Disturbing Developments: An Archaeobotanical Perspective on Pinyon-Juniper Woodland Fire Ecology, Economic Resource Production, and Ecosystem History

Author(s): Alan P. Sullivan III, Jean N. Berkebile, Kathleen M. Forste, and Ryan M. Washam
Source: Journal of Ethnobiology, 35(1):37-59.
Published By: Society of Ethnobiology

DOI: http://dx.doi.org/10.2993/0278-0771-35.1.37
URL: http://www.bioone.org/doi/full/10.2993/0278-0771-35.1.37

Journal of Ethnobiology 35(1): 37–59 2015

DISTURBING DEVELOPMENTS: AN ARCHAEOBOTANICAL PERSPECTIVE ON PINYON-JUNIPER WOODLAND FIRE ECOLOGY, ECONOMIC RESOURCE PRODUCTION, AND ECOSYSTEM HISTORY

Alan P. Sullivan III[1]*, Jean N. Berkebile[2], Kathleen M. Forste[3], and
Ryan M. Washam[2]

*It has long been thought that the only means by which the American Southwest's extensive pinyon-juniper woodlands, with their inherently low primary productivity, could have supported indigenous populations during prehispanic times was with the transformative consequences associated with the widespread cultivation of low-moisture-intolerant domesticated plants, principally maize (*Zea mays *L.). In this paper we present an alternative to this orthodox view which posits that anthropogenic fire was a vegetation-community management technology that was used to create disturbance patches and to propagate abundant, edible seed-rich ruderals in them. This perspective allows us, as well, to introduce and illustrate the interpretive possibilities of a conceptual scheme that focuses on three resource production types—cultivated wild plants, gathered wild plants, and domesticated plants—with multi-contextual macrobotanical data from a partially burned and rapidly abandoned multi-room settlement (occupied between AD 1070–1080) located south of the Grand Canyon in northern Arizona. By integrating these data with previous archaeobotanical, pollen, and sedimentary micro-charcoal studies, we propose that the systematic cultivation of wild plants in pyrogenic resource patches was a sustainable practice that enhanced food-supply security by insulating populations from the effects of short-term environmental variability and long-term climate change that challenge maize farmers. Importantly, these investigations indicate that low-intensity burning did not involve widespread deforestation, as some models of Holocene climate change suggest, and that prehistoric depopulation and modern fire suppression have altered fundamentally the composition and economic potential of contemporary pinyon-juniper ecosystems.*

Keywords: *fire, pinyon-juniper woodlands, ruderal production, archaeobotanical analysis*

Despite its romantic appeal as a time of renewal, springtime in America can be a wicked season marked by floods, drought, and devastating wildfires, particularly in the arid West. As predictable as the appearance of tornadoes and dandelions, warnings are issued routinely for residents in wildfire-prone areas to brace themselves for yet another active fire season (e.g., Banks and Noel 2014). Although anthropogenic climate change is commonly invoked as one cause of the increasing frequency and severity of these dangerous conditions (e.g., Schwinning et al. 2008), it is worth remembering that humans have been coping with blazing landscapes for millennia (Pyne 2012). In fact, the ''early anthropogenic'' hypothesis of William F. Ruddiman (2003) posits that the expansion of farming and the clearing of forests by burning may have increased atmospheric levels of methane and carbon dioxide well before the Industrial Age (Smith and Zeder 2013). Although one could quibble with Ruddiman's terminology (e.g.,

---

[1] Department of Anthropology, University of Cincinnati, 481 Braunstein Hall, P.O. Box 210380, Cincinnati, OH 45221-0380, USA
[2] Bighorn Archaeological Consultants, Santa Clara, UT, USA
[3] Department of Archaeology, Boston University, Boston, MA, USA
*Corresponding author (alan.sullivan@uc.edu)

''simple peasant agriculture'') and scale of analysis (e.g., the entire environmentally and culturally diverse American Southwest is one case), his proposition has exposed the extent of our embryonic knowledge about the role of anthropogenic fire in ancient economies and vegetation management (Glikson 2013).

For instance, despite the attention fire receives in modern life, considerations of its effects have rarely figured in archaeologists' accounts of North American indigenous subsistence practices (e.g., Barton 2014:313; Minnis 2000:279; Smith 2011a:597–598; Sullivan 1982)—fire ecologists, environmental historians, geographers, and cultural anthropologists have assumed the bulk of that responsibility (e.g., Allen 2002; Lewis and Anderson 2002; Myers and Doolittle 2014; Parker 2002; Pyne 1982; Stewart 2002; Williams 2002:182–185). Historically, Southwest archaeologists, in contrast to their European counterparts (e.g., Mason 2000; Mellars 1976; Rösch et al. 2002), have developed a host of creative non-fire-based models to understand the economies that sustained the ancient societies that once occupied the region's extensive pinyon-juniper woodlands, such as those that cloak the uplands of the Colorado Plateau (e.g., Euler et al. 1979), where archaeological sites are thickly concentrated (Ortman et al. 2012; Tainter 1984). These models, however, invariably focus almost exclusively on the environmental conditions that affect the production of low-moisture-intolerant domesticated plants, principally maize (*Zea mays* L.) (e.g., Benson et al. 2013; Spielmann et al. 2011). In fact, it has long been suggested that, because of their comparatively low natural primary productivity (Haberl et al. 2007), pinyon-juniper woodlands could support aboriginal occupation only after maize agriculture had been adapted to the variable growing conditions that prevail in these widespread, heterogeneous ecosystems (Ford 1984; Matson 1991; Peeples et al. 2006).

The core tenets of these understandings about maize-centric societies have become so deeply ingrained in Southwest archaeological theory and method (e.g., Benson 2011; Gumerman et al. 2003) that they have assumed paradigmatic status in view of their pervasiveness and ostensible unassailability (e.g., Kohler et al. 2012). Consequently, the frequently attributed riskiness of maize farming in pinyon-juniper ecosystems, regionally (e.g., Dean et al. 1994) or locally (e.g., Bellorado and Anderson 2013), is the inspiration for inferences regarding, for example, the variable expression (temporally and spatially) of trade and exchange networks (e.g., Nelson 1996), settlement relocation (e.g., Kohler et al. 2000), ecological impacts (e.g., Dickson 1993; Minnis 2000), and ultimately occupational curtailment (e.g., Axtell et al. 2002; Betancourt and VanDevender 1981). Nonetheless, despite widespread theoretical commitment to the centrality of maize farming in ancient Southwest societies, maize production itself has rarely been substantiated empirically with archaeological data (in contrast to evidence for maize consumption; see Fish and Donaldson [1991] in regards to this important distinction). In fact, as Gleichman and Gleichman (1992:30) candidly report: ''Exactly where they farmed is therefore left open to question.'' Such lacunae in our knowledge about the basic aspects of food supply systems (Schroeder 2013; Wills and Dorshow 2012), however, has not prevented Southwest archaeologists from simulating the locations and extent of maize farming and projecting their demographic and socio-ecological consequences (e.g., Barton 2014; Johnson et al. 2005; Pool 2013).

With these considerations in mind, we intend to nudge the archaeological study of ancient subsistence economies in pinyon-juniper ecosystems in a direction that is unconstrained by the assumptions of the ''maize paradigm,'' as sketched above (for additional details see Sullivan in press). First, we introduce and explore the interpretive advantages of a conceptual scheme for thinking about variation in pinyon-juniper subsistence economies based on differences among three *resource production types*: 1) cultivated wild plants; 2) gathered wild plants; and 3) domesticated plants (cf. Diehl 2005:78–79; Harris 2007:28–30; Smith 2011b:839, 841). We illustrate the effectiveness of conceptualizing plant-use patterns in these terms with new multi-contextual macrobotanical data from a partially burned, multi-room masonry ruin (occupied AD 1070–1080) located in a dense pinyon-juniper woodland south of the Grand Canyon in northern Arizona (Berkebile 2014). Second, we discuss the economic implications of a food-supply model for the ancient occupants of pinyon-juniper ecosystems that features the productive advantages of anthropogenic, indigenous fire ecology (Fowler 2013). By focusing on the effects of human-controlled ignitions of surface/understory fuels in pinyon-juniper woodlands, we show how our archaeobotanical data align with the production of ruderals—plants that thrive in pyrogenic disturbances (Grime 2001) and whose productive capacities are largely unaffected by variation in factors, such as soil nutrients, temperature, and precipitation patterning, that bedevil maize farming (Benson et al. 2013; Toll 1995). Finally, we conclude with some thoughts about the necessity of incorporating archaeological data for understanding pinyon-juniper ecosystem histories, particularly for those periods that predate fire-scar chronologies, and for appreciating the profound compositional differences between prehistoric and modern vegetation communities (cf. Briggs et al. 2006).

The Upper Basin and Its Pinyon-Juniper Woodland

Our study area is the Upper Basin, a down-faulted and tilted portion of the Coconino Plateau in north-central Arizona that is approximately 251.3 km^2 in area (Figure 1) (Morales 2003; Strahler 1944a). The northern terminus of this graben is the South Rim of the Grand Canyon with an elevation of 2286 m at Desert View; from there, the Upper Basin slopes south to the base of the Coconino Rim (the lowest elevation is 1860 m at Lee Canyon; Sullivan and Ruter 2006:182–183).

Precipitation Patterns

For tens of millions of years, the Upper Basin has been capped by fossiliferous Kaibab Limestone, which is the uppermost member of the Grand Canyon sequence (Hopkins and Thompson 2003). Kaibab Limestone is heavily fractured and, consequently, does not retain precipitation; hence, today, the Upper Basin has no streams, seeps, springs, or other sources of surface water (Metzger 1961; Rand 1965:210). However, during the period when the Upper Basin was occupied, principally between the tenth and twelfth centuries AD (Euler 1988), its residents built a variety of strategically-placed catchments to capture rainwater and snowmelt (Norr 1997).[1] Nonetheless, an analysis of the

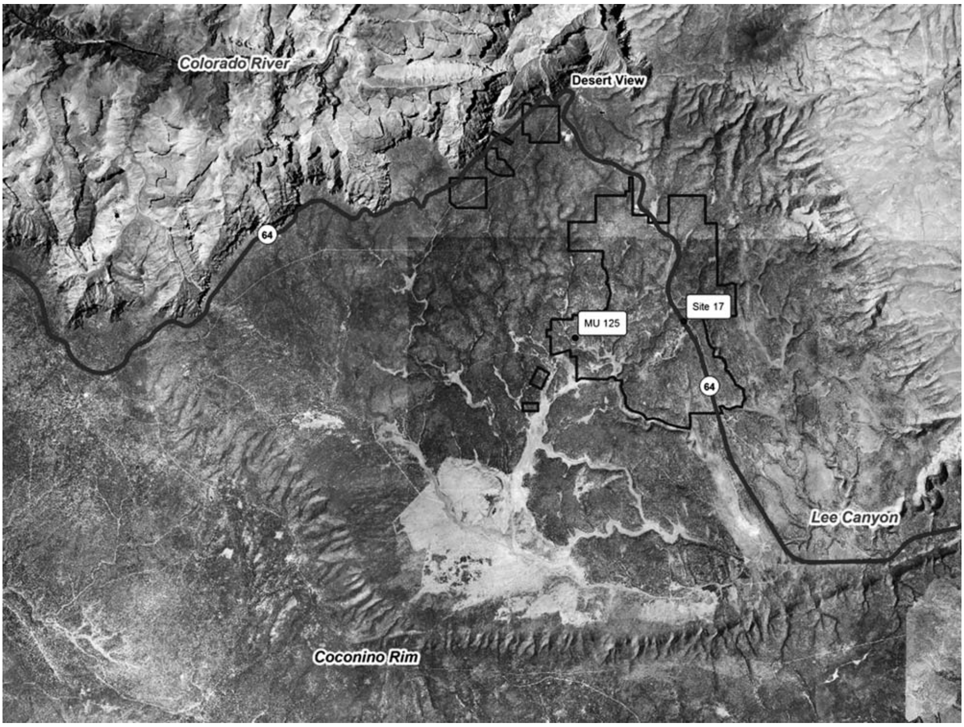

Figure 1. View of the Upper Basin, north-central Arizona. This figure, which is a composite of several overlapping satellite images, shows the Colorado River, the South Rim of the Grand Canyon, Desert View, locations of two archaeological sites (MU 125 and Site 17) whose archaeobotanical assemblages are featured in the text, Lee Canyon, which is a tributary of the Little Colorado River, and the Coconino Rim. Polygons are the boundaries of intensively surveyed areas of the Upper Basin.

area's historic precipitation record reveals that two periods of low rainfall can be expected yearly: one develops in late spring and another in the fall,[2] precisely bracketing the traditional growing season for maize (Sullivan and Forste 2014:141–142). Paleo-dendroclimatological research indicates that this pattern was in place when the area was occupied prehistorically (Dean 1996). In addition, tree-ring reconstructed precipitation values for this area of the Coconino Plateau suggest that Upper Basin maize farmers would have been challenged profoundly to successfully produce harvests annually (Sullivan and Ruter 2006:185–188), which helps explain why direct evidence of maize from well-dated archaeological contexts is scarce in the region (Sullivan 1996, in press).

Vegetation Patterns

The Upper Basin is covered by a dense woodland, dominated by pinyon (*Pinus edulis* Engelm.) and juniper (*Juniperus* sp.) (Brown 1994), that thins to a savanna-like grassland in its southern and southeastern reaches, and merges with ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and Gambel oak (*Quercus gambelii* Nutt.) in its western stretches as the forest ascends the slopes of the Coconino Rim (Figure 1) (Huffman et al. 2008). Paleoecological analysis of pack-rat middens in the eastern Grand Canyon has determined that these vegetation communities (woodlands and grasslands) have been around at least since the terminal Middle Holocene to Late Holocene (ca. 5000–4000 yrs BP [Cole 1982, 1990]), although abundances of pinyon and juniper trees have varied considerably within the community through time (Cole and Cannella 2005).

The composition and dynamics of modern pinyon-juniper woodlands in the Grand Canyon area have been intensively studied for nearly a century (e.g., Darling 1967; Merkle 1952; Miller 1921; Rand 1965; Strahler 1944b; Vankat 2013). Even though the factors that influence the spatial extent and boundaries between grassland/savannas and woodlands are fairly well understood, specific local effects that are attributable to complicated interactions among ''drivers'' such as climate, ungulate population dynamics, lightning-caused fires, anthropogenic fires, fire exclusion, and grazing, are differentially expressed (Romme et al. 2009). Informed by these considerations, the pinyon-juniper woodland of the Upper Basin has been classified as a *persistent* type (Vankat 2013:272; see also Huffman et al. 2013) in view of its variable stand structure (e.g., heterogeneous densities of pinyon and juniper trees of various sizes), discontinuous (patchy) surface distributions of fine-fuels, and inconstant understory ''litter'' accumulation depths (Darling 1967)—factors that consequentially affect the ability of forests to carry fires (Rand 1965; Tausch and Hood 2007; Wright and Bailey 1982).

The Hidden Legacy of Economic Fire

From the perspective of fire history, Fulé et al. (2002) posit that the strong synergistic effects between fire exclusion and grazing during the twentieth century have so thoroughly influenced fuel loads that it is fair to assume that widespread lethal ''stand killing'' fires in these ecosystems were infrequent during historic times, although there is less than unanimous agreement on the subject (Baker and Shinneman 2004). One point of common agreement among these and other studies that focus on fire in the pinyon-juniper ecosystems of the eastern Grand Canyon, however, is that they are constrained by time depth, particularly for ''pre-Euro-American'' periods of occupation that date half a millennium or more before the present (Fulé et al. 2003; Romme et al. 2009:211; Williams and Baker 2013).

We contend, however, that archaeology can contribute to an understanding of fire and its use by humans in these forests during prehispanic times, well before they were dramatically transformed during the last century[3] and, furthermore, that anthropogenic fire, rather than maize agriculture, made pinyon-juniper woodlands suitable for sustained habitation (cf. Gillson and Marchant 2014:321). For instance, pollen assemblages recovered from tenth to twelfth century AD prehistoric fire-cracked-rock piles (Sullivan et al. 2001), rock alignments (Bozarth 1992; Sullivan 2000), and buried alluvial surfaces (Sullivan and Ruter 2006) are dominated by cheno-ams and grasses whereas maize pollen accounts for less than 1% of all economic species (Jelinek 1966; Sullivan 1996). Also, macrobotanical samples recovered from ceramic vessels and hearths in one-room structures (Becher 1992; Huckell 1992) and a multi-structure site (Site 17 [Sullivan 1987]) reveal the same pattern—maize remains (cobs, kernels) are significantly less frequent and ubiquitous (when they occur) than chenopods, amaranths, pinyon nuts, and various grass seeds, which are common and omnipresent (Sullivan and Forste 2014). Thus, decades of archaeobotanical research conducted by different specialists involving samples excavated from a wide variety of contexts by different teams of archaeologists, support the inference that the prehistoric occupants of the Upper Basin relied on disturbance-responsive wild plants—ruderals—and not on low-moisture-intolerant domesticated plants (Sullivan in press). From an economic perspective, importantly, the effects of fire on the phenology and productivity of ruderals are well known: ''Ruderals are highly adapted to disturbance because of their copious and rapid seed production'' (Kramp et al. 1983:2; see also Adams and Bohrer 1998; Wright et al. 1979). To enhance the robustness of these understandings, we present the results of recent archaeobotanical analyses that confirm the pervasiveness of ruderals, and other wild plants, in the subsistence economies of people who populated pinyon-juniper ecosystems in the past (Bayman and Sullivan 2008; Berkebile 2014).

Sampling for Subsistence at MU 125

Nestled at the base of a low mesa in the Upper Basin, and sporting an unobstructed view of the San Francisco Peaks 96 km to the south near Flagstaff, AZ, archaeological site MU 125 was excavated with the express purpose of acquiring archaeo-economic data to test the reliability of interpretations based on the samples recovered from the aforementioned sites. Upon excavation, MU 125, which produced tree-ring cutting dates of AD 1070 and 1080, disclosed the remains of six architectural spaces (Figure 2) (Fugate 2003). However, in sharp contrast to nearby Site 17, which produced the region's most robust ''Pompeii'' assemblage of archaeobotanical remains (Sullivan 1987), MU 125 had a different formation history. First, unlike Site 17, where four structures were destroyed by fire simultaneously (Sullivan 1986), MU 125 was not consumed entirely by fire—only Room 2 burned catastrophically; Room 3 was partially burned but was repaired and reused prior to abandonment; all the other rooms were unburned. Second, with the exception of Room 2, rooms at MU 125 lack assemblages of floor-contact artifacts (in contrast, three of four structures at Site 17 had extensive floor-contact artifact arrays [Sullivan 2008a]). Third, MU 125 failed to disclose a single whole ceramic vessel, unlike Site 17 (Sullivan 2008b). And fourth, in contrast to Site 17, MU 125 lacks conventional ''cooking'' hearths; only the remains of two shallow ash-filled basins (which probably represent repositories of once-hot coals for heating and seed-parching) were discovered in Room 2, and Room 3 disclosed a small, asymmetric thermal feature.

In view of these differences, and to enable synthetic inference building regarding plant-use patterns in the Upper Basin, the 28 sediment samples from MU 125 that form the core of this study were selected and analyzed with respect to four context types (Figure 2): (1) Thermal Processing Contexts (which include samples from one thermal feature, one roasting pit, three ash-filled basins, and two fire-cracked-rock piles); (2) Metate Grinding Surfaces (n = two metates); (3) Post-Hole and Floor-Contact Contexts (which include samples from six post-holes, two post-hole trenches, four floor-contact ''areal'' [featureless and artifact-free] zones, and sediments from beneath two metates); and (4) Other Contexts (which include samples from an anthropogenic ''limestone ledge'' in Room 2, a

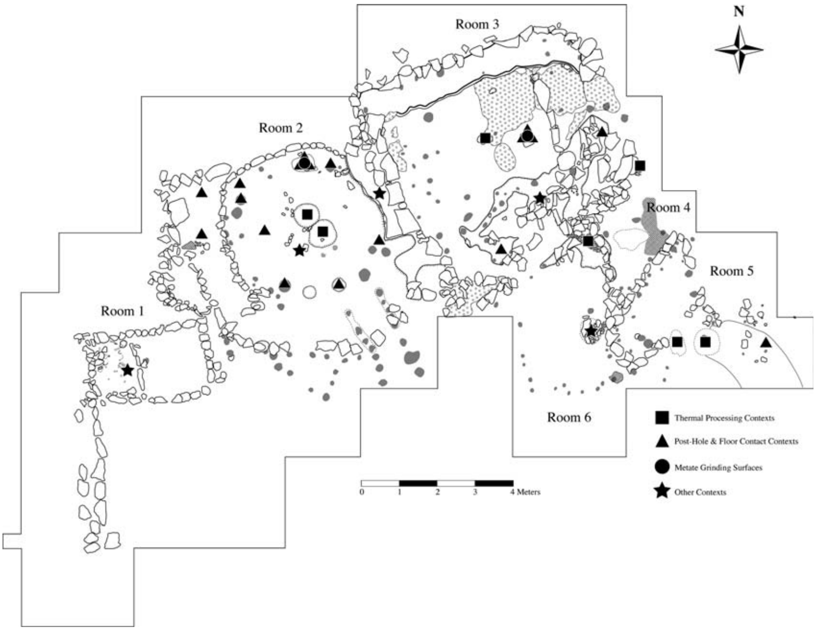

Figure 2. Map of archaeological site MU 125, showing extent of excavations, post-holes (gray solids), architecture (open irregular polygons are individually-placed rocks), and locations of the 28 archaeobotanical samples (differentiated by recovery-context type) that are discussed in the text.

bowl sherd associated with a burial in Room 1, a bowl sherd in Room 2, and the contents of two unburned pits in Room 6).

This contextually heterogeneous sample was designed specifically to disclose aspects of plant use that may not have been revealed in the analysis of samples recovered from the *de facto* Pompeii situation at Site 17 (Sullivan 1987), as well as of samples recovered from three non-Pompeii single-room sites in the region (Becher 1992; Cummings and Puseman 2010; Huckell 1992). Furthermore, adopting a *time perspectivism* view of the different behavioral clocks registered by the MU 125 samples enables a determination of the extent to which plant-use patterns inferred for the other sites and contexts mentioned above may have been misinterpreted (Sullivan 2008a). For example, these ''clocks'' chronicle the by-products of activities that range from routine (multiple, daily plant-grinding events) to exceptional (single disposal episode of disarticulated human remains), from early construction (roof-support post-holes) to last-minute domestic events (shallow ash-filled basins), from casual long-term deposition (floor sediment accumulations) to intentional short-term discard (rock-filled unburned pit). If, however, the same picture emerges from these contexts—the samples are dominated by cultivated and gathered wild plants—it clearly would go a long way toward alleviating doubts about the prevalence of non-maize-based foodways in the Upper Basin (Sullivan in press).

Measures of Archaeobotanical Assemblage Variability

To ensure comparability with previous analyses (Sullivan and Ruter 2006), relative frequency and ubiquity values were calculated to assess compositional

Table 1. Species that pertain to three Resource Production Types—cultivated wild plants, gathered wild plants, and domesticated plants—recovered from archaeological contexts in the Upper Basin.

Cultivated wild plants	Gathered wild plants	Domesticated plants
Chenopod (*Chenopodium* sp.)[3]	Pinyon (*Pinus* sp.)	Maize (*Zea mays*)[2]
Amaranth (*Amaranthus* sp.)[3]	Juniper (*Juniperus* sp.)	Bean (*Phaseolus* sp.)[2]
Tansy mustard (*Descurainia pinnata*)[3]	Cactus (Cactaceae)[1]	Cotton (*Gossypium* sp.)[2]
Purslane (*Portulaca* sp.)[4]	Cattail (*Typha* sp.)	
Bugseed (*Corispermum* sp.)[4,a]		
Globemallow (*Sphaeralcea* sp.)[4]		
Sunflower family (Asteraceae)[4,a]		
Panicoid and other small-seed grasses (*Panicum* sp. and Poaceae)[5]		

[1–5] These plants correspond to Diehl's (2005:78–79) First through Fifth Resource Groups, respectively; note that plants in his Third Resource Group are considered ''high-density crop weeds'' whereas those in his Fourth Resource Group are categorized as ''low-density crop weeds.''

[a] According to Bohrer (1983:122), ''burned patches of vegetation would foster an increased abundance of game and annual plants like sunflower (*Helianthus*) and bugseed (*Corispermum*) whose seeds were consumed directly.''

similarities and differences among the four context types. Relative frequency is the percentage of the remains of a specific taxon within a context type (Miksicek 1987). However, relative frequency values should be supplemented with another, independent measure to ensure they have not been unduly influenced by uncontrollable preservation or inadvertent recovery biases (Minnis 1986). Ubiquity analysis (Popper 1988:61) serves this function and is a measure of the frequency (expressed as a percentage) with which a particular taxon appears among samples within a context type. It is important to bear in mind that whereas ''ubiquity controls for spatial variation among macrofloral samples, it exaggerates differences in content diversity by inflating the importance of uncommon types'' (Sullivan 1987:145). In determining assemblage variability, therefore, both measures need to be employed in a complementary fashion to avoid privileging preservation or sampling.

Finally, to develop fine-grained interpretations about the relations between plant-use patterns inferred from processing and domestic contexts and those that may typify production contexts, three *resource production types* were defined (Berkebile 2014; these categories are broadly similar to Diehl's [2005:78–79] Plant Resource Group concept; Table 1). First, cultivated wild plants are those whose growth patterns, distribution, density, and yields can be influenced by humans (e.g., Geib 2011:10). Second, gathered wild plants are those whose growth patterns, distribution, density, and yields can rarely, if ever, be influenced by humans (Winter and Hogan 1986). Finally, domesticated plants are those genetically-modified plants whose establishment, growth, and yields are dependent upon humans (Smith 2001).

Results

Figures 3 and 4 show that cultivated and gathered wild-plant remains are both far more numerous and widespread than domesticated-plant remains among all context types at MU 125, which is the typical Upper Basin plant-use pattern (Sullivan and Forste 2014). What is particularly noteworthy about these results is that they include material from archaeological contexts that previously

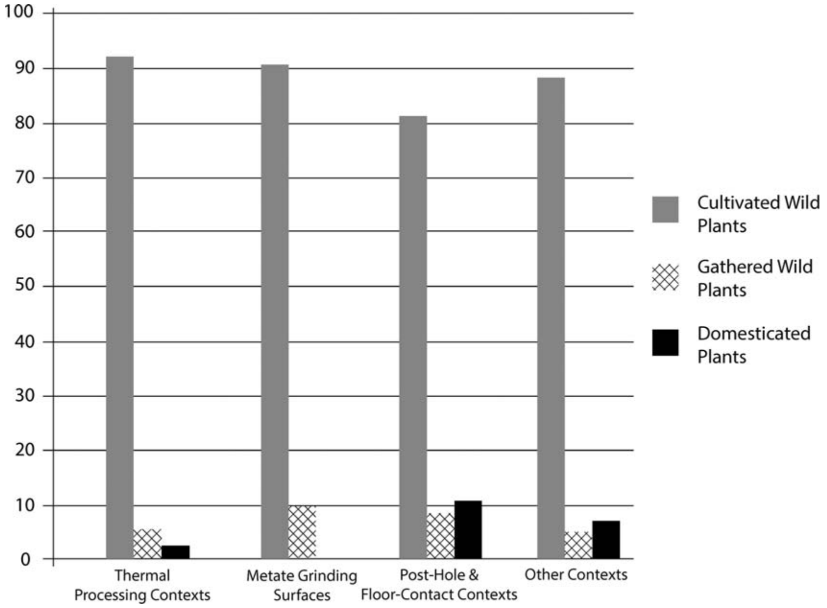

Figure 3. Bar charts of the relative frequencies of archaeobotanical remains categorized by resource-production type and by recovery-context type at archaeological site MU 125.

have not been investigated—burials, post-hole trenches, and metate grinding surfaces. With these new results from MU 125, it is reasonable to claim that, based on the abundance and ubiquity of cultivated and gathered wild-plant macrobotanical remains recovered from consumption, processing, storage, and discard contexts at a multi-structure ''Pompeii'' site (Sullivan 1987), non-Pompeii single-structure sites (Becher 1992; Cummings and Puseman 2010; Huckell 1992), and extramural processing localities (Sullivan et al. 2001), domesticated plants (maize in particular) were not the principal foods by which prehistoric groups in the Upper Basin sustained themselves. To argue otherwise would entail claiming that the least common and least ubiquitous plant remains represent the primary resources upon which the subsistence economies of these pinyon-juniper woodland-dwelling populations depended, which would constitute an epistemologically precarious position (Lucas 2012).

Pyrogenic Resource Production: Theory and Socio-ecological Consequences

We return to a central question: Where would these plants have been produced? Even if domesticated plants were grown exclusively on all the ''agricultural'' features that have been discovered in the Upper Basin (Figure 5), they would have accounted for an extremely low amount of the per capita food supply, in view of their small aggregate production area (639 m^2 combined from 110 terraces[4]). Considering that the majority of the cultivated and gathered wild plants recovered from archaeological contexts are drought-tolerant and fire-responsive (Sullivan and Forste 2014:138), their production is not limited by the

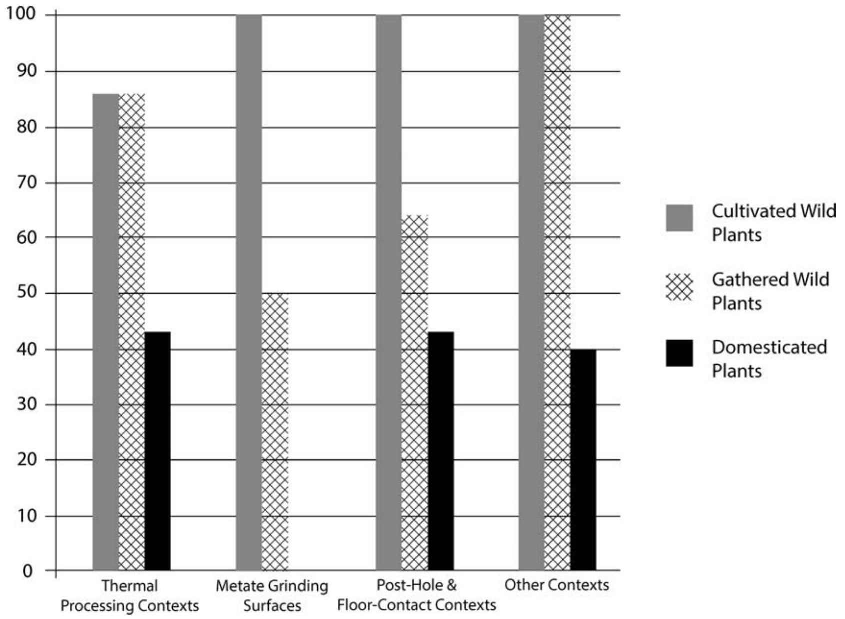

Figure 4. Bar charts of the ubiquities (N=28 samples) of plant taxa categorized by resource-production type and by recovery-context type (Thermal Processing Contexts = seven samples, Metate Grinding Surfaces = two samples, Post-Hole and Floor-Contexts = 14 samples, and Other Contexts = five samples) at archaeological site MU 125.

two principal uncontrollable or ecologically ''bound'' variables (stipulated by an obligate ecological theoretical framework; Sullivan in press) that affect domesticated plant production—suitable soil (in terms of depth, moisture, nutrient availability, and extent; Homburg and Sandor 2011) and sufficient rainfall (that must be available within a specific *growing window*; Doolittle 2000:219–234; Muenchrath and Salvador 1995:309–318). Hence, we propose that food-supply systems in pinyon-juniper ecosystems, such as the Upper Basin, involved the creation by fire of anthropogenic micro-habitats, or disturbance niches (Smith 2011b), in places and at times selected by humans, which is a strategy that would have enabled people to control the factors that affect edible resource production. In this facultative ecological theoretical framework, pyrogenic disturbances in pinyon-juniper woodlands encouraged the production of ruderal species (Adams and Dockter 2013), such as those cultivated wild plants identified in the archaeological samples from MU 125 and other archaeological phenomena in the Upper Basin, anywhere sufficient surface fuel loads could be ignited (Roos et al. 2010). In support of our pyrogenic-disturbance model, the results of controlled studies have shown that low-intensity surface fires release nutrients, such as phosphorous, potassium, and nitrogen, that are essential to plant growth (DeBano et al. 1998; Rösch et al. 2002; Viro 1974), particularly in early successional stages (Smith 2011a:598; West 1984). Also, low-intensity fire may enhance the productivity of gathered wild resources (Winter and Hogan 1986), such as nut-bearing pinyon trees, by reducing competition for nutrients (Ford 2000; Smith 2011b:841–842).

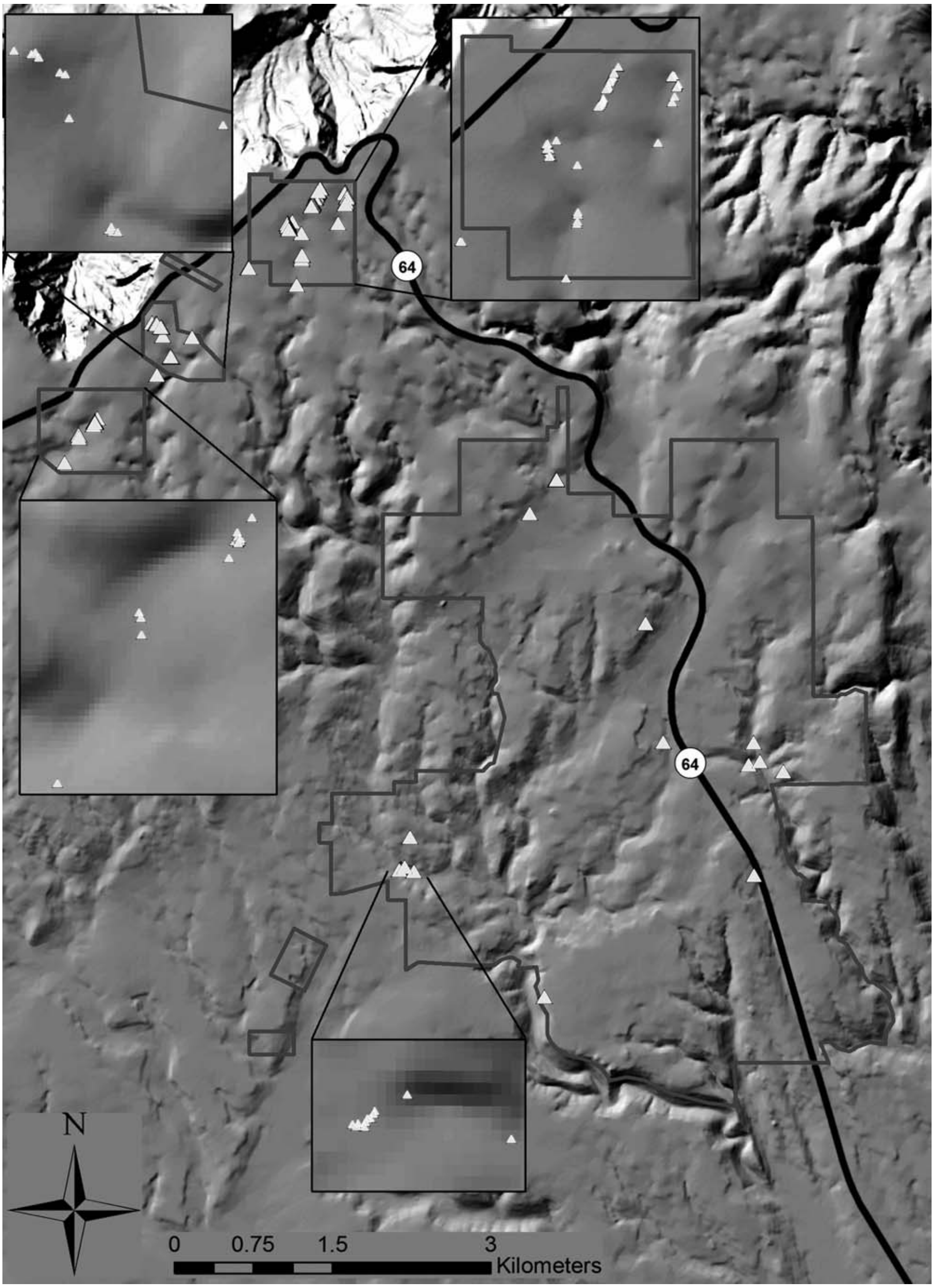

Figure 5. Spatial distribution of 110 rock alignments and associated terraces, often implicated in models of maize production, which have been discovered in the intensively surveyed polygons of the Upper Basin.

Overall, the body of archaeobotanical, pollen, and sedimentary micro-charcoal evidence recovered from prehistoric consumption and production contexts in the Upper Basin supports the idea that ruderal agriculture unbinds economic resource production from the environmental constraints that affect maize farming, thereby increasing the predictability, productivity, and security of the local food-supply system (Smith 2011b:845). Moreover, our estimates (Table 2) indicate that the yields and nutritional qualities of ruderals, which are available throughout the year (Berkebile 2014; Bohrer 1975, 1983; Doebley 1984), are comparable to or exceed those of maize.

These considerations create epistemological space to contemplate the possibility that, despite their continuing use in Southwest archaeology (e.g., Freeman 2012), terms such as forager (wild-plant gatherer) and farmer (domesticated-plant grower) may actually muddle our thinking about ancient subsistence economies (Harris 2007:28–29; Iriarte 2007:176). If agriculture is broadly considered the systematic and intentional manipulation of vegetation communities (Hunt and Rabett 2013; Mabry 2005; Smith 2001)—the creation of alien (anthropogenic) niches in otherwise natural ecosystems (Smith 2011a:596)—then these pinyon-juniper forest-dwellers indeed were farmers who focused on wild-plant production by the application of fire (Smith 2011b:844). Moreover, it is fair to say that the remains of ruderals recovered in these upland conifer archaeological contexts should no longer be considered ''weeds'' or the unintended consequences of maize farming (Geib 2011:369). Again, to make the case that ruderals are weeds, and hence economically inconsequential, necessitates claiming that the most common and ubiquitous remains of cultivated and gathered wild plants actually register dependence on maize agriculture. Only an uncritical commitment to the ''corn paradigm'' can explain why ruderals are not considered the objects of food production and the keystone plant species of prehistoric subsistence economies in upland coniferous woodlands (Sullivan in press).

Summary and Conclusions

It is little wonder that many archaeologists might think that pinyon-juniper woodlands are comparatively unproductive and somewhat inhospitable places to live—formerly cultivated wild plants are no longer observable on the modern landscape. In fact, a comparison of species compositions determined by a modern ecosystem survey (Brewer et al. 1991), a hazardous-fuels-reduction experimental burn (Huffman et al. 2013), a multi-site review of archaeological findings (involving macrobotanicals, pollen, and micro-charcoal; Sullivan and Forste 2014), and results of the multi-contextual analysis of macrobotanical samples from MU 125 reported here, reveals the degree to which the pinyon-juniper woodlands in the Grand Canyon area have changed since they were abandoned as locations of permanent habitation in the late twelfth century AD (Table 3). As these data show, the economically important ruderals that populate our archaeological samples do not occur or rarely occur in today's pinyon-juniper woodlands, except as a consequence of burning. Such species diversity attenuation is attributable not only to the discontinuance of anthropogenic

Table 2. Nutritional values of some economic resources broken down by Resource Production Type (CWP = cultivated wild plant, GWP = gathered wild plant, and DP = domesticated plant).

					Nutrient content (g/100 g)					
Taxon	**Resource production type**	**Part**	**Kcal/kg**	**Kcal/m^2**	**Carb**	**Fat**	**Protein**	**Fiber**	**Notable nutrients**	**Source**
Amaranthus sp.	CWP	seed	1388–4220	347–1055.5	63.90	6.57	15.02	6.08	Ca	Cummings 1995
	CWP	green	210–330	33–82.5	4.11	0.18	2.11	1.31	Vitamins A & C Ca	Fowler and Rhode 2011 O'Brien and Price 2008
Chenopodium sp.	CWP	seed	3726–4140	-	42.40	5.23	16.80	15.60	Ca, Fe, K	Cummings 1995
	CWP	green	320–340	-	5.00	5.00	3.20	1.80	Vitamins A & C Ca	Fowler and Rhode 2011
Helianthus annus	CWP	seed	3650–5800	567	19.26	48.44	23.90	4.06	K, P	Cummings 1995 Fowler and Rhode 2011 Simms 1985
Juniperus sp.	GWP	berry	4800	-	-	-	-	-	-	Darling 1967 Lentz 1984
Pinus edulis	GWP	nut	5180–7140	60–260	20.35	61.00	11.80	2.90	Ca, Fe, Mg	Darling 1967 Farris 1982 Fowler and Rhode 2011 Madsen 1986 Phillips 1909
Zea mays	DP	kernel	1080	30.51	25.11	1.28	3.32	0.60	Vitamin A, Fe, K, Zn	Cummings 1995 Hegmon 1996

Table 3. Differences in pinyon-juniper woodland species composition recorded among a modern vegetation survey (Brewer et al. 1991), a hazardous-fuel control burn (Huffman et al. 2013), and two archaeological studies (Berkebile [2014] and Sullivan and Forste [2014]): CWP = cultivated wild plant, GWP = gathered wild plant, and DP = domesticated plant.

Category/Taxa	**Resource production type**	**Study**			
		Brewer et al. 1991	**Huffman et al. 2013**	**Berkebile 2014**	**Sullivan and Forste 2014**
Herbs and forbs					
Achillea sp.	CWP	X			X
Amaranthus sp.	CWP			X	X
Brassica sp.	CWP				X
Chenopodium sp.	CWP		X	X	X
Cleome sp.	CWP				X
Descurainia sp.	CWP		X	X	
Eriogonum sp.	CWP	X	X	X	
Helianthus sp.	CWP			X	X
Mentzelia sp.	GWP		X		X
Phaseolus sp.	DP			X	
Plantago sp.	CWP		X		X
Portulaca sp.	CWP			X	X
Sphaeralcea sp.	CWP	X	X	X	X
Shrubs					
Artemisia sp.	GWP	X	X	X	X
Atriplex sp.	GWP	X		X	X
Ephedra sp.	GWP				X
Gossypium hirsutum	DP			X	
Shepherdia sp.	GWP			X	
Prunus virginiana	GWP				X
Grasses					
Alopecurus sp.	CWP				X
Bromus sp.	CWP				X
Panicum sp.	CWP			X	
Poaceae sp.	CWP	X		X	X
Typha sp.	GWP			X	
Zea mays	DP			X	X
Cacti and succulents					
Harrisia sp.	GWP			X	
Echinocatus sp.	GWP			X	
Mammillaria sp.	GWP			X	
Opuntia sp.	GWP	X	X	X	X
Agave sp.	GWP				X
Yucca sp.	GWP	X	X		X
Trees					
Juniperus sp.	GWP	X	X	X	X
Pinus edulis	GWP	X	X	X	X

surface fires in late prehistory, when populations withdrew from the area, but to the suppression of all fires in the twentieth century and to the introduction of domesticated animals (principally cattle and sheep), whose palates preferred the same suite of cultivated wild plants as did the Upper Basin's prehistoric inhabitants, and whose grazing habits eventually led to the local extinction of many of these economically important species (Bohrer 1978; Bond and Keeley 2005:389; see also Bird et al. 2008).

With regard to the ''early anthropogenic'' hypothesis, it seems reasonable to posit that, although humans indeed could have been responsible for introducing elevated amounts of methane and carbon dioxide to the atmosphere by systematic burning, such burning, particularly for agricultural purposes, need not have entailed deforestation of the landscape (Barton 2014; Kohler 1992; Minnis 2000:279–280). Actually, cutting down pinyon trees—the sources of nutritious and tasty pinyon nuts—to clear land for intensive farming does not make much sense when the fine fuels and litter around them can be ignited without damaging the trees themselves (see Power et al. 2008). More likely, in prehistoric times, upland conifer woodlands in the American Southwest were arguably pyrogenic ecosystems created and managed by human-controlled ignitions of understory vegetation (Roos et al. 2010); such biomass burning may have affected the black carbon content of the atmosphere that, in turn, influenced regional temperature (Cadzow 2012:213–214). Whatever the atmospheric consequences, the important point is that these were ''fire woods'' whose occupants sustained themselves on ruderals and other wild plants, which have long use-histories in Southwest prehistory (e.g., Dobyns 1972; Doebley 1984; Huckell 1996; Lentz 1984; Morrow 2006).

In essence, twenty-first century pinyon-juniper ecosystems are a complex and imperfectly understood historical precipitate of vegetation communities whose origin and structure are ultimately anthropogenic (Williams and Baker 2013:299). Based on comparisons with the returns of paleoecological data recovered by archaeological investigations in the Upper Basin, today's pinyon-juniper woodlands are indeed characterized by low net primary productivity—thanks to grazing and fire suppression—and, without artificial supplies of water, are completely unsuitable for permanent human habitation. In addition, for at least 700 years before the twentieth century, the structure of the forest was determined by neither grazing nor fire suppression but by fuel loads that materialized as a consequence of the absence of humans and that presumably were ignited by lightning exclusively (Allen 2002). During the tenth to twelfth centuries, however, these forests were alive with people and their fires, and were punctuated with pyrogenic disturbances, which were the sources of food that sustained these ancient societies without, evidently, much call for maize.

Notes

[1] Rand observes (1965:210) that runoff ''is carried swiftly down the wash and permanent streams or standing water are absent, most of the water simply sinking into the soil at the conclusion of the rain.'' Her observation pertains equally to snowmelt. Hence, any form of precipitation in the Upper Basin gets absorbed rapidly and, save for small exposures of unfractured bedrock that have been modified to disrupt and capture runoff, such as the features described by Norr (1997), is unavailable for harvesting.

[2] Huffman et al. (2013:480) report mean annual precipitation was 408 mm for 1976–2012, which agrees with our previously reported value of 16.06 inches for 1904–1983 (Sullivan and Ruter 2006:185).

[3] The Upper Basin pinyon-juniper ecosystem is currently experiencing extreme fragmentation and degradation that is attributable to differences in land-use policies between the

two federal agencies that authorize (USDA Forest Service) or prohibit (USDI National Park Service) ''recreational'' activities, such as unrestricted camping, wood cutting, and hunting, within their jurisdictions (Balsom et al. 2005; Uphus et al. 2006; Vankat 2013:291–292; Washam 2014).

[4] The terrace area (639 m^2 or .000639 km^2) is .00027% of the area (23.8 km^2) intensively surveyed in the Upper Basin. Applying this percentage to the unsurveyed terrain in the Upper Basin yields a potential terrace area there of .0614 km^2; combining these two values yields a total potential terrace area of the Upper Basin of .062 km^2, or 6.2 ha, or 15.32 acres.

References Cited

Adams, K. R., and V. L. Bohrer. 1998. Archaeobotanical Indicators of Seasonality: Examples from Arid Southwestern United States. In *Seasonality and Sedentism: Archaeological Perspectives from Old and New World Sites*, edited by T. R. Rocek and O. Bar-Yosef, pp. 129–141. Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA.

Adams, K. R., and A. R. Dockter. 2013. *Five Years of Fire Recovery in Mesa Verde National Park*. Crow Canyon Archaeological Center, Cortez, CO.

Allen, C. D. 2002. Lots of Lightning and Plenty of People: An Ecological History of Fire in the Upland Southwest. In *Fire, Native People, and the Natural Landscape*, edited by T. R. Vale, pp. 143–193. Island Press, Washington, D.C.

Axtell, R. L., J. M. Epstein, J. S. Dean, G. J. Gumerman, A. C. Swedlund, J. Harburger, S. Chakravarty, R. Hammond, J. Parker, and M. Parker. 2002. Population Growth and Collapse in a Multiagent Model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences* 99:7275–7279.

Baker, W. L., and D. J. Shinneman. 2004. Fire and Restoration of Piñon-Juniper Woodlands in the Western United States: A Review. *Forest Ecology and Management* 189:1–21.

Balsom, J. R., J. G. Ellis, A. Horn, and L. M. Leap. 2005. Using Cultural Resources as Part of the Plan: Grand Canyon Management and Implications for Resources Preservation. In *The Colorado Plateau II: Biophysical, Socioeconomic, and Cultural Research*, edited by C. van Ripper III and D. J. Mattson, pp. 367–377. University of Arizona Press, Tucson, AZ.

Banks, J., and H. Noel. 2014. Red Flag Warning in Effect Today for Kaibab and Coconino Forests. Available at: http://www.fs.usda.gov/detail/kaibab/news-events/?cid=STELPRD3796361. Accessed on April 22, 2014.

Barton, C. M. 2014. Complexity, Social Complexity, and Modeling. *Journal of Archaeological Method and Theory* 21:306–324.

Bayman, J. M., and A. P. Sullivan, III. 2008. Property, Identity, and Macroeconomy in the Prehispanic Southwest. *American Anthropologist* 110:6–20.

Becher, M. E. 1992. Archaeological Investigations at a Pueblo II Kayenta Anasazi Ruin Located in the Tusayan Ranger District, Kaibab National Forest, Arizona. Unpublished Bachelor's Thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

Bellorado, B. A., and K. C. Anderson. 2013. Early Pueblo Responses to Climate Variability: Farming Traditions, Land Tenure, and Social Power in the Eastern Mesa Verde Region. *Kiva* 78:377–416.

Benson, L. V. 2011. Factors Controlling Pre-Columbian and Early Historic Maize Productivity in the American Southwest, Part 1: The Southern Colorado Plateau and Rio Grande Regions. *Journal of Archaeological Method and Theory* 18:1–60.

Benson, L. V., D. K. Ramsey, D. W. Stahle, and K. L. Petersen. 2013. Some Thoughts on the Factors that Controlled Prehistoric Maize Production in the American Southwest with Application to Southwestern Colorado. *Journal of Archaeological Science* 40:2869–2880.

Berkebile, J. N. 2014. Investigating Diversity in the Upper Basin: A Second Look at the Archaeobotanical Remains from MU 125, A Late Pueblo II Settlement. Unpublished Master's Thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

Betancourt, J. L., and T. R. VanDevender. 1981. Holocene Vegetation in Chaco Canyon, New Mexico. *Science* 214:656–658.

Bird, R. B., D. W. Bird, B. F. Codding, C. H. Parker, and J. H. Jones. 2008. The ''Fire Stick Farming'' Hypothesis: Australian Aboriginal Foraging Strategies, Biodiversity, and Anthropogenic Fire Mosaics. *Proceedings of the National Academy of Science* 105:14796–14801.

Bohrer, V. L. 1975. The Prehistoric and Historic Role of the Cool-Season Grasses in the Southwest. *Economic Botany* 29:199–207.

Bohrer, V. L. 1978. Plants that Have Become Locally Extinct in the Southwest. *New Mexico Journal of Science* 18:10–19.

Bohrer, V. L. 1983. New Life from Ashes: The Tale of the Burnt Bush (*Rhus trilobata*). *Desert Plants* 5:122–124.

Bond, W. J., and J. E. Keeley. 2005. Fire as a Global ''Herbivore'': The Ecology and Evolution of Flammable Ecosystems. *Trends in Ecology and Evolution* 20:387–394.

Bozarth, S. 1992. Fossil Pollen and Phytolith Analysis. In *Archaeological Investigations at Lee Canyon: Kayenta Anasazi Farmsteads in the Upper Basin, Coconino Country, Arizona*, edited by S. M. Whittlesey, pp. 135–144. Technical Series 38. Statistical Research, Inc., Tucson, AZ.

Brewer, D. G., R. K. Jorgensen, L. P. Munk, W. A. Robbie, and J. L. Travis. 1991. *Terrestrial Ecosystem Survey of the Kaibab National Forest*. USDA Forest Service, Albuquerque, NM.

Briggs, J. M., K. A. Spielmann, H. Schaafsma, K. W. Kintigh, M. Kruse, K. Morehouse, and K. Schollmeyer. 2006. Why Ecology Needs Archaeologists and Archaeology Needs Ecologists. *Frontiers in Ecology and the Environment* 4:180–188.

Brown, D. E. 1994. Great Basin Conifer Woodland. In *Biotic Communities: Southwestern United States and Northwestern Mexico*, edited by D. E. Brown, pp. 52–57. University of Utah Press, Salt Lake City, UT.

Cadzow, D. M. 2012. Hunter-Gatherers, Agriculturalists, and Climate: Insights from a Cross-Disciplinary Review. In *Climates, Landscapes, and Civilizations,* edited by L. Giosan, D. Q. Fuller, K. Nicoll, R. K. Flad, and P. D. Clift, pp. 209–216. American Geophysical Union, Washington, D.C.

Cole, K. L. 1982. Late Quaternary Zonation of Vegetation in the Eastern Grand Canyon. *Science* 217:1142–1145.

Cole, K. L. 1990. Late Quaternary Vegetation Gradients through the Grand Canyon. In *Packrat Middens*, edited by J. Betancourt, T. R. VanDevender, and P. S. Martin, pp. 241–258. University of Arizona Press, Tucson, AZ.

Cole, K. L., and J. A. Cannella. 2005. Species-Based Vegetation Mapping: An Example from the Grand Canyon. In *The Colorado Plateau II: Biophysical, Socioeconomic, and Cultural Research*, edited by C. van Ripper III and D. J. Mattson, pp.151–162. University of Arizona Press, Tucson, AZ.

Cummings, L. S. 1995. Agriculture and the Mesa Verde Anasazi Diet: Description and Nutritional Analysis. In *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture*, edited by H. W. Toll, pp. 335–352. Special Publication No. 2. New Mexico Archaeological Council, Albuquerque, NM.

Cummings, L. S., and K. Puseman. 2010. Pollen, Macrofloral, and Organic Residue (FTIR) Analysis for Site AZ B:16:105, Northern Arizona. In *Archaeological Excavations at Site B:16:105, Grand Canyon National Park*, edited by C. E. Downum, pp. 83–115. NAU Archaeological Report 1247. Northern Arizona University, Flagstaff, AZ.

Darling, M. L. S. 1967. Structure and Productivity of Pinyon-Juniper Woodland in Northern Arizona. Unpublished Doctoral Dissertation, Department of Zoology, Duke University, Durham, NC.

Dean, J. S. 1996. Demography, Environment, and Subsistence Stress. In *Evolving Complexity and Environmental Risk in the Prehistoric Southwest*, edited by J. A. Tainter and B. B. Tainter, pp. 25–56. Addison-Wesley, Reading, MA.

Dean, J. S., W. H. Doelle, and J. D. Orcutt. 1994. Adaptive Stress, Environment, and Demography. In *Themes in Southwest Prehistory*, edited by G. J. Gumerman, pp. 53–86. School of American Research Press, Santa Fe, NM.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. *Fire's Effects on Ecosystems*. John Wiley and Sons, New York, NY.

Dickson, D. B. 1993. Anthropogenic Environmental Destruction in Prehistory: Hard Evidence and Harsh Conclusions. In *Culture and Environment: A Fragile Existence*, edited by R. W. Jamieson, S. Abonyi, and N. A. Mirau, pp. 289–295. University of Calgary Archaeological Association, Calgary, AB.

Diehl, M. W. 2005. Early Agricultural Period Foraging and Horticulture in Southern Arizona: Implications from Plant Remains. In *Subsistence and Resource Use Strategies of Early Agricultural Communities in Southern*

Arizona, edited by M. W. Diehl, pp. 73–90. Anthropological Papers No. 34. Center for Desert Archaeology, Tucson, AZ.

Dobyns, H. F. 1972. Altitude Sorting of Ethnic Groups in the Southwest. *Plateau* 47:42–48.

Doebley, J. F. 1984. ''Seeds'' of Wild Grasses: A Major Food of Southwestern Indians. *Economic Botany* 38:52–64.

Doolittle, W. E. 2000. *Cultivated Landscapes of Native North America*. Oxford University Press, Oxford, UK.

Euler, R. C. 1988. Demography and Cultural Dynamics on the Colorado Plateau. In *The Anasazi in a Changing Environment*, edited by G. J. Gumerman, pp. 192–229. Cambridge University Press, Cambridge, UK.

Euler, R. C., G. J. Gumerman, T. N. V. Karlstrom, J. S. Dean, and R. H. Hevly. 1979. The Colorado Plateaus: Cultural Dynamics and Paleoenvironment. *Science* 205:1089–1101.

Farris, G. J. 1982. Pine Nuts as an Aboriginal Food Source in California and Nevada: Some Contrasts. *Journal of Ethnobiology* 2:114–122.

Fish, S. K., and M. Donaldson. 1991. Production and Consumption in the Archaeological Record: A Hohokam Example. *Kiva* 56:255–275.

Ford, R. I. 1984. Ecological Consequences of Early Agriculture in the Southwest. In *Papers on the Archaeology of Black Mesa, Arizona, Volume II*, edited by S. Plog and S. Powell, pp. 127–138. Southern Illinois University Press, Carbondale, IL.

Ford, R. I. 2000. Human Disturbance and Biodiversity: A Case Study from Northern New Mexico. In *Biodiversity and Native America*, edited by P. Minnis and W. J. Elisens, pp. 207–222. University of Oklahoma Press, Norman, OK.

Fowler, C. 2013. *Ignition Stories: Indigenous Fire Ecology in the Indo-Australian Monsoon Zone*. Carolina Academic Press, Durham, NC.

Fowler, C. S., and D. E. Rhode. 2011. Plant Foods and Foodways among the Great Basin's Indigenous Peoples. In *The Subsistence Economies of Indigenous North American Societies*, edited by B. D. Smith, pp. 233–269. Smithsonian Institution Scholarly Press, Washington, D.C.

Freeman, J. 2012. Alternative Adaptive Regimes for Integrating Foraging and Farming Activities. *Journal of Archaeological Science* 39:3008–3017.

Fugate, T. I. 2003. *Inferring Settlement Formation Patterns: a GIS-Based Harris Matrix Analysis of a Prehistoric Masonry Ruin in the Upper Basin, Kaibab National Forest, Northern Arizona*. Unpublished Master's Thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

Fulé, P. Z., W. W. Covington, M. M. Moore, T. A. Heinlein, and A. E. M. Waltz. 2002. Natural Variability in Forests of the Grand Canyon, USA. *Journal of Biogeography* 29:31–47.

Fulé, P. Z., T. A. Heinlein, W. W. Covington, and M. M. Moore. 2003. Assessing Fire Regimes on Grand Canyon Landscapes with Fire-Scar and Fire-Record Data. *International Journal of Wildland Fire* 12:129–145.

Geib, P. R. 2011. *Foragers and Farmers of the Northern Kayenta Region: Excavations along the Navajo Mountain Road*. University of Utah Press, Salt Lake City, UT.

Gillson, L., and R. Marchant. 2014. From Myopia to Clarity: Sharpening the Focus of Ecosystem Management through the Lens of Palaeoecology. *Trends in Ecology and Evolution* 29:317–325.

Gleichman, C. L., and P. J. Gleichman. 1992. The Lower Sand Canyon Survey. In *The Sand Canyon Archaeology Project: A Progress Report*, edited by W. D. Lipe, pp. 25–31. Crow Canyon Archaeological Center, Cortez, CO.

Glikson, A. 2013. Fire and Human Evolution: The Deep-Time Blueprints of the Anthropocene. *Anthropocene* 3:89–92.

Grime, J. P. 2001. *Plant Strategies, Vegetation Processes, and Ecosystem Properties*. John Wiley and Sons, New York, NY.

Gumerman, G. J., A. C. Swedlund, J. S. Dean, and J. M. Epstein. 2003. The Evolution of Social Behavior in the Prehistoric American Southwest. *Artificial Life* 9:435–444.

Haberl, H., K. Heinz Erb, F. Krausmann, V. Gaube, A. Bondeau, C. Plutzar, S. Gingrich, W. Lucht, and Ma. Fischer-Kowalski. 2007. Quantifying and Mapping the Human Appropriation of Net Primary Production in Earth's Terrestrial Ecosystems. *Proceedings of the National Academy of Sciences* 104:12942–12947.

Harris, D. R. 2007. Agriculture, Cultivation, and Domestication: Exploring the Conceptual Framework of Early Food Production. In *Rethinking Agriculture: Archaeological and Ethnoarchaeological Perspectives*, edited by T. Denham, J. Iriarte, and L. Vrydaghs, pp. 16–35. Left Coast Press, Inc., Walnut Creek, CA.

Hegmon, M. 1996. Variability in Food Production, Strategies of Storage and Sharing, and the Pithouse-to-Pueblo Transition in the Northern Southwest. In *Evolving Complexity* *and Environmental Risk in the Prehistoric Southwest*, edited by J. A. Tainter and B. B. Bagley, pp. 223–250. Santa Fe Institute, Addison-Wesley, Reading, MA.

Homburg, J. A., and J. A. Sandor. 2011. Anthropogenic Effects on Soil Quality of Ancient Agricultural Systems of the American Southwest. *Catena* 85:144–154.

Hopkins, R. L., and K. L. Thompson. 2003. Kaibab Formation. In *Grand Canyon Geology*, 2nd edition, edited by S. S. Beus and M. Morales, pp. 196–211. Oxford University Press, New York, NY.

Huckell, B. B. 1996. The Archaic Prehistory of the North American Southwest. *Journal of World Prehistory* 10:305–373.

Huckell, L. W. 1992. Plant Remains. In *Archaeological Investigations at Lee Canyon: Kayenta Anasazi Farmsteads in the Upper Basin, Coconino Country, Arizona*, edited by S. M. Whittlesey, pp. 119–133. Technical Series 38. Statistical Research, Inc., Tucson, AZ.

Huffman, D. W., P. Z. Fulé, K. M. Pearson, and J. E. Crouse. 2008. Fire History of Pinyon-Juniper Woodlands at Upper Ecotones with Ponderosa Pine Forests in Arizona and New Mexico. *Canadian Journal of Forest Research* 38:2097–2108.

Huffman, D. W., M. T. Stoddard, J. D. Springer, J. E. Crouse, and W. W. Chancellor. 2013. Understory Plant Community Responses to Hazardous Fuels Reduction Treatments in Pinyon-Juniper Woodlands of Arizona, USA. *Forest Ecology and Management* 289: 478–488.

Hunt, C. O., and R. J. Rabett. 2013. Holocene Landscape Intervention and Plant Food Production Strategies in Island and Mainland Asia. *Journal of Archaeological Science* Available at: http://dx.doi.org/10/1016/j.jas.2013.12.011. Accessed on May 3, 2014.

Iriarte, J. 2007. New Perspectives on Plant Domestication and the Development of Agriculture in the New World. In *Rethinking Agriculture: Archaeological and Ethnoarchaeological Perspectives*, edited by T. Denham, J. Iriarte, and L. Vrydaghs, pp. 167–188. Left Coast Press, Inc., Walnut Creek, CA.

Jelinek, A. J. 1966. Correlation of Archaeological and Palynological Data. *Science* 152:1507–1509.

Johnson, C. D., T. A. Kohler, and J. Cowan. 2005. Modeling Historical Ecology, Thinking about Contemporary Systems. *American Anthropologist* 107:96–107.

Kohler, T. A. 1992. Prehistoric Human Impact on the Environment in the Upland North American Southwest. *Population and Environment: A Journal of Interdisciplinary Studies* 13:255–268.

Kohler, T. A., J. Kresl, C. Van West, E. Carr, and R. H. Wilshusen. 2000. Be There Then: A Modeling Approach to Settlement Determinants and Spatial Efficiency among Late Ancestral Pueblo Populations of the Mesa Verde Region, U.S. Southwest. In *Dynamics in Human and Primate Societies*, edited by T. A. Kohler and G. J. Gumerman, pp. 145–178. Oxford University Press, New York, NY.

Kohler, T. A., R. K. Bocinsky, D. Cockburn, S. A. Crabtree, M. D. Varien, K. E. Kolm, S. Smith, S. G. Ortman, and Z. Kobti. 2012. Modelling Prehispanic Pueblo Societies in their Ecosystems. *Ecological Modelling* 241:30–41.

Kramp, B. A., D. R. Patton, and W. W. Brady. 1983. *The Effects of Fire on Wildlife Habitat and Species.* Wildlife Unit Technical Series. Southwestern Region, United States Department of Agriculture, Forest Service, Albuquerque, NM.

Lentz, D. L. 1984. Utah Juniper (*Juniperus osteosperma*) Cones and Seeds from Salmon Ruin, New Mexico. *Journal of Ethnobiology* 4:191–200.

Lewis, H. T., and M. K. Anderson. 2002. Introduction. In *Forgotten Fires: Native Americans and the Transient Wilderness*, by O. C. Stewart, pp. 3–16. University of Oklahoma Press, Norman, OK.

Lucas, G. 2012. *Understanding the Archaeological Record*. University of Cambridge Press, Cambridge, MA.

Mabry, J. B. 2005. Diversity in Early Southwestern Farming and Optimization Models of Transitions to Agriculture. In *Subsistence and Resource Use Strategies of Early Agricultural Communities in Southern Arizona*, edited by M. W. Diehl, pp. 113–152. Anthropological Papers No. 34. Center for Desert Archaeology, Tucson, AZ.

Madsen, D. B. 1986. Great Basin Nuts: A Short Treatise on the Distribution, Productivity, and Prehistoric Use of Pinyon. In *Anthropology of the Desert West: Essays in Honor of Jesse D. Jenkins*, edited by C. J. Condie and D. D. Fowler, pp. 21–41. University of Utah Anthropological Papers, No. 110, University of Utah Press, Salt Lake City, UT.

Mason, S. L. R. 2000. Fire and Mesolithic Subsistence—Managing Oaks for Acorns in Northwest Europe? *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:139–150.

Matson, R. G. 1991. *The Origins of Southwestern Agriculture*. University of Arizona Press, Tucson, AZ.

Mellars, P. 1976. Fire Ecology, Animal Populations and Man: A Study of Some Ecological Relationships in Prehistory. *Proceedings of the Prehistoric Society* 42:15–45.

Merkle, J. 1952. An Analysis of a Pinyon-Juniper Community at Grand Canyon, Arizona. *Ecology* 33:375–384.

Metzger, D. G. 1961. *Geology in Relation to Availability of Water along the South Rim, Grand Canyon National Park, Arizona*. Government Printing Office, Washington, D.C.

Miksicek, C. H. 1987. Formation Processes of the Archaeobotanical Record. In *Advances in Archaeological Method and Theory, Vol. 10*, edited by M. B. Schiffer, pp. 211–247. Academic Press, New York, NY.

Miller, F. H. 1921. Reclamation of Grass Lands by Utah Juniper on the Tusayan National Forest, Arizona. *Journal of Forestry* 6:647–651.

Minnis, P. E. 1986. Macroplant Remains. In *Short-Term Sedentism in the American Southwest: The Mimbres Valley Salado*, edited by B. A. Nelson and S. A. LeBlanc, pp. 205–218. Maxwell Museum of Anthropology and University of New Mexico Press, Albuquerque, NM.

Minnis, P. E. 2000. Prehistoric Agriculture and Anthropogenic Ecology of the North American Southwest. In *The Archaeology of Drylands: Living at the Margin*, edited by G. Barker and D. Gilbertson, pp. 271–287. Routledge, London, UK.

Morales, M. 2003. Mesozoic and Cenozoic Strata of the Colorado Plateau near the Grand Canyon. In *Grand Canyon Geology*, 2nd edition, edited by S. S. Beus and M. Morales, pp. 212–221. Oxford University Press, New York, NY.

Morrow, B. H. 2006. The Berry Gardens of Quarai and the Pocket Terraces of Abo. In *Canyon Gardens: The Ancient Pueblo Landscapes of the American Southwest*, edited by V. B. Price and B. H. Morrow, pp. 17–31. University of New Mexico Press, Albuquerque, NM.

Muenchrath, D. A., and R. J. Salvador. 1995. Maize Productivity and Agroecology: Effects of Environment and Agricultural Practices on the Biology in Maize. In *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture*, edited by H. Wolcott Toll, pp. 303–333. Special Publication No. 2. New Mexico Archaeological Council, Albuquerque, NM.

Myers, M. D., and W. E. Doolittle. 2014. The New Narrative on Native Landscape Transformations. In *North American Odyssey: Historical Geographies for the Twenty-first Century*, edited by C. E. Colton and G. L. Buckley, pp. 9–26. Rowan and Littlefield, Lanham, MD.

Nelson, M. C. 1996. Technological Strategies Responsive to Subsistence Stress. In *Evolving Complexity and Environmental Risk in the Prehistoric Southwest*, edited by J. A. Tainter and B. Bagley Tainter, pp. 107–144. Addison-Wesley, Reading, MA.

Norr, J. A. 1997. Archaeological Investigation of a Prehistoric Water Collection Feature in the Upper Basin, Kaibab National Forest, Northern Arizona. Unpublished Master's Thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

O'Brien, G. K, and M. L. Price. 2008. *Amaranth: Grain and Vegetable Types*. ECHO Technical Note. Available at https://c.ymcdn.com/sites/www.echocommunity.org/resource/collection/E66CDFDB-0A0D-4DDE-8AB1-74D9D8C3EDD4/Amaranth_Grain_&_Vegetable_Types. Accessed on April 30, 2014.

Ortman, S. G., D. M. Glowacki, M. D. Varien, and C. D. Johnson. 2012. The Study Area and the Ancestral Pueblo Occupation. In *Emergence and Collapse of Early Villages: Models of Central Mesa Verde Archaeology*, edited by T. A. Kohler and M. D. Varien, pp. 15–40. University of California Press, Berkeley, CA.

Parker, K. C. 2002. Fire in the Pre-European Lowlands of the American Southwest. In *Fire, Native Peoples, and the Natural Landscape*, edited by Thomas R. Vale, pp. 101–141. Island Press, Washington, D.C.

Peeples, M. A., C. M. Barton, and S. Schmich. 2006. Resilience Lost: Intersecting Land Use and Landscape Dynamics in the Prehistoric Southwestern United States. *Ecology and Society* 11:656–673.

Phillips, F. J. 1909. A Study of Piñon Pine. *Botanical Gazette* 48:216–222.

Pool, M. D. 2013. Mimbres Mogollon Farming. In *Soils, Climate, and Society: Archaeological Investigations in Ancient America*, edited by J. D. Wingard and S. E. Hayes, pp. 85–107. University Press of Colorado, Boulder, CO.

Popper, V. S. 1988. Selecting Quantitative Measures in Paleoethnobotany. In *Current Paleoethnobotany: Analytical Methods and Cultural Implications of Archaeological Plant Remains*, edited by C. A. Hastorf and V. S. Popper, pp.

53–71. University of Chicago Press, Chicago, IL.

Power, M. J. J. Marlon, N. Ortiz, P. J. Bartlein, S. P. Harrison, F. E. Mayle, A. Ballouche, R. H. W. Bradshaw, C. Carcaillet, C. Cordova, S. Mooney, P. I. Moreno, I. C. Prentice, K. Thonicke, W. Tinner, C. Whitlock, Y. Zhang, Y. Zhao, A. A. Ali, R. S. Anderson, R. Beer, H. Behling, C. Briles, K. J. Brown, A. Brunelle, M. Bush, P. Camill, G. Q. Chu, J. Clark, D. Colombaroli, S. Connor, A.-L. Daniau, M. Daniels, J. Dodson, E. Doughty, M. E. Edwards, W. Finsinger, D. Foster, J. Frechette, M.-J. Gaillard, D. G. Gavin, E. Gobet, S. Haberle, D. J. Hallett, P. Higuera, G. Hope, S. Horn, J. Inoue, P. Kaltenrieder, L. Kennedy, Z. C. Kong, C. Larsen, C. J. Long, J. Lynch, E. A. Lynch, M. McGlone, S. Meeks, S. Mensing, G. Meyer, T. Minckley, J. Mohr, D. M. Nelson, J. New, R. Newnham, R. Noti, W. Oswald, J. Pierce, P. J. H. Richard, C. Rowe, M. F. Sanchez Goñi, B. N. Shuman, H. Takahara, J. Toney, C. Turney, D. H. Urrego-Sanchez, C. Umbanhowar, M. Vandergoes, B. Vanniere, E. Vescovi, M. Walsh, X. Wang, N. Williams, J. Wilmshurst, and J. H. Zhang. 2008. Changes in Fire Regimes since the Last Glacial Maximum: An Assessment Based on Global Synthesis and Analysis of Charcoal Data. *Climate Dynamics* 30:887–907.

Pyne, S. J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire*. Princeton University Press, Princeton, NJ.

Pyne, S. J. 2012 *Fire*. Reaktion Books, London, UK.

Rand, P. J. 1965. Factors Related to the Distribution of Ponderosa and Pinyon Pines at Grand Canyon, Arizona. Unpublished Doctoral Dissertation, Department of Botany, Duke University, Durham, NC.

Romme, W. H., C. D. Allen, J. D. Bailey, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, Karen S. Eisenhart, M. L. Floyd, D. W. Huffman, B. F. Jacobs, R. F. Miller, E. H. Muldavin, T.W. Swetnam, R. J. Tausch, and P. J. Weisberg. 2009. Historical and Modern Disturbance Regimes, Stand Structures, and Landscape Dynamics in Piñon-Juniper Vegetation of the Western United States. *Rangeland Ecology and Management* 62:203–222.

Roos, C. I., A. P. Sullivan III, and C. McNamee. 2010. Paleoecological Evidence for Systematic Indigenous Burning in the Upland Southwest. In *The Archaeology of Anthropogenic Environments*, edited by R. M. Dean, pp. 142–171. Southern Illinois University Press, Carbondale, IL.

Rösch, M., O. Ehrmann, L. Herrmann, E. Shulz, A. Bogenrieder, J. P. Goldammer, M. Hall, H. Page, and W. Schier. 2002. An Experimental Approach to Neolithic Shifting Cultivation. *Vegetation History and Archaeobotany* 11:143–154.

Ruddiman, W. F. 2003. The Anthropogenic Greenhouse Era Began Thousands of Years Ago. *Climatic Change* 61:261–293.

Schroeder, S. 2013. How Can We Know? The Epistemological Foundation of Ecological Modeling in Archaeology. In *Soils, Climate and Societies: Archaeological Investigations in Ancient America*, edited by J. D. Wingard and S. E. Hayes, pp. 205–223. University of Colorado Press, Boulder, CO.

Schwinning, S., J. Belnap, D. R. Bowling, and J. R. Ehleringer. 2008. Sensitivity of the Colorado Plateau to Change: Climate, Ecosystems, and Society. *Ecology and Society* 13:28–47.

Simms, S. R. 1985. Acquisition Cost and Nutritional Data on Great Basin Resources. *Journal of California and Great Basin Anthropology* 7:117–126.

Smith, B. D. 2001. Low-Level Food Production. *Journal of Archaeological Research* 9:1–43.

Smith, B. D. 2011a. Shaping the Natural World: Patterns of Human Niche Construction by Small-Scale Societies in North America. In *The Subsistence Economies of Indigenous North American Societies*, edited by B. D. Smith, pp. 593–609. Smithsonian Institution Press, Washington, D.C.

Smith, B. D. 2011b. General Patterns of Niche Construction and the Management of 'Wild' Plant and Animal Resources by Small-Scale Pre-Industrial Societies. *Philosophical Transactions of the Royal Society B* 366:836–848.

Smith, B. D., and M. A. Zeder. 2013. The Onset of the Anthropocene. *Anthropocene* 4:8–13.

Spielmann, K. A., M. Nelson, S. Ingram, and M. A. Peeples. 2011. Mitigating Environmental Risk in the U.S. Southwest. In *Sustainable Lifeways: Cultural Persistence in an Ever-Changing Environment*, edited by N. F. Miller, K. M. Moore, and K. Ryan, pp. 180–211. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, PA.

Stewart, O. C. 2002. The Effects of Burning of Grasslands and Forests by Aborigines the World Over. In *Forgotten Fires: Native Americans and the Transient Wilderness*, pp. 67–312. University of Oklahoma Press, Norman, OK.

Strahler, A. N. 1944a. A Guide to the East Kaibab Monocline in the Grand Canyon Region. *Plateau* 17:1–13.

Strahler, A. N. 1944b. Valleys and Parks of the Kaibab and Coconino Plateaus, Arizona. *Journal of Geology* 6:361–387.

Sullivan, A. P., III. 1982. Mogollon Agrarian Ecology. *The Kiva* 48:1–15.

Sullivan, A. P., III. 1986. *Prehistory of the Upper Basin, Coconino County, Arizona.* Arizona State Museum Archaeological Series 167. University of Arizona, Tucson, AZ.

Sullivan, A. P., III. 1987. Seeds of Discontent: Implications of a ''Pompeii'' Archaeobotanical Assemblage for Grand Canyon Anasazi Subsistence Models. *Journal of Ethnobiology* 7:137–153.

Sullivan, A. P., III. 1996. Risk, Anthropogenic Environments and Western Anasazi Subsistence. In E*volving Complexity and Environmental Risk in the Prehistoric Southwest*, edited by J. A. Tainter and B. B. Tainter, pp. 145–167. Addison-Wesley, Reading, MA.

Sullivan, A. P., III. 2000. Effects of Small-Scale Prehistoric Runoff Agriculture on Soil Fertility: The Developing Picture from Upland Terraces in the American Southwest. *Geoarchaeology: An International Journal* 15:291–313.

Sullivan, A. P., III. 2008a. Time Perspectivism and the Interpretive Potential of Palimpsests: Theoretical and Methodological Considerations of Assemblage Formation History and Contemporaneity. In *Time in Archaeology: Time Perspectivism Revisited,* edited by S. Holdaway and L. Wandsnider, pp. 31–45. University of Utah Press, Salt Lake City, UT.

Sullivan, A. P., III. 2008b. Ethnoarchaeological and Archaeological Perspectives on Ceramic Vessels and Annual Accumulation Rates of Sherds. *American Antiquity* 73:121–135.

Sullivan, A. P., III. In press. The Archaeology of Ruderal Agriculture. In *Traditional Arid Lands Agriculture: Understanding the Past for the Future,* edited by S. Ingram and R. C. Hunt. University of Arizona Press, Tucson, AZ.

Sullivan, A. P., III, and K. M. Forste. 2014. Fire-Reliant Subsistence Economies and Anthropogenic Coniferous Ecosystems in the Pre-Columbian Northern American Southwest. *Vegetation History and Archaeobotany* 23:135–151.

Sullivan, A. P., III, and A. H. Ruter. 2006. The Effects of Environmental Fluctuations on Ancient Livelihoods: Implications of Paleoeconomic Evidence from the Upper Basin, Northern Arizona. In *Environmental Change and Human Adaptation in the Ancient American Southwest*, edited by D. E. Doyel and J. S. Dean, pp. 180–203. University of Utah Press, Salt Lake City, UT.

Sullivan, A. P., III, R. A. Cook, M. P. Purtill, and P. M. Uphus. 2001. Economic and Land-Use Implications of Prehistoric Fire-Cracked-Rock Piles, Northern Arizona. *Journal of Field Archaeology* 28:367–382.

Tainter, J. A. 1984. Foragers in the Southwest Forests. In *Stage I Site Locational Modeling in the Southwestern Region*, edited by L. S. Cordell and D. F. Green, pp. 21–44. Cultural Resources Management Report No. 5, USDA Forest Service, Washington, D.C.

Tausch, R. J., and S. Hood. 2007. Pinyon/Juniper Woodlands. In *Fire Ecology and Management of the Major Ecosystems of Southern Utah*, edited by S. M. Hood and M. Miller, pp. 57–71. USDA Forest Service General Technical Report RMRS-GTR-202, Washington, D.C.

Toll, H. W. ed., 1995. *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture*. Special Publication No. 2. New Mexico Archaeological Council, Albuquerque, NM.

Uphus, P. M., A. P. Sullivan, III, and P. B. Mink. 2006. Identifying At-Risk Heritage Resources with GIS: Modeling the Impact of Recreational Activities on the Archaeological Record. *International Journal of Risk Assessment and Management* 6:330–343.

Vankat, J. L. 2013. *Vegetation Dynamics on the Mountains and Plateaus of the American Southwest*. Springer Science+Business Media, Dordrecht, NL.

Viro, P. J. 1974. Effects of Forest Fire on Soil. In *Fire and Ecosystems*, edited by T. T. Kozlowski and C. E. Ahlgren, pp. 7–45. Academic Press, New York, NY.

Washam, R. M. 2014. Archaeology in Distress: Federal Land Management and Archaeological Vulnerability. Unpublished Master's Thesis, Department of Anthropology, University of Cincinnati, Cincinnati, OH.

West, N. E. 1984. Successional Patterns and Productivity Potentials of Pinyon-Juniper Ecosystems. In *Developing Strategies for Rangeland Management*, pp. 1301–1332. National Research Council and National Academy of Sciences. Westview Press, Boulder, CO.

Williams, G. W. 2002. Aboriginal Use of Fire: Are There Any ''Natural'' Plant Communities? In *Wilderness and Political Ecology: Aboriginal Influence and the Original State of*

Nature, edited by C. E. Kay and R. T. Simmons, pp. 179–214. University of Utah Press, Salt Lake City, UT.

Williams, M. A., and W. L. Baker. 2013. Variability of Historical Forest Structure and Fire across Ponderosa Pine Landscapes of the Coconino Plateau and South Rim of Grand Canyon National Park, Arizona, USA. *Landscape Ecology* 28:297–310.

Wills, W. H., and W. B. Dorshow. 2012. Agriculture and Community in Chaco Canyon: Revisiting Pueblo Alto. *Journal of Anthropological Archaeology* 31:138–155.

Winter, J. C., and P. F. Hogan. 1986. Plant Husbandry in the Great Basin and Adjacent Northern Colorado Plateau. In *Anthropology of the Desert West: Essays in Honor of Jesse D. Jennings*, edited by C. J. Condie and D. D. Fowler, pp. 117–144. Anthropological Papers No. 110. University of Utah Press, Salt Lake City, UT.

Wright, H. A, L. F. Neuenschwander, and C. M. Britton. 1979. *The Role and Use of Fire in Sagebrush-Grass and Pinyon-Juniper Plant Communities: A State-of-the-Art Review*. General Technical Report INT-58. USDA Forest Service, Washington, D.C.

Wright, H. A., and A. W. Bailey. 1982. *Fire Ecology*. John Wiley and Sons, New York, NY.