue to do so and, simultaneously, conserve and, ideally, enhance the environment (FAO 1997, 2014a, b; Pretty 2008; WCED 1987). The components of food and agriculture are complex, and so it is helpful to invoke the language of systems to describe their many interrelated parts. I use *agricultural system* (and occasionally *food system*) to describe the people, institutions, and processes involved in agriculture. Lastly, the framework of *agroecology* is important to my approach. Agroecology refers to the integration of science and social action that brings sustainability into all levels of the food system (Altieri 1995; Gliessman 2018). It is an action-oriented approach and calls for the advancement of scientific research, the application and sharing of farmers' practical knowledge, and advocacy for social change.

Technologies and Approaches for the Archaeology of Sustainable Agriculture

As sustainability science has evolved over the last few decades, archaeology has been assembling in tandem the tools and approaches needed to study agricultural sustainability in the past. These developments employ interdisciplinary approaches and have allowed our field to evaluate not just past agriculture but to address explicitly past agricultural sustainability.

Technological advances enable us to study ecological relationships and the physical environment underlying past agricultural systems. Analyses of ancient plant, animal, and human remains have advanced to the point that we can reconstruct many details about ancient farming and diet (e.g., Beck et al. 2018; Clutton-Brock 1989;

Evershed 2008; Graff 2018; Lentz et al. 2014; Piperno 2011; Piperno and Flannery 2001). Soil chemistry can now tell us about land-use practices in areas with little to no visible archaeological traces (e.g., Beach 1998; Rodrigues et al. 2017; Wells et al. 2018; Wingard and Hayes 2013). Paleoclimate data allow us to situate our archaeological findings within the larger context of environmental and climate fluctuations (e.g., Bocinsky and Kohler 2014; d'Alpoim Guedes et al. 2016; Kintigh and Ingram 2018). Innovations in survey technology, particularly geophysical methods and LiDAR (Light Detection and Ranging), have accelerated our ability to document and analyze landscape modifications and settlement patterns (e.g., Chase et al. 2011; Kirch et al. 2012; McCoy and Ladefoged 2009). Computational modeling allows us to tinker with the many variables in agriculture and other complex systems (e.g., Altaweel 2008; Crabtree and Kohler 2012; Kohler and Reese 2014). When combined with more traditional kinds of archaeological investigation, these technological advances greatly enhance our capacity for understanding the components and parameters of past agricultural systems.

In tandem with these technologies, explanatory frameworks have developed to address questions of agricultural and environmental sustainability in past contexts. These frameworks draw on the work of environmental anthropologists (e.g., Netting 1993; Rapoport 1976; Steward 1955; Wolf 1982) but explicitly and deliberately connect to the larger sustainability discourse as it has developed since the late 20th century. Many of these approaches have adopted the landscape as the primary unit of analysis (e.g., Ashmore and Knapp 1999; Scarborough 2003). Among these, historical ecology (e.g., Balée 1998, 2006; Crumley 1994; Isendahl and Stump 2015) and political ecology (e.g., Ashmore 2018; Lohse 2013; Morehart et al. 2018) stand out as productive frameworks for integrating multiple kinds of data and scales to understand human–environment interactions. Anthropological archaeologists have also addressed agricultural sustainability using perspectives and themes drawn from a larger discourse of climate change (e.g., Lucero et al. 2011; Van de Noort 2011), particularly the Anthropocene (e.g., Braje 2015; Crumley 2015; Lane 2015; Laparidou and Rosen 2015), anthropogenic environments (e.g., Bush et al. 2015; Chase and Chase 2016), and resilience thinking (e.g., Bogaard et al. 2017; Davies and Moore 2016; Goodman-Elgar 2008).

Where Are We Now?

Making our agricultural systems more sustainable is a challenge that demands collaboration across disciplines and the application of creative new approaches. Archaeologists have been a part of this conversation for a while now. We contend that we have something to say for modern agricultural sustainability, that the past holds lessons for the future (e.g., Barthel and Isendahl 2013; Chase and Scarborough 2014; Kennett and Beach 2013; Minnis 1999; Scarborough et al. 2012a; Tainter 2014; van der Leeuw 2014). Our field's innovative approaches have generated long-term, multiscalar narratives of social and environmental change. With these discoveries, archaeologists have shown definitively that we are capable of participating in the larger discourse of agricultural sustainability.

Yet this moment we live in is an urgent one. Our food systems are straining under rising populations, political inequality, ecologically unsound agricultural and dietary practices, and the environmental crises associated with anthropogenic climate change (FAO 2014a, b; FAO et al. 2017; Giovannucci et al. 2012; Sanz et al. 2017). Archaeology, like other environmental social sciences and the environmental humanities, has offered its services as a pathway forward into some imagined, improved future. How do we transform this offer of service into meaningful action? What steps would create an archaeology *for* sustainable agriculture, rather than simply an archaeology *of* sustainable agriculture?

This overview sits with the tension of that question and sets out to do a couple of things with it. First, this is a starting point for anyone unfamiliar with how archaeology can document and explain agricultural sustainability in the past. Second, for those of us who *are* archaeologists studying agricultural sustainability, this overview is an invitation to pause and take stock of the field's progress during the past few decades. It is time to clarify what exactly we are contributing and think about how we might transform those proposed contributions into meaningful action. I have laid out what I perceive to be two of archaeology's potential contributions to the larger agricultural sustainability discourse: its capacity to enrich our understanding of agricultural sustainability as historically contingent, and its attention to outcomes, or "finished" cycles of agricultural development. I find these two contributions compelling, but there are hopefully many more. I welcome the expansion of this list; this challenge can be met effectively only if our perspectives are many and diverse. How these conceptual contributions might be transformed into action is a challenge explored at the end of the paper, and while admittedly speculative, these proposals offer ideas for future directions. We might take this as an opportunity to look ahead while reflecting on how we got here, to be critically introspective while also being hopefully optimistic. As we prepare to enter the third decade of the century, this overview is an invitation to ask ourselves, how will we create an archaeology for sustainable agriculture?

Archaeology for Sustainable Agriculture

Archaeological research on past sustainable agriculture has generated insights with potential applications for our modern food systems. One of my goals in this paper is to make these potential applications more accessible. To do that, we need to situate archaeological research in the frameworks already in use by the scientists, policy makers, economists, and others working on these initiatives at an international level. We should, in other words, strive to meet the conversation where it is rather than wait for it to come to us. With that end, I organize this overview around the sustainable agriculture guidelines used by the Food and Agriculture Organization of the United Nations.

The FAO has been a leader in global campaigns for sustainable agriculture as part of its declared mission to eradicate world hunger (FAO 2014a, b, 2017, 2018; Giovannucci et al. 2012; WCED 1987). The FAO coordinates agricultural development and resource management, conducts research, provides technical assistance and support, runs educational programs, manages production and consumption data, and disseminates information through various formats. However, the FAO is a huge intergovernmental organization, and it has all the baggage of one. The organization has its problems (see especially critiques of neoliberal and neocolonial practices, e.g., Goldsmith et al. 1991), and my use of FAO guidelines is not an endorsement of all of the FAO's policies and actions. Bearing that in mind, the organization's guidelines still provide an accessible entry point into the ongoing global discourse around agricultural sustainability.

The FAO (2014a) outlines five key principles for a common vision of sustainable agriculture. These are cast as a response to the current and coming challenges of rising population, increasing resource competition, and changing climate. These five principles emphasize that sustainability is not only an environmental challenge, it is equally social, economic, and political. The five principles of sustainable agriculture, as outlined in the FAO (2014a) report, *Building a Common Vision for Sustainable Food and Agriculture: Principles and Approaches*, are efficiency, conservation, rural livelihoods, resilience, and governance.

These five principles illustrate the balance between the social and environmental dynamics of agricultural sustainability. Because archaeology operates at the interface of the social and natural sciences, these principles invite full consideration of archaeology's potential contribution to this issue.

These five principles structure my overview of archaeology's contribution to sustainable agriculture. Examples and more in-depth discussion of archaeological research are linked to each principle. Some of the examples I describe could have been discussed under multiple (or all five) principles. This underscores how interrelated these concepts are.

I organize the FAO's principles into two groups. Efficiency and conservation deal with practical agricultural strategies. In terms of archaeology, these principles are all about the materials, technologies, and infrastructure that past societies used to farm. These first two principles assemble a toolkit: the stuff and strategies used in sustainable agriculture.

The remaining principles of sustainable agriculture—rural livelihoods, resilience, and governance—deal with holistic considerations of how those agricultural toolkits play out in the messy context of social and environmental change. Archaeology is at its best here, and I introduce what I consider to be some of the leading research programs related to these principles. I begin with efficiency.

Efficiency

> "Improving efficiency in the use of resources is crucial to sustainable agriculture." (FAO 2014a, p. 20)

The FAO's first principle of sustainable agriculture is about doing more with less. How can farmers maximize agricultural products while minimizing impacts on natural resources? The process of manipulating inputs to increase agricultural efficiency is often called intensification (e.g., Boserup 1965; Tilman et al. 2011).

Intensification frequently relies on physical infrastructure. For this reason, it often leaves traces that are recognizable to archaeologists. Archaeologists have documented ancient agricultural intensification around the world (e.g., Kirch 1994; Smith and Price 1994; Stone 1994; Thurston and Fisher 2007). Thinking more specifically about how the archaeological study of intensification informs our understanding of past agricultural sustainability, we can home in on major strategies used by past farming societies to use resources efficiently. These include water management (both in dryland and tropical settings), raised-field farming, and infield agriculture. Although archaeologists have studied these techniques and technologies for some time, our ability to analyze their sustainability is a more recent development. Most of the coverage I provide here is sweeping (intensification has been documented archaeologically all over the world), but I draw attention to examples of archaeology's ability to show how "inherently sustainable" strategies can and do fail.

Even with just this first principle of efficiency, we begin to see some of the complications that arise when we try to pin down what sustainable agriculture is and is not. Efficiency has its costs, and the way we understand those costs depends greatly on where and how value is placed (Hegmon 2017; Nelson et al. 2010). This in itself is a subject that merits greater attention and should be kept in mind while considering the archaeology of intensive agriculture.

Dryland Water Management

For past people living in arid environments, efficient water management made agriculture possible, and agriculture made aggregated settlements possible. There is a wide range of strategies that allowed past farmers to conserve moisture (e.g., Fish et al. 1985; Stone and Downum 1999), but the technique that has received the most attention from archaeologists is irrigation. Irrigation was key to using water efficiently in deserts. This technology developed independently among past farming societies around the world and continues to be practiced today (FAO 2018). Irrigation agriculture let farmers minimize water usage while prolonging the growing season and expanding the amount of arable land around rivers and oases (e.g., Adams et al. 1974; Marcus and Stanish 2006).

Yet the sustainability of irrigation agriculture should not be automatically assumed. While irrigation has been portrayed as a crux of early civilization (e.g., Wittfogel 1957), it also can be difficult to maintain for long periods of time. Farmers who practiced irrigation agriculture had to deal with increased soil salinity, whether they were in the Middle East or the southwestern United States (e.g., Benson 2010; Benson et al. 2009; White et al. 2014). Living around irrigation canals also could make people sick from the parasites that lived in canals (Paseka et al. 2018). At the same time, archaeologists continue to find evidence that past farmers were able to mitigate the potential drawbacks of irrigation using sophisticated ecological knowledge (Altaweel and Watanabe 2012; Tankersley et al. 2016; Wills and Dorshow 2012). Like other ostensibly sustainable practices, irrigation's success or failure depends on a complex relationship of social and environmental factors (McCool et al. 2018; Nelson et al. 2006, 2012, 2016; Spielmann et al. 2016; Strawhacker 2013).

Archaeologists and others recognize that some ancient water management techniques are inherently more sustainable than some practiced now. Qanats or chain wells, the underground irrigation canals that developed in ancient Iran, are remarkably renewable systems of desert water management that have been targeted for revival by modern advocates of sustainable irrigation agriculture (e.g., Manuel et al. 2018). Overall, ancient people's dryland water management techniques are among the most popular candidates for repurposing in modern agricultural contexts (e.g., Holt 2017; Mays 2017).

Tropical Water Management

Farming in the tropics came with its own set of challenges for water management. Extreme seasonality meant that water was scarce for part of the year and abundant—sometimes devastatingly abundant—during the rainy months. Ancient tropical farmers learned to mitigate these extremes through systems of drains, canals, and reservoirs (e.g., Lucero and Fash 2006).

Some tropical civilizations became so skilled in hydraulic engineering that they were able to support sprawling urban settlements. Two of the best-documented civilizations are the Classic (AD 250–900) Maya of Mesoamerica and the medieval (AD 800–1500) Khmer of Angkor in modern Cambodia. Evidence suggests that cities in both civilizations were fed through infield or urban agriculture. They managed this by combining diverse water storage techniques, ranging from state-sponsored hydraulic infrastructure to drains, canals, and constructed reservoirs managed by households (e.g., Chase 2016; Evans et al. 2013; Fletcher et al. 2008; Lucero 2002, 2006, 2018; Lucero et al. 2015; Scarborough and Isaac 1993; Scarborough et al. 1995, 2012b; Stark et al. 2015). These hydraulic systems were integrated directly into urban settlements and incorporated measures to maintain water quality and recycle graywater to agricultural fields. Yet ultimately, the sustainability of water management strategies in the tropics depended on a complex set of human and environmental relationships.

Raised-Field Farming

Raised fields allowed ancient farmers to cultivate wet and waterlogged areas they otherwise could not have farmed. Raised fields were constructed in wetlands by mounding up soil into beds above the water level and then planting on them. Canals separated the beds and allowed for easy watering. Raised fields conserved thermal energy, facilitated drainage, and possibly allowed multiple harvests per year by extending the growing season (Darch 1983; Kolata and Ortloff 1989). Farmers also could spread the organic matter (muck) that accumulated in the canals onto the beds to enhance soil fertility (Biesboer et al. 1999; Binford et al. 1996; Carney et al. 1993, 1996; Kolata 1991). Additionally, the canals of raised-field farming systems may have offered opportunities for fish farming (Thompson 1974; but see Puleston 1977).

Raised-field farming was one of the first ancient agricultural strategies to be studied in a sustainability framework. Though ancient raised-field farming systems are found throughout the world (e.g., Gallagher et al. 1985; Golson et al. 2017; Groenman-van Waateringe and van Geel 2017), archaeological study of raised fields has been especially productive in Mesoamerica and South America (e.g., Armillas 1971; Erickson 2008; Kolata 1986, 1991; Nichols and Frederick 1993; Parsons 1991; Sanders et al. 1979).

As archaeological investigations of land-use practices employ new and interdisciplinary methodologies, we are learning that raised-field agriculture is much more diverse than previously assumed. Some of the best insights about this diversity are emerging from research in the Amazon Basin. There, for example, ancient Amazonian farmers may have used raised fields as a short-term strategy for dealing with the risks of intense flooding, rather than for continuous cultivation as had been assumed (Lombardo et al. 2011; Rodrigues et al. 2015, 2018; but see also Rodrigues et al. 2017). Even within a single Amazonian raised-field system, agricultural strategies could shift over time (Whitney et al. 2014). The emerging picture of Amazonian raised-field agriculture is best characterized by great temporal and regional diversity, a patchwork in which people had different levels of direct involvement and engineering (McKey et al. 2010; Rostain 2016). We can expect to learn much more about the sustainability of Amazonian raised-field agriculture, and raised-field agriculture in general, as this research continues.

Infield Agriculture

Infield agriculture refers to intensively cultivated plots of land situated near the homes of farmers (and/or gardeners). Along with more traditional infield agriculture (see Netting 1993), we can expand this category to include homegardens (also called dooryard gardens, houselot gardens, kitchen gardens, and *solares*) (Killion 1992; Wilken 1987). Infield agriculture lets farmers use space efficiently, since infield agriculture is characterized by highly productive polycultural arrangements of plants and animals in relatively small spaces. By situating the agricultural holding near the residence, infield strategies have the added advantage of convenience. Weeding, watering, pruning, and the other constant tasks of intensification can be practiced more frequently and with less effort in an infield simply because there is little to no “commute” required to get there. Infield agriculture allows farmers to use both their space and their time more efficiently (Gleason and Miller 1994; Netting 1993; Stone et al. 1990).

In the tropics, we are finding that ancient cities may have relied on infield agriculture to feed their urban residents. Under the right conditions, this arrangement could sustain urban populations for centuries. Cities like the medieval Khmer capital of Angkor in Cambodia (Fletcher 2009, 2012), the Sinhalese capital of Anuradhapura in Sri Lanka (fourth century BC to 11th century AD) (Coningham et al. 2007), and many Classic period Maya cities of southern

Mesoamerica (Chase and Chase 1998; Fisher 2014; Isendahl 2012; Isendahl and Smith 2013; Lemonnier and Vannière 2013; Masson and Peraza Lope 2014) appear to have managed this by following a similar urban layout: their settlements are sprawling, with open spaces preserved between and around houses (see Lucero et al. 2015 for comparative analysis of these low-density cities). Targeted research in those seemingly empty open spaces has revealed that they were often intensively cultivated (Manzanilla and Barba 1990; Robin 2002, 2006). These findings have prompted many archaeologists to call these settlements "garden cities," "low-density cities," and "agro-urban." As urban agriculture is increasingly recognized as a key strategy for sustainability and food sovereignty initiatives today (e.g., Colasanti et al. 2012; Lovell 2010), the research on ancient urban agriculture stands to contribute to this discussion.

Conservation

> "Sustainability requires direct action to conserve, protect, and enhance natural resources." (FAO 2014a, p. 23)

According to the FAO's guidelines, conservation is an intuitive and necessary next step after efficiency. As an agricultural system is made more efficient, it may at first alleviate strain on local ecosystems. But efficiency will also produce greater agricultural yields, and, according to the FAO, greater yields incentivize the expansion of agricultural production. If agriculture expands unchecked it will eventually deplete natural resources. So, for an agricultural system to be sustainable it must combat resource depletion by actively conserving natural resources (e.g., Hobbs et al. 2008; Pittelkow et al. 2015). It is important to reiterate that any conception of "sustainability" will value some elements at the cost of others. The FAO, as any organization would, harbors presumptions of what is worth conserving and what is not, and these values are not always clearly defined. When we think about conservation, it is important that we do so from a position of critical reflection, asking *what* is being conserved, at what cost, and why?

To maintain high productivity while simultaneously enhancing natural resources, the FAO recommends a suite of strategies, together called "conservation agriculture" (FAO 2014a; Knowler and Bradshaw 2007; Palm et al. 2014). The modern strategies of conservation agriculture draw on traditional farming practices (FAO 2018; Sanz et al. 2017). Archaeologists have shown that many of these strategies trace their origins far back into the past. Here I examine three kinds of conservation agriculture with ancient roots: terrace farming, slash-fire farming, and agriculture that emulates nature. As in the previous section, my coverage tends toward the sweeping, but I draw attention to examples that highlight archaeology's ability to demonstrate the historical contingency and outcomes of conservation agriculture in the past.

Terrace Farming

Terrace farming transforms naturally sloping terrain in hilly or mountainous regions into narrow, graduated steps (terraces) that can be used for cultivation (FAO 2018; Sanz et al. 2017). Terraces conserve soil health by preventing erosion. They promote crop growth through the creation of microclimates and can be integrated with water management networks.

Because terrace agriculture involves substantial landscape modifications, it is one of the most archaeologically recognizable forms of ancient conservation agriculture. Past terrace farming systems have been documented all over the world (e.g., Acabado 2009; Beach et al. 2018; Bayliss-Smith and Hviding 2015; Jiang et al. 2017; Krahtopoulou and Charles 2008; Londoño et al. 2017; Pérez Rodríguez 2006, 2016).

The ubiquity of terrace agriculture defies any hard and fast rules about its relationship with overall sustainability. One consensus of this work as a whole suggests that while terracing may seem to be an inherently sustainable form of agriculture, the variable longevity and outcomes of the ancient world's terrace systems show that in practice, the story is rarely (if ever) that simple.

A good example of this complexity comes from east African terraced landscapes. Geoarchaeology of agricultural terraces at Konso, Ethiopia (which perhaps date as early as the 16th century AD and continued into the 20th century) (Ferro-Vázquez et al. 2017), and Engaruka, Tanzania (15th–18th centuries AD) (Lang and Stump 2017), investigated how these terraced landscapes formed over time. While we typically assume that terraces counteract soil erosion, the geoarchaeology showed that these terraces actually *depended* on large-scale soil erosion (compare to similar systems in the Mixteca Alta, Oaxaca, e.g., Leigh et al. 2013; Pérez Rodríguez and Anderson 2013). In Konso and Engaruka, terraces captured soil that had already eroded from upslope areas. They localized this soil into farmable "traps" next to rivers, where they could be easily irrigated. Thus, even while the terraced field systems of Konso and Engaruka could be considered sustainable on their own, in the larger context of the local environment they capitalized on soil erosion that occurred elsewhere. Examples like these caution us to remember that even accepted forms of conservation agriculture can have detrimental impacts on local environment when considered at certain scales.

Slash-Fire Farming

Slash-fire farming is a kind of extensive agriculture practiced in tropical forest environments. Sometimes it is called swidden, slash-and-burn, or milpa, but by any name it involves cycles of burning, planting, and fallowing parcels of farmland (e.g., Kleinman et al. 1995). After selecting a parcel of land, farmers chop vegetation, let it dry, and then burn it. Because the burned organic matter enriches the soil, the parcel will be able to support one or two years of cultivation. By the third year, the soil will be exhausted, and the parcel will have to "rest" or lay fallow for several years.

In the meantime, farmers must move on to another parcel. Because farmers have to move their fields around every few years, slash-fire farming is considered shifting cultivation.

We know slash-fire farming was practiced in the past, but figuring out how closely it resembles today's slash-fire farming has been a cause for debate among archaeologists. In the Maya area, farmers were making milpa (as slash-fire farming is known there) at the time of Spanish contact (Roys 1972), and many Maya farmers continue to make milpa today (Nigh and Diemont 2013; Schmook et al. 2013). But archaeologists initially dismissed milpa as incapable of supporting prehispanic Classic period Maya civilization. This was largely because archaeologists were extrapolating data from short-term studies of 20th-century milpa agriculture, which overlooked both the legacy effects of colonial violence as well as the multigenerational rhythms of forest management followed in the past (Ford and Nigh 2009, 2015; Hammond 1978). Maya archaeologists now tend to recognize milpa as one of a "mosaic" of diverse subsistence practices (Fedick 1996; Flannery 1982; Harrison and Turner 1978; Turner and Harrison 1983). As to whether or not these practices were sustainable, evidence is emerging from historical–ecological approaches to suggest that the Maya milpa could have been sustainable when pursued at a multigenerational scale and when complemented by other coeval practices (Ford and Nigh 2015; Wells 2015).

One of the most exciting topics in ancient conservation agriculture has been the role of *terra preta* in the Amazon Basin. *Terra preta*, or Amazonian dark earth, is an ancient anthropogenic soil, produced by a kind of slash-fire agriculture and found in patches throughout the Amazon Basin. Through its mixture of burned material, human and animal waste, shell, bone, and other refuse, terra preta is an incredibly fertile soil, especially for the region (Bush et al. 2015; Kern et al. 2017). Exactly how terra preta was made is still not entirely known. However, it seems that charring, as opposed to outright burning, is key to its high fertility (Glaser 2007; Kern et al. 2017). Patches of terra preta are almost always associated with prehispanic settlements. Some archaeologists think that these patches supported large-scale farming and agroforestry in the past, challenging previous assumptions of the Amazon as a pristine wilderness (Bush et al. 2016; Erickson 2008; Heckenberger et al. 2003, 2008; McKey et al. 2010). While this idea continues to stir debate, many archaeologists and environmental activists would agree that terra preta and "slash-and-char" have potential applications in modern conservation agriculture (e.g., Factura et al. 2010). This idea is worth continued attention, but it is important to approach modern applications of ancient farming techniques carefully. I return to this idea later on.

Emulating Nature

Many of the practices of conservation agriculture mimic the arrangements and processes of nature. This idea of emulating nature is inherent in many agricultural strategies, but two that do it particularly well are agropastoralism and agroforestry. The sustainability of these strategies is based on their ability to achieve and maintain high biodiversity (FAO 2018; Sanz et al. 2017).

Agropastoralism is mixed agriculture that integrates crops and livestock. As a practice it has been identified and studied archaeologically around the world, particularly through the analysis of preserved plant and animal remains (e.g., Alexander and Hernández Álvarez 2018; Graffam 1992; Li et al. 2017; Zeder 1991, 2008). Agropastoralism emulates the biodiversity of natural ecosystems by integrating plants and animals. When managed with the goals of conservation agriculture in mind, agropastoralism increases agricultural productivity while also preventing soil erosion and improving land-use and resource efficiency. Today it is recognized as a climate-change mitigation strategy (Sanz et al. 2017). Long-term archaeological studies of agropastoral systems can provide important longitudinal data for understanding its resilience.

Agroforestry, another mixed strategy, integrates trees with crops (and sometimes animals) within the same parcel. Agroforestry is a form of conservation because it promotes soil health and water retention while reducing soil erosion and nutrient loss (Sanz et al. 2017). In archaeology, landscape-based approaches and advances in paleoethnobotany have helped recognize the remnants of ancient agroforestry practices (e.g., Bush et al. 2015; Gallagher et al. 2016; Lentz et al. 2015; Stahl and Pearsall 2012). Homegardens can be considered a form of agroforestry since they often mimic the multitiered arrangements of forest ecosystems (e.g., De Clerck and Negreros-Castillo 2000). Because gardens are typically located around people's houses, they are often easier to recognize archaeologically. The study of past gardening practices is a robust subfield within archaeology and an important component of archaeology's potential contribution to sustainability (e.g., Farahani et al. 2017; Fedick et al. 2008; Gleason and Miller 1994; Marcus 1982; Pyburn 1998; Scarry and Scarry 2005; Sheets 2000).

Rural Livelihoods

> "Agriculture that fails to protect and improve rural livelihoods, equity, and social well-being is unsustainable." (FAO 2014a, p. 26)

Efficiency and conservation provide the toolkit of sustainable agriculture. But how do those tools actually play out in the messiness of human decision making, politics, economics, and cultural and environmental change? This is where archaeology's potential contributions to sustainable agriculture really become apparent, starting with rural livelihoods. Through consideration of rural well-being over time, archaeology can emphasize the historical contingency of agricultural sustainability. Archaeological approaches can highlight how assumptions about sustainability are entangled with environmental justice issues.

The FAO's principle of rural livelihoods asserts that if farming communities do not benefit from an agricultural system, their agriculture will not be sustainable (FAO 2014a, 2017; FAO et al. 2017); rural communities have to be able to access resources and economic opportunities, participate in markets, and stay involved in decision making. The importance of decision making is particularly crucial in matters of land tenure (FAO 2012, 2014a). Land tenure insecurity incentivizes transient (i.e., unsustainable) land-use practices, while also jeopardizing the well-being of rural communities.

Archaeological study of rural livelihoods draws from the approaches of household and community archaeology (e.g., Allison 1999; Wilk and Ashmore 1988). Combining household archaeology with investigations of land-use practices and foodways reveals how rural communities fit into larger dynamics of agricultural sustainability. Here I present two leading examples of this kind of research, first at Chan in Belize and then in the Banda region of Ghana. Another way that archaeology intersects with rural livelihoods is in the application of past farming strategies in modern contexts (see Davies 2012; Stump 2010, 2013). While exciting, this applied component carries certain risks. To explore the complicated business of marshaling the past to improve rural life in the present, I look at how ancient raised-field rehabilitation projects played out in South America in the late 20th century.

Social and Environmental Sustainability at Chan, Belize

The archaeological site of Chan, Belize, was home to a rural community of Maya farmers for 2000 years (800 BC–AD 1200). While Chan's larger and more powerful neighbors rose and fell, this small agricultural village thrived (Robin 2012, 2013). The seemingly mundane daily practices of everyday life at Chan were the keys to its social and environmental sustainability.

Chan's farmers managed a complex system of conservation agriculture that coupled some 1223 terraces with limited irrigation and drainage infrastructure (Robin 2013; Wyatt 2008, 2012, 2014). By keeping the terraces watered and adding household ash and food waste, Chan's farmers were likely able to keep them in near constant production. Farming households lived directly among the terraces they cultivated and seem to have cooperated together to build, maintain, and farm this landscape. The layout of Chan's terraces suggests organic, accretional growth over time: they are a material expression of the generational transfer of ecological knowledge and deep familiarity with local environment. People at Chan reaffirmed their household and community relationships with the local environment through ritual practices (Blackmore 2012; Robin 2002, 2006; Robin et al. 2012a).

The Chan community also practiced sustainable agroforestry. Analysis of wood ash and other preserved botanical remains shows that people at Chan had access to mature stands of fruit and preferred hardwood trees throughout 20 centuries of occupation (Lentz et al. 2012). Elsewhere in the Maya area, exploitation of forest resources resulted in the disappearance of desirable woods (Lentz and Hockaday 2009). That this never happened in Chan's long history is a testament to the community's long-term stewardship of its forest resources.

By several measures, people at Chan enjoyed a fairly high quality of life (Robin et al. 2014). They flourished while other centers faltered by relying on a deep history of flexible innovations and multigenerational transmission of ecological, ritual, agricultural, and social knowledge (Robin 2016). Chan's community leaders appear to have actively worked to create an inclusive political rhetoric, rather than emphasize social differences (Robin et al. 2012a, b, 2014). Research at Chan makes a strong case for the power of coupling local knowledge with inclusive, cooperative management strategies for long-term sustainable agriculture with direct benefits for rural communities.

Food Security and Colonialism in Banda, Ghana

For people anywhere and in any era, food security is a fundamental part of livelihood. The UN defines food security as existing "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1997). Today, Africa has the highest food insecurity in the world (FAO et al. 2017). Mainstream narratives have portrayed African famines and food shortages as apolitical, ahistorical phenomena. Blame is cast on environmental factors (e.g., Watts 2012). Archaeology in the Banda region of Ghana is helping correct this narrative by providing an "alternative archive" of food security in Africa (Logan 2016a). Through archaeological and archaeobotanical approaches, research at Banda is showing how Africa's current food insecurity is a direct result of the structural violence of European colonialism (Logan 2012, 2016a, b; Logan and Cruz 2014).

Centuries ago in the Banda region, people made it through the worst drought in the past millennium without any noticeable effects on food security. Importantly, this was *before British colonialism had made substantial inroads*. During the years of this severe drought (the Kuulo phase, AD 1450–1650), Banda people maintained complex exchange networks (Stahl 2001, 2007; Stahl and Logan 2014; Stahl et al. 2008). They continued to cultivate preferred indigenous grains, like pearl millet (Logan 2016a, b). Even though New World crops like maize and cassava had been introduced by this time, and even though today those crops are grown as a stopgap measure to deal with economic and environmental stress, Banda people did not grow them during the Kuulo drought (Logan 2016a, b; McCann 2005; Stahl 1999, 2001). That people in Banda stuck with their preferred crops shows that they possessed the social organization and ecological knowledge to manage resilient agricultural systems, even when facing extreme environmental stress.

All of this changed in the mid- to late-19th century. The violence and political instability inflicted by British colonialism devastated Banda's systems of rural land tenure (Stahl 1999). With the threat of upheaval constantly looming, Banda farmers had to start relying on fast-growing New World crops. Their reliance on these less culturally preferred foods was further amplified by the colonial imposition of a cash economy (Logan and Cruz 2014; Stahl 2001). For the first time, certain kinds of wild weedy plants show up in the archaeobotanical record, indicating that people were forced to resort to wild foods they would not have eaten previously (Logan 2016a, b). This narrative of upheaval and desperation runs counter to those that would have us believe that British colonialism was a savior for rural African populations (e.g., Thurow 2013). The Banda research shows how archaeology can document the ways structural violence devastates agricultural sustainability and livelihoods in rural communities.

Raised-Field Rehabilitation Projects in South America

A third example of archaeology and rural livelihoods deals with the practice of "resurrecting" ancient agricultural strategies as a means of improving the livelihoods of modern rural communities, particularly in the Global South (e.g., Burstein 2012; Eulich 2018). The first real example of this practice was the movement to rehabilitate ancient raised-field agriculture in the late 20th century.

The remnants of prehispanic raised fields are found throughout South America. Archaeologists over the past several decades have been keen to study the many raised fields around the marshy edges of Lake Titicaca (e.g., Erickson 1994, 1998; Smith et al. 1968). These raised fields provided the agricultural surpluses needed to support the powerful, expansionist Tiwanaku empire (AD 300–1150) (Janusek and Kolata 2004; Stanish 1994, 2003). Raised fields have yielded insights into ancient agriculture. But in the late 20th century, they also were at the center of a multimillion dollar campaign to aid indigenous communities across South America, a campaign that, many would say, failed. How did this happen?

Archaeologists working in highland and lowland South America in the 1980s wanted to know more about how raised fields could have bolstered ancient agriculture, and a few archaeologists began building and planting their own (Erickson 1988a; Kolata 1991). The initial results were shocking. The experimental fields produced bumper crops of potatoes, with harvests that could nearly quadruple the yields of nearby dryland fields (Erickson 1985; Kolata 1991). Raised fields seemed capable of producing two crops in a single growing season, with no need for fallowing (Erickson 1993; Erickson and Candler 1989). These results surely had implications for ancient agriculture, since the apparent hyperproductivity of raised fields offered an explanation of how Tiwanaku could have supported its empire (Erickson 1982, 1988a; Janusek and Kolata 2004; Kolata 1986, 1991; Kolata and Ortloff 1996a, b). The high-yielding experimental fields seemed to hold promise for modern agriculture (Erickson 1988b, 1992), too, and they soon attracted the attention of nonarchaeologists. Could these seemingly miraculous raised fields hold the solution for ending world hunger?

The newly formed international aid community certainly thought so. Millions of dollars were channeled into the resurrection of raised-field agriculture in Peru and Bolivia over the next dozen years (Bandy 2005; Swartley 2000, 2002). The enthusiasm surrounding raised-field rehabilitation projects—an enthusiasm almost exclusively held by foreigners, not by the indigenous South American farmers who were actually supposed to farm these fields—was very much part of the 1980s–1990s zeitgeist of international relief and environmentalism (Swartley 2000, 2002). Yet despite NGOs' efforts to coax indigenous farming families to embrace raised fields, almost all of the rehabilitation projects had been abandoned by the mid 1990s. The reasons given to explain the projects' failure range from misunderstanding raised-field ecology, to misunderstanding indigenous farmers' worldviews.

Decades later, though the hype of rehabilitation projects has cooled, archaeologists continue to advance our understanding of prehispanic South American raised-field agriculture (Bruno 2014; Lombardo et al. 2011, 2013; Rodrigues et al. 2015, 2017, 2018; Whitney et al. 2014). We are learning that at least in the Titicaca case, raised fields may not necessarily have been a boon to rural populations. Rather, the advantages of raised-field farming may have been restricted to the political economy and primarily enjoyed by Tiwanaku elites (Bandy 2005; Janusek and Kolata 2004). It is perhaps ironic that the 20th-century attempts to rehabilitate these fields in the name of humanitarianism in fact echoed the same social inequalities of Tiwanaku, neglecting the actual concerns of rural communities in the pursuit of political goals. While there is still talk of reviving South American-raised fields (e.g., Renard et al. 2012), such applications have to be treated with caution. Though campaigns to reintroduce ancient farming techniques into modern contexts are exciting, they carry with them a burden of risks, not least among them the perpetuation of neocolonial relationships. I included this particular case not so much to illustrate a conceptual contribution, but rather to highlight some of the possible pitfalls archaeologists face when we try to translate conceptual contributions into action. I return to this idea at the end of the paper.

Resilience

> "Enhanced resilience of people, communities, and ecosystems is key to sustainable agriculture." (FAO 2014a, p. 28)

The FAO's fourth principle of sustainable agriculture acknowledges that change is unavoidable. When change comes, how will a food system respond? How will it mitigate stress, internal and external? How will it bounce back from crisis? Change and its inevitability are the reason that sustainable agriculture must be resilient (FAO 2014a, 2017). Resilience is the "ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, by ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (IPCC 2012, p. 5; see also Folke 2006; Holling 1973, 1986; Walker and Salt 2006; Walker et al. 2004).

Many archaeologists have applied resilience thinking in their own studies of how socioecological systems resist, absorb, and bounce back from change (e.g., Bradtmöller et al. 2017; Cooper and Sheets 2012; Fisher and Feinman 2009; Redman 1999, 2005; Redman and Kinzig 2003). In particular, archaeologists studying major social and political transformations—events commonly referred to as collapses—have used resilience approaches effectively to help untangle the many causes and effects that underlie such events (e.g., Faulseit 2016; McAnany and Yoffee 2010; Middleton 2012, 2017; Tainter 1988). Other core concepts like climate change and the Anthropocene have been at the forefront of anthropological archaeological applications of resilience thinking (e.g., Crumley 2015; Kennett et al. 2012; Lucero et al. 2011).

Archaeology stands to make a meaningful contribution to the resilience aspect of sustainable agriculture because it examines "completed cycles" of systems change (Spielmann et al. 2016), or what I call "outcomes." Examination of those outcomes quickly reveals that an agricultural system's resilience is not a simple equation. The political and social dynamics—what we might call interpersonal dynamics—are critical. Agricultural systems are inextricably embedded in these interpersonal dynamics. So when we explore the resilience and sustainability of agricultural systems, we must also contend with the resilience and sustainability of everyday practice and lifeways as well as of households, communities, polities, states, and all the rest of the "social units" with which we are accustomed to working. I address these interpersonal dimensions of resilience in varying degrees for the Classic period Maya collapse, the downfall of Greenland's Norse colonies, and the variable trajectories of Ancestral Puebloan groups in the southwestern United States, but this is an area that calls for greater attention moving forward. As with the other principles outlined by the FAO, it is critical that we continue to ask ourselves, what is being sustained, why, and at what cost?

The overarching theme across these three very different cases of resilience is that flexibility is key to surviving change. Even with that shared through line, the ways in which resilience is treated in archaeological discourse vary widely. This must be kept in mind when we think about how archaeology will contribute to this particular dimension of agricultural sustainability.

Agriculture and the Classic Maya Collapse

When Classic period Maya political structures collapsed around AD 900, the civilization experienced a series of transformations that affected many dimensions of everyday life. Even while the "Maya collapse" is sometimes glossed as a single monolithic event, it actually involved multiple waves of change, occurring at different times and at different rhythms in different parts of the Maya area (Aimers 2007; Douglas et al. 2015; Dunning et al. 2012; Haug et al. 2003; Hoggarth et al. 2017; Iannone 2014; Marcus 1992, 1998; Masson 2012; Webster 2002). No single explanation can account for this large-scale transformation.

With that said, the Classic Maya collapse was likely linked to agriculture and state-level management of labor and land. In the centuries before the collapse, many Maya cities situated their agriculture directly into urban settlements (e.g., Arnauld 2008; Barthel and Isendahl 2013; Chase and Chase 1998). This pattern seems to have been abandoned with the collapse of Classic period political institutions. Farmers who formerly lived in cities dispersed to farm, as rural farmers had been doing all along (Culbert 1973; Harrison and Turner 1978; Turner and Sabloff 2012). This exodus, and the complexities of how agricultural decision making factored into the collapse, have been studied through the framework of resilience thinking.

The emerging picture suggests that while Classic Maya kingship fell apart, small-scale Maya farmers managed to carry on. Small-scale Maya farming households continued to practice terrace agriculture, agroforestry, and wetland cultivation while powerful urban centers—sometimes practicing the same agricultural strategies, just on a larger scale—fell apart and were abandoned (Beach et al. 2009; Chase and Chase 2014; Chase et al. 2011; Ford and Nigh 2015; Kunen 2004; Lentz and Hockaday 2009; Lentz et al. 2012, in press; Luzzadder-Beach and Beach 2009; Luzzadder-Beach et al. 2012). Growing attention to households, communities, and smaller-scale settlements is showing us that Maya farmers were remarkably resilient in their agriculture and water management practices, even as political institutions crumbled around them (Iannone et al. 2014; Robin 2012, 2013; Smyth et al. 2017).

Agropastoralism and Wild Resource Exploitation in the Norse North Atlantic

The abandonment of Greenland's Norse colonies exemplifies the role of resilience in food systems. Norse seafarers from Scandinavia began to colonize the North Atlantic in the ninth to 10th centuries AD (Arge et al. 2005; Arneborg 2008; McGovern et al. 2007). By the 15th century, Greenland's Norse colonies had been abandoned, even while the other North Atlantic colonies in Iceland and the Faroe Islands persisted. Research on the Greenland colony failure demonstrates how the complex relationships between human decision making and climate change affect resilience, often in completely unanticipated ways (Dugmore et al. 2012; Hartman et al. 2017; Nelson et al. 2016).

Norse Greenlanders mixed the agropastoralism of their native Scandinavia with the exploitation of wild resources (Madsen 2014; Mainland and Halstead 2005; Ross and Zutter 2007; Smiarowski et al. 2017). Livestock were paramount in the Scandinavian subsistence system, and so it was animals' needs that drove initial decisions about where to settle and what to grow. Farmers scattered their homes to ensure access to summer pasture, and they labored over infield plots to grow fodder to keep their animals alive through the winter.

Yet even slight variations in year-to-year rainfall could devastate the colonists' herds. Agropastoralism was almost always precarious in Greenland (Church et al. 2005; Fredskild and Humle 1991; Trigg et al. 2009). Even in good years, colonists had to supplement agriculture with marine resources (Dugmore et al. 2012), and in bad years, small-scale farmers would be hit so hard that they had to become tenants of magnate farmers (Arneborg 2012; McGovern et al. 2006; Zori et al. 2013).

Over time, Norse Greenlanders developed strategies to cope with the continued environmental stress on their herds and farms. They buffered against the yearly anxiety of interannual climate fluctuations by drawing on traditional ecological knowledge: they increased hunting of wild marine seals (Dugmore et al. 2012; Nelson et al. 2016). Yet seal hunting, which had once been more of a fallback or supplement, became more and more central to the Norse Greenlanders' subsistence (Arneborg et al. 2012; Smiarowski et al. 2017).

At first, the increase in seal hunting was a successful short-term adaptation to interannual climate variations. But the Norse Greenlanders had no way of knowing that larger-scale climate cycles were converging. Their newfound reliance on wild marine resources was not viable amid rising sea levels, increasing sea ice, and shortened summers (Ogilvie et al. 2009). These environmental changes, along with changes in the larger geopolitical system, ultimately resulted in the extreme vulnerability and eventual failure of the Greenland colonies (Dugmore et al. 2007, 2012; Hartman et al. 2017). The decision to shift efforts from agropastoralism to seal hunting was a short-term solution that unexpectedly left the food system vulnerable to larger-scale climatic change.

Ancestral Puebloan Irrigation Agriculture

In the southwestern United States, Ancestral Puebloan societies learned to coax harvests from the deserts by using irrigation, along with other kinds of drylands water management (Haynes 2010; Herhahn and Hill 1998; Homburg and Sandor 2011; Huckleberry and Billman 1998; McCool et al. 2018; Minnis 1985; Sandor and Homburg 2017). Irrigation agriculture mitigated rainfall variability and extended the growing season. It provided the food security needed for people to aggregate into large communities. But irrigation agriculture came with its own set of risks (Nelson et al. 2012, 2014, 2016). Floods could devastate entire communities just by overwhelming canal infrastructure. Dependence on irrigation could put strain on local resources as communities became entrenched over generations. Irrigated landscapes could be so irresistible as to attract populations so large they could outstrip the carrying capacity of the local environment.

Despite these shared risks, the trajectories of Ancestral Puebloan groups that practiced irrigation agriculture show remarkable diversity (Hegmon et al. 2008; Kohler et al. 2012; Nelson et al. 2012, 2016; Spielmann et al. 2016). This diversity speaks to the resilience of each group's particular social and political management of irrigation agriculture.

When Ancestral Puebloan societies took a more flexible approach to irrigation agriculture, they tended to be much better at bouncing back from extreme floods and droughts. In the Zuni (AD 850–1540) area, for instance, people invested heavily in irrigation, but for centuries their hydraulic infrastructure was decentralized, small-scale, and could be adjusted to deal with short-term changes (Kintigh 1985, 1996; Kintigh et al. 2004; Nelson et al. 2012). People in the Mimbres (AD 650–1450) area practiced irrigation agriculture but also were ready to walk away from it if necessary. Faced with extreme climate events, Mimbres people left their villages and dispersed to live in temporary field houses until conditions improved (Anderies and Hegmon 2011; Hegmon et al. 2000, 2008; Nelson 1999; Nelson et al. 2006). Being flexible enabled Zuni and Mimbres communities to make it through climatic stresses relatively unscathed, at least for a few centuries.

But when their commitment to irrigation was more rigid, Ancestral Puebloan groups did not fare as well. The Hohokam (AD 700–1450) developed a complex network of irrigated agriculture that supported aggregated populations for over a millennium. Yet at the end of the 14th century, extreme droughts and flooding devastated irrigation infrastructure (Abbott 2003; Doelle and Wallace 1991; Nelson et al. 2012; Purdue and Berger 2015). Hohokam people were so entrenched in this particular landscape that many remained through these disasters, suffering declining health until eventually political and community institutions collapsed (Hegmon et al. 2008; Ingram 2010; Nelson et al. 2012). In the Mesa Verde region, irrigated population centers were rife with social inequality and conflict. Given this strife, when severe climate events damaged irrigation infrastructure, it may have been an easy choice for many Mesa Verde people to leave their settlements for good (Kuckelman et al. 2002; Schwindt et al. 2016; Varien et al. 2007). Irrigation, with all the wonders it could do at first, could also be a rigidity trap that held people down while their livelihoods deteriorated around them (Hegmon et al. 2008; Nelson et al. 2012).

Governance

> "Sustainable food and agriculture requires responsible and effective governance mechanisms." (FAO 2014a, p. 30)

The FAO's fifth principle of sustainable agriculture recognizes that food systems are implicated inherently in political structures. For agriculture to be sustainable, it requires "good governance": political leaders have to embrace social justice, recognize and defend people's rights to land and resources, and offer avenues for people to participate in management and decision making (FAO 2012, 2014a). They do so from a perspective of long-term care and protection of natural resources (IFAD 1999). In good governance, political leaders work and learn alongside people to get them to comply with agricultural goals and, as a result, are recognized as legitimate by all levels of society.

Putting aside any skepticism about whether governance this "good" is actually attainable, this dimension of agricultural sustainability can be examined in the archaeological record. As with resilience, our understanding of the interpersonal dynamics of governance—and how historical changes in those interpersonal dynamics led to different agricultural outcomes—stands to be enhanced by archaeological perspectives. So far much of the archaeological work done on political and interpersonal dimensions of agricultural sustainability has focused on mismanagement and collapse. Moving forward it will be equally important that we draw out the governing practices and interpersonal relationships through which agricultural systems were made more sustainable. In thinking about the role of governance in past agriculture, I draw from research on Aztec era Central Mexico, medieval Cambodia, and Roman period Anatolia.

Chinampa Farming at Xaltocan, Mexico

There is no ecological reason that chinampas—the raised-field farming that developed in Central Mexico—should fail. Theoretically speaking, they boost agricultural yields while remaining conservation oriented and self-sustaining (Frederick 2007; Gómez Pompa and Jiménez Osornio 1989; Merlin-Uribe et al. 2013; Parsons 1976, 1991). The widespread abandonment of chinampas around Central Mexico's Lake Xaltocan, a process catalyzed by the imposition of Aztec rule, exemplifies how politics can undermine otherwise highly productive and sustainable agricultural systems.

From AD 900 to 1350, farmers living around saline Lake Xaltocan transformed its marshy edges into chinampas. These chinampas, along with other subsistence practices, supported the development of an independent and prosperous city-state at Xaltocan (Brumfiel 2005; De Lucia 2013; De Lucia and Overholtzer 2014; Millhauser et al. 2011; Morehart 2012a, b, 2016a, b, in press; Morehart and Frederick 2014; Nichols 1987; Nichols et al. 2002). Under the local rule of Xaltocan, the chinampas were sustainable and highly productive.

But Xaltocan was conquered during one of the Aztec empire's expansionist campaigns at the end of the 14th century. Under the control of foreign invaders, Lake Xaltocan's hydraulic infrastructure was reconfigured, which served the Aztecs' larger vision for the lake system but damaged local chinampa agriculture (Morehart 2011, 2012a; Morehart and Frederick 2014). Xaltocan farmers who had usually given their attention to chinampas now had to deal with filling Aztec tribute demands (Brumfiel 1980, 2005; Morehart 2012a; Parsons et al. 2008). The damage to the chinampas themselves, along with the damage to the local social and economic mechanisms that had previously supported them, was irreversible. The chinampas fell into neglect and were abandoned.

These decisions made sense from the perspective of the Aztec rulers, whose larger designs for the empire's political economy envisioned a different use for Xaltocan (Millhauser and Morehart 2018; Morehart 2011, 2012b). Yet from the local perspective of Xaltocan, a great deal of agricultural potential was lost. Further solidifying this as a case of governance disrupting agricultural sustainability, local people from Xaltocan were excluded from decisions about reconfiguring the lake's hydraulic system, and their overall quality of life declined under Aztec rule (Brumfiel 2005; De Lucia and Overholtzer 2014; Millhauser et al. 2011; Morehart and Eisenberg 2010). Xaltocan's highly productive, otherwise sustainable agricultural system collapsed for almost purely political reasons.

The Hydraulic Network at Angkor, Cambodia

A web of state-sponsored hydraulic infrastructure fed water through the sprawling urban landscape of Angkor and its environs, where the medieval Khmer lived and ruled between the ninth and 15th centuries AD (Evans et al. 2007; Fletcher et al. 2008, 2015). Though archaeologists have long known about this hydraulic network, the application of LiDAR has revolutionized the study of Angkor's water management (Evans 2016; Evans and Fletcher 2015; Evans et al. 2013; Hanus and Evans 2015; Klassen 2018, Lustig et al. 2018; O'Reilly et al. 2017).

Every monsoon season, tremendous amounts of water flood down from the Kulen Hills, through Angkor, and drain out across the floodplain of the Tonle Sap River. The Angkor water management system used channels, embankments, ponds, and huge reservoirs to control the floodwater: slowing it down, spreading it out, storing it, getting rid of it, or redirecting it according to their needs (Evans and Fletcher 2015; Fletcher et al. 2008; Kummu 2009; Stark et al. 2015). Perhaps most significantly, Angkor's hydraulic system let farmers control the watering of their fields at the critical beginning and end of the rice growing season, which is what allowed agriculture to move beyond a basic subsistence level and create the kinds of surpluses needed to support a vast urban complex. Angkor's sprawling settlement has been described as low-density urban agricultural or agro-urban, similar to other tropical civilizations (Fletcher 2009, 2012; Hawken 2013; Lucero et al. 2015). Angkor's water management network was intrinsically connected to its politics. The system required centralized management to engineer it and a large labor force to maintain it (Lucero et al. 2015). The network was wrapped in religious significance and served to legitimize Angkor's political leaders (Feneley et al. 2016; Lustig et al. 2018; Pottier 2012).

Yet as the hydraulic network continued to grow, it became rigid: more convoluted, more costly to maintain, and ultimately more vulnerable. Floods in the 14th and 15th centuries devastated Angkor's hydraulic infrastructure (Buckley et al. 2010). Signs of hydraulic mismanagement at other places in the region, like Koh Ker, show that cycles of failure and renovation were common for water management systems across the region (Klassen 2018; Lustig 2012; Lustig et al. 2018; Penny et al. 2007). Angkor's later government could not easily expand or modify the hydraulic network. Despite a popularized image of Angkor kings as masters of their natural environment (e.g., Engelhardt 1995), in reality theirs was a constant struggle against the entropy of their own infrastructure. When the kings could no longer deliver their end of the bargain (i.e., harnessing the yearly floods in exchange for political legitimacy), the population of Greater Angkor dispersed in urban diaspora, similar to the fate of other low-density, agro-urban settlements in the tropics (Lucero et al. 2015). As future research clarifies the intricacies of Angkor water management, particularly its role in agriculture, we stand to learn much more about the delicate balance between decision making, climate change, and urban food systems.

Imperial Intervention in Agriculture at Roman Gordion

The site of Gordion in central Anatolia was occupied for more than 3000 years, spanning the Early Bronze Age (before 2000 BC) through the medieval period (13th–14th centuries AD) (Kealhofer 2005; Voigt 2002). During that long history, people basically grew the same crops (bread wheat and barley) and raised the same animals (sheep and goats); what changed was the balance between farming and herding strategies (Marston 2010, 2015; Marston and Branting 2016; Miller 2010, 2018; Miller and Marston 2012; Zeder and Arter 1994). As Gordion fell into and out of the hands of different Mediterranean political powers, the balance struck in the region's agriculture could similarly shift. Analysis of botanical and zoological remains from those different political phases shows that some imperial strategies, namely, those used by the Romans, directly undermined Gordion's agricultural sustainability (Marston 2017; Miller et al. 2009; Smith and Miller 2009).

During their time under Roman rule (c. AD 50–400), Gordion farmers shifted to a fairly narrow—and risky—set of agropastoral strategies (Marston 2015; Marston and Miller 2014). They predominantly focused on growing bread wheat, upending long traditions of cultivating a wide variety of agricultural products. Diversifying agricultural holdings had long been a form of risk management for the region's farmers, who now invested mostly in a single crop, itself a precarious one, since bread wheat depends on good rainfall (Marston 2011; Riehl 2009). At the same time, pastoral strategies became riskier: livestock were eating more grass and less grain, leading to overgrazing of pastureland, which itself led to greater erosion (Marston 2011; Marston and Miller 2014). Rural populations across the region were at an all-time high (Kealhofer 2005). Gordion's agricultural system had never been more perilous, or less sustainable.

In the Roman period, Gordion's generations of sustainable agricultural management and decision making were upended because the managers and decision makers were no longer living in Gordion. They were in Rome. External demands of taxes and tribute were swept with broad strokes across the Roman Empire, with little concern for the nuances of local environment (Marston 2012, 2015, 2017; Marston and Miller 2014). Gordion's agricultural strategies were redirected to fulfill these extra-local imperial demands, at the cost of sustainability.

Discussion and Future Directions

What will an archaeology for sustainable agriculture look like? I return to this question after having examined archaeological research through the lens of international policy on sustainable food systems. As an invitation to reflect, this overview shows that a deep time perspective can enhance understanding of the interconnected social and environmental dynamics underlying agricultural sustainability. This perspective is illuminating, but it also entrusts us with uncomfortable realities. We face the truth that even ecologically sound agricultural systems do not last forever. We face the truth that a food system that benefits some may simultaneously disenfranchise others. We face the truth that our short-term solutions to environmental crisis may ultimately cause more damage than we can anticipate. The question of how to sit with these existential realities and still choose to take meaningful action is a challenge faced by all scientists working in the 21st century.

As I see it, the promises of an archaeology for sustainable agriculture include (1) its ability to demonstrate that agricultural sustainability is historically contingent and, closely related, (2) its attention to outcomes of past agricultural systems. The FAO principles operate holistically; they draw attention to the interrelationships between environment, society, politics, economy, and unexpected change. This is positive. Yet even when taken all together, as they ought to be, the FAO's principles lack a robust consideration of historical dynamics. The messiness of changing interpersonal and political dynamics is critical for understanding how agricultural systems slide up and down a spectrum of sustainability over time. Archaeology excels in explaining this messiness. The field's capacity to demonstrate that sustainability is historically contingent and its attention to outcomes stand to enhance the frameworks used by organizations like the FAO. Moving forward, these are among our strongest conceptual contributions in creating an archaeology for sustainable agriculture.

Transforming these conceptual contributions into meaningful action is its own challenge. The genesis and implementation of such action will require interdisciplinary and imaginative collaboration, as well as a willingness to take risks. The call to action is not something that can be mapped out neatly in a few paragraphs. Bearing that in mind, the calls to action I offer here are not prescriptions but simply suggestions for how this conversation might transition into action.

One of the first things that became clear to me looking over the sustainability-focused archaeological research of the last decades is that the projects themselves matter. Long-term, interdisciplinary projects that address not only particular sites but also larger regional dynamics (e.g., Eastern Mimbres Archaeological Project; Angkor Research Program; Gordion Archaeological Project) are essential for creating the kind of datasets that build our archive of past agricultural systems. To maximize archaeology's contribution to sustainable agriculture, we need research programs that leverage emerging technologies and methodologies (e.g., LiDAR, paleoclimate reconstruction) without supplanting more traditional archaeological methods (e.g., excavation, pedestrian survey). Traditional archaeological methods remain our best strategy for understanding individual, household, and community decision making and the implementation of diverse agricultural strategies. As the presented research has made clear, no matter how much attention we might give the ecological parameters of agricultural systems, those data will reveal very little about sustainability without equal attention to the people and communities involved. It is important to acknowledge that these illuminating datasets are hard-won. They require the long-term investment of time and money in particular places and research questions. Dedicating years and grant money (when logistically possible) to these kinds of interdisciplinary projects is part of creating an archaeology for sustainable agriculture.

Remaining in one place or region will also create opportunities for archaeologists to engage with the modern food and agricultural systems in the places they work. This engagement is essential for developing the "connective tissue" between past and present, which I see as key to an archaeology for sustainable agriculture. We can enhance the way modern sustainability is understood by putting present agricultural systems in conversation with past outcomes. Of the ways we can connect past and present, I am particularly encouraged by place-based approaches, which trace out long-term and still unfolding histories of human–environment interaction in landscapes. This suggestion also carries with it a call for more historical archaeological research dedicated to understanding more recent agricultural systems, particularly during the sustained transformations of colonialism (see Lightfoot and Gonzalez 2018). Logan's (2016a, b) work in Banda exemplifies such an approach. Such place-based connections are different from sweeping thematic connections between past and present (e.g., comparing Classic Maya urban agricultural cities to urban agriculture in modern Detroit). Sweeping comparisons may make for interesting thought experiments, but when they are not handled with sensitivity, they can undermine the critical message that sustainability is historically contingent. Place-based approaches, on the other hand, draw out legacies of past political, economic, social, and environmental dynamics that reside in specific food and agricultural systems. They draw attention to more recent historical dynamics and the environmental justice implications of those dynamics.

Place-based approaches also promote the development of collaborative relationships among archaeologists and local communities. Cultivating relationships, particularly with local farmers, over multiple years will also yield insights as to how farming communities are dealing with change in real time; this information is valuable for understanding "on-the-ground" responses to climate change, neoliberalization, and other factors. These collaborations could adopt many forms and take many paths toward advancing our understanding of local food systems. However, in charting these relationships we must be prepared to reckon with archaeology's own residual colonialism. Asserting that our archaeological findings have direct applications for living communities (i.e., resurrecting ancient farming techniques) runs a great risk of perpetuating colonial attitudes and power structures. This is especially true since so often these endeavors seem to target indigenous and disenfranchised communities (e.g., Swartley 2002). As a field, we need to work away from the kinds of practices that fail to decolonize archaeology. In part, this means surrendering the myth that there is a "silver bullet," some ancient farming technique that we will "give back" to rural farmers and thereby end global hunger. This is not to say, and is in fact far from saying, that there are no lessons to be learned from past farming. On the contrary, many of the ancient agricultural techniques discussed here work so well that they continue to be practiced today (FAO 2018). But instead of treating ancient agriculture like it holds a world-saving secret, we might do better to consider how we can develop mutually beneficial partnerships between academic researchers and modern farming communities. This work includes valuing traditional ecological knowledge (TEK; e.g., Inglis 1993, Pierotti 2010), actively decolonizing archaeology through community-based approaches (e.g., Atalay 2012), and aligning components of our research with themes of modern food sovereignty, public health, and environmental justice.

I also suggest that it is critical we develop creative and effective ways to communicate our research with the public. This challenge is not limited to archaeologists. Making our food and agriculture more sustainable will require social change. Archaeology has the ability to unlock human narratives within long-term environmental processes. Along with other humanist approaches espoused by the emerging field of environmental humanities, this capacity could be used to build support for sustainability initiatives among a wider audience. Developing the skills to "translate" science into nonscientific paradigms does not undermine the legitimacy of the research. If anything, archaeology's ability to humanize the long and sterile timescales of climate change could be one of the field's most compelling roles in the larger endeavor toward agricultural sustainability.

My final point is one I have danced around throughout this paper: an archaeology for sustainable agriculture may need to reconsider its relationship with the word "sustainability" itself. "Sustainability" (as well as "resilience") as a term is used widely in all sorts of discourse; it has become a buzzword. So much of what archaeology could contribute toward food sovereignty and environmental justice initiatives is bound up in its ability to challenge assumptions about what sustainability is and is not. This overview has demonstrated that archaeologists are equipped to complicate the sustainability discourse by showing that sustainability itself is historically contingent and a construct: it comes at a cost, and it benefits some individuals (or institutions) more than others. Maximizing archaeology's potential contribution to sustainability initiatives will likely require that we become more precise about what we mean when we use words like "sustainability" and "resilience." It may even mean, ironically, relying less on those words as we better learn to articulate our place in this conversation.

Conclusion

Making our agricultural systems more sustainable is a complex endeavor. It is also an urgent one. To effectively deal with this combination of complexity and urgency will require creative and sustained collaboration among researchers from diverse fields, policy makers, farmers, stakeholders, and the public at large. Archaeology can be one of the scientific fields to contribute to this movement. My goals in this overview were to give a sense of what archaeology has offered to agricultural sustainability so far, to reflect on where we stand, and to take stock as we look ahead to what we can do to further advance our contribution in the coming years.

Archaeologists have sensed for some time now that our approaches stand to contribute to sustainability initiatives. Over the past decades, advances in our technologies and explanatory frameworks have backed this claim: we can assess the sustainability of past agricultural systems, and we can show how those systems play out over time under a variety of different circumstances. As we move forward, we ask, how will we work toward an archaeology for sustainable agriculture? How will we deliver on what we have claimed?

Throughout this overview I examined archaeological research on agricultural sustainability through the lens of the UN's guiding principles on sustainable food and agriculture. These principles—efficiency, conservation, rural livelihoods, resilience, and governance—allow us to identify specific and direct ways that archaeology can enhance how we think about long-term narratives of agricultural change. I laid out what I see as two of archaeology's strongest conceptual contributions to sustainable agriculture: (1) its ability to demonstrate that agricultural sustainability is historically contingent, and (2) its attention to outcomes, or completed cycles of agricultural development. If we can continue to develop these contributions, the archaeological perspective stands to enhance the way sustainable agriculture is considered across disciplines. Equally important, if we can transform these conceptual contributions into strategic action, we may be able to advance agricultural sustainability initiatives in meaningful ways.

As we move into the third decade of this century, we can expect to see archaeology advance ever further into the collaborative efforts of agricultural sustainability. It is worth examining how we got here and taking this chance to pause as an opportunity to clarify how we will meet the challenges of the coming years. If we can give those challenges our persistent attention, we will show that the agricultural past is, as the poet and environmental activist Wendell Berry (2015, p. 184) knew it to be, "a resource, a fund of experience, (and) a lexicon of proven possibilities and understood mistakes."

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References Cited

Abbey, E. (1968). *Desert Solitaire: A Season in the Wilderness*, McGraw Hill, New York.
Abbott, D. R. (ed.) (2003). *Centuries of Decline during the Hohokam Classic Period at Pueblo Grande*, University of Arizona Press, Tucson.
Acabado, S. (2009). A Bayesian approach to dating agricultural terraces: A case from the Philippines. *Antiquity* **83**: 801–814.
Adams, R. M., Downing, T. E., and Gibson, M. (1974). *Irrigation's Impact on Society*, University of Arizona Press, Tucson.
Aimers, J. J. (2007). What Maya collapse? Terminal Classic variation in the Maya Lowlands. *Journal of Archaeological Research* **15**: 329–377.
Alexander, R. T., and Hernández Álvarez, H. (2018). Agropastoralism and household ecology in Yucatán after the Spanish invasion. *Environmental Archaeology* **23**: 69–79.
Allison, P. M. (1999). *The Archaeology of Household Activities*, Routledge, New York.
Altaweel, M. (2008). Investigating agricultural sustainability and strategies in northern Mesopotamia: Results produced using a socio-ecological modeling approach. *Journal of Archaeological Science* **35**: 821–835.
Altaweel, M., and Watanabe, C. E. (2012). Assessing the resilience of irrigation agriculture: Applying a social–ecological model for understanding the mitigation of salinization. *Journal of Archaeological Science* **39**: 1160–1171.
Altieri, M. A. (1995). *Agroecology: The Science of Sustainable Agriculture*, Westview Press, Boulder, CO.
Anderies, J. M., and Hegmon, M. (2011). Robustness and resilience across scales: Migration and resource degradation in the prehistoric US Southwest. *Ecology and Society* **16**: 22–43.
Arge, S. V., Sveinbjarnardóttir, G., Edwards, K. J., and Buckland, P. C. (2005). Viking and medieval settlement in the Faroes: People, place and environment. *Human Ecology* **33**: 597–620.
Armillas, P. (1971). Gardens on swamps. *Science* **174**: 653–661.
Arnauld, M. C. (2008). Maya urbanization: Agrarian cities in a preindustrial world. In Mastache, A. G., Cobean, R. H., García Cook, Á, and Hirth, K. G. (eds.), *Urbanism in Mesoamerica*, Pennsylvania State University, University Park, pp. 1–36.
Arneborg, J. (2008). The Norse settlements in Greenland. In Brink, S., and Price, N. (eds.), *The Viking World*, Routledge, New York, pp. 588–597.
Arneborg, J. (2012). Churches, Christianity, and magnate farmers in the Norse eastern settlement. In Gullov, H. C., Toft, P. A., and Hansgaard, C. P. (eds.), *Challenges and Solutions: Northern Worlds*, National Museum of Denmark, Copenhagen, pp. 167–170.
Arneborg, J., Heinemeier, J., and Lynnerup, N. (2012). *Greenland Isotope Project: Diet in Norse Greenland AD 1000–AD 1450*, Journal of the North Atlantic, Steuben.
Ashmore, W. (2018). Why the archaeology of political ecology matters. In Millhauser, J. K., Morehart, C. T., and Juarez, S. (eds.), *Uneven Terrain: Archaeologies of Political Ecology*, Archeological Papers No. 29, American Anthropological Association, Washington, DC, pp. 175–184.
Ashmore, W., and Knapp, A. B. (1999). *Archaeologies of Landscape: Contemporary Perspectives*, Blackwell, Malden.
Atalay, S. (2012). *Community-Based Archaeology: Research With, By, and For Indigenous and Local Communities*, University of California Press, Berkeley.
Balée, W. (ed.) (1998). *Advances in Historical Ecology*, Columbia University Press, New York.
Balée, W. (2006). The research program of historical ecology. *Annual Review in Anthropology* **35**: 75–98.
Bandy, M. S. (2005). Energetic efficiency and political expediency in Titicaca Basin raised field agriculture. *Journal of Anthropological Archaeology* **24**: 271–296.
Barthel, S., and Isendahl, C. (2013). Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities. *Ecological Economics* **86**: 224–234.

Bayliss-Smith, T. P., and Hviding, E. (2015). Landesque capital as an alternative to food storage in Melanesia: Irrigated taro terraces in New Georgia, Solomon Islands. *Environmental Archaeology* **20**: 425–436.

Beach, T. (1998). Soil constraints on northwest Yucatán, Mexico: Pedoarchaeology and Maya subsistence at Chunchucmil. *Geoarchaeology* **13**: 759–791.

Beach, T., Luzzadder-Beach, S., Cook, D., Krause, S., Doyle, C., Eshleman, S., et al. (2018). Stability and instability on Maya Lowlands tropical hillslope soils. *Geomorphology* **305**: 185–208.

Beach, T., Luzzadder-Beach, S., Dunning, N., Jones, J., Lohse, J., Guderjan, T., et al. (2009). A review of human and natural changes in Maya lowland wetlands over the Holocene. *Quaternary Science Reviews* **28**: 1710–1724.

Beck, J., Díaz-Zorita Bonilla, M., Bocherens, H., and Díaz-del-Río, P. (2018). Feeding a third millennium BC mega-site: Bioarchaeological analyses of palaeodiet and dental disease at Marroquíes (Jaén, Spain). *Journal of Anthropological Archaeology* **52**: 23–43.

Bender, B. (1978). Gatherer-hunter to farmer: A social perspective. *World Archaeology* **10**: 204–222.

Benson, L. V. (2010). Factors controlling pre-Columbian and early historic maize productivity in the American Southwest, part 2: The Chaco Halo, Mesa Verde, Pajarito Plateau/Bandelier, and Zuni archaeological regions. *Journal of Archaeological Method and Theory* **18**: 61–109.

Benson, L. V., Stein, J. R., and Taylor, H. E. (2009). Possible sources of archaeological maize found in Chaco Canyon and Aztec ruins, New Mexico. *Journal of Archaeological Science* **36**: 387–407.

Berry, W. (2015). *The Unsettling of America: Culture & Agriculture*, 3rd ed., Counterpoint, Berkeley.

Biesboer, D. D., Binford, M. W., and Kolata, A. L. (1999). Nitrogen fixation in soils and canals of rehabilitated raised-fields of the Bolivian altiplano. *Biotropica* **31**: 255–267.

Binford, M. W., Brenner, M., and Leyden, B. W. (1996). Paleoecology and Tiwanaku agroecosystems. In Kolata, A. L. (ed.), *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Smithsonian Institution Press, Washington, DC, pp. 89–108.

Blackmore, C. (2012). Recognizing difference in small-scale settings: An examination of social identity formation at the Northeast Group, Chan. In Robin, C. (ed.), *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville, pp. 173–191.

Bocinsky, R. K., and Kohler, T. A. (2014). A 2,000-year reconstruction of the rain-fed maize agricultural niche in the US Southwest. *Nature Communications* **5**: 5618.

Bogaard, A., Filipovic, D., Fairbairn, A., Laura, G., Stroud, E., Fuller, D., and Charles, M. (2017). Agricultural innovation and resilience in a long-lived early farming community: The 1,500-year sequence at Neolithic to early Chalcolithic Çatalhöyük, central Anatolia. *Anatolian Studies* **67**: 1–28.

Boserup, E. (1965). *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure*, Aldine, Chicago.

Bradtmöller, M., Grimm, S., and Riel-Salvatore, J. (2017). Resilience theory in archaeological practice: An annotated review. *Quaternary International* **446**: 3–16.

Braje, T. J. (2015). Earth systems, human agency, and the Anthropocene: Planet Earth in the human age. *Journal of Archaeological Research* **23**: 369–396.

Brumfiel, E. (1980). Specialization, market exchange, and the Aztec state: A view from Huexotla. *Current Anthropology* **21**: 459–478.

Brumfiel, E. (2005). Conclusions: Production and power at Xaltocan. In Brumfiel, E. (ed.), *Production and Power at Postclassic Xaltocan*, Instituto Nacional de Antropología e Historia, Mexico, pp. 349–360.

Bruno, M. C. (2014). Beyond raised fields: Exploring farming practices and processes of agricultural change in the ancient Lake Titicaca basin of the Andes. *American Anthropologist* **116**: 130–145.

Buckley, B. M., Anchukaitis, K. J., Penny, D., Fletcher, R., Cook, E. R., Sano, M., et al. (2010). Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences USA* **107**: 6748–6752.

Burstein, D. (2012). How biochar will help Kenya go green and save money. *Fast Company* (https://www.fastcompany.com/1805296/how-biochar-will-help-kenya-go-green-and-save-money).

Bush, M. B., Correa-Metrio, A., McMichael, C. H., Sully, S., Shadik, C. R., Valencia, B. G., et al. (2016). A 6900-year history of landscape modification by humans in lowland Amazonia. *Quaternary Science Reviews* **141**: 52–64.

Bush, M. B., McMichael, C. H., Piperno, D. R., Silman, M. R., Barlow, J., Peres C. A., Mitchell, P., and Palace, M. W. (2015). Anthropogenic influence on Amazonian forests in prehistory: An ecological perspective. *Journal of Biogeography* **42**: 2277–2288.

Carney, H., Binford, M., and Kolata, A. L. (1996). Nutrient fluxes and retention in Andean raised-field agriculture: Implications for long-term sustainability. In Kolata, A. L. (ed.), *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Smithsonian Institution Press, Washington, DC, pp. 169–180.

Carney, H. J., Binford, M. W., Kolata, A. L., Marin, R. R., and Goldman, C. R. (1993). Nutrient and sediment retention in Andean raised-field agriculture. *Nature* **364**: 131–133.

Carson, R. (1962). *Silent Spring*, Houghton-Mifflin, Boston.

Chase, A. F., and Chase, D. Z. (1998). Scale and intensity in Classic period Maya agriculture: Terracing and settlement at the "garden city" of Caracol, Belize. *Culture & Agriculture* **20**: 60–77.

Chase, A. F., and Chase, D. Z. (2016). Urbanism and anthropogenic landscapes. *Annual Review of Anthropology* **45**: 361–376.

Chase, A. F., Chase, D. Z., Weishampel, J. F., Drake, J. B., Shrestha, R. L., Slatton, K. C., et al. (2011). Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize. *Journal of Archaeological Science* **38**: 387–398.

Chase, A. F., and Scarborough, V. L. (2014). Diversity, resilience, and IHOPE-Maya: Using the past to inform the present. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 1–10.

Chase, A. S. Z. (2016). Beyond elite control: Residential reservoirs at Caracol, Belize. *Wiley Interdisciplinary Reviews: Water* **3**: 885–897.

Chase, D. Z., and Chase, A. F. (2014). Path dependency in the rise and denouement of a Classic Maya city: The case of Caracol, Belize. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 142–154.

Church, M. J., Arge, S. V., Brewington, S., McGovern, T. H., Woollett, J. M., Perdikaris, S., et al. (2005). Puffins, pigs, cod and barley: Palaeoeconomy at Undir Junkarinsfløtti, Sandoy, Faroe Islands. *Environmental Archaeology* **10**: 179–197.

Clutton-Brock, J. (ed.) (1989). *The Walking Larder: Patterns of Domestication, Pastoralism, and Predation*, Unwin Hyman, London.

Colasanti, K. J. A., Hamm, M. W., and Litjens, C. M. (2012). The city as an "agricultural powerhouse"? Perspectives on expanding urban agriculture from Detroit, Michigan. *Urban Geography* **33**: 348–369.

Coningham, R., Gunawardhana, P., Manuel, M., Adikari, G., Katugampola, M., Young, R., et al. (2007). The state of theocracy: Defining an early medieval hinterland in Sri Lanka. *Antiquity* **81**: 699–719.

Cooper, J., and Sheets, P. (eds.) (2012). *Surviving Sudden Environmental Change: Answers from Archaeology*, University Press of Colorado, Boulder.

Crabtree, S. A., and Kohler, T. A. (2012). Modelling across millennia: Interdisciplinary paths to ancient socio-ecological systems. *Ecological Modelling* **241**: 2–4.

Crumley, C. L. (1994). *Historical Ecology: Cultural Knowledge and Changing Landscapes*, School of American Research Press, Santa Fe, NM.

Crumley, C. L. (2015). New paths into the Anthropocene: Applying historical ecologies to the human future. In Isendahl, C., and Stump, D. (eds.), *The Oxford Handbook of Historical Ecology and Applied Archaeology*, Oxford University Press, Oxford, pp. 1–19.

Culbert, T. P. (1973). *The Classic Maya Collapse*, University of New Mexico Press, Albuquerque.

Curwen, E. C. (1927). Prehistoric agriculture in Britain. *Antiquity* **1**: 261–289.

d'Alpoim Guedes, J., Crabtree, S. A., Bocinsky, R. K. and Kohler, T. A. (2016). 21st century approaches to ancient problems: Climate and society. *Proceedings of the National Academy of Sciences USA* **113**: 14483–14491.

Darch, J. (ed.) (1983). *Drained Field Agriculture in Central and South America*, BAR International Series 189, Archaeopress, Oxford.

Davies, M. I. J. (2012). Some thoughts on a "useable" African archaeology: Settlement, population and intensive farming among the Pokot of northwest Kenya. *African Archaeological Review* **29**: 319–353.

Davies, M. I. J., and Moore, H. L. (2016). Landscape, time and cultural resilience: A brief history of agriculture in Pokot and Marakwet, Kenya. *Journal of Eastern African Studies* **10**: 67–87.

De Clerck, F. A. J., and Negreros-Castillo, P. (2000). Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. *Agroforestry Systems* **48**: 303–317.

De Lucia, K. (2013). Domestic economies and regional transition: Household multicrafting and lake exploitation in pre-Aztec central Mexico. *Journal of Anthropological Archaeology* **32**: 353–367.
De Lucia, K., and Overholtzer, L. (2014). Everyday action and the rise and decline of ancient polities: Household strategy and political change in Postclassic Xaltocan, Mexico. *Ancient Mesoamerica* **25**: 441–458.
Doelle, W. H., and Wallace, H. D. (1991). The changing role of the Tucson Basin in the Hohokam regional system. In Gumerman, G. J. (ed.), *Exploring the Hohokam: Prehistoric Desert Peoples of the American Southwest*, University of New Mexico Press, Albuquerque, pp. 279–346.
Douglas, P. M. J., Pagani, M., Canuto, M. A., Brenner, M., Hodell, D. A., Eglinton, T. I., and Curtis, J. H. (2015). Drought, agricultural adaptation, and sociopolitical collapse in the Maya Lowlands. *Proceedings of the National Academy of Sciences USA* **112**: 5607–5612.
du Pisani, J. A. (2006). Sustainable development: Historical roots of the concept. *Environmental Sciences* **3**: 83–96.
du Pisani, J. A. (2015). Sustaining sustainable development: The shifting moral base of the concept, 1972–2002. *Ekonomska i Ekohistorija* **11**: 19–32.
Dugmore, A. J., Keller, C., and McGovern, T. H. (2007). Norse Greenland settlement: Reflections on climate change, trade, and the contrasting fates of human settlements in the North Atlantic Islands. *Arctic Anthropology* **44**: 12–36.
Dugmore, A. J., McGovern, T. H., Vésteinsson, O., Arneborg, J., Streeter, R., and Keller, C. (2012). Cultural adaptation, compounding vulnerabilities and conjunctures in Norse Greenland. *Proceedings of the National Academy of Sciences USA* **109**: 3658–3663.
Dunning, N. P., Beach, T. P., and Luzzadder-Beach, S. (2012). Kax and kol: Collapse and resilience in lowland Maya civilization. *Proceedings of the National Academy of Sciences USA* **109**: 3652–3657.
Engelhardt, R. A. (1995). Two thousand years of engineering genius on the Angkor plain. *Expedition* **37**(3): 18–26.
Erickson, C. L. (1982). *Experiments in Raised Field Agriculture, Huatta, Peru, 1981–1982*, University of Illinois, Champaign.
Erickson, C. L. (1985). *Applications of Prehistoric Andean Technology: Experiments in Raised Field Agriculture, Huatta, Lake Titicaca, 1981 to 1982,* BAR International Series 232, Archaeopress, Oxford.
Erickson, C. L. (1988a). *An Archaeological Investigation of Raised Field Agriculture in the Lake Titicaca Basin of Peru*, Ph.D. dissertation, Department of Anthropology, University of Illinois, Urbana-Champaign.
Erickson, C. L. (1988b). Raised field agriculture in the Lake Titicaca basin: Putting ancient agriculture back to work. *Expedition* **30**(3): 8–16.
Erickson, C. L. (1992). Applied archaeology and rural development: Archaeology's potential contribution to the future. *Journal of the Steward Anthropological Society* **20**: 1–16.
Erickson, C. L. (1993). The social organization of prehispanic raised field agriculture in the Lake Titicaca basin. In Scarborough, V. L., and Isaac, B. L. (eds.), *Economic Aspects of Water Management in the Prehispanic New World*, JAI Press, Greenwich, CT, pp. 369–426.
Erickson, C. L. (1994). Methodological considerations in the study of ancient Andean field systems. In Miller, N. F., and Gleason, K. L. (eds.), *The Archaeology of Garden and Field*, University of Pennsylvania Press, Philadelphia, pp. 111–152.
Erickson, C. L. (1998). Applied archaeology and rural development: Archaeology's potential contribution to the future. In Whiteford, M., and Whiteford, S. (eds.), *Crossing Currents: Continuity and Change in Latin America*, Prentice-Hall, Upper Saddle River, NJ, pp. 34–45.
Erickson, C. L. (2008). Amazonia: The historical ecology of a domesticated landscape. In Silverman, H., and Isbell, W. H. (eds.), *Handbook of South American Archaeology*, Springer, New York, pp. 157–183.
Erickson, C. L., and Candler, K. (1989). Raised fields and sustainable agriculture in the Lake Titicaca basin of Peru. In Browder, J. (ed.), *Fragile Lands of Latin America: Strategies for Sustainable Development*, Westview Press, Boulder, CO, pp. 230–248.
Eulich, W. (2018). Why ancient farming practices have resurged in a storied part of Mexico City. *The Christian Science Monitor* (https://www.csmonitor.com/World/Making-a-difference/2018/0719/Why-ancient-farming-practices-have-resurged-in-a-storied-part-of-Mexico-City).
Evans, D. (2016). Airborne laser scanning as a method for exploring long-term socio-ecological dynamics in Cambodia. *Journal of Archaeological Science* **74**: 164–175.
Evans, D., and Fletcher, R. (2015). The landscape of Angkor Wat redefined. *Antiquity* **89**: 1402–1419.

Evans, D. H., Fletcher, R., Pottier, C., Chevance, J.-B., Soutif, D., Tan, B. S., et al. (2013). Uncovering archaeological landscapes at Angkor using LiDAR. *Proceedings of the National Academy of Sciences USA* **110**: 12595–12600.

Evans, D., Pottier, C., Fletcher, R., Hensley, S., Tapley, I., Milne, A., and Barbetti, M. (2007). A comprehensive archaeological map of the world's largest preindustrial settlement complex at Angkor, Cambodia. *Proceedings of the National Academy of Sciences USA* **104**: 14277–14282.

Evershed, R. P. (2008). Organic residue analysis in archaeology. *Archaeometry* **50**: 895–924.

Factura, H., Bettendorf, T., Buzie, C., Pieplow, H., Reckin, J., and Otterpohl, R. (2010). Terra preta sanitation: Re-discovered from an ancient Amazonian civilization, integrating sanitation, bio-waste management and agriculture. *Water Science and Technology* **61**: 2673–2679.

FAO (Food and Agriculture Organization) (1997). *Report of the World Food Summit, 13–17 November 1996*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization) (2012). *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization) (2014a). *Building a Common Vision for Sustainable Food and Agriculture: Principles and Approaches*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization) (2014b). *Sustainability Assessment of Food and Agriculture Systems Guidelines*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization) (2017). *Strategic Work of FAO to Reduce Rural Poverty*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization) (2018). *Globally Important Agricultural Heritage Systems*, Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization), IFAD, UNICEF, WFP, and WHO (2017). *The State of Food Security and Nutrition in the World 2017: Building Resilience for Peace and Food Security*, Food and Agriculture Organization of the United Nations, Rome.

Farahani, A., Chiou, K. L., Harkey, A., Hastorf, C. A., Lentz, D. L., and Sheets, P. (2017). Identifying "plantscapes" at the Classic Maya village of Joya de Cerén, El Salvador. *Antiquity* **91**: 980–997.

Faulseit, R. K. (ed.) (2016). *Beyond Collapse: Archaeological Perspectives on Resilience, Revitalization, and Transformation in Complex Societies*, Southern Illinois University Press, Carbondale.

Fedick, S. L. (ed.) (1996). *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, University of Utah Press, Salt Lake City.

Fedick, S. L., Flores-Delgadillo, M. D. L., Sedov, S., Solleiro-Rebolledo, E., and Palacios-Mayorga, S. (2008). Adaptation of Maya homegardens by "container gardening" in limestone bedrock cavities. *Journal of Ethnobiology* **28**: 290–304.

Feneley, M., Penny, D., and Fletcher, R. (2016). Claiming the hydraulic network of Angkor with Viṣṇu: A multidisciplinary approach including the analysis of archaeological remains, digital modelling and radiocarbon dating with evidence for a 12th century renovation of the West Mebon. *Journal of Archaeological Science: Reports* **9**: 275–292.

Ferro-Vázquez, C., Lang, C., Kaal, J., and Stump, D. (2017). When is a terrace not a terrace? The importance of understanding landscape evolution in studies of terraced agriculture. *Journal of Environmental Management* **202**: 500–513.

Fish, S. K., Fish, P. R., Miksicek, C., and Madsen, J. H. (1985). Prehistoric agave cultivation in southern Arizona. *Desert Plants* **7**: 107–112.

Fisher, C. (2014). The role of infield agriculture in Maya cities. *Journal of Anthropological Archaeology* **36**: 196–210.

Fisher, C. T., and Feinman, G. M. (eds.) (2009). *The Archaeology of Environmental Change: Socionatural Legacies of Degradation and Resilience*, University of Arizona Press, Tucson.

Flannery, K. V. (ed.) (1982). *Maya Subsistence: Studies in Memory of Dennis E. Puleston*, Academic Press, New York.

Flannery, K. V. (ed.) (1986). *Guilá Naquitz: Archaic Foraging and Early Agriculture in Oaxaca, Mexico*, Academic Press, Orlando, FL.

Fletcher, R. (2009). Low-density, agrarian-based urbanism: A comparative view. *Insights (Institute of Advanced Study, Durham University)* **2**: 1–19.

Fletcher, R. (2012). Low-density, agrarian-based urbanism: Scale, power, and ecology. In Smith, M. E. (ed.), *The Comparative Archaeology of Complex Societies*, Cambridge University Press, Cambridge, pp. 285–320.

Fletcher, R., Evans, D., Pottier, C., and Rachna, C. (2015). Angkor Wat: An introduction. *Antiquity* **89**: 1388–1401.
Fletcher, R., Penny, D., Evans, D., Pottier, C., Barbetti, M., Kummu, M., and Lustig, T. (2008). The water management network of Angkor, Cambodia. *Antiquity* **82**: 658–670.
Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* **16**: 253–267.
Ford, A., and Nigh, R. (2009). Origins of the Maya forest garden: Maya resource management. *Journal of Ethnobiology* **29**: 213.
Ford, A., and Nigh, R. (2015). *The Maya Forest Garden: Eight Millennia of Sustainable Cultivation in the Tropical Wetlands*, Left Coast Press, Walnut Creek, CA.
Frederick, C. D. (2007). Chinampa cultivation in the Basin of Mexico: Observations on the evolution of form and function. In Thurston, T. L., and Fisher, C. T. (eds.), *Seeking a Richer Harvest: The Archaeology of Subsistence Intensification, Innovation and Change*, Springer, Boston, pp. 107–124.
Fredskild, B., and Humle, L. (1991). Plant remains from the Norse farm Sandnes in the western settlement, Greenland. *Acta Borealia* **8**: 69–81.
Gallagher, D. E., Dueppen, S. A., and Walsh, R. (2016). The archaeology of shea butter (*Vitellaria paradoxa*) in Burkina Faso, West Africa. *Journal of Ethnobiology* **36**: 150–171.
Gallagher, J. P., Boszhardt, R. F., Sasso, R. F., and Stevenson, K. (1985). Oneota ridged field agriculture in southwestern Wisconsin. *American Antiquity* **50**: 605–612.
Giovannucci, D., Scherr, S., Nierenberg, D., Hebebrand, C., Shapiro, J., Milder, J., and Wheeler, K. (2012). *Food and Agriculture: The Future of Sustainability. A Strategic Input to the Sustainable Development in the 21st Century (SD21) Project*, United Nations Department of Economic and Social Affairs, Division for Sustainable Development, New York.
Glaser, B. (2007). Prehistorically modified soils of central Amazonia: A model for sustainable agriculture in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences* **362**: 187–196.
Gleason, K. L., and Miller, N. F. (1994). *The Archaeology of Garden and Field*, University of Pennsylvania Press, Philadelphia.
Gliessman, S. (2018). Defining agroecology. *Agroecology and Sustainable Food Systems* **42**: 599–600.
Goldsmith, E., and Allen, R. (1972). *A Blueprint for Survival*, Houghton-Mifflin, Boston.
Goldsmith, E., Hildyard, N., Bunyard, P., and McCully, P. (eds.) (1991). *The UN Food and Agriculture Organization: Promoting World Hunger*, *The Ecologist* **21**.
Golson, J., Denham, T., Hughes, P., Swadling, P., and Muke, J. (eds.) (2017). *Ten Thousand Years of Cultivation at Kuk Swamp in the Highlands of Papua New Guinea*, Australian National University Press, Canberra.
Gómez Pompa, A., and Jiménez Osornio, J. (1989). Some reflections on intensive traditional agriculture. In Gladwin, C., and Truman, K. (eds.), *Food and Farm: Current Debates and Policies*, University Press of America, New York, pp. 231–253.
Goodman-Elgar, M. (2008). Evaluating soil resilience in long-term cultivation: A study of pre-Columbian terraces from the Paca Valley, Peru. *Journal of Archaeological Science* **35**: 3072–3086.
Graff, S. R. (2018). Archaeological studies of cooking and food preparation. *Journal of Archaeological Research* **26**: 305–351.
Graffam, G. (1992). Beyond state collapse: Rural history, raised fields, and pastoralism in the south Andes. *American Anthropologist* **94**: 882–904.
Groenman-van Waateringe, W., and van Geel, B. (2017). Raised bed agriculture in northwest Europe triggered by climatic change around 850 BC: A hypothesis. *Environmental Archaeology* **22**: 166–170.
Hammond, N. (1978). The myth of the milpa: Agricultural expansion in the Maya Lowlands. In Harrison, P. D., and Turner II, B. L. (eds.), *Pre-Hispanic Maya Agriculture*, University of New Mexico Press, Albuquerque, pp. 23–34.
Hanus, K., and Evans, D. (2015). Imaging the waters of Angkor: A method for semi-automated pond extraction from LiDAR data. *Archaeological Prospection* **23**: 87–94.
Harrison, P. D., and Turner, B. L. (eds.) (1978). *Pre-Hispanic Maya Agriculture*, University of New Mexico Press, Albuquerque.
Hartman, S., Ogilvie, A. E. J., Ingimundarson, J. H., Dugmore, A. J., Hambrecht, G., and McGovern, T. H. (2017). Medieval Iceland, Greenland, and the new human condition: A case study in integrated environmental humanities. *Global and Planetary Change* **156**: 123–139.

Hastorf, C. A. (1990). The effect of the Inka state on Sausa agricultural production and crop consumption. *American Antiquity* **55**: 262–290.
Haug, G. H., Günther, D., Peterson, L. C., Sigman, D. M., Hughen, K. A., and Aeschlimann, B. (2003). Climate and the collapse of Maya civilization. *Science* **299**: 1731–1735.
Hawken, S. (2013). Designs of kings and farmers: Landscape systems of the Greater Angkor urban complex. *Asian Perspectives* **52**: 347–367.
Haynes, G. M. (2010). Cross-cultural implications for Ancestral Puebloan agriculture in the Mojave Desert. *Journal of Anthropological Research* **66**: 305–328.
Heckenberger, M. J., Kuikuro, A., Kuikuro, U. T., Russell, J. C., Schmidt, M., Fausto, C., and Franchetto, B. (2003). Amazonia 1492: Pristine forest or cultural parkland? *Science* **301**: 1710–1714.
Heckenberger, M. J., Russell, J. C., Fausto, C., Toney, J. R., Schmidt, M. J., Pereira, E., Franchetto, B., and Afukaka, K. (2008). Pre-Columbian urbanism, anthropogenic landscapes, and the future of the Amazon. *Science* **321**: 1214–1217.
Hegmon, M. (2016). Archaeology of the human experience: An introduction. In Hegmon, M. (ed.), *Archaeology of the Human Experience*, Archeological Papers No. 27, American Anthropological Association, Washington, DC, pp. 7–21.
Hegmon, M. (ed.) (2017). *The Give and Take of Sustainability: Archaeological and Anthropological Perspectives on Tradeoffs*, Cambridge University Press, Cambridge.
Hegmon, M., Ennes, M., and Nelson, M. C. (2000). Corrugated pottery, technological style, and population movement in the Mimbres region of the American Southwest. *Journal of Anthropological Research* **56**: 217–240.
Hegmon, M., Peeples, M. A., Kinzig, A. P., Kulow, S., Meegan, C. M., and Nelson, M. C. (2008). Social transformation and its human costs in the prehispanic US Southwest. *American Anthropologist* **110**: 313–324.
Herhahn, C. L., and Hill, J. B. (1998). Modeling agricultural production strategies in the northern Rio Grande Valley, New Mexico. *Human Ecology* **26**: 469–487.
Hobbs, P. R., Sayre, K., and Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**: 543–555.
Hoggarth, J. A., Restall, M., Wood, J. W., and Kennett, D. J. (2017). Drought and its demographic effects in the Maya Lowlands. *Current Anthropology* **58**: 82–113.
Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* **4**: 1–23.
Holling, C. S. (1986). The resilience of terrestrial ecosystems: Local surprise and global change. In Clark, W. C., and Munn, R. E. (eds.), *Sustainable Development of the Biosphere*, Cambridge University Press, Cambridge, pp. 292–317.
Holt, E. (2017). Experts on the past, working in the present: What archeologists can contribute to current water management. *Wiley Interdisciplinary Reviews* **4**: 1–9.
Homburg, J. A., and Sandor, J. A. (2011). Anthropogenic effects on soil quality of ancient agricultural systems of the American Southwest. *CATENA* **85**: 144–154.
Huckleberry, G. A., and Billman, B. R. (1998). Floodwater farming, discontinuous ephemeral streams, and Puebloan abandonment in southwestern Colorado. *American Antiquity* **63**: 595–616.
Iannone, G. (ed.) (2014). *The Great Maya Droughts in Cultural Context: Case Studies in Resilience and Vulnerability*, University Press of Colorado, Boulder.
Iannone, G., Prufer, K., and Chase, D. Z. (2014). Resilience and vulnerability in the Maya hinterlands. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 155–170.
IFAD (International Fund for Agricultural Development) (1999). *Good Governance: An Overview*, Food and Agriculture Organization of the United Nations, Rome.
Inglis, J. (ed.) (1993). *Traditional Ecological Knowledge: Concepts and Cases*, Canadian Museum of Nature, Ottawa.
Ingram, S. E. (2010). *Human Vulnerability to Climatic Dry Periods in the Prehistoric U.S. Southwest*, Ph.D. dissertation, Department of Anthropology, Arizona State University, Tempe.
IPCC (Intergovernmental Panel on Climate Change) (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
Isendahl, C. (2012). Agro-urban landscapes: The example of Maya Lowland cities. *Antiquity* **86**: 1112–1125.

Isendahl, C., and Smith, M. E. (2013). Sustainable agrarian urbanism: The low-density cities of the Mayas and Aztecs. *Cities* **31**: 132–143.

Isendahl, C., and Stump, D. (eds.) (2015) *The Oxford Handbook of Historical Ecology and Applied Archaeology*, Oxford University Press, Oxford.

Janusek, J. W., and Kolata, A. L. (2004). Top-down or bottom-up: Rural settlement and raised field agriculture in the Lake Titicaca basin, Bolivia. *Journal of Anthropological Archaeology* **23**: 404–430.

Jiang, Y., Li, S., Chen, W., Cai, D., and Liu, Y. (2017). The evolution of crop cultivation and paleoenvironment in the Longji terraces, southern China: Organic geochemical evidence from paleosols. *Journal of Environmental Management* **202**: 524–531.

Kealhofer, L. (ed.) (2005). *The Archaeology of Midas and the Phrygians: Recent Work at Gordion*, University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia.

Kennett, D. J., and Beach, T. P. (2013). Archeological and environmental lessons for the Anthropocene from the Classic Maya collapse. *Anthropocene* **4**: 88–100.

Kennett, D. J., Breitenbach, S. F. M., Aquino, V. V., Asmerom, Y., Awe, J., Baldini, J. U. L., et al. (2012). Development and disintegration of Maya political systems in response to climate change. *Science* **338**: 788–791.

Kern, D. C., Pinto Lima, H., Amorim da Costa, J., Veras de Lima, H., Browne Ribeiro, A., Marcos Moraes, B., and Kämpf, N. (2017). Terras pretas: Approaches to formation processes in a new paradigm. *Geoarchaeology* **32**: 694–706.

Kidd, C. V. (1992). The evolution of sustainability. *Journal of Agricultural and Environmental Ethics* **5**: 1–26.

Killion, T. W. (ed.) (1992). *Gardens of Prehistory: The Archaeology of Settlement Agriculture in Greater Mesoamerica*, University of Alabama Press, Tuscaloosa.

Kintigh, K. W. (1985). *Settlement, Subsistence, and Society in Late Zuni Prehistory*, University of Arizona Press, Tucson.

Kintigh, K. W. (1996). The Cibola region in the post-Chacoan era. In Adler, M. A. (ed.), *The Prehistoric Pueblo World, AD 1150–1350*, University of Arizona Press, Tucson, pp. 131–144.

Kintigh, K. W., Glowacki, D. M., and Huntley, D. L. (2004). Long-term settlement history and the emergence of towns in the Zuni area. *American Antiquity* **69**: 432–456.

Kintigh, K. W., and Ingram, S. E. (2018). Was the drought really responsible? Assessing statistical relationships between climate extremes and cultural transitions. *Journal of Archaeological Science* **89**: 25–31.

Kirch, P. V. (1994). *The Wet and the Dry: Irrigation and Agricultural Intensification in Polynesia*, University of Chicago Press, Chicago.

Kirch, P. V., Asner, G., Chadwick, O. A., Field, J., Ladefoged, T., Lee, C., et al. (2012). Building and testing models of long-term agricultural intensification and population dynamics: A case study from the Leeward Kohala Field System, Hawai'i. *Ecological Modelling* **227**: 18–28.

Klassen, S. (2018). *Adaptive Capacity of the Water Management Systems of Two Medieval Khmer Cities, Angkor and Koh Ker*, Ph.D. dissertation, School of Human Evolution and Social Change, Arizona State University, Tempe.

Kleinman, P. J. A., Pimentel, D., and Bryant, R. B. (1995). The ecological sustainability of slash-and-burn agriculture. *Agriculture, Ecosystems & Environment* **52**: 235–249.

Knowler, D., and Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* **32**: 25–48.

Kohler, T. A., Bocinsky, R. K., Cockburn, D., Crabtree, S. A., Varien, M. D., Kolm, K. E., et al. (2012). Modelling prehispanic Pueblo societies in their ecosystems. *Ecological Modelling* **241**: 30–41.

Kohler, T. A., and Reese, K. M. (2014). Long and spatially variable Neolithic demographic transition in the North American Southwest. *Proceedings of the National Academy of Sciences USA* **111**: 10101–10106.

Kolata, A. L. (1986). The agricultural foundations of the Tiwanaku state: A view from the heartland. *American Antiquity* **51**: 748–762.

Kolata, A. L. (1991). The technology and organization of agricultural production in the Tiwanaku state. *Latin American Antiquity* **2**: 99–125.

Kolata, A. L., and Ortloff, C. (1989). Thermal analysis of Tiwanaku raised field systems in the Lake Titicaca basin of Bolivia. *Journal of Archaeological Science* **16**: 233–263.

Kolata, A. L., and Ortloff, C. (1996a). Agroecological perspectives on the decline of the Tiwanaku state. In Kolata, A. L. (ed.), *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Smithsonian Institution Press, Washington, DC, pp. 181–202.

Kolata, A. L., and Ortloff, C. (1996b). Tiwanaku raised-field agriculture in the Lake Titicaca basin of Bolivia. In Kolata, A. L. (ed.), *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Smithsonian Institution Press, Washington, DC, pp. 109–152.

Krahtopoulou, A., and Charles, F. (2008). The stratigraphic implications of long-term terrace agriculture in dynamic landscapes: Polycyclic terracing from Kythera Island, Greece. *Geoarchaeology* **23**: 550–585.

Kuckelman, K. A., Lightfoot, R. R., and Martin, D. L. (2002). The bioarchaeology and taphonomy of violence at Castle Rock and Sand Canyon pueblos, southwestern Colorado. *American Antiquity* **67**: 486–513.

Kummu, M. (2009). Water management in Angkor: Human impacts on hydrology and sediment transportation. *Journal of Environmental Management* **90**: 1413–1421.

Kunen, J. L. (2004). *Ancient Maya Life in the Far West Bajo: Social and Environmental Change in the Wetlands of Belize*, University of Arizona Press, Tucson.

Lane, P. J. (2015). Archaeology in the age of the Anthropocene: A critical assessment of its scope and societal contributions. *Journal of Field Archaeology* **40**: 485–498.

Lang, C., and Stump, D. (2017). Geoarchaeological evidence for the construction, irrigation, cultivation, and resilience of 15th–18th century AD terraced landscape at Engaruka, Tanzania. *Quaternary Research* **88**: 382–399.

Laparidou, S., and Rosen, A. M. (2015). Intensification of production in medieval Islamic Jordan and its ecological impact: Towns of the Anthropocene. *The Holocene* **25**: 1685.

Leigh, D., Kowalewski, S. A., and Holdridge, G. (2013). 3400 years of agricultural engineering in Mesoamerica: Lama-bordos of the Mixteca Alta, Oaxaca, Mexico. *Journal of Archaeological Science* **40**: 4107–4111.

Lemonnier, E., and Vannière, B. (2013). Agrarian features, farmsteads, and homesteads in the Río Bec nuclear zone, Mexico. *Ancient Mesoamerica* **24**: 397–413.

Lentz, D. L., Dunning, N. P., and Scarborough, V. L. (eds.) (2015). *Tikal: Paleoecology of an Ancient Maya City*. Cambridge University Press, New York.

Lentz, D. L., Dunning, N. P., Scarborough, V. L. and Grazioso, L. (in press). Imperial resource management at the ancient Maya city of Tikal: A resilience model of sustainability and collapse. *Journal of Anthropological Archaeology*.

Lentz, D. L., Dunning, N. P., Scarborough, V. L., Magee, K. S., Thompson, K. M., Weaver, E., et al. (2014). Forests, fields, and the edge of sustainability at the ancient Maya city of Tikal. *Proceedings of the National Academy of Sciences USA* **111**: 18513–18518.

Lentz, D. L., and Hockaday, B. (2009). Tikal timbers and temples: Ancient Maya agroforestry and the end of time. *Journal of Archaeological Science* **36**: 1342–1353.

Lentz, D., Woods, S., Hood, A., and Murph, M. (2012). Agroforestry and agricultural production of the ancient Maya at Chan. In Robin, C. (ed.), *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville, pp. 89–109.

Li, Y., Storozum, M. J., Wang, X., and Guo, W. (2017). Early irrigation and agropastoralism at Mohuchahangoukou (MGK), Xinjiang, China. *Archaeological Research in Asia* **12**: 23–32.

Lightfoot, K. G., and Gonzalez, S. L. (2018). The study of sustained colonialism: An example from the Kashaya Pomo homeland in northern California. *American Antiquity* **83**: 427–443.

Logan, A. L. (2012). *A History of Food Without History: Food, Trade, and Environment in West-Central Ghana in the Second Millennium AD*, Ph.D. dissertation, Department of Anthropology, University of Michigan, Ann Arbor.

Logan, A. L. (2016a). An archaeology of food security in Banda, Ghana. In Hegmon, M. (ed.) *Archaeology of the Human Experience*, Archeological Papers No. 27, American Anthropological Association, Washington, DC, pp. 106-119.

Logan, A. L. (2016b). "Why can't people feed themselves?": Archaeology as alternative archive of food security in Banda, Ghana. *American Anthropologist* **118**: 508–524.

Logan, A.L. and Cruz, M. D. (2014). Gendered taskscapes: Food, farming, and craft production in Banda, Ghana in the eighteenth to twenty-first centuries. *African Archaeological Review* **31**: 203–231.

Lohse, J. C. (ed.) (2013). *Classic Maya Political Ecology: Resource Management, Class Histories, and Political Change in Northwestern Belize*, Cotsen Institute of Archaeology, University of California, Los Angeles.

Lombardo, U., Canal-Beeby, E., Fehr, S., and Veit, H. (2011). Raised fields in the Bolivian Amazonia: A prehistoric green revolution or a flood risk mitigation strategy? *Journal of Archaeological Science* **38**: 502–512.

Lombardo, U., Denier, S., May, J.-H., Rodrigues, L., and Veit, H. (2013). Human-environment interactions in pre-Columbian Amazonia: The case of the Llanos de Moxos, Bolivia. *Quaternary International* **312**: 109–119.

Londoño, A. C., Williams, P. R., and Hart, M. L. (2017). A change in landscape: Lessons learned from abandonment of ancient Wari agricultural terraces in southern Peru. *Journal of Environmental Management* **202**: 532–542.

Lovell, S. T. (2010). Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability* **2**: 2499–2522.

Lucero, L. J. (2002). The collapse of the Classic Maya: A case for the role of water control. *American Anthropologist* **104**: 814–826.

Lucero, L. J. (2006). *Water and Ritual: The Rise and Fall of Classic Maya Rulers*, University of Texas Press, Austin.

Lucero, L. J., Fletcher, R., and Coningham, R. (2015). From "collapse" to urban diaspora: The transformation of low-density, dispersed agrarian urbanism. *Antiquity* **89**: 1139–1154.

Lucero, L. J. (2018). A cosmology of conservation in the ancient Maya world. *Journal of Anthropological Research* **74**: 327–359.

Lucero, L. J., and Fash, B. W. (eds.) (2006). *Precolumbian Water Management: Ideology, Ritual, and Power*, University of Arizona Press, Tucson.

Lucero, L. J., Gunn, J. D., and Scarborough, V. L. (2011). Climate change and Classic Maya water management. *Water* **3**: 479–494.

Lustig, T. (2012). Linking downstream to upstream in landscape archaeology: Two Southeast Asian examples. In Bonatz-Tjoa, M. L., Reinecke, A., and Bonatz, D. (eds.) *Connecting Empires and States: Selected Papers from the 13th International Conference of the European Association of Southeast Asian Archaeologists*, NUS Press, Singapore, pp. 209–225.

Lustig, T., Klassen, S., Evans, D., French, R., and Moffat, I. (2018). Evidence for the breakdown of an Angkorian hydraulic system, and its historical implications for understanding the Khmer empire. *Journal of Archaeological Science: Reports* **17**: 195–211.

Luzzadder-Beach, S., and Beach, T. (2009). Arising from the wetlands: Mechanisms and chronology of landscape aggradation in the northern coastal plain of Belize. *Annals of the Association of American Geographers* **99**: 1–26.

Luzzadder-Beach, S., Beach, T. P., and Dunning, N. P. (2012). Wetland fields as mirrors of drought and the Maya abandonment. *Proceedings of the National Academy of Sciences USA* **109**: 3646–3651.

Madsen, C. K. (2014). *Pastoral Settlement, Farming, and Hierarchy in Norse Vatnahverfi, South Greenland*, Ph.D. dissertation, Department of Middle Ages and Renaissance, University of Copenhagen, Copenhagen.

Mainland, I., and Halstead, P. (2005). The economics of sheep and goat husbandry in Norse Greenland. *Arctic Anthropology* **42**: 103–120.

Manuel, M., Lightfoot, D., and Fattahi, M. (2018). The sustainability of ancient water control techniques in Iran: An overview. *Water History* **10**: 13–30.

Manzanilla, L., and Barba, L. (1990). The study of activities in Classic households: Two case studies from Coba and Teotihuacan. *Ancient Mesoamerica* **1**: 41–49.

Marcus, J. (1982). The plant world of the sixteenth- and seventeenth-century Lowland Maya. In Flannery, K. V. (ed.), *Maya Subsistence: Studies in Memory of Dennis E. Puleston*, Academic Press, New York, pp. 239–273.

Marcus, J. (1992). Dynamic cycles of Mesoamerican states. *National Geographic Research & Exploration* **8**: 392–411.

Marcus, J. (1998). The peaks and valleys of ancient states: An extension of the dynamic model. In Feinman, G. M., and Marcus, J. (eds.), *Archaic States*, School of American Research Press, Santa Fe, NM, pp. 59–94.

Marcus, J., and Flannery, K. V. (1996). *Zapotec Civilization: How Urban Society Evolved in Mexico's Oaxaca Valley*, Thames and Hudson, New York.

Marcus, J., and Stanish, C. (eds.) (2006). *Agricultural Strategies*, Cotsen Institute of Archaeology, University of California, Los Angeles.

Marston, J. M. (2010). *Evaluating Risk, Sustainability, and Decision Making in Agricultural and Land-use Strategies at Ancient Gordion*, Ph.D. Dissertation, Department of Archaeology, University of California, Los Angeles.

Marston, J. M. (2011). Archaeological markers of agricultural risk management. *Journal of Anthropological Archaeology* **30**: 190-205.

Marston, J. M. (2012). Agricultural strategies and political economy in ancient Anatolia. *American Journal of Archaeology* **116**: 377–403.
Marston, J. M. (2015). Modeling resilience and sustainability in ancient agricultural systems. *Journal of Ethnobiology* **35**: 585–605.
Marston, J. M. (2017). *Agricultural Sustainability and Environmental Change at Ancient Gordion*, University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia.
Marston, J. M., and Branting, S. (2016). Agricultural adaptation to highland climate in Iron Age Anatolia. *Journal of Archaeological Science: Reports* **9**: 25–32.
Marston, J. M., and Miller, N. F. (2014). Intensive agriculture and land use at Roman Gordion, central Turkey. *Vegetation History and Archaeobotany* **23**: 761–773.
Masson, M. A. (2012). Maya collapse cycles. *Proceedings of the National Academy of Sciences USA* **109**: 18237–18238.
Masson, M. A., and Peraza Lope, C. (2014). *Kukulcan's Realm: Urban Life at Ancient Mayapán*, University Press of Colorado, Boulder.
Mays, L. W. (2017). Survey of ancient water technologies in semi-arid and arid regions: Traditional knowledge for the future. *Water Science & Technology* **17**: 1278–1286.
McAnany, P. A., and Yoffee, N. (eds.) (2010). *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire*, Cambridge University Press, Cambridge.
McCann, J. (2005). *Maize and Grace: Africa's Encounter with A New World Crop, 1500–2000*, Harvard University Press, Cambridge, MA.
McCool, J.-P. P., Fladd, S. G., Scarborough, V. L., Plog, S., Dunning, N. P., Owen, L. A., et al. (2018). Soil analysis in discussions of agricultural feasibility for ancient civilizations: A critical review and reanalysis of the data and debate from Chaco Canyon, New Mexico. *PLoS One* **13**: 1–35.
McCoy, M. D., and Ladefoged, T. N. (2009). New developments in the use of spatial technology in archaeology. *Journal of Archaeological Research* **17**: 263–295.
McGovern, T. H., Perdikaris, S., Einarsson, Á., and Sidell, J. (2006). Coastal connections, local fishing, and sustainable egg harvesting: Patterns of Viking Age inland wild resource use in Mývatn district, northern Iceland. *Environmental Archaeology* **11**: 187–205.
McGovern, T. H., Vésteinsson, O., Fridriksson, A., Church, M., Lawson, I., Simpson, I. A., et al. (2007). Landscapes of settlement in northern Iceland: Historical ecology of human impact and climate fluctuation on the millennial scale. *American Anthropologist* **109**: 27–51.
McKey, D., Rostain, S., Iriarte, J., Glaser, B., Birk, J. J., Holst, I., Renard, D., and Linares, O. F. (2010). Pre-Columbian agricultural landscapes, ecosystem engineers, and self-organized patchiness in Amazonia. *Proceedings of the National Academy of Sciences USA* **107**: 7823–7828.
Merlin-Uribe, Y., Gonzalez-Esquivel, C. E., Contreras-Hernandez, A., Zambrano, L., Moreno-Casasola, P. and Astier, M. (2013). Environmental and socio-economic sustainability of chinampas (raised beds) in Xochimilco, Mexico City. *International Journal of Agricultural Sustainability* **11**: 216–233.
Middleton, G. D. (2012). Nothing lasts forever: Environmental discourses on the collapse of past societies. *Journal of Archaeological Research* **20**: 257–307.
Middleton, G. D. (2017). *Understanding Collapse: Ancient History and Modern Myths*, Cambridge University Press, Cambridge.
Miller, N. F. (2010). *Botanical Aspects of Environment and Economy at Gordion, Turkey*, University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia.
Miller, N. F. (2018). Historic landscape and site preservation at Gordion, Turkey: An archaeobotanist's perspective. *Vegetation History and Archaeobotany* **28**: 1–8.
Miller, N. F., and Marston, J. M. (2012). Archaeological fuel remains as indicators of ancient west Asian agropastoral and land-use systems. *Journal of Arid Environments* **86**: 97–103.
Miller, N. F., Zeder, M. A., and Arter, S. R. (2009). From food and fuel to farms and flocks. *Current Anthropology* **50**: 915–924.
Millhauser, J. K., and Morehart, C. T. (2018). Sustainability as a relative process: A long-term perspective on sustainability in the northern Basin of Mexico. In Millhauser, J. K., Morehart, C. T., and Juarez, S. (eds.), *Uneven Terrain: Archaeologies of Political Ecology*, Archeological Papers No. 29, American Anthropological Association, Washington, DC, pp. 134–156.
Millhauser, J. K., Rodríguez-Alegría, E., and Glascock, M. D. (2011). Testing the accuracy of portable x-ray fluorescence to study Aztec and colonial obsidian supply at Xaltocan, Mexico. *Journal of Archaeological Science* **38**: 3141–3152.

Minnis, P. E. (1985). *Social Adaptation to Food Stress: A Prehistoric Southwestern Example*, University of Chicago Press, Chicago.
Minnis, P. E. (1999). Sustainability: The long view from archaeology. *New Mexico Journal of Science* **39**: 23–41.
Mitcham, C. (1995). The concept of sustainable development: Its origins and ambivalence. *Technology in Society* **17**: 311–326.
Morehart, C. T. (2011). Sustainable ecologies and unsustainable politics: Chinampa farming in ancient central Mexico. *Anthropology News* **52**: 9–10.
Morehart, C. T. (2012a). Mapping ancient chinampa landscapes in the Basin of Mexico: A remote sensing and GIS approach. *Journal of Archaeological Science* **39**: 2541–2551.
Morehart, C. T. (2012b). What if the Aztec empire never existed? The prerequisites of empire and the politics of plausible alternative histories. *American Anthropologist* **114**: 267–281.
Morehart, C. T. (2016a). Chinampa agriculture, surplus production, and political change at Xaltocan, Mexico. *Ancient Mesoamerica* **27**: 183–196.
Morehart, C. T. (2016b). Let the earth forever remain! Landscape legacies and the materiality of history in the northern Basin of Mexico. *Journal of the Royal Anthropological Institute* **22**: 939–961.
Morehart, C. T. (2018). Inherited legacies of ecological imperialism in central Mexico. *Journal of Anthropological Archaeology*.
Morehart, C. T., and Eisenberg, D. T. A. (2010). Prosperity, power, and change: Modeling maize at Postclassic Xaltocan, Mexico. *Journal of Anthropological Archaeology* **29**: 94–112.
Morehart, C. T., and Frederick, C. (2014). The chronology and collapse of pre-Aztec raised field (chinampa) agriculture in the northern Basin of Mexico. *Antiquity* **88**: 531–548.
Morehart, C. T., Millhauser, J. K., and Juarez, S. (2018). Archaeologies of political ecology: Genealogies, problems, and orientations. In Millhauser, J. K., Morehart, C. T., and Juarez, S. (eds.), *Uneven Terrain: Archaeologies of Political Ecology*, Archeological Papers No. 29, American Anthropological Association, Washington, DC, pp. 5–29.
Nelson, B. A., Chase, A. S. Z., and Hegmon, M. (2014). Transformative relocation in the U.S. Southwest and Mesoamerica. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 171–182.
Nelson, M. C. (1999). *Mimbres during the Twelfth Century: Abandonment, Continuity, and Reorganization*, University of Arizona Press, Tucson.
Nelson, M. C., Hegmon, M., Kintigh, K. W., Kinzig, A. P., Nelson, B. A., Anderies, J. M., et al. (2012). Long-term vulnerability and resilience: Three examples from archaeological study in the Southwestern United States and Northern Mexico. In Cooper, J., and Sheets, P. (eds.), *Surviving Sudden Environmental Change: Understanding Hazards, Mitigating Impacts, Avoiding Disasters*, University Press of Colorado, Boulder, pp. 197–221.
Nelson, M. C., Hegmon, M., Kulow, S., and Schollmeyer, K. G. (2006). Archaeological and ecological perspectives on reorganization: A case study from the Mimbres region of the U.S. Southwest. *American Antiquity* **71**: 403–432.
Nelson, M. C., Ingram, S. E., Dugmore, A. J., Streeter, R., Peeples, M. A., McGovern, T. H., et al. (2016). Climate challenges, vulnerabilities, and food security. *Proceedings of the National Academy of Sciences USA* **113**: 298–303.
Nelson, M. C., Kintigh, K., Abbott, D. R., and Anderies, J. M. (2010). The cross-scale interplay between social and biophysical context and the vulnerability of irrigation-dependent societies. *Ecology and Society* **15**: 31.
Netting, R. M. (1993). *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*, Stanford University Press, Stanford.
Nichols, D. L. (1987). Risk and agricultural intensification during the Formative period in the northern Basin of Mexico. *American Anthropologist* **89**: 596–616.
Nichols, D. L., Brumfiel, E. M., Neff, H., Hodge, M., Charlton, T. H., and Glascock, M. D. (2002). Neutrons, markets, cities, and empires: A 1000-year perspective on ceramic production and distribution in the Postclassic Basin of Mexico. *Journal of Anthropological Archaeology* **21**: 25–82.
Nichols, D. L., and Frederick, C. D. (1993). *Irrigation Canals and Chinampas: Recent Research in the Northern Basin of Mexico*, JAI Press, Greenwich, CT.
Nigh, R., and Diemont, S. A. (2013). The Maya milpa: Fire and the legacy of living soil. *Frontiers in Ecology and the Environment* **11**: 45–54.

Ogilvie, A. E. J., Woollett, J. M., Smiarowski, K., Arneborg, J., Troelstra, S., Kuijpers, A., Pálsdóttir, A., and McGovern, T. H. (2009). Seals and sea ice in medieval Greenland. *Journal of the North Atlantic* **2**: 60–80.

O'Reilly, D., Evans, D., and Shewan, L. (2017). Airborne LiDAR prospection at Lovea, an Iron Age moated settlement in central Cambodia. *Antiquity* **91**: 947–965.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., and Grace, P. (2014). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems & Environment* **187**: 87–105.

Parsons, J. R. (1976). The role of chinampa agriculture in the food supply of Aztec Tenochtitlan. In Cleland, C. (ed.), *Cultural Change and Continuity: Essays in Honor of James B. Griffin*, Academic Press, New York, pp. 233–257.

Parsons, J. R. (1991). Political implications of prehispanic chinampa agriculture in the Valley of Mexico. In Harvey, H. (ed.), *Land and Politics in the Valley of Mexico: A Two-Thousand Year Perspective*, University of New Mexico Press, Albuquerque, pp. 17–42.

Parsons, J. R., Gorenflo, L. J., Parsons, M. H., and Wilson, D. J. (2008). *Prehispanic Settlement Patterns in the Northwestern Valley of Mexico: The Zumpango Region*, Memoirs No. 45, Museum of Anthropology, University of Michigan, Ann Arbor.

Paseka, R. E., Heitman, C. C., and Reinhard, K. J. (2018). New evidence of ancient parasitism among Late Archaic and Ancestral Puebloan residents of Chaco Canyon. *Journal of Archaeological Science: Reports* **18**: 51–58.

Penny, D., Pottier, C., Kummu, M., Fletcher, R., Zoppi, U., Barbetti, M., and Tous, S. (2007). Hydrological history of the West Baray, Angkor, revealed through palynological analysis of sediments from the West Mebon. *Bulletin de l'École Française d'Extrême-Orient* **92**: 497–521.

Pérez Rodríguez, V. (2006). States and households: The social organization of terrace agriculture in Postclassic Mixteca Alta, Oaxaca, Mexico. *Latin American Antiquity* **17**: 3–22.

Pérez Rodríguez, V. (2016). Terrace agriculture in the Mixteca Alta region, Oaxaca, Mexico: Ethnographic and archeological insights on terrace construction and labor organization. *Culture, Agriculture, Food and Environment* **38**: 18–27.

Pérez Rodríguez, V., and Anderson, K. C. (2013). Terracing in the Mixteca Alta, Mexico: Cycles of resilience of an ancient land-use strategy. *Human Ecology* **41**: 335–349.

Pierotti, R. (2010). *Indigenous Knowledge, Ecology, and Evolutionary Biology*, Routledge, New York.

Piperno, D. R. (2011). The origins of plant cultivation and domestication in the New World tropics. *Current Anthropology* **52**: S453–S470.

Piperno, D. R., and Flannery, K. V. (2001). The earliest archaeological maize (*Zea mays* L.) from highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences USA* **98**: 2101–2103.

Piperno, D. R., and Pearsall, D. M. (1998). *The Origins of Agriculture in the Lowland Neotropics*, Academic Press, San Diego.

Pittelkow, C. M., Liang, X., Linquist, B. A., van Groenigen, K. J., Lee, J., Lundy, M. E., et al. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature* **517**: 365–368B.

Pottier, C. (2012). Beyond the temples: Angkor and its territory. In Haendel, A. (ed.), *Old Myths, New Approaches: Interpreting Ancient Religious Sites in Southeast Asia*, Monash University, Clayton, Australia, pp.12–27.

Pretty, J. (2008). Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**: 447–465.

Puleston, D. E. (1977). The art and archaeology of hydraulic agriculture in the Maya Lowlands. In Hammond, N. (ed.), *Social Processes in Maya Prehistory: Studies in Memory of Sir Eric Thompson*, Academic Press, New York, pp. 449–467.

Purdue, L. E., and Berger, J.-F. (2015). An integrated socio-environmental approach to the study of ancient water systems: The case of prehistoric Hohokam irrigation systems in semi-arid central Arizona, USA. *Journal of Archaeological Science* **53**: 586–603.

Pyburn, K. A. (1998). Smallholders in the Maya Lowlands: Homage to a garden variety ethnographer. *Human Ecology* **26**: 267–286.

Rapoport, A. (ed.) (1976). *The Mutual Interaction of People and Their Built Environment*, Mouton Publishers, The Hague.

Redman, C. L. (1999). *Human Impact on Ancient Environments*, University of Arizona Press, Tucson.

Redman, C. L. (2005). Resilience theory in archaeology. *American Anthropologist* **107**: 70–77.

Redman, C. L., and Kinzig, A. P. (2003). Resilience of past landscapes: Resilience theory, society, and the longue durée. *Conservation Ecology* **7**: 14–32.

Renard, D., Iriarte, J., Birk, J. J., Rostain, S., Glaser, B., and McKey, D. (2012). Ecological engineers ahead of their time: The functioning of pre-Columbian raised-field agriculture and its potential contributions to sustainability today. *Ecological Engineering* **45**: 30–44.
Riehl, S. (2009). Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East. *Quaternary International* **197**: 93–114.
Robin, C. (2002). Outside of houses: The practices of everyday life at Chan Nòohol, Belize. *Journal of Social Archaeology* **2**: 245–268.
Robin, C. (2006). Gender, farming, and long-term change: Maya historical and archaeological perspectives. *Current Anthropology* **47**: 409–433.
Robin, C. (ed.) (2012). *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville.
Robin, C. (2013). *Everyday Life Matters: Maya Farmers at Chan*, University Press of Florida, Gainesville.
Robin, C. (2016). Neither dopes nor dupes: Maya farmers and ideology. *Ancient Mesoamerica* **27**: 221–230.
Robin, C., Kosakowsky, L., Keller, A., and Meierhoff, J. (2014). Leaders, farmers, and crafters: The relationship between leading households and households across the Chan community. *Ancient Mesoamerica* **25**: 371–387.
Robin, C., Meierhoff, J., Kestle, C., Blackmore, C., Kosakowsky, L. J., and Novotny, A. C. (2012a). Ritual in a farming community. In Robin, C. (ed.), *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville, pp. 113–132.
Robin, C., Meierhoff, J., and Kosakowsky, L. J. (2012b). Nonroyal governance at Chan's community center. In Robin, C. (ed.), *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville, pp. 133–149.
Rodrigues, L., Lombardo, U., Canal-Beeby, E., and Veit, H. (2017). Linking soil properties and pre-Columbian agricultural strategies in the Bolivian lowlands: The case of raised fields in Exaltación. *Quaternary International* **437**: 143–155.
Rodrigues, L., Lombardo, U., Fehr, S., Preusser, F., and Veit, H. (2015). Pre-Columbian agriculture in the Bolivian lowlands: Construction history and management of raised fields in Bermeo. *Catena* **132**: 126–138.
Rodrigues, L., Lombardo, U., and Veit, H. (2018). Design of pre-Columbian raised fields in the Llanos de Moxos, Bolivian Amazon: Differential adaptations to the local environment? *Journal of Archaeological Science: Reports* **17**: 366–378.
Ross, J. M., and Zutter, C. (2007). Comparing Norse animal husbandry practices: Paleoethnobotanical analyses from Iceland and Greenland. *Arctic Anthropology* **44**: 62–86.
Rostain, S. (2016). *Islands in the Rainforest: Landscape Management in Pre-Columbian Amazonia*, Routledge, New York.
Roys, R. L. (1972). *The Indian Background of Colonial Yucatan*, University of Oklahoma Press, Norman.
Sanders, W. T., Parsons, J. R., and Santley, R. S. (1979). *Basin of Mexico: Ecological Processes in the Evolution of a Civilization*, Academic Press, New York.
Sandor, J. A. and Homburg, J. A. (2017). Anthropogenic soil change in ancient and traditional agricultural fields in arid to semiarid regions of the Americas. *Journal of Ethnobiology* **37**: 196–218.
Sanz, M. J., de Vente, J., Chotte, J.-L., Bernoux, M., Kust, G., Ruiz, I., et al. (2017). *Sustainable Land Management Contribution to Successful Land-based Climate Change Adaptation and Mitigation: A Report of the Science-Policy Interface*, United Nations Convention to Combat Desertification, Bonn, Germany.
Scarborough, V. L. (2003). *The Flow of Power: Ancient Water Systems and Landscapes*, School of American Research Press, Santa Fe, NM.
Scarborough, V. L. and Isaac, B. L. (1993). *Economic Aspects of Water Management in the Prehispanic New World,* JAI Press, Greenwich, CT.
Scarborough, V. L., Becher, M. E., Baker, J. L., Harris, G., and Valdez, F. (1995). Water and land at the ancient Maya community of La Milpa. *Latin American Antiquity* **6**: 98–119.
Scarborough, V. L., Chase, A. F., and Chase, D. Z. (2012a). Low-density urbanism, sustainability, and IHOPE-Maya: Can the past provide more than history? *UGEC Viewpoints (Urbanization and Global Environmental Change)* **8**: 20–24.
Scarborough, V. L., Dunning, N. P., Tankersley, K. B., Carr, C., Weaver, E., Grazioso, L., et al. (2012b). Water and sustainable land use at the ancient tropical city of Tikal, Guatemala. *Proceedings of the National Academy of Sciences USA* **109**: 12408–12413.

Scarry, C. M., and Scarry, J. F. (2005). Native American 'garden agriculture' in southeastern North America. *World Archaeology* **37**: 259–274.
Schmook, B., van Vliet, N., Radel, C., Manzón-Che, M. de J., and McCandless, S. (2013). Persistence of swidden cultivation in the face of globalization: A case study from communities in Calakmul, Mexico. *Human Ecology* **41**: 93–107.
Schwindt, D. M., Bocinsky, R. K., Ortman, S. G., Glowacki, D. M., Varien, M. D., and Kohler, T. A. (2016). The social consequences of climate change in the central Mesa Verde region. *American Antiquity* **81**: 74–96.
Sheets, P. (2000). Provisioning the Ceren household: The vertical economy, village economy, and household economy in the southeastern Maya periphery. *Ancient Mesoamerica* **11**: 217–230.
Smiarowski, K., Harrison, R., Brewington, S., Hicks, M., Feeley, F. J., Dupont-Hébert, C., et al. (2017). Zooarchaeology of the Scandinavian settlements in Iceland and Greenland: Diverging pathways. In Albarella, U., Rizzetto, M., Russ, H., Vickers, K., and Viner-Daniels, S. (eds.), *The Oxford Handbook of Zooarchaeology*, Oxford University Press, Oxford, pp. 1–24.
Smith, A., and Miller, N. F. (2009). Reports: Integrating plant and animal data: Delving deeper into subsistence: Introduction to the special section. *Current Anthropology* **50**: 883–884.
Smith, C., Denevan, W., and Hamilton, P. (1968). Ancient ridged fields in the region of Lake Titicaca. *Geographical Journal* **134**: 353–366.
Smith, M. E., and Price, T. J. (1994). Aztec-period agricultural terraces in Morelos, Mexico: Evidence for household-level agricultural intensification. *Journal of Field Archaeology* **21**: 169–179.
Smyth, M., Dunning, N., Weaver, E., van Beynen, P., and Zapata, D. (2017). The perfect storm: Climate change and ancient Maya response in the Puuc Hills region of Yucatan. *Antiquity* **91**: 490.
Spielmann, K. A., Peeples, M. A., Glowacki, D. M., and Dugmore, A. (2016). Early warning signals of social transformation: A case study from the US Southwest. *PLoS One* **11**:1-19.
Stahl, A. (1999). The archaeology of global encounters viewed from Banda, Ghana. *African Archaeological Review* **16**: 5–81.
Stahl, A. (2001). *Making History in Banda: Anthropological Visions of Africa's Past*, Cambridge University Press, Cambridge.
Stahl, A. (2007). Entangled lives: The archaeology of daily life in the Gold Coast hinterlands, AD 1400–1900. In Falola, T., and Ogundiran, A. (eds.), *Archaeology of Atlantic Africa and the African Diaspora*, Indiana University Press, Bloomington.
Stahl, A., Dores Cruz, M., Neff, H., Glascock, M. D., Speakman, R. J., Giles, B., and Smith, L. (2008). Ceramic production, consumption and exchange in the Banda area, Ghana: Insights from compositional analyses. *Journal of Anthropological Archaeology* **27**: 363–381.
Stahl, A., and Logan, A. (2014). Resilient villagers: Eight centuries of continuity and change in Banda village life. In Anquandah, J., Kankpeyeng, B., and Apoh, W. (eds.), *Current Perspectives in the Archaeology of Ghana*, Sub-Saharan, Accra, pp. 44–63.
Stahl, P. W., and Pearsall, D. M. (2012). Late pre-Columbian agroforestry in the tropical lowlands of western Ecuador. *Quaternary International* **249**: 43–52.
Stanish, C. (1994). The hydraulic hypothesis revisited: Lake Titicaca basin raised fields in theoretical perspective. *Latin American Antiquity* **5**: 312–332.
Stanish, C. (2003). *Ancient Titicaca: The Evolution of Social Complexity in Southern Peru and Northern Bolivia*, University of California Press, Los Angeles.
Stark, M. T., Evans, D., Rachna, C., Piphal, H., and Carter, A. (2015). Residential patterning at Angkor Wat. *Antiquity* **89**: 1439–1455.
Steward, J. H. (1955). *Theory of Culture Change: The Methodology of Multilinear Evolution*, University of Illinois Press, Urbana.
Stone, G. D. (1994). Agricultural intensification and perimetrics: Ethnoarchaeological evidence from Nigeria. *Current Anthropology* **35**: 317–324.
Stone, G. D., and Downum, C. E. (1999). Non-Boserupian ecology and agricultural risk: Ethnic politics and land control in the arid southwest. *American Anthropologist* **101**: 113–128.
Stone, G. D., Netting, R. M., and Stone, M. P. (1990). Seasonality, labor scheduling, and agricultural intensification in the Nigerian savanna. *American Anthropologist* **92**: 7–23.
Strawhacker, C. (2013). *Sustaining Irrigation Agriculture for the Long-Term: Lessons on Maintaining Soil Quality from Ancient Agricultural Fields in the Phoenix Basin and on the North Coast of Peru*, Ph. D. dissertation, School of Human Evolution and Social Change, Arizona State University, Tempe.

Stump, D. (2010). "Ancient and backward or long-lived and sustainable?" The role of the past in debates concerning rural livelihoods and resource conservation in eastern Africa. *World Development* **38**: 1251–1262.
Stump, D. (2013). On applied archaeology, indigenous knowledge, and the usable past. *Current Anthropology* **54**: 268–298.
Swartley, L. (2000). *Inventing Indigenous Knowledge: Archaeology, Rural Development, and the Raised Field Rehabilitation Project in Bolivia*, Ph.D. dissertation, Department of Anthropology, University of Pittsburgh, Pittsburgh.
Swartley, L. (2002). *Inventing Indigenous Knowledge: Archaeology, Rural Development, and the Raised Field Rehabilitation Project in Bolivia*, Routledge, London.
Tainter, J. A. (1988). *The Collapse of Complex Societies*, Cambridge University Press, New York.
Tainter, J. A. (2014). Collapse and sustainability: Rome, the Maya, and the modern world. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 201–214.
Tankersley, K. B., Dunning, N. P., Thress, J., Owen, L. A., Huff, W. D., Fladd, S. G., et al. (2016). Evaluating soil salinity and water management in Chaco Canyon, New Mexico. *Journal of Archaeological Science: Reports* **9**: 94–104.
Thompson, J. E. S. (1974). "Canals" of the Rio Candelaria basin, Campeche, Mexico. In Hammond, N. (ed.), *Mesoamerican Archaeology: New Approaches*, Duckworth, London, pp. 297–302.
Thurow, R. (2013). *The Last Hunger Season: A Year in an African Farm Community on the Brink of Change*, PublicAffairs, New York.
Thurston, T., and Fisher, C. T. (eds.) (2007). *Seeking a Richer Harvest: The Archaeology of Subsistence Intensification, Innovation, and Change*, Springer, Boston.
Tilman, D., Balzer, C., Hill, J., and Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences USA* **108**: 20260–20264.
Trigg, H., Bolender, D., Johnson, K. M., Patalano, M. D., and Steinberg, J. M. (2009). Note on barley found in dung in the lowest levels of the farm mound midden at Reynistaöur, Skagafjöröur, Iceland. *Archaeologica Islandica* **7**: 64–73.
Turner, B. L., and Harrison, P. D. (eds.) (1983). *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*, University of Texas Press, Austin.
Turner, B. L., and Sabloff, J. A. (2012). Classic period collapse of the central Maya Lowlands: Insights about human—environment relationships for sustainability. *Proceedings of the National Academy of Sciences USA* **109**: 13908–13914.
Van de Noort, R. (2011). Conceptualising climate change archaeology. *Antiquity* **85**: 1039–1048.
van der Leeuw, S. E. (2014). Transforming lessons from the past into lessons for the future. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 215–231.
Varien, M. D., Ortman, S. G., Kohler, T. A., Glowacki, D. M., and Johnson, C. D. (2007). Historical ecology in the Mesa Verde region: Results from the Village Ecodynamics Project. *American Antiquity* **72**: 273–299.
Voigt, M. M. (2002). Gordion: The rise and fall of an Iron Age capital. In Hopkins, D. C. (ed.), *Across the Anatolian Plateau: Readings in the Archaeology of Ancient Turkey*, American Schools of Oriental Research, Boston, pp.187–196.
Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* **9**: 5–13.
Walker, B., and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*, Island Press, Washington, DC.
Warner, M. S. (2015). *Eating in the Side Room: Food, Archaeology, and African American Identity*. University Press of Florida, Gainesville.
Watson, P. J. (1995). Explaining the transition to agriculture. In Price, D., and Gebauer, A. (eds.), *Last Hunters, First Farmers: New Perspectives on the Prehistoric Transition to Agriculture*, School of American Research Press, Santa Fe, NM, pp. 21–38.
Watts, M. (2012). *Silent Violence: Food, Famine, and Peasantry in Northern Nigeria*, University of California Press, Berkeley.
WCED (World Commission on Environment and Development) (1987). *Our Common Future (The Brundtland Report)*, Oxford University Press for the United Nations, Oxford.

Webster, D. L. (2002). *The Fall of the Ancient Maya: Solving the Mystery of the Maya Collapse*, Thames & Hudson, London.
Wells, E. C. (2015). Culture, power, history: Implications for understanding global environmental change. In Isendahl, C., and Stump, D. (eds.), *The Oxford Handbook of Historical Ecology and Applied Archaeology*, Oxford University Press, Oxford, pp.1–21.
Wells, E. C., Pratt, S. M., Fox, G. L., Siegel, P. E., Dunning, N. P., and Murphy, A. R. (2018). Plantation soilscapes: Initial and cumulative impacts of colonial agriculture in Antigua, West Indies. *Environmental Archaeology* **23**: 23–35.
White, C. E., Chesson, M. S., and Schaub, R. T. (2014). A recipe for disaster: Emerging urbanism and unsustainable plant economies at Early Bronze Age Ras an-Numayra, Jordan. *Antiquity* **88**: 363–377.
Whitney, B. S., Dickau, R., Mayle, F. E., Walker, J. H., Soto, J. D., and Iriarte, J. (2014). Pre-Columbian raised-field agriculture and land use in the Bolivian Amazon. *The Holocene* **24**: 231.
Wilk, R. R., and Ashmore, W., (eds.) (1988). *Household and Community in the Mesoamerican Past*, University of New Mexico Press, Albuquerque.
Wilken, G. C. (1987). *Good Farmers: Traditional Agricultural Resource Management in Mexico and Central America*, University of California Press, Berkeley.
Wills, W. H., and Dorshow, W. B. (2012). Agriculture and community in Chaco Canyon: Revisiting Pueblo Alto. *Journal of Anthropological Archaeology* **31**: 138–155.
Wingard, J. D., and Hayes, S. E. (eds.) (2013) *Soils, Climate, and Society: Archaeological Investigations in Ancient America*, University Press of Colorado, Boulder.
Wittfogel, K. A. (1957). *Oriental Despotism: A Comparative Study of Total Power*, Yale University Press, New Haven, CT.
Wolf, E. (1982). *Europe and the People without History*, University of California Press, Berkeley.
Wyatt, A. R. (2008). *Gardens on Hills: Ancient Maya Terracing and Agricultural Production at Chan, Belize*, Ph.D. dissertation, Department of Anthropology, University of Illinois at Chicago, Chicago.
Wyatt, A. R. (2012). Agricultural practices at Chan: Farming and political economy in an ancient Maya community. In Robin, C. (ed.), *Chan: An Ancient Maya Farming Community*, University Press of Florida, Gainesville, pp. 71–88.
Wyatt, A. R. (2014). The scale and organization of ancient Maya water management. *Wiley Interdisciplinary Reviews* **1**: 449–467.
Zeder, M. A. (1991). *Feeding Cities: Specialized Animal Economy in the Ancient Near East*, Smithsonian Institution Press, Washington, DC.
Zeder, M. A. (2008). Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences USA* **105**: 11597–11604.
Zeder, M. A. (2011). The origins of agriculture in the Near East. *Current Anthropology* **52**: S221–S235.
Zeder, M. A., and Arter, S. R. (1994). Changing patterns of animal utilization at ancient Gordion. *Paléorient* **22**: 105–118.
Zori, D., Byock, J., Erlendsson, E., Martin, S., Wake, T., and Edwards, K. J. (2013). Feasting in Viking Age Iceland: Sustaining a chiefly political economy in a marginal environment. *Antiquity* **87**: 150–165.

Bibliography of Recent Literature

Acabado, S. (2018). Zones of refuge: Resisting conquest in the northern Philippine highlands through environmental practice. *Journal of Anthropological Archaeology* **52**: 180–195.
Allcock, S. L. (2017). Long-term socio-environmental dynamics and adaptive cycles in Cappadocia, Turkey during the Holocene. *Quaternary International* **446**: 66–82.
Arıkan, B. (2012). Don't abhor your neighbor for he is a pastoralist: The GIS-based modeling of the past human–environment interactions and landscape changes in the Wadi el-Hasa, west-central Jordan. *Journal of Archaeological Science* **39**: 2908–2920.
Balbo, A. L., Martinez-Fernández, J., and Esteve-Selma M.-A. (2017). Mediterranean wetlands: Archaeology, ecology, and sustainability. *Wiley Interdisciplinary Reviews: Water* **4**: 1-16.
Balée, W., and Erickson, C. L. (eds.) (2006). *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*, Columbia University Press, New York.

Bevan, A., Conolly, J., Colledge, S., Frederick, C., Palmer, C., Siddall, R., and Stellatou, A. (2013). The long-term ecology of agricultural terraces and enclosed fields from Antikythera, Greece. *Human Ecology* **41**: 255–272.
Bogaard, A., and Whitehouse, N. (2010). Early agriculture in uncertain climates: Themes and approaches. *Environmental Archaeology* **15**: 109–112.
Boger, R., Perdikaris, S., Potter, A. E., Mussington, J., Murphy, A. R., Thomas, L., Gore, C., and Finch, D. (2014). Water resources and the historic wells of Barbuda: Tradition, heritage and hope for a sustainable future. *Island Studies Journal* **9**: 327–342.
Borisov, A. V., Korobov, D. S., Simakova, A. N., Zanina, O. G., Bukhonov, A. V., and Demidov, V. V. (2012). Ancient agricultural terraces in the Kislovodsk Depression: History and modern state of the soils. *Eurasian Soil Science* **45**: 561–577.
Branch, N. P., Kemp, R. A., Silva, B., Meddens, F. M., Williams, A., Kendall, A., and Vivanco Pomacanchari, C. (2007). Testing the sustainability and sensitivity to climatic change of terrace agricultural systems in the Peruvian Andes: A pilot study. *Journal of Archaeological Science* **34**: 1–9.
Bravard, J., Mostafa, A., Garcier, R., Tallet, G., Ballet, P., Chevalier, Y., and Tronchère, H. (2016). Rise and fall of an Egyptian oasis: Artesian flow, irrigation soils, and historical agricultural development in El-Deir, Kharga Depression, Western Desert of Egypt. *Geoarchaeology* **31**: 467-486.
Brite, E. B., and Marston, J. M. (2013). Environmental change, agricultural innovation, and the spread of cotton agriculture in the Old World. *Journal of Anthropological Archaeology* **32**: 39-53.
Brown, A., and Walsh, K. (2017). Societal stability and environmental change: Examining the archaeology-soil erosion paradox. *Geoarchaeology* **32**: 23–35.
Carmody, S. B., Sherwood, S. C. and Hoagland, C. (2017). From the past… A more sustainable future? Prehistoric plant use in the Eastern Woodlands. *The SAA Archaeological Record* **17**: 10–16.
Catlin, K. A. (2016). Archaeology for the Anthropocene: Scale, soil, and the settlement of Iceland. *Anthropocene* **15**: 13-21.
Colledge, S., Conolly, J., and Shennan, S. (2004). Archaeobotanical evidence for the spread of farming in the eastern Mediterranean. *Current Anthropology* **45**: S35–S58.
Coughlan, M. R., and Nelson, D. R. (2018). Influences of Native American land use on the colonial Euro-American settlement of the South Carolina Piedmont. *PLoS One* **13**: 1–23.
Dahlin, B., Beach, T., Luzzader-Beach, S., Hixson, D., Hutson, S., Magnoni, A., Mansell, E., and Mazeau, D. E. (2005). Reconstructing agricultural self-sufficiency at Chunchucmil, Yucatan, Mexico. *Ancient Mesoamerica* **16**: 229–247.
Davies, M. (2010). A view from the east: An interdisciplinary "historical ecology" approach to a contemporary agricultural landscape in northwest Kenya. *African Studies* **69**: 279–297.
Davis-Salazar, K. L. (2003). Late Classic Maya water management and community organization at Copan, Honduras. *Latin American Antiquity* **14**: 275–299.
Dillehay, T. D., Quivira, M. P., Bonzani, R., Silva, C., Wallner, J., and Quesne, C. L. (2007). Cultivated wetlands and emerging complexity in south-central Chile and long distance effects of climate change. *Antiquity* **81**: 949–960.
Downey, S. S., Haas, W. R., and Shennan, S. J. (2016). European Neolithic societies showed early warning signals of population collapse. *Proceedings of the National Academy of Sciences USA* **113**: 9751–9756.
Field, J. S., and Graves, M. W. (eds.) (2015). *Abundance and Resilience: Farming and Foraging in Ancient Kaua'i*, University of Hawai'i Press, Honolulu.
Field, J. S., Ladefoged, T. N., and Kirch, P. V. (2011). Household expansion linked to agricultural intensification during emergence of Hawaiian archaic states. *Proceedings of the National Academy of Sciences USA* **108**: 7327–7332.
Fisher, C. T. (2005). Demographic and landscape change in the Lake Pátzcuaro basin, Mexico: Abandoning the garden. *American Anthropologist* **107**: 87–95.
French, K. D., and Duffy, C. J. (2014). Understanding ancient Maya water resources and the implications for a more sustainable future. *Wiley Interdisciplinary Reviews* **1**: 305–313.
Fuks, D., Weiss, E., Tepper, Y., and Bar-Oz, G. (2016). Seeds of collapse? Reconstructing the ancient agricultural economy at Shivta in the Negev. *Antiquity* **90**: 1–5.
Gunn, J. D., Folan, W. J., Isendahl, C., Domínguez Carrasco, M. del R., Faust, B. B., and Volta, B. (2014). Calakmul: Agent risk and sustainability in the western Maya Lowlands. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 101–123.

Guttmann-Bond, E. (2010). Sustainability out of the past: How archaeology can save the planet. *World Archaeology* **42**: 355–366.

Gronenborn, D., Strien, H. C., Dietrich, S., and Sirocko, F. (2014). 'Adaptive cycles' and climate fluctuations: A case study from Linear Pottery culture in western Central Europe. *Journal of Archaeological Science* **51**: 73–83.

Harrower, M. J. (2008). Hydrology, ideology, and the origins of irrigation in ancient southwest Arabia. *Current Anthropology* **49**: 497–510.

Harrower, M.J. (2009) Is the hydraulic hypothesis dead yet? Irrigation and social change in ancient Yemen. *World Archaeology* **41**: 58–72.

Hill, J. B., Lyons, P. D., Clark, J. J., and Doelle, W. H. (2015). The "collapse" of cooperative Hohokam irrigation in the lower Salt River valley. *Journal of the Southwest* **57**: 643–674.

Hoggarth, J. A., Breitenbach, S. F. M., Culleton, B. J., Ebert, C. E., Masson, M. A., and Kennett, D. J. (2016). The political collapse of Chichén Itzá in climatic and cultural context. *Global and Planetary Change* **138**: 25–42.

Holtorf, C. (2013). The need and potential for an archaeology orientated towards the present. *Archaeological Dialogues* **20**: 12–18.

Hudson, M. J., Aoyama, M., Hoover, K. C., and Uchiyama, J. (2012). Prospects and challenges for an archaeology of global climate change. *Wiley Interdisciplinary Reviews: Climate Change* **3**: 313-328.

Ingram, S. E., and Hunt, R. C. (eds.) (2015). *Traditional Arid Lands Agriculture: Understanding the Past for the Future*, University of Arizona Press, Tucson.

Isendahl, C. (2011). The weight of water: A new look at pre-Hispanic Puuc Maya water reservoirs. *Ancient Mesoamerica* **22**: 185–197.

Isendahl, C. (2016). Historical ecology coming of age. *Reviews in Anthropology* **45**: 127–147.

Jackson, R. C., Dugmore, A. J., and Riede, F. (2018). Rediscovering lessons of adaptation from the past. *Global Environmental Change* **52**: 58–65.

Johnston, K. J. (2003). The intensification of pre-industrial cereal agriculture in the tropics: Boserup, cultivation lengthening, and the Classic Maya. *Journal of Anthropological Archaeology* **22**: 126-161.

Johnston, K. J. (2004). Lowland Maya water management practices: The household exploitation of rural wells. *Geoarchaeology* **19**: 265–292.

Kaptijn, E. (2018). Learning from ancient water management: Archeology's role in modern-day climate change adaptations. *Wiley Interdisciplinary Reviews* **5**: 1–11.

Kondolf, G. M., and Farahani, A. (2018). Sustainably managing reservoir storage: Ancient roots of a modern challenge. *Water* **10**: 117–130.

Korobov, D. S., and Borisov, A. V. (2013). The origins of terraced field agriculture in the Caucasus: New discoveries in the Kislovodsk Basin. *Antiquity* **87**: 1086–1103.

Kurashima, N., and Kirch, P. V. (2011). Geospatial modeling of pre-contact Hawaiian production systems on Moloka'i Island, Hawaiian Islands. *Journal of Archaeological Science* **38**: 3662–3674.

Langlie, B. S. (in press). Building ecological resistance: Late intermediate period farming in the south-central highland Andes (CE 1100–1450). *Journal of Anthropological Archaeology*.

Lesure, R. G., Wake, T. A., Borejsza, A., Carballo, J., Carballo, D. M., López, I. R., and de Ángeles Guzmán, M. (2013). Swidden agriculture, village longevity, and social relations in Formative central Tlaxcala: Towards an understanding of macroregional structure. *Journal of Anthropological Archaeology* **32**: 224–241.

Liendo, R., Solleiro-Rebolledo, E., Solis-Castillo, B., Sedov, S., and Ortiz-Pérez, A. (2014). Population dynamics and its relation to ancient landscapes in the northwestern Maya Lowlands: Evaluating resilience and vulnerability. In Chase, A. F. and Scarborough, V. L. (eds.) *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 84–100.

Lincoln, N., and Ladefoged, T. (2014). Agroecology of pre-contact Hawaiian dryland farming: The spatial extent, yield and social impact of Hawaiian breadfruit groves in Kona, Hawai'i. *Journal of Archaeological Science* **49**: 192–202.

Lucero, L. J., Fedick, S. L., Dunning, N. P., Lentz, D. L., and Scarborough, V. L. (2014). Water and landscape: Ancient Maya settlement decisions. In Chase, A. F. and Scarborough, V. L. (eds.) *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 30–42.

Macrae, S., and Iannone, G. (2016). Understanding ancient Maya agricultural terrace systems through LiDAR and hydrological mapping. *Advances in Archaeological Practice* **4**: 371–392.

Marsh, E. J. (2016). The disappearing desert and the emergence of agropastoralism: An adaptive cycle of rapid change in the mid-Holocene Lake Titicaca basin (Peru–Bolivia). *Quaternary International* **422**: 123–134.

Miller, N. F. (2013). Agropastoralism and archaeobiology: Connecting plants, animals and people in west and central Asia. *Environmental Archaeology* **18**: 247–256.

Melton, M. A. (2018). Cropping in an age of captive taking: Exploring evidence for uncertainty and food insecurity in the seventeenth-century North Carolina Piedmont. *American Antiquity* **83**: 204–223.

Morehart, C. T., and Morell-Hart, S. (2015). Beyond the ecofact: Toward a social paleoethnobotany in Mesoamerica. *Journal of Archaeological Method and Theory* **22**: 483–511.

Morell-Hart, S. (2012). Foodways and resilience under apocalyptic conditions. *Culture, Agriculture, Food and Environment* **34**: 161–171.

Murtha, T. M. (2002). *Land and Labor: Classic Maya Terraced Agriculture at Caracol, Belize*, Ph.D. dissertation, Department of Anthropology, Pennsylvania State University, State College.

Naudinot, N., and Kelly, R. L. (2017). Climate change and archaeology. *Quaternary International* **428**: 1–2.

Nabhan, G. P. (2013). *Growing Food in a Hotter, Drier Land: Lessons from Desert Farmers on Adapting to Climate Uncertainty*, Chelsea Green Publishers, White River Junction, VT.

Paris, E. H., Peraza Lope, C., Masson, M. A., Delgado Kú, P. C., and Escamilla Ojeda, B. C. (2018). The organization of stingless beekeeping (meliponiculture) at Mayapán, Yucatan, Mexico. *Journal of Anthropological Archaeology* **52**: 1–22.

Peters, R., and Zimmermann, A. (2017). Resilience and cyclicity: Towards a macrohistory of the central European Neolithic. *Quaternary International* **446**: 43–53.

Price, S., and Nixon, L. (2005). Ancient Greek agricultural terraces: Evidence from texts and archaeological survey. *American Journal of Archaeology* **109**: 665–694.

Proebsting, E. (2016). Plowing prairies and raising stock: Historical ecology and community life on the cotton frontier of southwest Arkansas. *Historical Archaeology* **50**: 114–134.

Rau, H., Goggins, G., and Fahy, F. (2018). From invisibility to impact: Recognising the scientific and societal relevance of interdisciplinary sustainability research. *Research Policy* **47**: 266–276.

Ridder, E., Galletti, C. S., Fall, P. L., and Falconer, S. E. (2017). Economic and social activities on ancient Cypriot terraced landscapes. *Journal of Environmental Management* **202**: 514–523.

Rosenzweig, M. S., and Marston, J. M. (in press). Archaeologies of empire and environment. *Journal of Anthropological Archaeology*.

Scarborough, V. L., and Burnside, W. R. (2010). Complexity and sustainability: Perspectives from the ancient Maya and the modern Balinese. *American Antiquity* **75**: 327–363.

Scarborough, V. L., and Lucero, L. J. (2010). The non-hierarchical development of complexity in the semitropics: Water and cooperation. *Water History* **2**: 185–205.

Scarborough, V. L., and Valdez, F. (2014). The alternative economy: Resilience in the face of complexity from the Eastern Lowlands. In Chase, A. F., and Scarborough, V. L. (eds.), *The Resilience and Vulnerability of Ancient Landscapes: Transforming Maya Archaeology through IHOPE*, Archeological Papers No. 24, American Anthropological Association, Washington, DC, pp. 124–141.

Schaan, D. P. (2012). *Sacred Geographies of Ancient Amazonia: Historical Ecology of Social Complexity*, Left Coast Press, Walnut Creek, CA.

Sheets, P., Dixon, C., Guerra, M., and Blanford, A. (2011). Manioc cultivation at Ceren, El Salvador: Occasional kitchen garden plant or staple crop? *Ancient Mesoamerica* **22**: 1–11.

Smith, B. D. (2009). Resource resilience, human niche construction, and the long-term sustainability of pre-Columbian subsistence economies in the Mississippi River valley corridor. *Journal of Ethnobiology* **29**: 167–183.

Spengler, R. N., Miller, N. F., Neef, R., Tourtellotte, P. A., and Chang, C. (2017). Linking agriculture and exchange to social developments of the central Asian Iron Age. *Journal of Anthropological Archaeology* **48**: 295–308.

Stoner, W. D. (2017). Risk, agricultural intensification, political administration, and collapse in the Classic period Gulf Lowlands: A view from above. *Journal of Archaeological Science* **80**: 83–95.

Storey, R., and Storey, G. R., (2017). *Rome and the Classic Maya: Comparing the Slow Collapse of Civilizations*, Routledge, New York.

Styring, A., Rösch, M., Stephan, E., and Stika, H.-P. (2017). Centralisation and long-term change in farming regimes: Comparing agricultural practices in Neolithic and Iron Age south-west Germany. *Proceedings of the Prehistoric Society* **83**: 357–380.

Thomas, D. C., and Kidd, F. J. (2017). On the margins: Enduring pre-modern water management strategies in and around the Registan Desert, Afghanistan. *Journal of Field Archaeology* **42**: 29–42.
Thompson, V. D., and Waggoner, J. C. (eds.) (2013). *The Archaeology and Historical Ecology of Small Scale Economies*, University Press of Florida, Gainesville.
Trombold, C. D. (2017). Agricultural intensification on the epi-Classic northern Mesoamerican frontier: The La Quemada terraces. *Journal of Anthropological Archaeology* **48**: 309–319.
Weisskopf, A., Qin, L., Ding, J., Ding, P., Sun, G., and Fuller, D. Q. (2015). Phytoliths and rice: From wet to dry and back again in the Neolithic Lower Yangtze. *Antiquity* **89**: 1051–1063.
Wesson, C. B. (2013). Rumors of our demise have been greatly exaggerated: Archaeological perspectives on culture and sustainability. *Sustainability* **5**: 100–122.

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