Early Agriculture and Indigenous Foodways in the US Southwest and Mesoamerica: Cuisine and Social Change in Mobile Farming Societies

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Early Agriculture and Indigenous Foodways in the US Southwest and Mesoamerica:
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Robert Jay Sinensky

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ABSTRACT OF THE DISSERTATION

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Professor Gregson Schachner, Chair

The development and spread of agricultural economies fundamentally changed the scale and scope of organizational forms evident in diverse human societies worldwide. In the past, many researchers adopted simple causal models to understand relationships among domesticated plants, population pressure, mobility, the formation of population aggregates, and burgeoning inequality. Early agricultural societies across the Americas, however, were culturally and economically diverse. The papers that compose this dissertation contribute to an ongoing re-evaluation of foodways, mobility, sociopolitical change, and village formation in early agricultural societies across the Americas and the world more broadly. Drawing on theoretical frameworks and models developed in anthropology, and the social and ecological sciences, each chapter presents theoretically rich, data-driven interpretations of themes central to the transformation of early farming societies–mobility, foodways, sociopolitical change, factors influencing the formation and trajectories of early population aggregates, and the resilience of early food production systems. Site-specific analyses of paleoethnobotanical data, food processing tools, and agricultural soils provide a foundation to explore the foodways and mobility strategies of 1700-1300 BC villagers in Mesoamerica, and 1250-750 BC farmers in the Sonoran Desert. The development and widespread adoption of a shared cuisine at Paso de la Amada, one the earliest sedentary villages and ceremonial centers in Mesoamerica, helped forge collective identities amongst households with diverse histories and mobility practices. Millennial-scale reconstructions of precipitation and temperature from tree-ring chronologies, and regional demographic reconstructions informed by settlement, dendrochronological, and radiocarbon data provide insight into the timing and tempo of social change when diverse Ancestral Pueblo communities across the Colorado Plateau of the northern US Southwest adopted a shared set of social, political, culinary, and landscape practices that provided a foundation for early villages and the rise of regional systems. Comparing and contrasting factors involved in the formation of first-wave and second-wave population aggregates within specific regions of the northern US Southwest highlights that early farming societies were diverse and dynamic. In the aggregate, the papers in this dissertation underscore that the development and spread of novel food production strategies and sociopolitical arrangements in early agricultural societies was not mechanistic or strictly economic–the foodways and culinary choices of early farmers were deeply intertwined with the identities of individuals and communities more broadly.

The dissertation of Robert Jay Sinensky is approved.

Richard G. Lesure

Monica L. Smith

Amber VanDerwarker

Gregson Schachner, Chair

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2023

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I feel that it is important for me to acknowledge that I am not Indigenous to the lands that are the focus of the research reported in this dissertation. This dissertation explores the histories of early farmers Indigenous to lands that are now located within the states of Arizona, New Mexico, Colorado, and Utah (USA), and Sonora and Chiapas (Mexico). The research presented in Chapter 3 explores the ingenuity and ecological knowledge of early O'Odham Ancestors in the Tucson Basin of the Sonoran Desert. These are the traditional homelands of Tohono O'odham peoples. Chapters 4 and 5 explore the histories of Ancestral Pueblo peoples on the Colorado Plateau. More specifically, the studies are deeply rooted in the far southwestern portion of the Colorado Plateau, on lands that were cared for, and continue to be cared for by Hopi and Zuni people. I thank Hopi and Zuni colleagues for visiting Ancestral places with me, and for sharing their perspectives on their history. I want to acknowledge, however, that I did not request permission to do the work reported herein in advance from descendant community members, nor have descendant communities specifically approved of the published research. The papers comprising this dissertation were written during my time at UCLA. The University is located on the traditional, ancestral, and unceeded lands of Tongva peoples.

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Portions of this dissertation were previously published in peer-reviewed journals and edited volumes, and are reprinted here with permission from publishers and editors. *Chapter 2* was published in a 2021 Cotsen Institute of Archaeology Press monograph entitled: *Paso de la Amada: An Early Mesoamerican Ceremonial Center*, edited by Richard G. Lesure (https://doi.org/10.2307/j.ctv1t1kfb5.16.) I thank Richard and the Cotsen Institute of Archaeology Press for supporting the inclusion of this paper.

Chapter 3 was published in *American Antiquity* Volume 83, Issue 2 pp. 281-301 in 2018 (https://doi.org/10.1017/aaq.2017.74), and is coauthored by Alan Farahani, then a postdoctoral scholar at the UCLA Cotsen Institute of Archaeology. The framing and analyses presented in the paper are the result of countless conversations and coding sessions between myself and Alan. I compiled and integrated all of the available macrobotanical data from Las Capas over the course of several months during my second year at UCLA. I wrote the initial draft of the paper, and the final product is the result of edits and refinements to analyses and code made Alan an I before and after receiving comments and suggestions from peer-reviews, and comments by then editor Bob Kelly. I thank Alan for supporting the inclusion of this paper, and Cambridge University Press for approving the paper's inclusion.

Chapter 4 was published in *Antiquity* Volume 96, Issue 385 pp. 123-141 in 2022 (https://doi.org/10.15184/aqy.2021.19), and is coauthored by Richard H. Wilshusen, Brian N. Damiata, and Gregson Schachner. I compiled and analyzed data, created figures, and wrote drafts of the paper before initial submission, and after receiving reviews. I took on the logistics of submission and ensuring that all authors had opportunities to review drafts and make intellectual contributions. Richard Wilshusen and Greg Schachner provided intellectual support and reviewed and made edits to many iterations of the paper. Brian Damiata pretreated and ran nearly 100 radiocarbon dates at the UC Irvine Keck AMS facility that I submitted for my dissertation research with funds from the Wenner-Gren Foundation and other organizations. These dates represent roughly ¼ of those included in our Bayesian model (Figure 7), and are also included in our kernel density estimations (Figure 5). Brian also reviewed the OxCal code and reviewed and suggested edits on drafts of the paper. The final product is the result of all of our contributions. I thank my coauthors for supporting the inclusion of this paper, and Cambridge University Press for approving the paper's inclusion.

Chapter 5 was published in *Kiva* Volume 85, Issue 1, pp. 49-80 (https://doi.org/10.1080/00231940.2019.1577059), and is coauthored by Gregson Schachner. I compiled and analyzed data, made figures, and wrote drafts of the paper before initial submission, and after receiving reviews. The paper includes primary data collected by Schachner and Sinensky on multiple projects since 2010, and a synthesis of previously published and unpublished research completed over the past century. The particular analyses presented in the paper were developed and refined by both authors. The final version of the paper is the result of many conversations and rounds of writing and editing by both authors. I thank Greg for supporting the inclusion of this paper, and Taylor and Francis for approving its inclusion.

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2021 Schachner, G., J. Nicholas, R. J. Sinensky, K. Throgmorton and K. Bishop – Kiikiqö: Early Communities. In *Becoming Hopi: A History*, edited by W. Bernardini, S. B. Koyiyumptewa, G. Schachner, and L. Kuwanwiswima, pp. 161-200. University of Arizona Press, Tucson. https://doi.org/10.2307/j.ctv1q8tg8h.13

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2019 Sinensky, R. J., and G. Schachner – Early Pueblo Period Population Aggregation and Dispersal in the Petrified Forest Region, East-Central Arizona. *Kiva* 85 (1):49-80. https://doi.org/10.1080/00231940.2019.1577059

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CHAPTER 1: Introduction

Reciprocal relationships between humans and non-humans following the emergence of food production culminated in the independent development of plant and animal domestication on nearly every continent. The subsequent spread of agricultural economies fundamentally changed the scale and scope of organizational forms evident in diverse human societies worldwide (Bellwood 2023; Rowley Conwy and Layton 2011). In the past, many researchers adopted simple, causal models to understand relationships among domesticated plant foods, population pressure, declining mobility, the formation of early villages, the development of increasingly complex political arrangements that cross-cut group identities, and burgeoning inequality.

Recent paleoethnobotanical and zooarchaeological studies, however, demonstrate more variability in the transition to agriculture across the globe (Larson and Fuller 2014; Marston 2021; McBrinn 2010; Mueller et al. 2020; Roth 2016; Russel 2022; B. Smith 2001; Quintus and Allen 2023; Vierra and Carvalho 2019; Zeder 2012, 2015). In some societies, increasing investment in agriculture was linked to rising sedentism and wealth accumulation (Ellyson et al. 2019; Flannery 2002; Kohler et al. 2023 Kohler et al. 2017). In others, however, groups adopted domesticates yet remained highly mobile and continued to consume a broad diversity of foraged and cultivated plant and animal resources (Chapter 3; Fritz 2019:50-51; Huckell and Toll 2004; Iriarte et al. 2017, 2020; also see M. Smith 2006a). In areas with concentrated wild resources surprisingly high degrees of inequality among households are apparent in societies that did not develop or adopt domesticated plants or animals (Ames and Grier 2020; Prentiss et al. 2012, Prentiss et al. 2018; Roscoe 2021; Smith and Codding 2021). Similarly, social stratification is evident in early agricultural societies with that coupled low-level food production systems focused on domesticates (see B. Smith 2001) with intensive exploitation of marine and aquatic resources (Killion 2013; Lesure et al. 2021; Rosenswig et al. 2015; VanDerwarker 2006; VanDerwarker and Kruger 2012).

Foodways, Cuisine, and Culinary Choice

Current research on domestication highlights the protracted relationship between early food producers and plants in particular, and centers narratives on mutualism and human agency (Allaby et al. 2022; Assouti and Fuller 2014; Bogaard et al. 2021; Kistler et al. 2018; B. Smith 2015, however see Kabukcu et al. 2021). There is growing evidence, for example, that proto- and early agricultural plant exploitation strategies were community-specific and deeply intertwined with local culinary choices and nascent identities (Asouti and Fuller 2013; Kabukcu et al. 2021; Lesure et al. 2021; VanDerwarker et al. 2012). Agriculture is no longer seen as an inevitable outcome of plant domestication (Fausto and Neves 2018; Neves and Heckenberger 2019), nor is domestication an inevitable outcome of intensive plant management (Carney et al. 2021; Lyons et al. 2021; Turner et al. 2021). Across Eurasia, Africa, and the Americas, early agricultural research has explored foodways, the social significance of the unique ways in which communities produced, prepared, consumed and shared food, rather than simply reconstructing diet and subsistence (Atalay and Hastorf 2006; Graff 2020; Hastorf 2017; Hastorf and Bruno 2020; M. Smith 2006b; Twiss 2012; VanDerwarker et al. 2016:137-143). Daily cycles of farming, hunting, gathering, production, preparation, and consumption make manifest social relationships and forge identities (Acabado 2018; Battle-Baptiste 2011; Berkes 2017; Franklin and Lee 2019; Warner 2015). The repeated use of particular ingredients and cooking practices within a cultural context and temporal setting can be conceived of as "cuisine" (Appadurai 1981; Crown 2000; Dietler 2001; Hastorf 2017; Mills 2007; Oas 2019, 2023; Twiss 2019). Activities, aromas, and tastes associated with cuisine conjure powerful memories of family and community. The development of shared cuisines and community-specific foodways in early agricultural societies likely played a critical role in integrating early villagers by forging shared identities (see Chapters 2-4).

Early Agriculture and Mobility

Researchers have also questioned simple, unicausal links between subsistence and sedentism since many early farming societies were highly mobile (Denham and Donohue 2022; Feinman and Neitzel 2023; Furholt 2021; Gibbs and Jordan 2016, also see Chapters 3 & 5). In "traditional" models, household mobility is expected to reduce concomitantly with investment in niche construction as groups seek to maintain control over value added landscapes (Adams 2004; Cole and Ostrom 2012; Odling-Smee and Laland 2011; Ostrom 2000; Rowley-Conwy and Layton 2011). Mobility, however, does not always decline in lock-step with agricultural intensification or investment in place. In the Southwest/Northwest of North America[1], for example, early farmers remained highly mobile even after investing significant effort in the construction and maintenance of spatially expansive canal systems (Gruner 2023; Roth 2015, 2016; Vint 2018; Chapter 3). Even centuries after seasonal mobility declined and communities built large villages, households continued to circulate within and among communities (Bernardini 2005; Cameron 2013; Duff 2002; Duwe and Preucel 2019; Peeples 2018; Schachner 2012; also see Birch and Hart 2021; Furholt 2019, 2021, Chapter 5). This situation is not unique

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[1] This wording acknowledges that the "culture area" many archaeologists call "the Southwest", "the US Southwest", or "the American Southwest" extends into northwest Mexico.

to the Southwest/Northwest. Recent research, for example, indicates that residents of early Mesoamerican villages also maintained diverse mobility practices (Inomatta et al. 2022; Kennett et al. 2020; Lesure 2009; Lesure et al. 2021a; Lesure et al. 2021b; Lohse et al. 2022).

In some regions of the Colorado Plateau, an extensive 100,000 km^2 arid yet temperate upland area that encompasses portions of what is now northern Arizona, northern New Mexico, southwestern Colorado, and southeastern Utah, there is robust evidence that Ancestral Pueblo residential mobility declined through time while population densities increased (Varien 1999, 2002, however see Throgmorton et al. 2023). In most regions, however, population densities remained low and household mobility fluctuated. In these areas, periods of aggregation and low residential mobility were often followed by more dispersed settlement patterns, indicating that Ancestral Pueblo farmers favored frequent residential moves (see Chapter 5). Similarly, on the Colorado Plateau we do not see a trajectory of slow and steady increase in social group size and the scale of political action. Instead, the trajectory is punctuated–social pressures and sudden climate shifts created openings for rapid and widespread political change (Chapter 4). The papers contained in this dissertation contribute to a theoretically diverse body of literature on early agricultural societies by exploring foodways, mobility, and the dynamics of village formation in the earliest farming villages in the Southwest/Northwest and Mesoamerica at scales ranging from individual sites to regions.

Perspectives on Early Agriculture in the Southwest/Northwest

In Southwest/Northwest archaeology there is a long history of researchers linking a trajectory of increasing sedentism with degrees of reliance on domesticated plant foods, most notably maize (*Zea mays L.*) (Diehl 2012:14-15; Diehl and Leblanc 2001; Minnis 1985, 1992;

Reed 2000; Roth 2016; Wills 1996, 2001; Herr and Young 2012; however see Fish 2004:134-136). Here, shifting foodways have been posited as a causal mechanism for, and evidence of, sweeping societal changes. While many of the material correlates of increasing sedentism become more common throughout the first millennium AD, such as larger and longer-lived settlements with more durable architecture, many late preceramic (1250 BC-AD 50) farmers in the southern Sonoran and Chihuahuan deserts (see Carpenter et al. 2015; Ezzo and Deaver 2000; Hard and Roney 2020; Lesure et al. 2021; Nakatsuka et al. 2023), and 450 BC-AD 200 Ancestral Pueblo farmers to the north on the Colorado Plateau (see Coltrain and Janetski 2006, 2013, 2019; Coltrain et al. 2007; Matson and Chisholm 1991) consumed nearly as much maize as their descendants centuries later, questioning the simple, underlying link to increasing agricultural production.

Perspectives on the relationship among reliance on domesticates, sedentism, and broader social changes in neighboring regions can be useful for recalibrating our expectations for similar interactions in the Southwest/Northwest, especially in light of changing perspectives on early farming societies more broadly. Since domesticated maize spread into the Southwest from Mesoamerica, a brief review of current (and changing) perspectives on maize agriculture during the Late Archaic (2700-1900 BC) and Early Formative (1900-1000 BC) periods can help researchers better situate expectations for relationship between dietary dependence on maize and mobility in the Southwest/Northwest as well.

Farming and Mobility in Early Formative Mesoamerica

For much of the past three decades there has been considerable debate concerning the dietary importance of maize for inhabitants of the earliest villages in Mesoamerica (1900-1000

BC). Many researchers argued that maize agriculture was not central to the formation of early population aggregates, but rather that maize only emerged as a dietary staple alongside increasing political complexity and social differentiation with the rise of proto-urban centers after 1000 BC (Clarke et al. 2007; Hart et al. 2023; Killion 2013; Rosenswig et al. 2015; Smalley and Blake 2003; Webster 2011). However, recent research in the Lowland Maya region of Central America provides unequivocal evidence for the increasing dietary importance of maize after 2700 BC, and farmers relying on maize as a dietary staple by the start of the second millennium BC (Kennett et al. 2017, 2020, 2022, 2023; Ray et al. 2023). These early intensive maize farmers, however, remained highly mobile, and unlike their neighbors to the north, did not aggregate in large villages, adopt ceramics, or build communal architecture for roughly a millennium (see Inomata et al. 2020; Inomata et al. 2022). Diverse subsistence and mobility strategies appear to have persisted throughout the second and early first millennia BC. Even at the earliest proto-urban centers with monumental architecture some residents remained primarily foragers (Inomata et al. 2022; Lohse et al. 2022).

Along the Pacific Coast of southern Mexico and Guatemala, an area known as the Soconusco, increasing reliance on maize and increasing diet breadth through time are evident at the earliest villages (1700-1300 BC), but this is followed by decreasing dietary diversity after roughly twelve generations of village life (1400-1300 BC, see Lesure et al. 2021b, 2021c; Lesure and Wake 2011; Wake et al. 2021). Here, the increasing dietary and social importance of maize was likely linked to social changes, namely a reciprocal relationship between the adoption of a shared cuisine at early villages and the promotion of common foodways by incipient elites that stood to benefit from the labor of residents (Chapter 2). Even still, early village residents appear to have retained diverse mobility and subsistence practices (Lesure 2009, 2021:557-559; Lesure et al. 2021b). By 1400 BC, most (but not all) village residents in the Soconusco likely consumed nearly as much maize as their Middle Formative (1000-400 BC) descendants centuries later (Lesure et al. 2021:496; Melton 2022:242-243), a finding bolstered by an analysis of food processing tools (Chapter 2). What we see in the Soconusco is that the importance of maize varied household to household in the early villages, but over time, foodways converged and became more maize-centric. The emerging picture in coastal Oaxaca suggests a similar trajectory to that of the Soconusco (Bérubé et al. 2020; Hepp 2019; Hepp et al. 2017, however see Joyce 2020), but data are limited.

Yet another pattern is evident along the southern coast of the Gulf of Mexico in the Olmec heartland. Here, researchers have argued that the increasing dietary and social importance of maize was linked to a political transformation that occurred with the decline of San Lorenzo and the rise of La Venta and Tres Zapotes as the preeminent Olmec centers of political power (around roughly 1000-800 BC, see Arnold 2009, 2022; Pool 2021; Rosenswig 2021; Rust and Leyden 1994; VanDerwarker 2006; VanDerwarker and Kruger 2012). Foodways in the earliest Olmec centers (~1400-1000 BC), by contrast, were focused on marine resources, and diet breadth remained broad (see Arnold 2009, 2022; Blomster and Cheetham 2017; Killion 2013; VanDerwarker and Kruger 2012; Wendt 2022).

Current archaeological evidence therefore suggests: *(a)* diverse foodways, some maize-centric, and others not, at the earliest Mesoamerican villages, *(b)* that some highly mobile farmers consumed considerably more maize than their village-dwelling and ceramic-using neighbors throughout the second millennium BC, and *(c)* that the increasing dietary importance of maize likely occurred at the household rather than group level prior to 1000 BC. It is not my intent to claim that researchers should never expect unidirectional relationships between maize consumption, sedentism, and sociopolitical organization, but rather that the diverse foodways and mobility strategies evident in Early Formative Mesoamerica should leave researchers wary of assuming these relationships rather than subjecting them to scrutiny through multiple methods aimed at assessing the full range of possibilities. And even while second millennium BC trajectories within each region were unique, they ultimately converged after 1000 BC with the widespread adoption of ceramics, maize-centric foodways, and the rapid appearance of large villages and proto-urban centers region-wide (Lesure et al. 2021a).

Revisiting Early Foodways and Mobility in the Southwest/Northwest

In the Southwest/Northwest, trajectories also ultimately converged during the sixth century AD (see Schachner et al. 2012; Young and Herr 2012) with the rapid and widespread appearance of sedentary farmers, adoption of ceramics, construction of more durable residential structures, and widespread acceptance of new shared forms of communal architecture (see Chapter 4), but we should not assume that this marks the point at which maize-centric foodways and intensive agriculture first emerged. Rather, we should expect culturally diverse communities with distinctive foodways and mobility practices throughout the first millennium BC and early first millennium AD, and not conflate evidence of decreasing seasonal or residential mobility with increasing dietary dependence on maize, or vice-versa, without clear and convincing evidence from specific communities.

It is also critical that we not conflate changing foodways, the adoption of ceramics and more efficient grinding tools, for example (see Chapter 4), with increasing dietary dependence on maize simply because these practices remained central elements of Pueblo and Hohokam foodways long after the sixth century AD. The adoption of new technologies is indicative of new ways of cooking and eating that more closely parallel later modern, historic, and early second millennium AD Pueblo and O'odham foodways, but even these changes alongside evidence for decreasing seasonal and residential mobility are not in and of themselves incontrovertible evidence for the increasing dietary importance of maize. Researchers should be open to the possibility that the social value ascribed to preparing specific maize-centric meals shifted regardless of the degree to which maize contributed to caloric intake. I am not arguing that there is necessarily a one-to-one parallel between early agricultural developments in Mesoamerica and the Southwest–these regions are environmentally and culturally very different. The emerging picture of the diverse foodways, forms of social organization, and mobility practices in third and second millennium BC Mesoamerica should nevertheless lead researchers to rethink long-held assumptions about similar dynamics across the Southwest/Northwest.

Organization of the Dissertation

The chapters presented herein each explore themes central to the transformation of Southwest/Northwest and Mesoamerican early agricultural communities, including, foodways, mobility, socio-political change, the formation of early population aggregates, and factors influencing the resilience and long-term trajectories of early food production systems. Site-specific analyses of macrobotanical data, agricultural soils and infrastructure, and food processing tools, provide platforms to explore the foodways and mobility strategies of 1700-1300 BC villagers in Mesoamerica, and 1250-750 BC farmers in the Sonoran Desert. Millennial-scale reconstructions of precipitation and temperature from tree-ring chronologies coupled with demographic reconstructions informed by settlement patterns, radiocarbon data, and archaeological tree-ring dates provide insight into the timing and tempo of early village formation on the Colorado Plateau, and the social climate when diverse Ancestral Pueblo communities adopted a shared set of social and political institutions that provided a foundation for early villages and the rise of regional systems.

Initial Formative Cuisine

Chapter Two presents an analysis of more than 900 grinding tools recovered from Paso de la Amada, a 1700-1300 BC village and ceremonial center located in the Soconusco region along the Pacific coast of southern Mexico. Paso de la Amada was one of the earliest and largest sedentary villages in southern Mexico at the time, and is well-known to archaeologists for hosting the earliest recorded ballcourt in Mesoamerica (Blake 1991, 2011; Blake and Clark 1999; Blake et al. 2006 Clark 1994, 2004; Clark and Blake 1994; Hill 1999; Hill and Clark 2001; Lesure 1995, 1997; Lesure and Blake 2002; Lesure et al 2021d). The analysis in Chapter Two provides an opportunity to explore *(a)* whether diachronic trends indicative of cuisine change are evident between 1700 and 1300 BC at Paso de la Amada, and *(b)* consider the degree to which 1700-1300 BC foodways compare or contrast to those during the earlier Late Archaic (2700-1900 BC) and subsequent Middle Formative periods (1000-400 BC).

Results of the analysis support the basic premise that maize was processed for daily meals with increasing frequency throughout this period, and that a technological style associated with intensive maize grinding for daily meals was already widely used by 1700 BC. Passive and active tools of a similar technological style dominate ground stone assemblages across Mesoamerica after 1000 BC, and their prominence at Paso de la Amada likely marks the inception of the “wet-grinding” tradition in Mesoamerica. This tradition, grinding soaked or lime-treated maize kernels rinsed of pericarps, remained the dominant way maize was processed for daily meals in Mesoamerica from 1000 BC forward. The study also suggests that even while the shift toward more frequent and more intensive maize processing for daily meals was under way, community members continued using mortars, pestles, and rotary-stroke manos–tools likely *designed* primarily for processing foods other than maize, or for processing maize using recipes that were no longer common after 1000 BC. Taken as a whole, the Paso de la Amada ground stone assemblage suggests that 1700-1300 BC routine food processing differed from earlier Late Archaic (2700-1900 BC) and subsequent Middle Formative (1000-400 BC) traditions. A shared culinary tradition emerged at Paso de la Amada during a period of social and political change (1700-1500 BC). I argue that this shared cuisine was critical to the growth and success of Paso de la Amada because it fostered a shared identity among household with diverse histories and traditions.

Mobility, Resilience, and Intensive Agriculture

Moving north to the Sonoran Desert of far northwestern Mexico and southern Arizona, Chapter Three explores continuity and change in agricultural, horticultural, and foraging practices in an early agricultural community that immediately postdates the period of the abandonment of Paso de la Amada–Las Capas. Located in the floodplain of the Santa Cruz River in the Tucson Basin, the 1220-730 BC component at Las Capas contains the earliest incontrovertible evidence for the intensification of maize agriculture in the Southwest/Northwest. Findings from this particular site also highlight the complex relationships amongst agricultural intensification, population growth, mobility, nascent inequality, and competition over resources. Here, early farmers constructed sophisticated and spatially extensive canal systems during the late-second millennium BC, and by the early-first millennium BC, irrigated roughly 40 acres of agricultural fields. The construction and upkeep of this intricate agroecosystem required regular cooperation between 100-300 people, making this the earliest known evidence for collective action by a group of this size in the Southwest/Northwest more broadly (Mabry 2008; Vint 2015, 2018, also see Hard and Roney 2020).

While unprecedented investment in irrigation infrastructure tied households to particular places on the landscape for generations, residents of early floodplain villages remained surprisingly mobile. Twenty generations of early farmers living at Las Capas built and inhabited very ephemeral residences. Limited investment in domestic architecture suggests that residential moves were frequent and anticipated, and the lack of a clear trajectory of increasing investment in architecture throughout the 1220-730 BC inhabitation indicates that this remained the case for centuries. Agricultural intensification and high mobility at Las Capas are coupled with limited evidence of population growth, and no clear evidence that this long-lived farming community negatively impacted the productivity of agricultural soils or the makeup of local fauna (however see Diehl et al. 2023).

Preceramic foodways in the Sonoran Desert have often been considered stable for over 2500 years following the introduction of maize (prior to 2500 BC, see Vint 2018), yet analyses of macrobotanical data, agricultural soils, and the construction and maintenance histories of irrigation canals during three well-dated intervals spanning 1220-930 BC, 930-800 BC, and 800-730 BC respectively reveal that moderate-intensity flood events (930–800 BC) preceded the greatest richness and diversity of gathered plants, when reliance on maize was reduced. The representation of maize parts present in the archaeological record at this time also shifted, indicating changing agricultural practices and/or routine on-site processing and consumption activities associated with the primary agricultural crop. During the earlier and subsequent periods with less frequent and intense environmental disturbances, however, maize was more dominant, with less diversity in other cultivated and foraged plants (also see Farahani and Sinensky 2022). These data indicate that 1250-750 BC villagers shifted cultivation techniques and incorporated different types and quantities of disturbance-tolerant native plants into food production systems depending on environmental conditions. Novel cultivation, processing, and foraging practices were initiated in response to environmental disturbances, but macrobotanical data and geoarchaeological analyses of irrigation infrastructure demonstrate that these persisted even after floodplain conditions stabilized and maize production intensified (800-730 BC). People-plant relationships and Indigenous knowledge extending well-beyond domesticates introduced from Mesoamerica thus fostered a more resilient food production system.

Disturbance, Reorganization, and Social Change

Chapter Four explores societal responses of Ancestral Pueblo farmers to nearly two decades of extreme cooling that severely restricted the productivity of maize agriculture on the Colorado Plateau during the AD 500s. Extreme cooling corresponding to massive volcanic eruptions during the late AD 530s and early AD 540s is evident in Northern Hemisphere tree-ring records worldwide (Büntgen et al. 2020; Büntgen et al. 2022; Helama 2018; Sigl et al. 2015). In Eurasia, the impacts of extreme cooling and a multi-year dust veil were likely catastrophic (Büntgen et al. 2022; Helama 2018; Strothers 1984; Strothers and Rampino 1983). On the Colorado Plateau, however, even though these eruptions correspond with a downturn in construction of habitation structures, and are potentially associated with population declines, they were followed by rapid and widespread social transformations, including dramatic population growth, the adoption of a shared set of food processing and cooking technologies, and new social, economic, and landscape practices. These changes facilitated the rapid reorganization of Ancestral Pueblo societies, providing a foundation for the formation of early villages and the rise of the Chaco Regional System during subsequent centuries.

Alternative Trajectories to Aggregation

Chapter Five focuses on the development of a large AD 650-800 sedentary village in a particularly arid region of the Colorado Plateau during the interval that immediately followed the reorganization of Ancestral Pueblo societies. Most models for the formation of early villages on the Colorado Plateau were developed in regions with high population densities and concentrated, productive land for maize agriculture (see Kohler and Varien 2010, 2012). Yet, it is unclear whether proposed causal factors, namely population pressure on resources and the resulting competition between households, were also causal factors for aggregation elsewhere. The founding of a large, sedentary eighth century village in a region with low population densities and no conceivable population pressure forcing competition suggests multiple trajectories led to the development of early population aggregates on the Colorado Plateau.

Ancestral Pueblo farmers in this region, however, did not remain in large aggregated settlements. During the ninth century AD, residents transitioned to a dispersed and highly mobile settlement pattern that remained in place until the formation of large villages during the thirteenth century AD. In neighboring regions, however, an inverse pattern is apparent–early villages formed during the ninth century AD and populations dispersed during the thirteenth century. This chapter highlights the non-linear trajectories of Ancestral Pueblo mobility practices. Farmers do not simply become increasingly sedentary through time–there are periods of aggregation and dispersal that are influenced by intra- and intercommunity dynamics.

Revisiting Early Agriculture

Overall, the papers that compose this dissertation contribute to an ongoing re-evaluation of foodways, mobility, and village formation in early agricultural societies across the Americas and beyond. Future investigations drawing on these themes require renewed emphasis on periods that immediately predate and post-date regional transformations, refining chronologies with high-quality data to better understand the social and environmental contexts when transformations occurred, and improving our understanding of when communities adopted new crops and technologies and how these were integrated into foodways. Prior paleoethnobotanical research on early agricultural societies primarily focused on reconstructing subsistence and diet, and more specifically in the Americas, the dietary consumption of maize. Few studies have explored the social significance of foodways in early farming societies, but those that have primarily investigate the role of public feasting in suprahousehold integration. The development and adoption of shared foodways–the routine ways that households produced, prepared, and consumed food, and the importance of shared cuisine for integrating households with diverse histories into early village life remains understudied in Mesoamerica and the Southwest/Northwest. In-depth studies of people-plant relationships drawing on robust paleoethnobotanical data from well-dated contexts, detailed studies of grinding tools and early ceramics, and more specifically, the extraction and analysis of microbotanical residues to directly identify the specific meals prepared using these new technologies, can reveal important information on the social lives of early farmers that extends well-beyond the component parts of diets.

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CHAPTER 2: Ground Stone Technology and Routine Food Processing at Paso de la Amada

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Abstract

This chapter examines ground stone tools recovered during the 1992–1997 excavations at Paso de la Amada, a 1700-1300 BC village and ceremonial center located in the Soconusco region of Mesoamerica. The assemblage includes more than 900 individual artifacts, and this analysis provides an opportunity to study grinding technology at the dawn of settled village life in Mesoamerica. The sizable assemblage allows for a detailed case study regarding not only the degree to which ground stone tools were manufactured and used to process particular foods during the second millennium BC, but also whether diachronic trends indicative of cuisine change are present between 1700 and 1300 BC.

Keywords: Mesoamerica, Early Formative, Initial Formative, Late Archaic, Middle Formative, Soconusco, Chiapas, early agriculture, village formation, cuisine, foodways, ground stone,

Introduction

This chapter examines a subset of ground stone tools from the 1992–1997 excavations at Paso de la Amada, those used principally for processing activities. The ground stone assemblage includes over 900 individual artifacts, and this analysis provides an opportunity to study grinding technology at the dawn of settled village life in Mesoamerica. The sizable assemblage allows for a detailed case study regarding not only the degree to which ground stone tools were manufactured and used to process particular foods during the second millennium BC, but whether diachronic trends indicative of cuisine change are present between 1700 and 1300 BC.

Food Processing and Daily Meals

Over the last 50 years the question of "how much maize?" has dominated discourse on food processing during the Initial Formative and Early Formative periods. As of late, a number of researchers have argued that maize did not comprise a significant part of the Mesoamerican diet until the Middle Formative transition, at around 1000 BC (Blake 2006; Blake and Neff 2011; Clark et al. 2007, 2010; Kennett et al. 2006; Rosenswig 2006, 2010; VanDerwarker and Kruger 2012). Some scholars have attributed this shift to the development or introduction of more productive varieties of maize (Webster 2011), while others argue for increasing social complexity during the early first millennium BC as the trigger for agricultural intensification (Rosenswig et al. 2015; VanDerwarker 2006). While ground stone artifacts have played a minor role in these arguments (see Arnold 2009; Blake and Neff 2011; Clark 1994; Clark et al. 2007; Rosenswig 2010; Rosenswig et al. 2015), sample sizes have been small, and studies have mainly compared Initial and Early Formative to Middle Formative assemblages. Furthermore, such models typically draw a sharp contrast between the development of increasingly complex social and political structures as an inherently social process (Blake et al. 1992; Chisholm and Blake 2006; Clark 2004; Clark and Pye 2001; Clark and Gosser 1995; Rosenswig 2010; Smalley and Blake 2003), or driven by non-social factors, including climate, demography, increasing sedentism, and perhaps most notably, the increasing productivity of maize agriculture (Flannery 1986; Marcus and Flannery 1996; Webster 2011).

Here, I argue that the Paso de la Amada ground stone assemblage can provide insight into an inherently social activity with important implications for the social, economic, and political trajectories of early villages in the Soconusco: routine food processing (Hastorf 2016; Kerner et al. 2015; Pollock 2015; Twiss 2007). This requires decoupling maize from its contentious status as either prime mover or prestige resource reserved for feasts during the Initial and Early Formative, and considering how a host of domesticated, cultivated, and wild resources were processed by community members through time at Paso de la Amada. Given that numerous archaeological studies have identified a strong relationship between cuisine change and social, economic, and political transformations (Bardolph 2014; Hastorf 1990, 2016; Hastorf and Johannessen 1993; Scarry 1993; Scarry and Steponitis 1997; VanDerwarker 2006; VanDerwarker and Kruger 2012), the dramatic pace of social change during the Initial Formative at Paso de la Amada offers an ideal case study to assess whether cuisine change occurred alongside burgeoning social complexity. Such an assessment, however, requires grounding our interpretation of Initial and Early Formative routine food processing in an assessment of similar practices by small-scale, mobile, farmer-foragers during the Late Archaic period, and proto-urban intensive agriculturalists during the Middle Formative period.

Research Questions

This study seeks to investigate the following questions:

1. What can the types of ground stone tools manufactured and used by community members at Paso de la Amada tell us about the routine processing activities that took place on the site?
2. Did the manufacture and use of ground stone change through time at Paso de la Amada? If so, how?
3. How does the ground stone assemblage at Paso de la Amada inform our understanding of change

and/or continuity of foodways during the second millennium BC in the Soconusco?

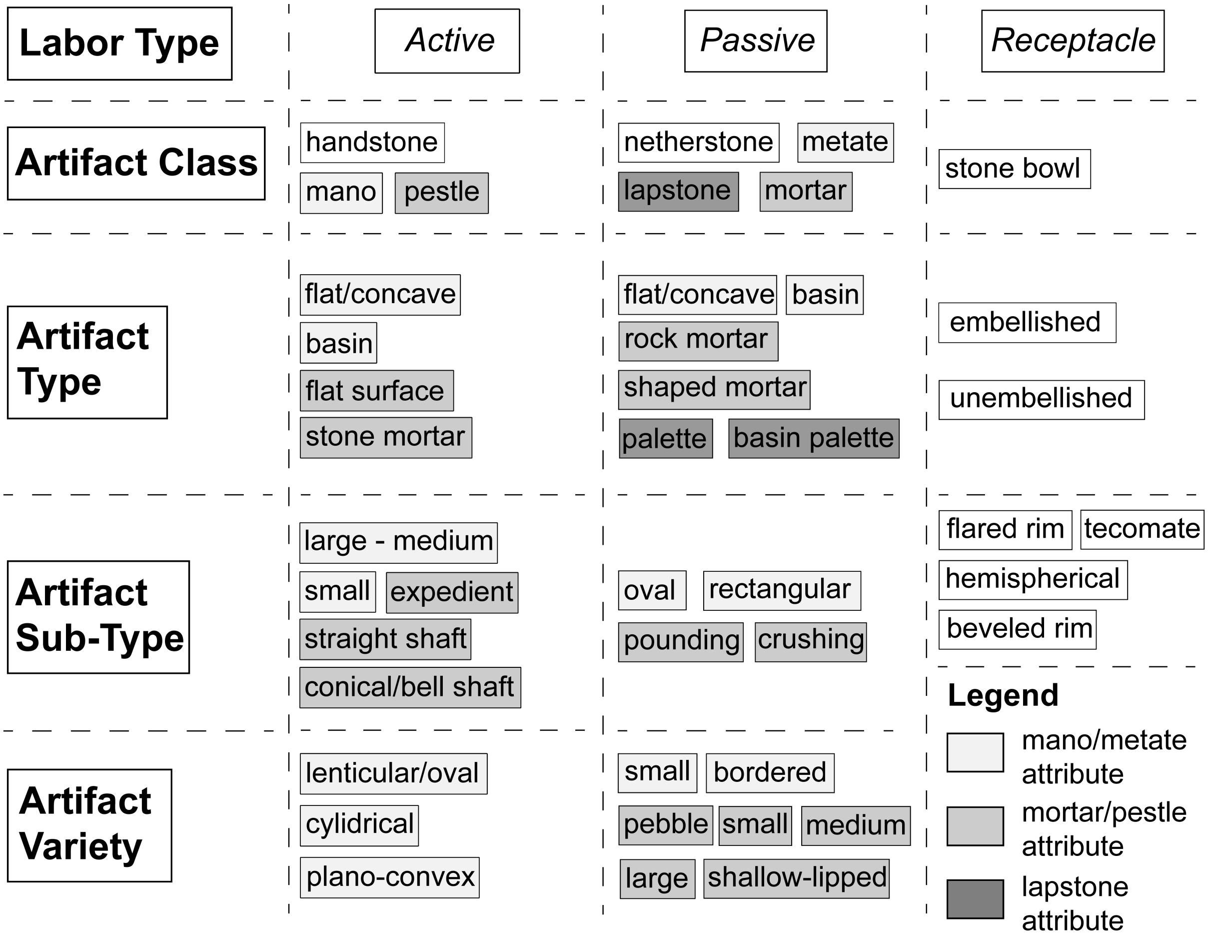
4. To what extent were routine food processing activities at Paso de la Amada comparable or distinct from Late Archaic, and Middle Formative strategies? We are particularly interested in whether punctuated changes or subtle shifts are visible during the Late Archaic to Initial Formative transition, and the Early Formative to Middle Formative transition.

The chapter begins with a review of methods. Then, the ground stone typology is presented. Trends in the use, manufacture, and discard of ground stone artifacts between 1700 and 1300 BC are explored, and implications for our understanding of routine food and non-food processing activities are discussed. The Paso de la Amada tools are then compared to Late Archaic ground stone tools from the Soconusco and to well-published stone grinding tools from the Middle Formative site of La Libertad in central Chiapas.

Methodology and Sampling Strategy

This analysis is structured to investigate the production, use, reuse, and discard of ground stone artifacts. It is assumed that several factors influence the production and use of such tools, including access to raw materials and the historical and technological traditions associated with particular forms of socioeconomic organization. Moreover, the technological style (*sensu* Dietler and Herbisch 1998) reflected in the manufacture of ground stone tools reproduces the social learning frameworks of individuals within a community (Dobres 2000; Ingold 2001; Wenger 1998). Strongly or weakly patterned manufacturing traditions, modes of use, and even discard behavior reflect the enculturative networks of individuals and the community more broadly. Building on Schiffer (1987), Hayden (1987), and Adams (2014), this study seeks to track the life histories of artifacts not only by identifying morphological differences attributable to deliberate manufacture, but also the differential use of artifacts through time. By tracking the manufacture, use, reuse, and discard of artifacts, this study seeks to simultaneously classify objects to a limited number of types and also account for the fact that Paso de la Amada community members used ground stone objects for multiple purposes, which may or may not match the initial task that an object was manufactured to achieve.

Excavations recovered ground stone artifacts from a variety of screened and unscreened contexts, including midden deposits, domestic features, and extramural features. All recovered artifacts were analyzed by the author at the New World Archaeological Foundation in San Cristóbal de Las Casas, Chiapas, in 2016, using a 20x magnification hand lens. All mortars, pestles, stone bowls, rare specimens, and intact or nearly intact tools were examined using a stereoscopic microscope with 40x magnification. Analysis under a microscope helped identify pigment adhering in cracks and pores of artifacts; however, all specimens were washed prior to analysis. It is likely that pigment was washed off an unknown number of tools prior to analysis.



Labor Type	Active	Passive	Receptacle
Artifact Class	handstone mano pestle	netherstone metate lapstone mortar	stone bowl
Artifact Type	flat/concave basin flat surface stone mortar	flat/concave basin rock mortar shaped mortar palette basin palette	embellished unembellished
Artifact Sub-Type	large - medium small expedient straight shaft conical/bell shaft	oval rectangular pounding crushing	flared rim tecomate hemispherical beveled rim
Artifact Variety	lenticular/oval cylidrical plano-convex	small bordered pebble small medium large shallow-lipped	

Legend
- ⬜ mano/metate attribute
- ▒ mortar/pestle attribute
- ■ lapstone attribute

Figure 2.1. Schematic of the Paso de la Amada ground stone typology. Artifacts were classified in a Linnaean fashion into discrete classes, types, subtypes, and varieties.

Typology and Attribute Analysis

Artifacts were classified in a hierarchical fashion (similar to a Linnaean taxonomy) into a number of discrete categories based on use, function, and morphology (Figures 2.1-2.6). At the broadest level, artifacts were classified into three categories. *Active ground stone* refers to objects that were physically manipulated to process a material, and *passive ground stone* to objects that were manufactured or used in conjunction with active ground stone. *Receptacles* were designed to contain and not process materials.

Within each category, artifacts were further subdivided into *classes* dependent on use. For example, an active artifact primarily used to process material via an up-and-down pounding or crushing motion was classified as a *pestle*, and an active tool primarily used to reduce material via the friction caused by a repetitive rubbing motion was classified as a *mano*. Active ground stone artifact classes include, *manos*, *pestles*, and *handstones*. Passive artifact classes include, *metates*, *mortars*, *netherstones*, and *lapstones*. The receptacle category only includes *stone bowls*. All of these artifact classes are described below.

Artifacts primarily designed for manufacturing activities, including abraders, hammerstones, polishing stones, pecking stones, reamers, perforators, and lithic anvils, are presented in Chapter 12. However, a number of ground stone tools were designed for processing activities and subsequently reused for manufacturing activities. These artifacts are included in the current analysis, and manufacturing activities were recorded as secondary and tertiary uses.

Within each artifact class, objects were further delineated into *types* dependent on use. Since active and passive tools are used together, and the current typology prioritizes artifact life-history and function over form, classification of active tools references passive counterparts (*sensu* Adams 2014). For example, an active tool designed for food processing that was used with a reciprocal grinding motion on a flat or concave metate, was given an artifact *class* of *mano*, and an artifact *type* of *flat/concave mano*. However, an active ground stone tool that was used with a circular stroke on a passive basin metate was given an artifact *class* of *mano*, and an artifact *type* of *basin mano*. If only a small mano fragment was recorded and type could not be discerned, the object was only categorized to the class level.

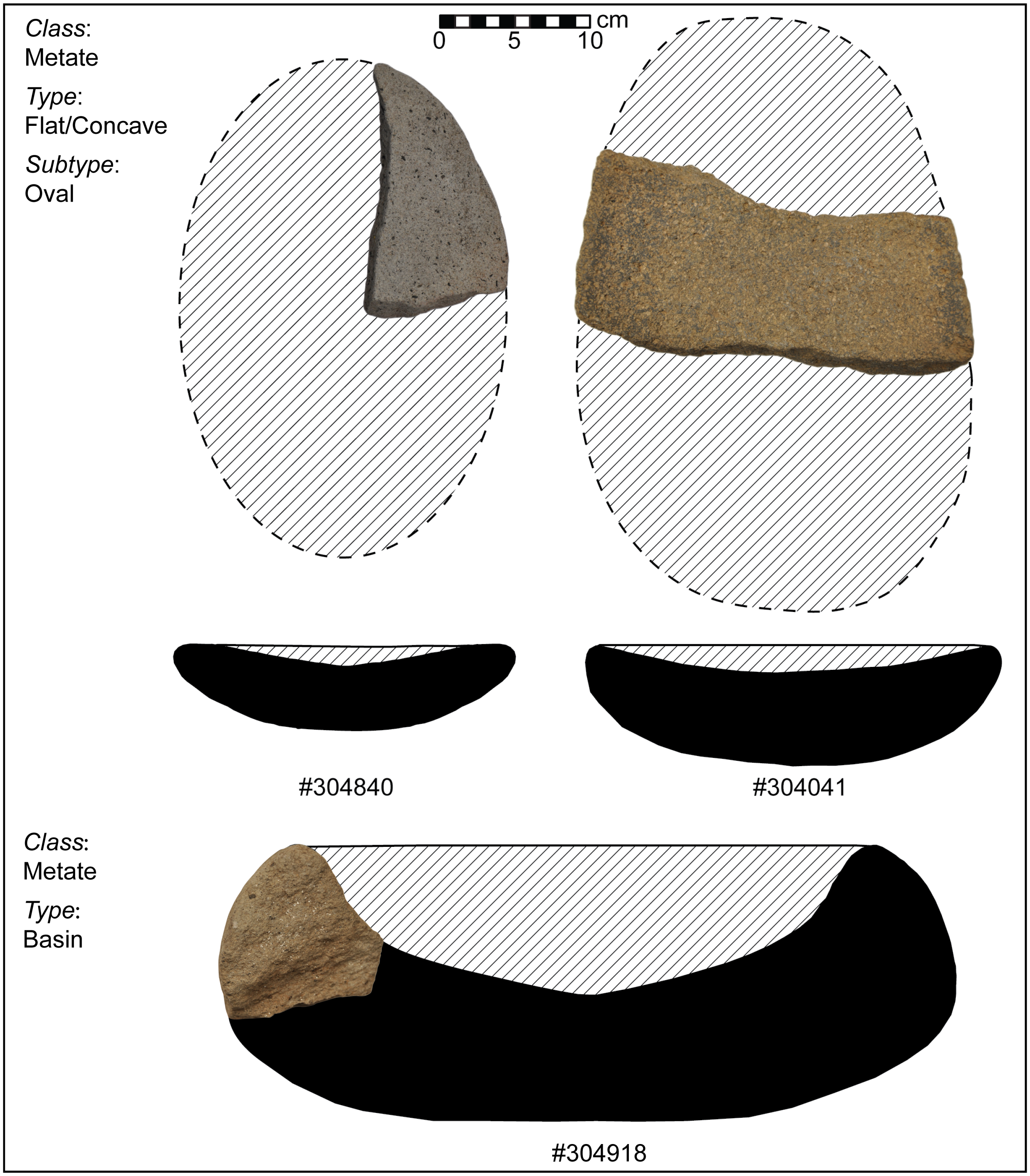


Figure 2.2. Oval flat/concave metates and basin metates from Paso de la Amada.

When a large enough sample of a particular artifact type was present objects were further delineated into *subtypes* and *varieties* based on morphological design and use-wear attributes. For example, flat/concave manos were classified as either *medium-large* or *small subtypes* based on their size (related to manufacture), and *lenticular/oval*, *plano-convex*, or *cylindrical varieties* based on their cross-section (related to use). Since this typology groups objects used in a similar fashion together (i.e., all manos used on a flat/concave metate as a single type), artifact *types* tend to be broader in comparison to earlier typologies devised for Formative period ground stone tools in Chiapas (see Clark 1988), and *subtype* and *variety* categories are more akin to these previous *type* classifications. By primarily focusing on function, however, this study hopes to document the how community members at Paso de la Amada processed food and non-food materials.

In addition to classifying artifacts into types, subtypes, and varieties, further attributes associated with artifact design, manufacture, use, and maintenance were recorded (Table 2.1). Recorded attributes associated with artifact manufacture and design include identifying whether objects were *strategically designed*, meaning intentionally shaped prior to use in order to increase grinding efficiency or conform to societal norms of tool production (Adams 2010, 2014:21; Buonasera 2012; Dietler and Herbisch 1998), or are *expedient* and were only shaped by grinding activities. The *raw material* type, *granularity,* and *durability* of materials were also recorded.

Table 2.1. Nonmetric Attributes Recorded for Ground Stone Artifacts.

Attribute	*First Trait*	*Second Trait*	*Examples*
Design	strategic or expedient	comfort features	(a) strategically designed reciprocal mano (b) river cobble used as an expedient mano with a circular stroke
Use/Reuse	primary, secondary, and tertiary uses	concomitant or sequential secondary uses	(a) nearly worn-out mano reused sequentially as a pestle (b) pestle used concomitantly as a hammerstone for bipolar reduction
Raw Material	type and color of raw material	granularity[a], durability[b], and density[c] of raw material	(a) coarse-grained, durable, black, vesicular basalt (b) medium-grained, less-durable, white, andesite
Use-Intensity[d]	degree of wear associated with primary use	degree of wear associated with secondary and tertiary use	(a) medium-large flat/concave mano no evidence (unused/mano blank) or little evidence (light-use) of modification from manufactured shape from use on a metate on either dorsal or ventral surfaces. (b) strategically designed metate with a prominent, well-worn concave grinding surface (moderate-use), or a deep, strongly concave grinding surface (heavy-use), or worn through the thickness of the metate and no longer usable (worn out).
Upkeep & maintenance	maintenance associated with primary use	maintenance associated with secondary use	(a) heavily worn metate with repecked basin to maintain roughness (b) mano with repecked ventral surface to maintain roughness
Use-Wear[e]	use-wear associated w/ primary use	use-wear associated w/ secondary use	(a) flat/convex mano with evidence of use with a reciprocal stroke on dorsal and ventral surfaces (b) mortar with evidence of use with crushing strokes
Redesign and/or Recycling	artifact intentionally *redesigned* for processing or manufacturing activities	artifact *recycled* for activity unrelated to processing or manufacture	(a) Broken oval flat/concave metate fragment redesigned as a lapstone by smoothing out rough edges along break and reshaping. (b) worn out or nearly worn out mano recycled as hot rock for stone-boiling.

[a] Granularity was classified into three categories, coarse, medium, or fine-grained.

[b] Durability was classified on a scale of 1-5 (low-to-high).

[c] Density was measured by dividing mass by volume. Volume was documented by placing each artifact in a graduated cylinder and measuring water displacement.

[d] Wear was classified to one of five categories, (1) unused, (2) light use, (3) moderate use, (4) heavy use, or (5) worn out.

[e] Use-wear was documented using 10x and 20x magnification hand lenses and a stereoscopic microscope with 40x magnification.

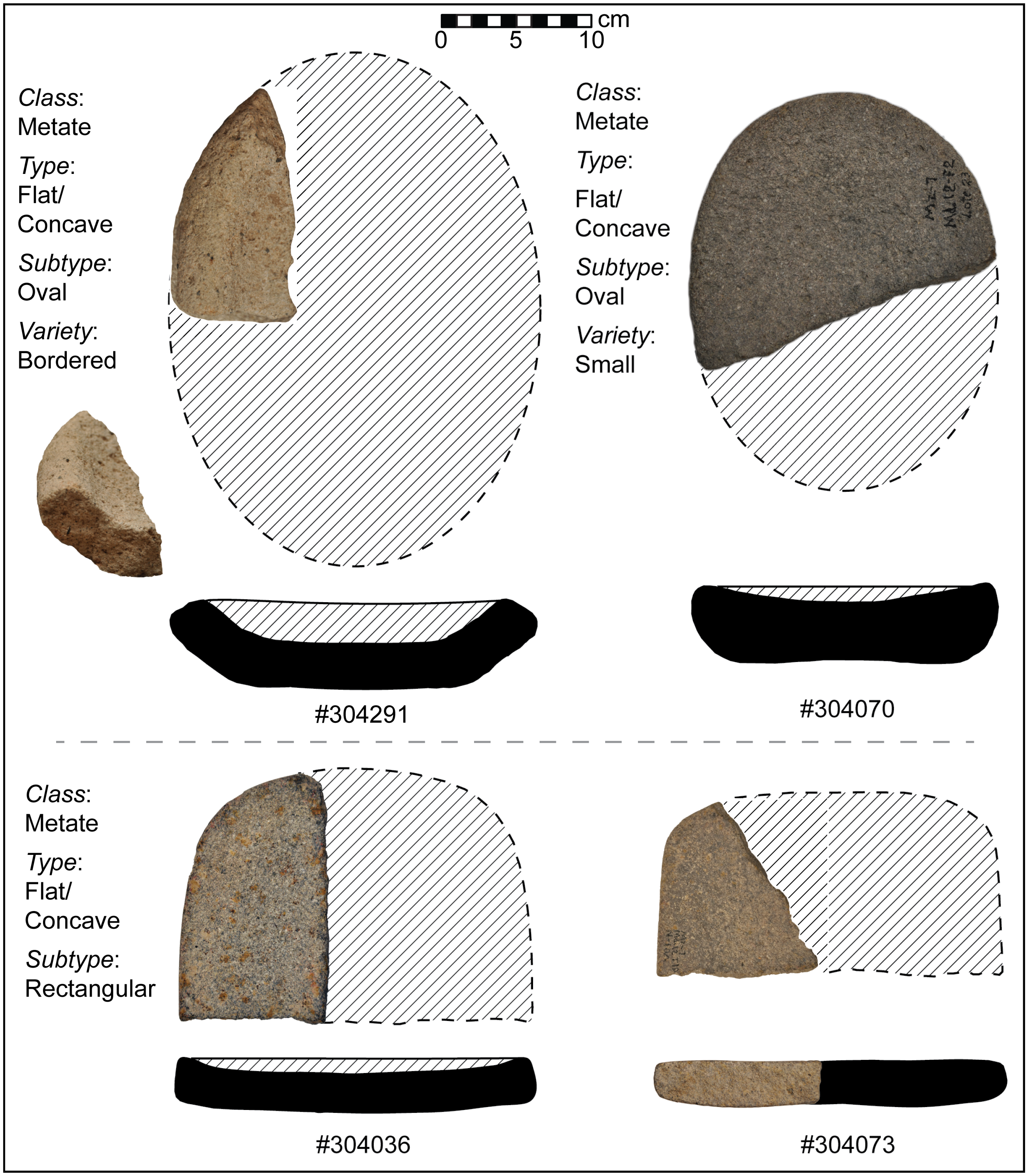


Figure 2.3. Oval flat/concave metate varieties and rectangular flat/concave metates.

Artifact use was assessed by identifying the *primary*, *secondary* and *tertiary* uses of objects, and considering whether non-primary uses took place *sequentially* or *concomitantly* with designed use. For example, a mano may have been used with a reciprocal motion to process food and then as a hammerstone for bipolar reduction. The sequence of reuse from such activities would be evident because impact fractures from percussion would be superimposed on the ground mano surface. The relative intensity of grinding activities was also assessed by the amount and type of wear visible on used surface (Table 2.1), and artifact *maintenance* was identified through use-wear analysis, for example, by examining whether manos or metates were re-roughened in order to maintain grinding efficiency.

Temporal Classification and Sample Size

A total of 927 artifacts are included in the assemblage (Figure 2.7). Of those, 476 artifacts could be assigned to Locona, Ocós, or Cherla contexts (Figure 2.8). Descriptions of the entire assemblage include all 927 specimens, while discussions of change through time include the 476 artifacts with detailed temporal information.

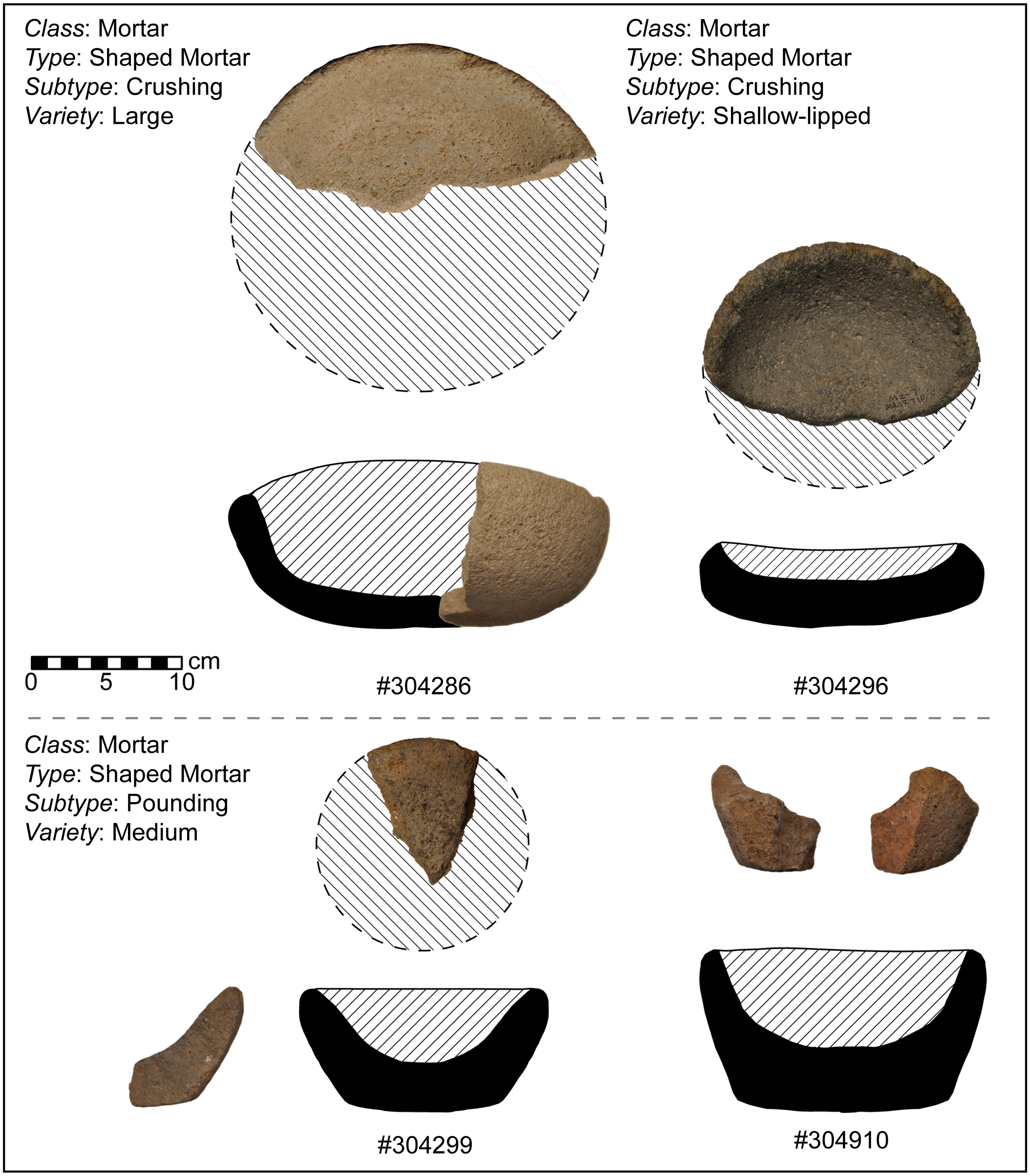


Figure 2.4. Large and medium-sized crushing and pounding mortars.

PASSIVE GROUND STONE

CLASS: METATE (n=395)

The artifact class *metate* refers to the object against which material is processed using the friction created by drawing a handheld stone against a passive surface. Metates in the assemblage were classified into types based on the configuration of grinding surfaces (*sensu* Adams 2014:103–116). Artifacts were further classified into subtypes and varieties based on morphological attributes (Figure 2.9a, Table 2.2). All 395 metates in the assemblage were fragmentary, and projections of length and width were only made for four objects. Metate fragments were the most common ground stone artifacts in the full assemblage (Figure 2.7) and each phase (Figure 2.8). Metates were classified as *flat/concave* or *basin* types (Figure 2.2), and two metate subtypes, *oval* and *rectangular* were also identified (Figure 2.3). Twenty six fragments could not be classified beyond class. A single metate with an intact width measuring less than 20 cm and a projected length less than 30 cm was classified as a *small* variety (Figure 2.3, #304070). Just over one-third of all metate fragments (n=134) were fire-cracked, suggesting frequent recycling of worn out and well-worn metates as hot-rocks for stone-boiling (Voorhies and Gose 2007).

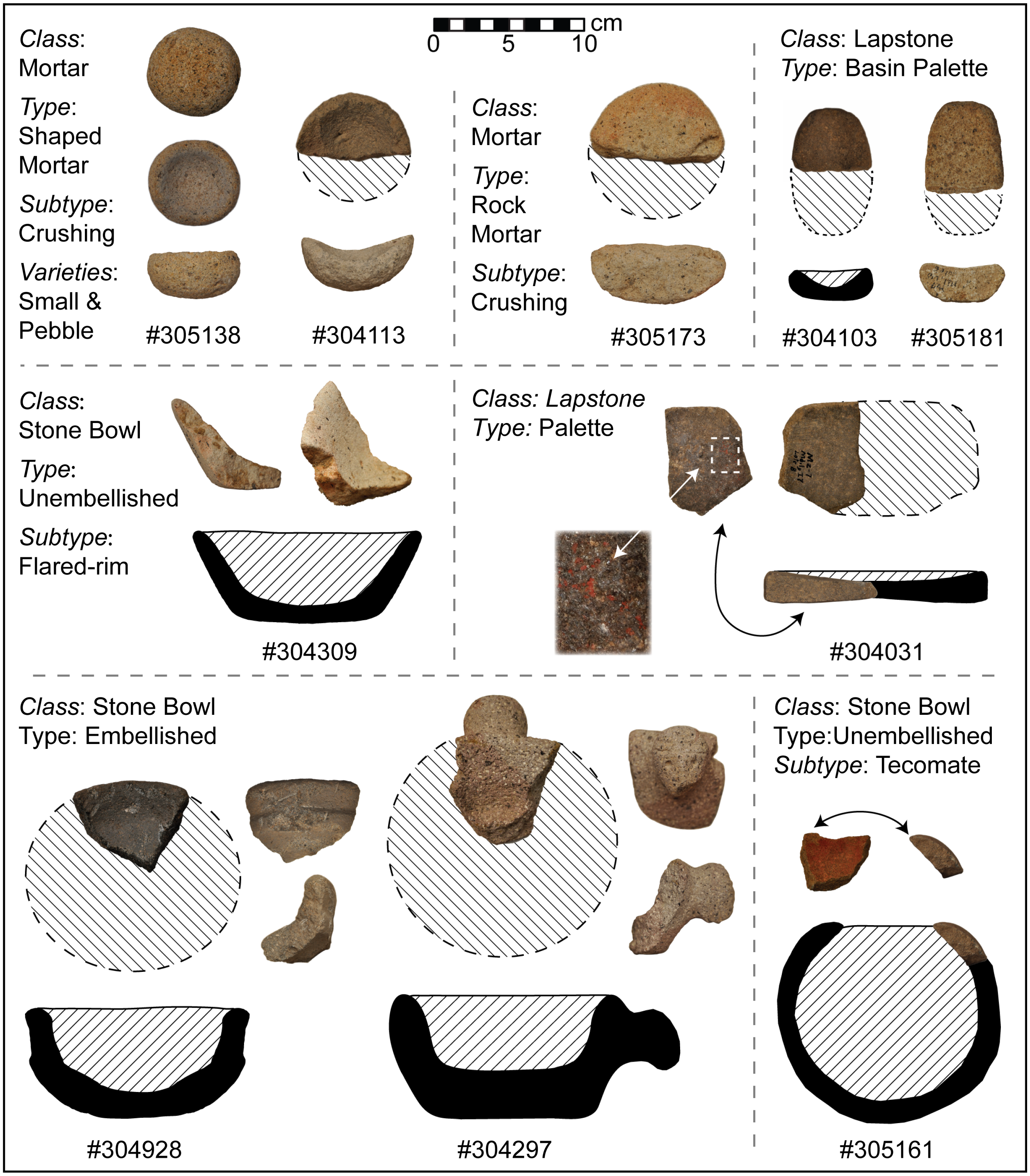


Figure 2.5. Small mortars, basin pallets, stone bowls, and lapstones from Paso de la Amada.

Type: Flat/Concave Metates (n=361)

Subtypes: Oval (n=76), Rectangular (n=16), Varieties: Bordered (n=7), Small (n=1)

Flat/concave metates begin with a flat surface. Use-wear from a back-and-forth (reciprocal) stroke eventually produces a shallow, elongated, concave basin and a gentle slope between the border and grinding surface. Artifacts comprising this type are morphologically similar to Searcy's (2011) "western style" metate, Biskowski and Watson's (2013:215) "open style trough" metate, and particularly "ovoid plano-convex" metates from the Tehuacan Valley (MacNeish et al. 1967:118–120). In the current typology, the "trough metate" type is reserved for metates used with a reciprocal stroke that were intentionally manufactured with bordered rectangular basins prior to use. The term is not applied to the concave grinding slick that develops from use on a flat metate surface. Trough metates strategically designed with a border that is maintained through time exhibit a sharp angle between the restricted border and the edge of the grinding surface (see Adams 2014:107; Biskowski and Watson 2013:216). Metates that exhibit a far less pronounced rounded obtuse juncture between the edge of the grinding surface and border are not considered trough metates since this shape can be formed by use. The current typology, therefore, contrasts with others that include any metate with a slight rim or a large deep basin in a "restricted" category (Clark 1988:94–95), and therefore includes specimens previously considered bordered types (such as Clark's [1988: 99–101] "Shallow Basin: Boulder Variety") and not bordered types (such as Clark's [1988: 106–107] "Shallow Basin: Curve-Sided", "Shallow Basin Straight-Sided" [109–110]) as flat/concave and not trough types. Several flat/concave metates did exhibit a rounded, obtuse, yet more distinctive border (Figure 2.3 #304673), that compare favorably with Searcy's (2011) "eastern style" metate and Biskowski's (1997) "closed style trough", but these were rare in the assemblage (n=7) and were classified as *bordered varieties* of flat/concave type metates since they were also used with a reciprocal motion, and did not exhibit evidence upkeep along the border and the grinding surface.

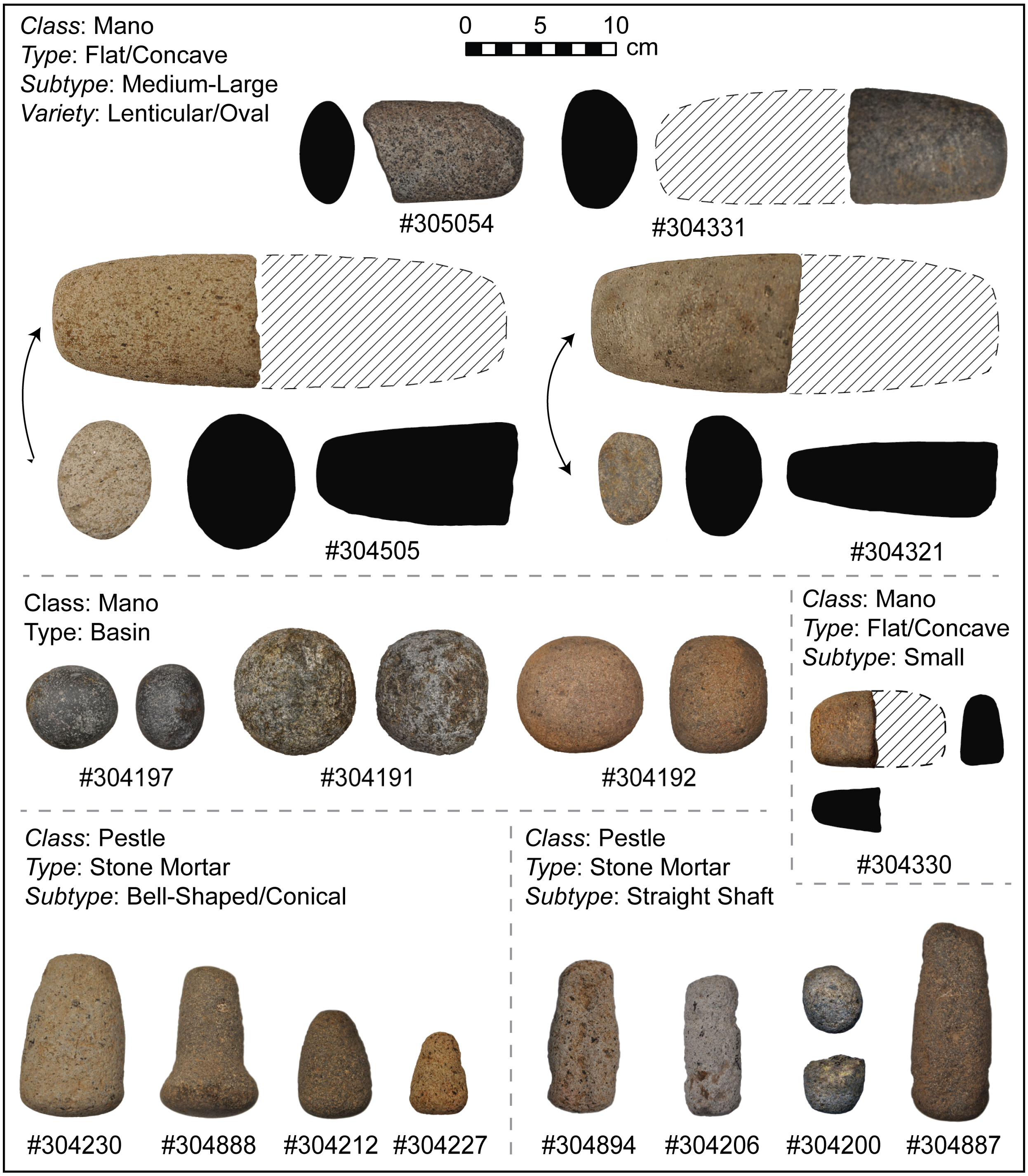


Figure 2.6. Manos and pestles from Paso de la Amada.

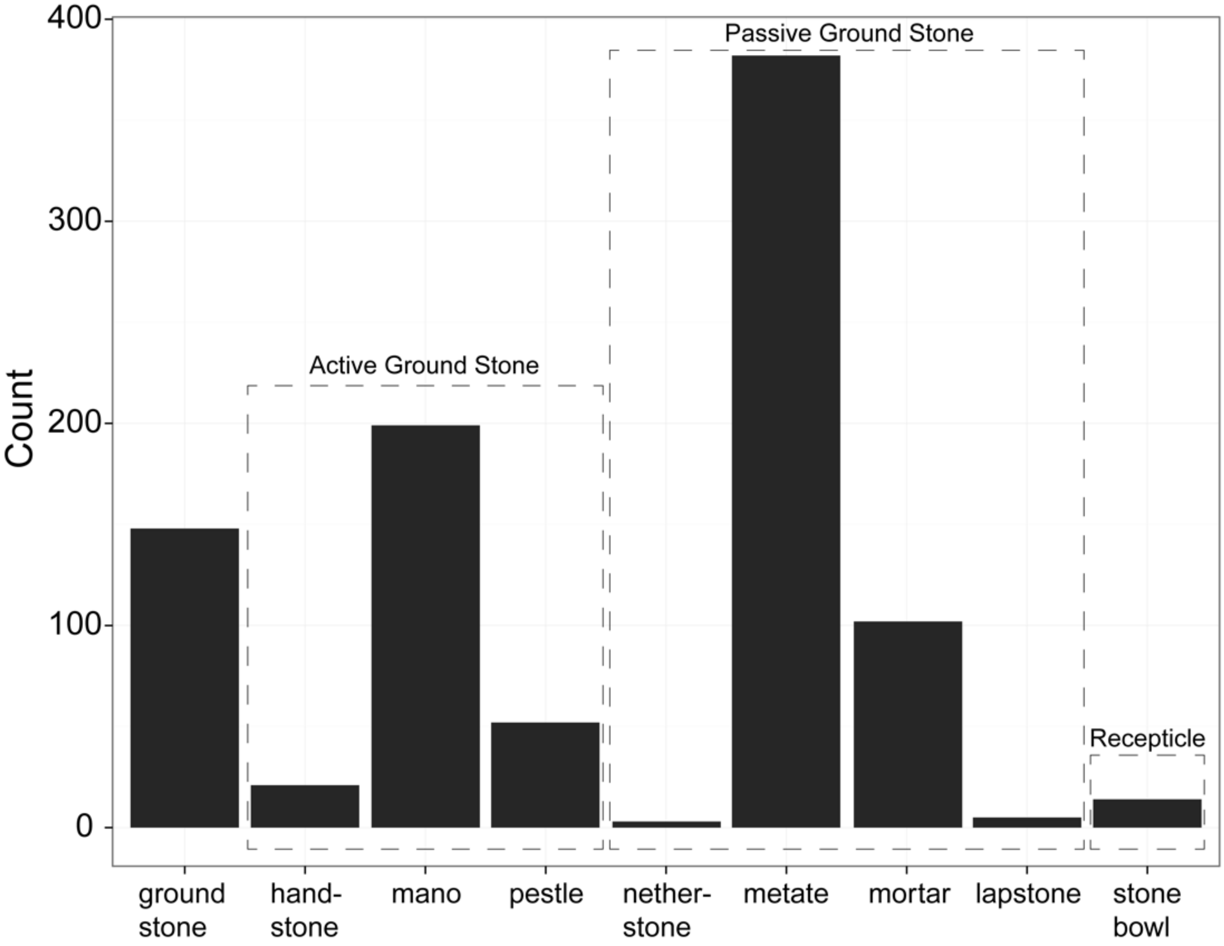


Figure 2.7. Ground stone tools organized by artifact class from the broader Initial Formative and Early Formative assemblage, 1700-1300 BC.

Most flat/concave metates were strategically designed, usually from medium-to-coarse-grained, moderately durable gray andesite, or less durable white andesite, but higher quality materials including vesicular basalt and granite were used in small quantities. Strategically designed, flat/concave metates have been used primarily to grind maize, and secondarily other foods, in Mesoamerica from the Formative period to modern times (Biskowski 1997; Biskowski and Watson 2013; Clark 1988, Hayden 1988; Searcy 2011). Ethnographic and archaeological research in Chiapas suggests that worn out and broken flat/concave metates were used for a variety of less-frequent processing tasks (Clark 1988:103; Hayden 1987:188; see also Searcy

2011:76), and the Paso de la Amada assemblage also exhibits common reuse of broken and worn out flat/concave metates for grinding tasks that did not require a reciprocal stroke. Two flat/concave metate subtypes were identified, although most specimens were too fragmentary to be classified to this degree of detail.

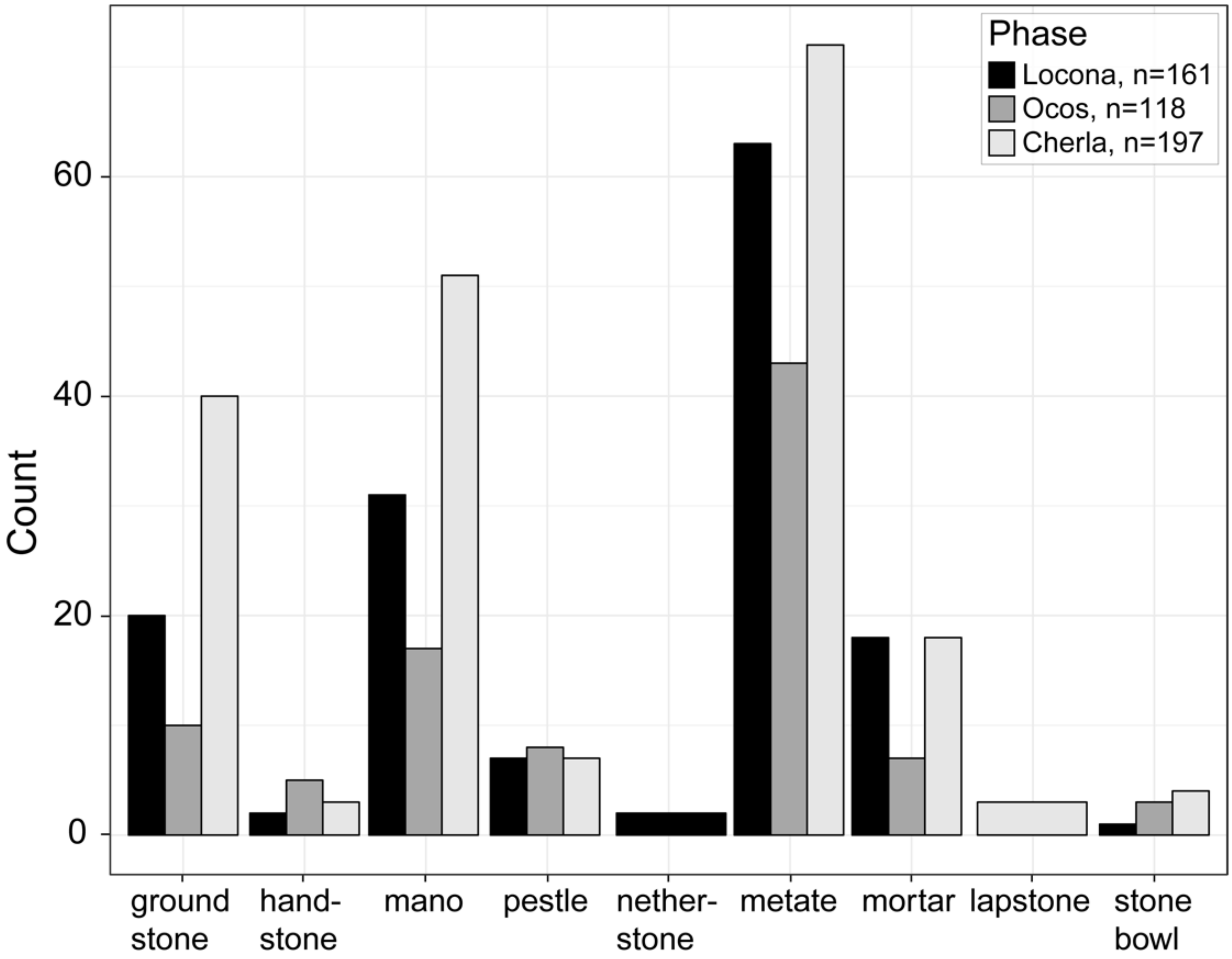


Figure 2.8. Ground stone tools organized by artifact class from Locona (1700–1500 BC), Ocós (1500–1400 BC), and Cherla (1400–1300 BC) contexts.

Subtype: Oval Flat/Concave Metates

The most common metate subtype had an oval-shape in plan-view with rounded corners (or lack of clear corners), and a slightly convex base (Figures 9.2-9.3). The four metates intact enough to project lengths and widths were oval- subtypes, measuring 40.0 x 27.1 cm (#304041, width intact), 32.5 x 24.5 cm (#304291), 32.1 x 23.1 cm (#304840), and 22.5 x 17.7 cm (#304070, width intact) respectively. The latter was classified as a *small variety* in order to distinguish this artifact from the overwhelming majority of flat/concave metate fragments in the assemblage, which were remnants of larger tools. Measurable specimens (n=37) had a mean thickness of 4.6 cm. Oval metates resemble Clark's (1988:107–108) "shallow basin: boulder/thin boulder varieties" from La Libertad, "legless slab metates" from Chiapa de Corzo (Lee 1969:118), the "ovoid plano-convex metates" from the Tehuacan Project (MacNeish et al. 1967:118–119), metates from Altamira (Green and Lowe 1967:28-29), and metates from La Victoria and Salinas La Blanca (Coe and Flannery 1967: PL 21-22). Oval flat/concave metates were the most common passive ground stone tools classified to subtype in the broader Initial Formative and Early Formative assemblage, and in each phase were likely the most common food processing tools throughout the occupation at Paso de la Amada.

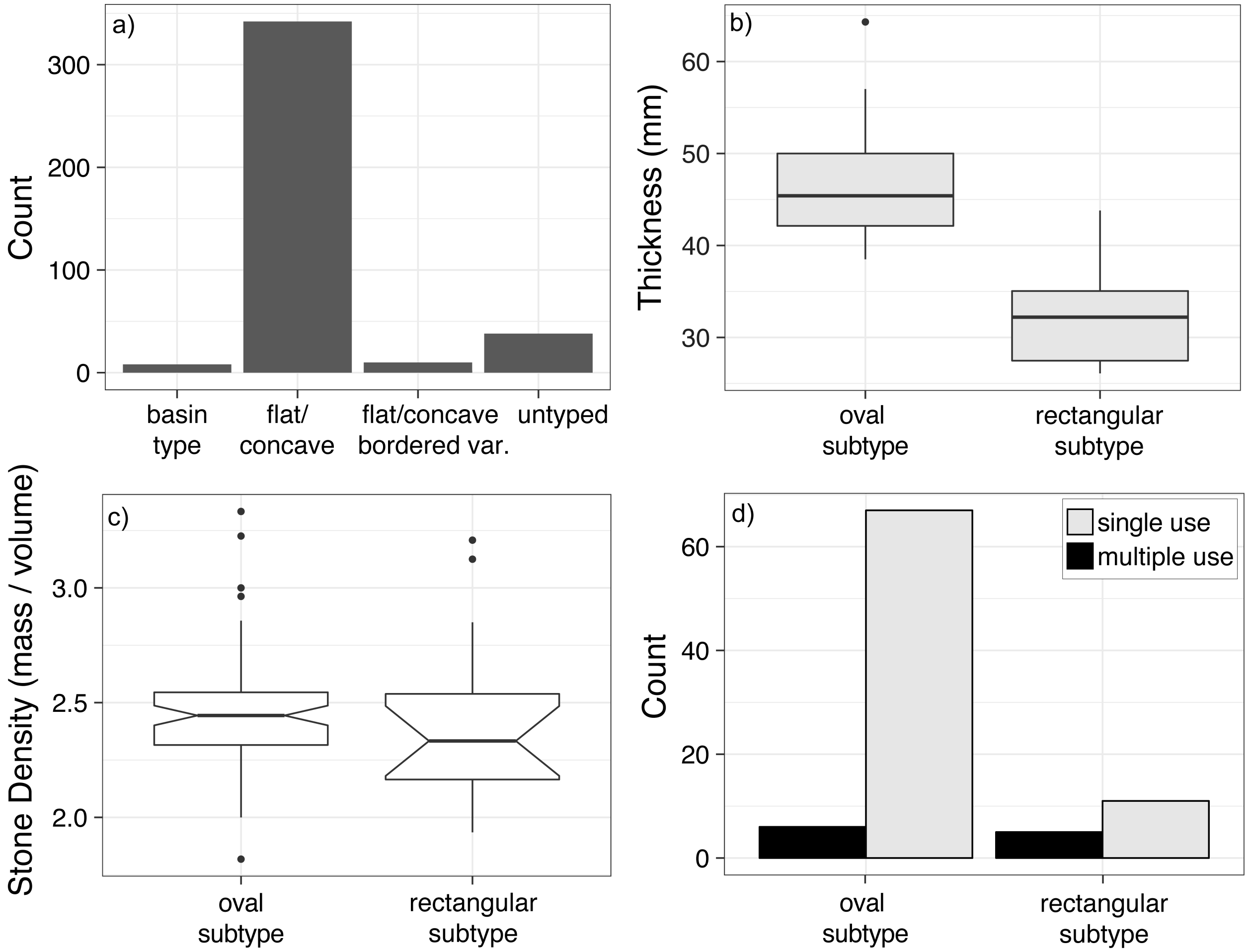


Figure 2.9. Analyses of metates in the broader Initial Formative and Early Formative assemblage: **(a)** Counts of metate types. **(b)** Oval and rectangular flat/concave metate thicknesses. **(c)** Oval and rectangular flat/concave metate stone densities. **(d)** Counts of single-use and multi-use oval and rectangular flat/concave metates.

Table 2.2. Attributes of Metate Type and Subtypes.

Type/ Subtype	**N=**	**Max Len.^{1}**	**Min Len.^{1}**	**Mean Len.^{1}**	**Max Width^2**	**Min Width^2**	**Mean Width^2**	**Mean Thick^3**	**Reuse**
Flat/Concave Type	361	40.0	25.0	-	27.1	17.7	-	4.1	7%
Basin Type	8	-	-	-	-	-		7.5	13%
Oval Subtype^4	76	40.0	32.1	36.0	27.1	23.1	24.9	4.6	9%
Rectangular Subtype	16	-	-	-	22.6	21.8	22.1	3.2	31%
Bordered Variety	8	-	-	32.5	-	-	24.5	5.2	20%
Small Variety	1	-	-	25.0	-	-	17.7	4.6	-

Note: All measurements are mean values in centimeters. ^{1} Length projected using the curvature of large metate edge-fragments. ^{2} Projected and intact widths included. ^{3} Only metates with intact thickness included. However, many fragments represent the grinding surface and not the shoulder, and shoulder thickness would be greater (see Figures 9.2 and 9.3). ^{4} Does not include small variety (n=1).

Subtype: Rectangular Flat/Concave Metates

The second identified subtype had a sub-rectangular shape in plan-view with more prominent “corners”, and parallel, flat to slightly convex margins nearly flush with the ventral surface (Figure 2.3, #304073, #304036). Projected widths for the two most intact specimens measure 22.6 cm and 21.8 cm respectively. No specimens were intact enough to project length. Although both oval and rectangular plan flat/concave metates were used with a reciprocal mano stroke, several lines of evidence suggest that rectangular metates were used for specialized functions. Oval metates are longer, wider, and thicker than their rectangular counterparts (Figure 2.9b). Oval metates were also made from higher quality, coarser, and denser materials compared to rectangular metates (Figure 2.9c). Furthermore, while 31% of rectangular metates were used for pigment processing and manufacturing activities, only 9% of oval plan metates exhibited similar evidence (Figure 2.9d). Rectangular flat/concave metates compare favorably to Ceja Tenorio’s (1985:112) “small slab-metates”, and Clark’s (1988:108) “thin, straight sided, square corner variety” (see also Coe 1961:102).

Type: Basin Metate (n=8)

Basin metates have circular to oval-shaped grinding basins, and are designed for, and primarily used with, a rotary motion using a small, circular or oval shaped mano that is held in a single hand. This sets basin metates apart from flat/concave and trough metates, which are designed for, and used exclusively with a reciprocal motion (Adams 2014:104–107; Clark 1988:95). It should be noted that the use of term “basin metate” in this chapter differs from that of some previous research in the region, in that others have referred to all tools used with a rotary motion as mortars (Biskowski and Watson 2013), or metates with pronounced concave grinding surfaces as “basin metates” regardless of whether they were used with a reciprocal or circular stroke (Clark 1988).

All examples recovered from Paso de la Amada were fragments too small to project length or width, but the mean thickness of three specimens with representative thickness intact measured 7.5 cm, greater than all other metate types and subtypes. Figure 2.2 displays a postulated reconstruction of a basin metate based on a fire-cracked shoulder fragment (#304918) in order to illustrate the contrast between the thinner, more portable reciprocal stroke metates that dominate the assemblage, and these thicker metates paired with a small circular mano, held in a single hand, and used with a circular stroke.

The basin metates fragments in the Paso de la Amada assemblage compare favorably to the “boulder metate milling stones” from the Tehuacan Project (MacNeish et al. 1967:117–118). Basin metates were used to process tougher foraged and cultivated foods throughout the Archaic period (MacNeish et al. 1967), and have been found at preceramic sites in Chiapas (MacNeish and Peterson 1962). Basin metates were found in Locona (n=2) and Ocós (n=2) contexts.

CLASS: MORTAR (n=93)

Mortars are distinguished from metates by being used primarily for crushing, pounding, and stirring actions with a pestle instead of a mano (Adams 2014:132–137). Mortars are usually circular and have basins deep enough to ensure that a substance is confined when processed using crushing or pounding strokes (Figure 2.5). I distinguished between stone bowls and shaped mortars on the basis of use-wear (see Adams 2014:140–141) and between mortar subtypes based on distinct wear patterns in the mortar basin. A pounding action (raising a pestle high and thrusting it down into a mortar) produces deep impact fractures. A crushing action (using the weight of a pestle in a downward motion) produces flattened stone grains and far less dramatic impact fractures (Adams 2014:30, 45). The use of rotary strokes with a pestle in a mortar basin, here referred to as stirring, can obliterate evidence of both pounding and crushing. While rotary strokes in a basin metate and stirring in a mortar produce similar wear patterns, a basin metate is designed to maximize the efficiency (see Buonasera 2015) of rotary strokes with a mano and can be used for crushing, while a mortar is designed to maximize the efficiency of pounding and crushing strokes with a pestle and can be used for stirring.

Ethnographic research in Mesoamerica likely does not provide a suitable analog for Initial Formative mortar use. For example, Hayden (1987) noted only a single household with a mortar and pestle (used primarily for making chile). At Paso de la Amada, mortars and pestles together make up 15.6% of the ground stone assemblage. To the author's knowledge, only a single strategically designed mortar is represented from all Late Archaic contexts in the Soconusco (Clark 1994:145; Clark et al. 2007:29–30; Voorhies 2004:381–384) and this artifact is poorly provenienced since it was recovered by a land owner on the site of San Carlos (Clark 1994:142). In the Tehuacan Valley, however, mortars have been found in small quantities in Late Archaic deposits, and larger quantities in Early and Middle Archaic deposits (MacNeish et al. 1967:114–115). It seems likely that mortars were used to process different types of food compared to flat/concave metates and basin metates, but it is currently unclear whether the mortars at Paso de la Amada represent continuity with Late Archaic food processing practices (see also Clark 1994:242). The latter point is addressed at greater lengths in the discussion portion of the chapter.

Two mortar types, *rock mortars* and *shaped mortars* were identified based on differences in design (Figure 2.4-9.5, 2.10a). Two mortar *subtypes* were distinguished based on use-wear and morphology, *crushing mortars* and *pounding mortars* (Figure 2.10b). Four mortar *varieties* were distinguished based on size, which likely corresponds to a degree with function (Figure 2.10c). *Large* varieties had an exterior diameter between 20 and 35 cm, *medium* mortars ranged from 10 to 20 cm, *small* mortars measured between 10 and 5 cm, and *pebble* mortars had an exterior diameter of less than 5 cm (Table 2.3). Seven mortars fragments were not categorized beyond class.

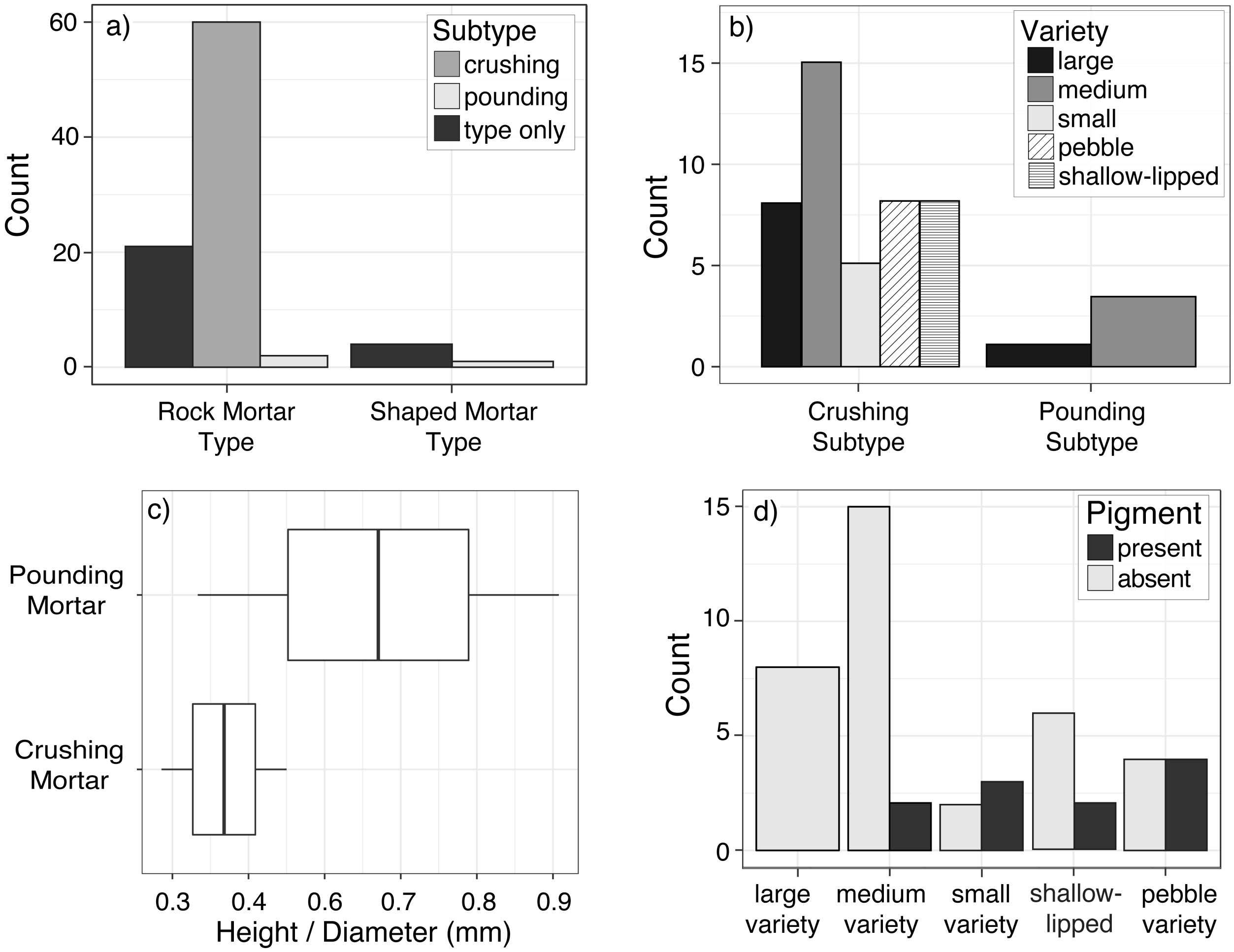


Figure 2.10. Analyses of mortars in the broader Initial Formative and Early Formative assemblage: **(a)** Mortar type and subtype counts. **(b)** Counts of crushing and pounding mortar varieties. **(c)** box plot showing the distinctive relationship between vessel height and vessel diameter when comparing pounding and crushing subtype mortars. **(d)** mortar varieties with evidence of pigment processing.

Table 2.3. Metric and Non-Metric Mortar Attributes.

Mortar Type, Subtype, or Variety	**N=**	**Diameter (cm) [a]**	**Height (cm)**	**Base Thick (cm)**	**Mortar Depth (cm)**	**Multi-Use**	**Pigment**
Rock Mortar type	5	7.0	5.4	4.9	0.5	20%	40%
Shaped Mortar type[b]	81	16.8	5.1	2.6	3.0	7%	9%
Crushing subtype	62	15.0	4.9	2.5	2.4	6%	11%
Pounding subtype	4	14.7	6.5	3.9	5.3	0%	0%
Large variety[c]	12	27.7	7.7	2.2	6.0	0%	0%
Medium variety[d]	21	15.7	5.8	2.3	4.7	8%	8%
Small variety	5	7.2	4.3	2.3	1.7	0%	40%
Pebble variety	8	5.2	2.7	1.5	1.0	13%	50%
Shallow-Lipped variety[e]	8	15 x 13	4.1	2.5	1.6	13%	25%

Note: All measurements are mean values in centimeters.

[a] Diameter was estimated using a sheet with projections.

[b] Includes fourteen designed artifacts designated to a mortar/stone bowl class. These artifacts were not classified to subtype.

[c] Includes four artifacts with a class of mortar/stone bowl.

[d] Includes three artifacts with a class of mortar/stone bowl.

[e] Lengths and width are listed for this oblong subtype.

Type: Rock Mortar (n=5)

Subtype: Pounding (n=1), Crushing (n=2)

Rock mortars are portable rocks with pecked basins for pestle use but little evidence for shaping of the exterior of the object (Adams 2014:128). Rock mortars represent only 5% of the mortar assemblage at Paso de la Amada. One rock mortar was found in a Locona context and two in Cherla contexts. Use-wear indicative of both pounding and crushing was visible in mortar basins. The single example of the "pounding" rock mortar subtype was larger (projected diameter of 15 cm) and taller (maximum height of 5.4 cm) compared to crushing subtype rock mortars, which ranged in thickness from 2.2 to 3.8 cm. All crushing rock mortars were classified as small or pebble varieties (Figure 2.5, #305173).

Type: Shaped Mortar (n=81)

Subtypes: Pounding (n=4), Varieties: Medium (n=3), (Large, n=1)

Shaped mortars are portable rocks with pecked basins that are intentionally manufactured into a particular shape. Shaped mortars were the most common mortar type at Paso de la Amada (with 81 of the 86 mortars identified to type classified as such). Two mortar subtypes were identified based on use-wear and artifact morphology.

Mortars interpreted as primarily used for pounding were identifiable from use-wear in mortar basins and by distinct morphology. *Pounding* mortars were not common in the assemblage, but had thicker bases and deeper basins compared to their crushing counterparts (Table 2.3). The juncture between the base and walls of pounding type mortar flares slightly outward creating a rounded but obtuse angle. The base of the interior basin is flat to slightly concave, and comprises far less surface area of the mortar basin due to the outward flaring walls (Figure 2.5, #304299, #304910). These flaring walls and small interior basin restrict the pounding action to direct contact with the substance being processed. This is quite different from *crushing subtype* mortars which have a larger interior basin area more suitable for crushing and stirring strokes. The morphological distinction between pounding type mortars and crushing type mortars is most succinctly displayed by dividing vessel height (maximum measurement of exterior rim to exterior base) by vessel diameter for these mortar subtypes (Figure 2.10c). Pounding type mortars appear to be morphologically similar to the “flat bottomed mortars with flaring rims" from the Tehuacan Project (MacNeish et al. 1967:116–117) and "thick-walled bowls or mortars" from Conchas phase deposits from La Victoria (Coe 1961:Plates 42, 61).

Subtypes: Crushing (n=62), Varieties: Large (n=8), Medium (n=15), Small (n=5), Pebble (n=8), Shallow-lipped (n=8).

Sixty two of the 81 shaped mortars are classified as crushing subtypes. While these mortars may also have been used periodically with pounding strokes, artifact morphology and use-wear suggests they were designed and used primarily with crushing and stirring strokes. Crushing mortars are round to oval in plan-view. They usually have shorter, gently sloping walls and very concave interior basins. Walls are generally thinner than bases, but this disparity is muted in comparison to pounding subtype mortars. Thickness at vessel rim ranged from 0.4 to 2.1 cm, vessel height (maximum measurement of exterior rim to exterior base) ranged from 8.5 to 3.0 cm, basin depth ranged from 6.5 to 0.3 cm, and vessel diameter ranged from 5.0 to 32.5 cm. Crushing mortars appear generally similar to the "hemispherical mortars" identified from the Tehuacan Project (MacNeish et al. 1967:116), and "hemispherical bowls or mortars" from prior excavations at Paso de la Amada (Ceja Tenorio 1985:Figures 59m-p, 60o-p).

Forty-four crushing mortars were classified to variety, with medium (n=15) and large (n=8) varieties making up the bulk of the assemblage, but small (n=5) and pebble (n=8) varieties also represented. Half of the small and pebble mortars in the assemblage were used to process red pigment (Figure 2.10d) and these tools and their active counterparts should not be considered food processing equipment.

Eight distinctive crushing mortars were classified as *shallow-lipped varieties.* These mortars are oval to oblong in plan-view, have short, thick, stubby walls that slope gently to a broad, shallow, slightly concave grinding area with an average depth of 1.6 cm from the rim to the base of the grinding surface (Figure 2.4, #304296). Projected lengths and widths fell between 18-12 cm. Shallow-lipped mortars compare favorably to the “saucer shaped lipped” and “oblong lipped” metates found almost exclusively in Early and Middle Formative deposits in the Tehuacan Valley (MacNeish et al. 1967:115). Indeed, MacNeish et al (1967:120) note that such passive tools reach their peak popularity during the Ajalpan phase, contemporary to our Initial Formative and Early Formative periods at Paso de la Amada. Many of the Tehuacan examples had red pigment adhering to the interior of grinding basins (MacNeish et al. 1967: 120). Two of the eight specimens from Paso de la Amada contain visible pigment, but all artifacts were washed prior to analysis. Coarse-grained, soft, light-weight raw materials were preferentially used to manufacture these artifacts at both Paso de La Amada and in the Tehuacan Valley (MacNeish et al. 1967:120).

Shallow lipped mortars occupy a grey area between metates and mortars. Use-wear suggests a combination of crushing, circular, and reciprocal strokes. While no manos were clearly designed as the counterpart to shallow-lipped mortars, several small conical-shaped pestles in the assemblage have flat or slightly convex grinding surfaces used for crushing and stirring, and are the most likely active compliment to these artifacts (Figure 2.6, #304227, see pestle discussion). Similar to shallow-lipped mortars, small conical pestles were also made from less-dense raw materials, usually a porous white andesite. Unlike pounding and crushing mortars the shallow height of the shallow-lipped mortar walls would not preclude use of a handstone. Shallow-lipped mortars were a minor but important component of Initial Formative, Early Formative, and Middle Formative toolkits, used mainly to process non-food materials.

CLASS: NETHERSTONE (n=3)

Type: Netherstone

Netherstones are passive ground stones that are too large to fit in the users' lap, but not manufactured to be used with a particular class of active ground stone. For example, a large unshaped object that exhibits use-wear indicative of a reciprocal or circular stroke, and impact fractures associated with crushing activities would be classified as a netherstone. The boundary between expedient metates and netherstones can be fuzzy, but in the current typology an unshaped object repeatedly used as a passive ground stone with a reciprocal mano stroke was considered an expedient flat/concave metate (only 1% of this type), while a large unshaped passive ground stone used for general grinding activities was considered a netherstone. Production of ground stone ornaments and bone tools often requires the use of a generalized passive ground stone such as a netherstone. A total of three objects used primarily as netherstones were present in the assemblage, although broken metates were frequently reused as netherstones. Two netherstones, one made from a medium-grained gray andesite and another made from a fine-grained siltstone were associated with Locona contexts while a less durable specimen made from a medium-grained white andesite could not be assigned to a phase.

CLASS: LAPSTONE (n=6)

Lapstones are small, hand-held, passive grinding stones used to shape objects or process substances. Lapstones are often associated with manufacturing activities such as shaping ornaments and tools, but can also be used for pigment processing. Adams (2014:151) notes that the difference between abraders and polishing stones in comparison to lapstones is that lapstones are the passive stones against which a material is worked, while abraders and polishing stones are active objects that are used against another object. Although lapstones are often expedient, most in the Paso de la Amada collection were strategically designed. Forty percent of the lapstones had evidence of pigment processing.

A total of six lapstones were present in the assemblage, and two of these could be assigned to the Cherla phase. Two are expedient and the four remaining artifacts were classified to two subtypes. Although few specimens were present, two distinct lapstone subtypes were identified.

Type: Palette

Two objects were classified as *palette* type lapstones (Figure 2.5, #304031). Both are fragmentary but share morphological similarities, including squared-off margins, a sub-rectangular plan view and measure between 1.5-2.5 cm in thickness. Both palettes displayed evidence of use with small, flat, or slightly convex handstones used with a reciprocal motion. This motion produced a slightly concave dorsal surface on both specimens. Abundant red pigment remains embedded in vesicles and pitted areas on the ventral surfaces of both palettes. It is somewhat counterintuitive that pigment is concentrated on the ventral surfaces of both palettes, but this is likely a result of the artifacts being washed prior to analysis, or infrequent processing on the ventral surface that did not produce clear evidence of use-wear. The dorsal surface of #304031, the palette from Cherla contexts, exhibited impact fractures along the broken edge that were not associated with artifact upkeep or reuse. and it seems likely that the palette was intentionally destroyed.

Type: Basin Palette

Two strategically designed lapstones were classified as *basin palette* types (Figure 2.5, #305181, #304103). These distinctive objects were oblong to oval in plan-view, and exhibit a shallow elongated basin with gently sloping interior walls. Both examples had designed, flat bases on the exterior. These elongated interior basins were designed prior to use, but accentuated by repeated reciprocal strokes with a tiny active grinding stone. Although the two objects have a similar designed shape in plan view and cross-section, one was made from less-durable, coarse-grained, porous white andesite (#305181), and the other, dating to the Cherla phase, was made from a durable, very fine-grained material, possibly a siltstone (#304103). The latter had experienced heavy use, with less-than one-third of its manufactured thickness remaining. Red pigment and striations indicative of a reciprocal stroke were visible in the Cherla-phase example. The less durable example exhibited far less-intensive use. Unlike the small and pebble mortars with pigment staining, evidence of crushing was not visible in either of the basin palettes.

Initial and Early Formative Pigment Processing

Although sample size is small (n=25), the Paso de la Amada assemblage offers considerable evidence for changing pigment processing practices. During the Initial Formative, community members processed pigment in shallow lipped mortars, small mortars, and pebble mortars (Table 2.4, Figure 2.11). Less-dense raw materials were preferred in the design of the larger, oblong-shaped, shallow lipped mortars (mean length 15.0 cm, mean stone density 2.16) in comparison to the smaller and rounder pebble/small mortars (mean diameter 6.1 cm, mean stone density 2.41). Contrasting design and raw material selection suggests that these Initial Formative passive pigment processing tools were designed and used for distinctive pigment processing activities. Following the onset of the Early Formative, shallow-lipped mortars fell out of use and were replaced by new pigment processing tools, palettes and basin palettes made from dense, fine-grained raw materials (mean stone density 2.81). The use of small and pebble mortars for pigment processing continued, but these are present in lower frequencies. It seems plausible that such changes are related to decreasing production of red-slipped ceramics in the Soconusco (Chapter 8), changes to ceremonial dress at Paso de la Amada (see Lesure 2011:140), and broader social changes following the onset of the Early Formative phase, but a more thorough analysis of this relationship is beyond the scope of the current work.

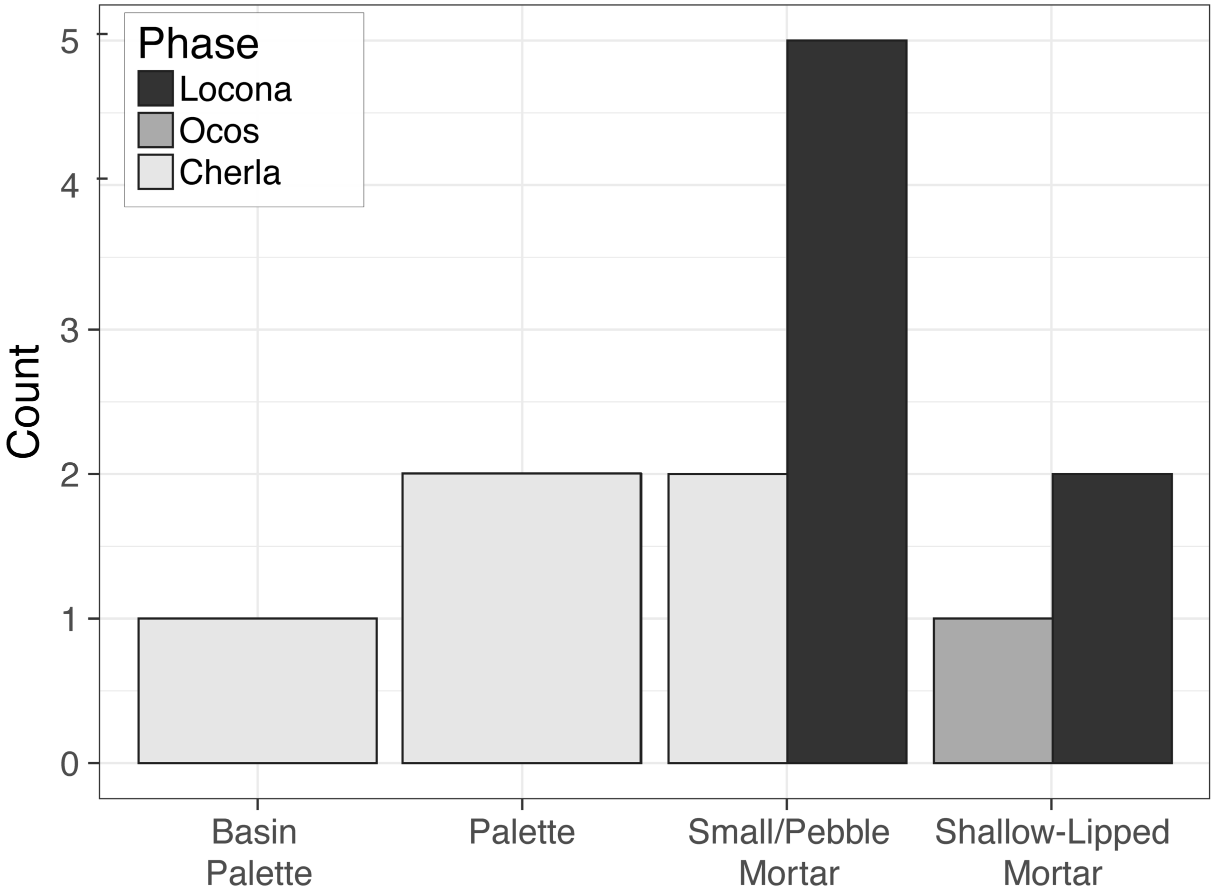


Figure 2.11. Counts of pigment processing tools from Locona, Ocós, and Cherla contexts.

Table 2.4. Passive Pigment Processing Tools Counts.

Phase	**Shallow-Lipped Mortar**	**Small & Pebble Mortars**	**Palette**	**Basin Palette**	***Total***
Locona	2	5	-	-	*7*
Ocos	1	-	-	-	*1*
Cherla	-	2	2	1	*5*
1700-1300 BC Undifferentiated	5	6	-	1	*12*
Total	*8*	*13*	*2*	*2*	*25*

ACTIVE GROUND STONE

CLASS: MANO (n=200)

Manos are the active grinding stones that are used against their passive counterpart, the metate. Manos can be strategically designed and pecked into a specific shape prior to use, or expedient, with no modification other than that the grinding. Of the 200 manos in the assemblage, 185 were classified to type, 80 were classified to subtype, and 74 specimens were classified to variety (Figure 2.12a, b). Mano types were limited to *flat/concave*, used with a reciprocal stroke in their counterpart the flat/concave metate, and *basin* types, used with a circular stroke in basin metates (see Adams 2014 regarding classifying active tools based on their passive counterparts). The latter are rare at Paso de la Amada. Two mano subtypes were identified for flat/concave type manos, *medium to large* and *small*. Some medium to large flat/concave manos were further subdivided into varieties. Varieties were delineated based on cross-section view, which is primarily the result of differential wear in a metate. Varieties include *lenticular/oval*, *cylindrical*, and *plano-convex*. Only seven complete manos were present in the assemblage and few additional specimens were intact enough to permit inference of a projected length or width (~50% intact). Complete and nearly complete specimens in the Paso de la Amada assemblage are heavily biased towards smaller artifacts. For example, although active tools measuring less than 15 cm in length only make up 10 percent of the ground stone assemblage, 90 percent of the complete artifacts fit into this category. This dramatic over representation is due to the more intensive reuse of larger broken and heavily worn artifacts as smaller active grinding and manufacturing tools, and the fact that the force load necessary to break a smaller, more circular object is far greater than that necessary to break an oblong or elongated object (see reuse and recycling discussion).

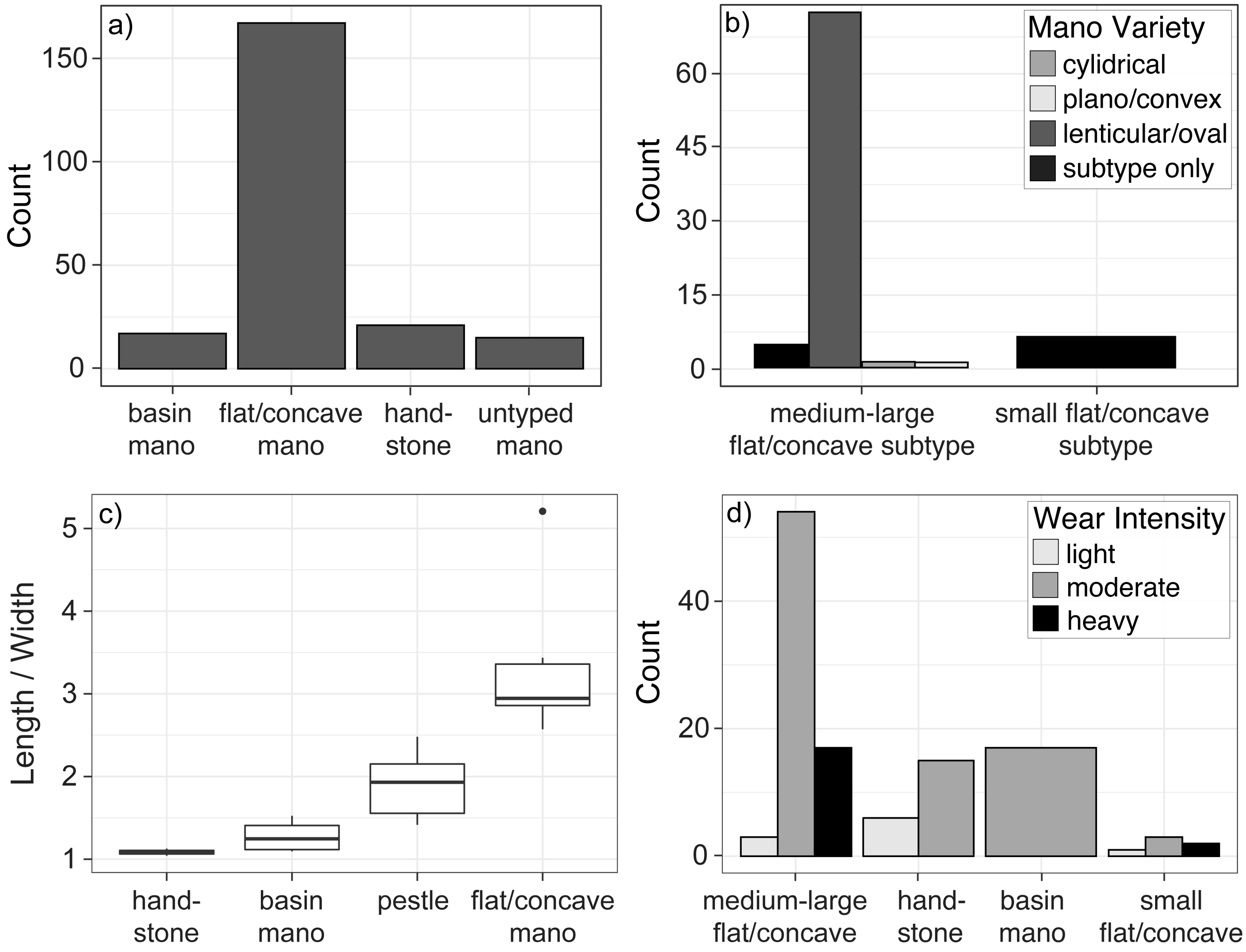


Figure 2.12. Analyses of manos in the broader Initial Formative and Early Formative assemblage: **(a)** Counts of mano types and handstones. **(b)** Counts of flat/concave mano subtypes and varieties. **(c)** Morphometric differences between active tool types. **(d)** Wear intensity of mano types, subtypes, and handstones.

Table 2.5. Metric and Non-Metric Attributes of Manos and Handstones.

Class, Type, Subtype	**N=**	**Mean Length (cm)**	**Mean Width (cm)**	**Mean Thickness (cm)**	**Strategic Design**	**Polished Distal and Proximal Ends**
flat/concave mano, medium-large subtype	74	23.1	7.1	5.0	100%	98%
flat/concave mano, small subtype	5	8.4	5.4	4.5	40%	0%
basin mano	17	8.4	7.1	5.2	60%	0%
handstone	21	8.9	6.4	4.9	0%	0%

Type: Flat/Concave (n=167)

Sub-types: Medium to Large (n=74), Small (n=6)

Varieties: Lenticular/Oval (n=71), Cylindrical (n=2), Plano-convex (n=1)

Flat/concave manos are substantially longer than they are wide. They are larger and more elongated in plan-view in comparison to basin manos, which tend to have roughly equivalent lengths and widths. The average length-to-width ratio of flat/concave manos in the Paso de la Amada assemblage was 3.2 while the same ratio for basin manos measured 1.2 (Figure 2.12c). This designed difference is related to grinding efficiency. Flat/concave manos are manufactured to increase the grinding efficiency of a reciprocal stroke using either two hands or a single hand, while basin manos are designed to increase the grinding efficiency of circular stroke using only a single hand. The grinding surfaces of flat/concave manos are flat to slightly convex from reciprocal strokes on a flat/concave metate (Adams 2014:109-110; Searcy 2011:106). Eighty two of the 167 flat/concave were collected from contexts with more detailed temporal information. Flat/concave manos were the dominant active ground stone tools in the broader Initial Formative and Early Formative assemblage, as well as contexts dating exclusively to Locona, Ocós and Cherla (Figure 2.12a, 9.12b).

Initially, flat/concave manos were identified to "two-handed" and "one-handed" subtypes dependent on whether they measured greater or less than 20 cm in length. However, the overwhelming majority of flat convex manos were fragmentary (Figure 2.12c), which restricted the utility of strictly a size-based typology. In addition, during analysis it became clear that such a dichotomy would not be conducive to describing the dominant type of active ground stone tools at Paso de la Amada, as manos ranging in length from 15 to 30 cm in length were strategically designed and used in a similar fashion, for food processing on flat/concave metates.

Subtype: Medium to Large Flat/Concave Manos.

These manos, 15 to 30 cm long, exhibited a number of unique defining characteristics that allowed some fragmentary specimens to be distinguished from *small flat/concave manos*, which were rare and likely served a specialized function. Unlike other types of active ground stone tools in the assemblage, medium to large flat/concave manos were *always* strategically designed (Table 2.5). The distal and proximal ends of these tools were well-shaped and often polished to a sheen (Figure 2.6 #304331, #304055), yet there was no evidence that this shaping was caused by wear against the wall of a trough or bordered metate. Several of the specimens on the smaller end of the medium-large subtype spectrum were manufactured from larger manos that had broken but continued to be used on a flat/concave metate (Figure 2.6, #305054), an analogous pattern to that noted for similar manos at La Libertad (Clark 1988:126).

Medium to large flat/concave manos were further classified into varieties based on their cross-section morphology, which is largely dictated by wear on a metate surface. Most medium to large flat/concave manos had a *lenticular* cross-section from moderate to heavy use on both dorsal and ventral surfaces on a flat/concave metate (Figure 2.6, #304331, #305054, #305055, Figure 2.12d). Similar manos with less intensive use on dorsal and ventral surfaces had a more oval appearance in cross-section (Figure 2.6, #304277). Since these manos differed only in terms of grinding intensity they are grouped together as a single *lenticular/oval* variety. These lenticular/oval, flat/concave manos are similar to Green and Lowe's (1967:29) "oblong" manos from Altamira, manos found at El Varal (Lesure 2009:150), manos previously found at Paso de la Amada (Ceja Tenorio 1985:111, Figure 59d and 60u), "oval with plain end", "round section" and "triangular section" manos from Chiapa de Corzo (Lee 1969:114-117), and "long subrectangular manos" from the Tehuacan Valley (MacNeish et al. 1967:11–112). They are strikingly similar in manufacturing technique, plan view, cross section view, and stone density to “two faceted oval: lenticular variety” and “two faceted oval: oval variety” manos from La Libertad (Clark 1988:116–118). MacNeish et al. (1967:111) note that such manos are “...the most common type in the two Formative phases of Ajalpan and Santa Maria”, and this is also the case throughout the Initial Formative and Early Formative phases at Paso de la Amada, as well as the Middle Formative occupations at La Libertad, Chiapa de Corzo, and Altamira.

One mano with moderate use on a single surface had a *plano/convex* appearance in cross-section view (similar to Clark’s 1988:124 “single faceted plano-convex mano”). No specimens exhibit use-wear similar to the “dog bone” manos seen in Mesoamerica later in time (Clark 1988:91; Searcy 2011:104–106), but *cylindrical* manos, although quite rare in the assemblage (n=2), could have been used with a similar reciprocal “rolling” stroke (see also Ceja Tenorio 1985:110: Figure 59d, f). The eight medium to large flat/concave manos large enough to project measurements (using the method outlined by Clark 1988:96–97) measured 15 to 30 cm in length, 4.1 to 8.2 cm in width, 4.4 to 6.6 cm in thickness, and had a mean projected length of 23.1 cm, a mean width of 7.3 cm, and a mean thickness of 5.6 cm.

Medium-large flat/concave manos were manufactured from a variety of material types, ranging from less-durable white andesite to very durable granite and vesicular basalt, but most specimens were made from moderately durable grey andesite. There was a clear preference for use of vesicular material for both flat/concave metates and flat/concave manos. High-quality, vesicular material types widely preferred for intensive maize processing later in time, such as vesicular basalt, are rare in the assemblage.

Regarding the possible use of these manos, there is now abundant direct evidence across Mesoamerica and the Neotropics that hand-held stones used with circular and reciprocal strokes were used to grind maize, manioc, beans, squash and foraged plants for thousands of years prior to the Initial Formative period (Aceituno and Loaiza 2018; Dickau et al. 2007, 2012; Haas et al. 2013; Pagan-Jimenez et al. 2016; Pearsall et al. 2004; Piperno 2011; Piperno et al. 2009; Pohl et al. 2007; Ranere et al. 2009; Zarrillo et al. 2008). However, Archaic-period ground stone assemblages with phytolith or starch grain evidence of maize are usually expedient, minimally shaped, and morphologically inconsistent. They were used to process a wide variety of foods. Similar ground stone tools have been documented on Late Archaic sites in the Soconusco (Voorhies 1976, 2004). In contrast, the dominant active ground stone tools at Paso de la Amada are strategically designed in a consistent fashion and used exclusively with a reciprocal stroke on strategically designed, morphologically consistent flat/concave metates. Such routine food processing practices bear a far greater resemblance to traditions that come to dominate much of Mesoamerica from the Middle Formative onwards. For example, strategically designed manos used with a reciprocal stroke on both dorsal and ventral surfaces, with an oval to oblong shape in plan-view and an oval to lenticular shape in cross-section view, dominate the Middle Formative ground stone assemblage at La Libertad (Clark 1988:116–122), Tlapacoya-Zohapico (Niederberger 1976:72–73), the Tehuacan Valley (MacNeish et al. 1967), Chiapa de Corzo (Lee 1969:114-117), Altamira (Green and Lowe 1967:29), and well-studied Late Formative period assemblages across broader Mesoamerica (Biskowski 1997; Biskowski and Watson 2013). Researchers agree that such changes during the Middle Formative period were related to a transition in food processing technology as intensive maize processing for daily meals became commonplace.

In summary, if we are to believe that; a), Late Archaic ground stone assemblages lacking strategically designed, morphologically consistent active and passive tools used exclusively with a reciprocal stroke were designed and used to process a wide variety of cultivated, and foraged foods, and; b), the reciprocal stroke manos that dominate Middle Formative assemblages in Soconusco and across Mesoamerica were *primarily* designed and used to process maize, it follows that the most parsimonious explanation for the dramatic increase in the relative proportion of stylistically and morphologically similar tools in the Paso de la Amada assemblage is that they were also designed and used *primarily* to process maize. This does not mean that other foods were not processed using such tools, or that Initial and Early Formative foodways were identical (or even similar to those during the Middle Formative) but, given the makeup of the ground stone assemblage, it is likely that grinding maize was an important component of Initial and Early Formative routine food processing for daily meals. This argument is explored in greater detail in the discussion portion of the current chapter and in Chapter 26.

Subtype: Small Flat/Concave Manos

These manos were comparably rare in the assemblage (n = 5). No subtypes or varieties were identified. Specimens ranged in length from 7.0 to 10.0 cm, in width from 4.0 to 7.7 cm, and 4.1 to 5.2 cm in thickness. Half of these were expedient tools used on flat/concave passive ground stones. Two of the strategically designed examples (Figure 2.6, #304330) were made from durable very fine-grained materials, and were likely paired with a palette (Figure 2.5, #304031), a small, oval, flat/concave metate (Figure 2.3, #304070) or a rectangular metate (Figure 2.3, #304036, #304073) for specific processing activities. An additional specimen (#305077) was the only flat/concave mano in the assemblage used with a rocking reciprocal stroke on a flat surface (*sensu* Adams 2014:110), which resulted in five distinct flat grinding facets. These relatively rare manos were likely used to process non-food substances such as pigment (Table 2.5), or else to process small amounts of seasonings or medicinal substances (cf. Hayden 1987:202). Small flat/concave manos compare favorably to Ceja Tenorio's rare (n=2) "miniature manos" (1985:110-111), several Middle Formative manos from Guatemalan Soconusco (Coe and Flannery 1967: Plate 22), and "oblong manos" from the Central Mexico (MacNeish et al. 1967:110-111).

Type: Basin Mano (n=17)

Basin manos are small, hand-held stones that are used with a rotary and/or a reciprocal motion on a basin metate. Basin manos have also been called "one-handed rotary manos" (see Clark 1988:95) and "pestles" (Biskowski and Watson 2013; Rosenswig 2010). The current typology distinguishes between basin manos and pestles since they are paired with very different passive ground stone tools (mortars and basin manos), and have contrasting strategic designs (see Figure 2.12a) in order to maximize the efficiency of different grinding actions (circular strokes in a basin metate versus crushing and pounding strokes in a mortar). Basin manos from Paso de la Amada are mostly circular to oval in plan-view, measure 9.5 to 7.2 cm in length and width, and exhibit a round to slightly lenticular cross-section (Figure 2.6). Most only displayed use-wear on ventral surfaces, but five specimens displayed wear on dorsal and ventral surfaces (Figure 2.5 #304191, #304192). All basin manos exhibited use with a circular stroke in a basin metate which produced use-wear along the edges of the tool (Adams 2014:108). Of the three intact basin manos, one was used for pigment processing. Sixty percent of basin manos were strategically designed by being pecked into a circular shape and the others were naturally rounded river cobbles. Although basin manos were rare in the assemblage, as previously noted they tended to be more complete than flat/concave manos. Basin manos were likely used primarily to process a variety of tougher foraged, cultivated, and domesticated wild plant foods, but may also have been used for manufacturing activities.

CLASS: PESTLE (n=52)

Types: Stone Mortar (n=20), Flat Surface (n=8)

Subtypes: Conical/Bell Shaped (n=23), Straight Shafted (n=11), Expedient (n=6)

Pestles are the active tools that are paired with mortars to pulverize substances using a pounding or crushing action. At the coarsest level, pestles were split into two distinct types dependent on whether they were used in the basin of a stone mortar or on a flat surface (Figure 2.13a-b). These different uses are identifiable by the morphology of the distal end of the pestle (Adams 2014:144). *Stone mortar type* pestles are slightly round at the distal end from repeated pounding, crushing, or stirring strokes in a concave mortar basin. At Paso de la Amada, wear on stone mortar type pestles often extended just above the distal end, and around the circumference of the shaft from contact with the walls of a stone mortar. *Flat surface type* pestles are relatively flat on the distal end from crushing and pounding strokes on a flat surface instead of a concave mortar basin, and lack wear extending above the distal end (Figure 2.6 #304227). Pestles were further subdivided into subtypes based on the morphology of the shaft and distal end (Figure 2.13c-d). The latter attributes are exclusively the result of strategic design prior to use, although an *expedient subtype* was reserved for unmodified cobbles with wear attributable to use as a pestle in a stone mortar or on a flat surface.

Conical pestles progressively flare out from the proximal to the distal end, and bell-shaped pestles flare out dramatically just above to the distal end (Figure 2.6) see also Ceja Tenorio 1985:111e, i, 112c, d, h). Since both bell-shaped and conical pestles have much larger distal compared to proximal ends (thus increasing the area of the primary grinding surface), they were grouped together as *conical/bell-shaped subtypes*. *Straight-shafted subtypes* have a relatively consistent diameter along the length of the shaft. Shaft cross-sections ranged from sub-square and sub-rectangular to ovate. Given these constraints on morphology straight shafted pestles are typically long and slender while conical/bell-shaped pestles are short and wide.

Pestle Use and Temporal Trends

Several trends are identifiable in the pestle assemblage, particularly when comparing the manufacture, use, and reuse of conical/bell-shaped and straight-shafted pestles. In addition to the designed differences noted above, conical/bell shaped pestles were primarily used on stone mortars while straight-shafted pestles were used on both stone mortars and flat surfaces in equal proportions (Table 2.6). Across the broader assemblage, pestles were used for secondary activities in far greater proportions than all other active and passive tools (Figure 2.13e-f). However, two subtypes, straight-shafted and expedient pestles, were frequently used as hammerstones for bipolar reduction while pestle use continued (concomitant secondary use) (Table 2.6). Pestles are the only ground stone tools in the Paso de la Amada assemblage regularly used for concomitant secondary activities (see artifact reuse section). Since 80% of all complete, straight-shafted pestles display evidence for concomitant use as bipolar hammerstones (sensu Crabtree 1972; Odell 2001; Whittaker 1994), and flaked stone reduction at Paso de la Amada was focused almost exclusively on obsidian (Ceja Tenorio 1985:107-108; Clark 1994), I find it unlikely that straight shafted pestles were designed or used for food processing (see further discussion in reuse section below). In summary, design and use attributes indicate straight-shafted pestles served as manufacturing and non-food processing tools, while larger bell-shaped and conical pestles were potentially designed and used to process food, albeit in small quantities given the small size of these tools (Clark 1994:235-236).

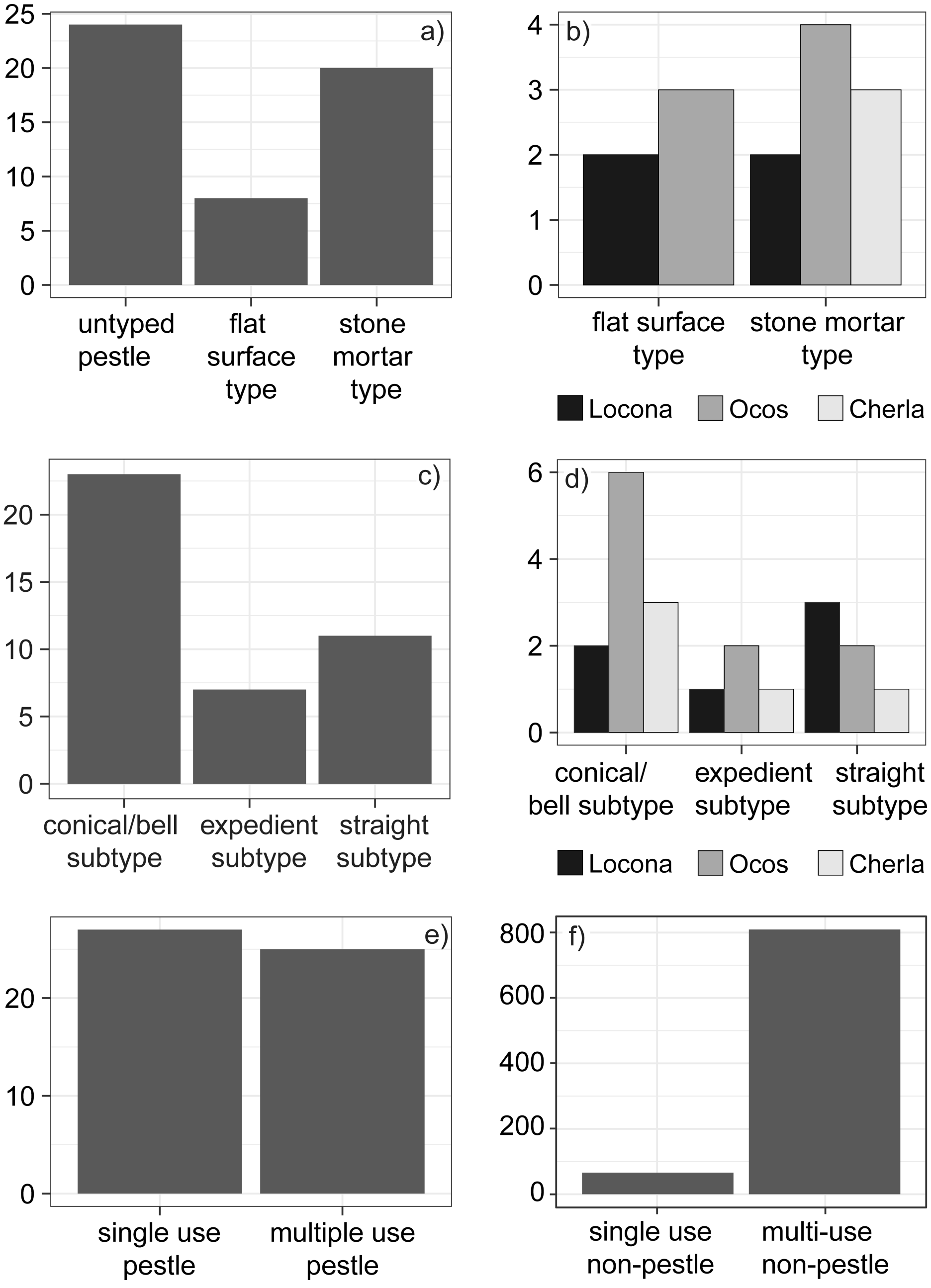


Figure 2.13. Analyses of pestles: **(a)** Pestle type counts in the broader Initial Formative and Early Formative assemblage. **(b)** Pestle type counts from Locona, Ocós, and Cherla contexts. **(c)** pestle subtype counts in the broader assemblage. **(d)** Pestle subtype counts from Locona, Ocós, and Cherla contexts. **(e)** Counts of pestles used only for their designed function and pestles used for multiple activities in broader assemblage. **(f)** Counts of all ground stone artifacts in the broader assemblage used for single or multiple activities.

Table 2.6. Pestle Measurements and Attributes.

Pestle Type and Subtype	**N=**	**Mean Length (cm)**	**Mean Width (cm)**	**Mean Density (mass/vol.)**	**Secondary Use**	**Concomitant Bipolar Hammerstone**	**Stone Mortar Use**
All Pestles	52	8.3	4.5	2.39	(f) 48% (c) 70%	(f) 44% (c) 60%	-
Stone Mortar type	20	8.9	4.7	2.33	(f) 45% (c) 63%	(f) 55% (c) 88%	-
Flat Surface type	8	6.3	4.1	2.36	(f) 25% (c) 40%	(f) 25% (c) 40%	-
Conical / Bell Shaped subtype	23	7.5	4.6	2.30	(f) 38% (c) 40%	(f) 33% (c) 20%	86%
Straight Shaft subtype	11	9.7	4.4	2.32	(f) 45% (c) 80%	(f) 45% (c) 80%	50%
Expedient subtype	7	8.4	4.9	2.70	(f) 43% (c) 66%	(f) 29% (c) 66%	43%

Note: (f) = fragmentary and complete artifacts; (c) = complete objects only.

Further analysis of the raw materials used in pestle manufacture illustrates that softer, less-dense raw materials were preferred (Figure 2.14). For example, the stone density of expedient pestles is significantly greater than that of strategically designed pestles at the 95% confidence level (Kruskal-Wallis, p-value = 0.008721, chi-squared = 9.484, df = 2), while the stone density of all pestles used as concomitant bipolar hammerstones is significantly lower than artifacts used exclusively as bipolar hammerstones at the 95% confidence level (Kruskal-Wallis, p-value = 0.01385, chi-squared = 8.5592, df = 2). The former suggests that soft raw materials were preferred for the processing that took place with designed pestles, while the latter suggests that pestles were used as bipolar hammerstones when a soft percussor was desired, a strategy long noted to reduce shatter and platform collapse in bipolar reduction (Crabtree 1967:61). Perhaps more noteworthy, this analysis supports a degree of intentionality in the design and use of multi-purpose, non-food processing and manufacturing tools that contrasts with the generalized multi-use grinding and percussion tools used by Late Archaic groups in the

Soconusco (Voorhies 2004:381–384). I return to the latter point in the artifact reuse and discussion sections of the current chapter.

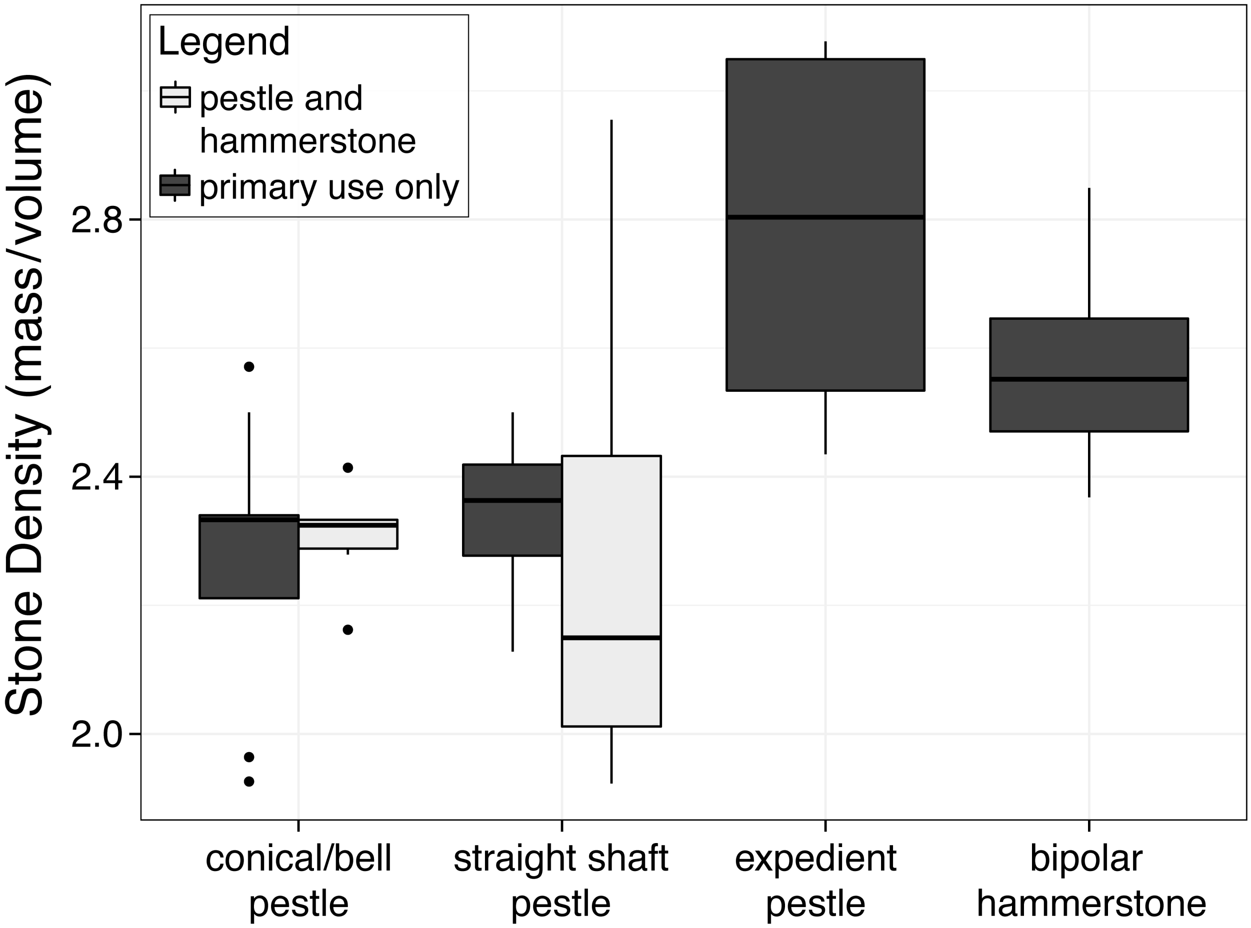


Figure 2.14. Stone density of single-use and multi-use pestles, expedient pestles, and hammerstones.

CLASS: HANDSTONE (n=21)

Handstone is a generic term that refers to active ground stone artifacts that were not clearly designed for or consistently used with a particular class of passive ground stone tools. All handstones were river cobbles used as expedient tools for a variety of processing tasks (Table 2.5). Use-wear typically indicated a combination of circular and reciprocal strokes as well as percussion activities. Several exhibited a heavy sheen and were likely used as polishing stones. These tools compare favorably to the Late Archaic handstones at shell mound and inland sites in the Soconusco described by Voorhies (2004), but are smaller in length and width. A total of 21 handstones were present in the Paso de la Amada assemblage.

Receptacles

CLASS: STONE BOWLS (n=18)

Types: unembellished (n =15), embellished (n=3)

Subtypes: flared rim (n=6), tecomate (n=2), hemispherical (n=1), beveled rim bowl (n=1)

Artifacts were identified as stone bowls (rather than mortars) when no use-wear was visible on the base and lower walls of interior basins. Similar to the mortars in the assemblage, stone bowls have tall, clearly defined walls that were designed to contain a substance. Stone bowls tend to have thinner bases and walls compared to shaped mortars of a similar diameter, but still exhibit substantial overlap with crushing subtype mortars (Table 2.7, Figure 2.15). A total of 16 stone bowls were present in the assemblage, with at least one vessel appearing in each phase (Table 2.8).

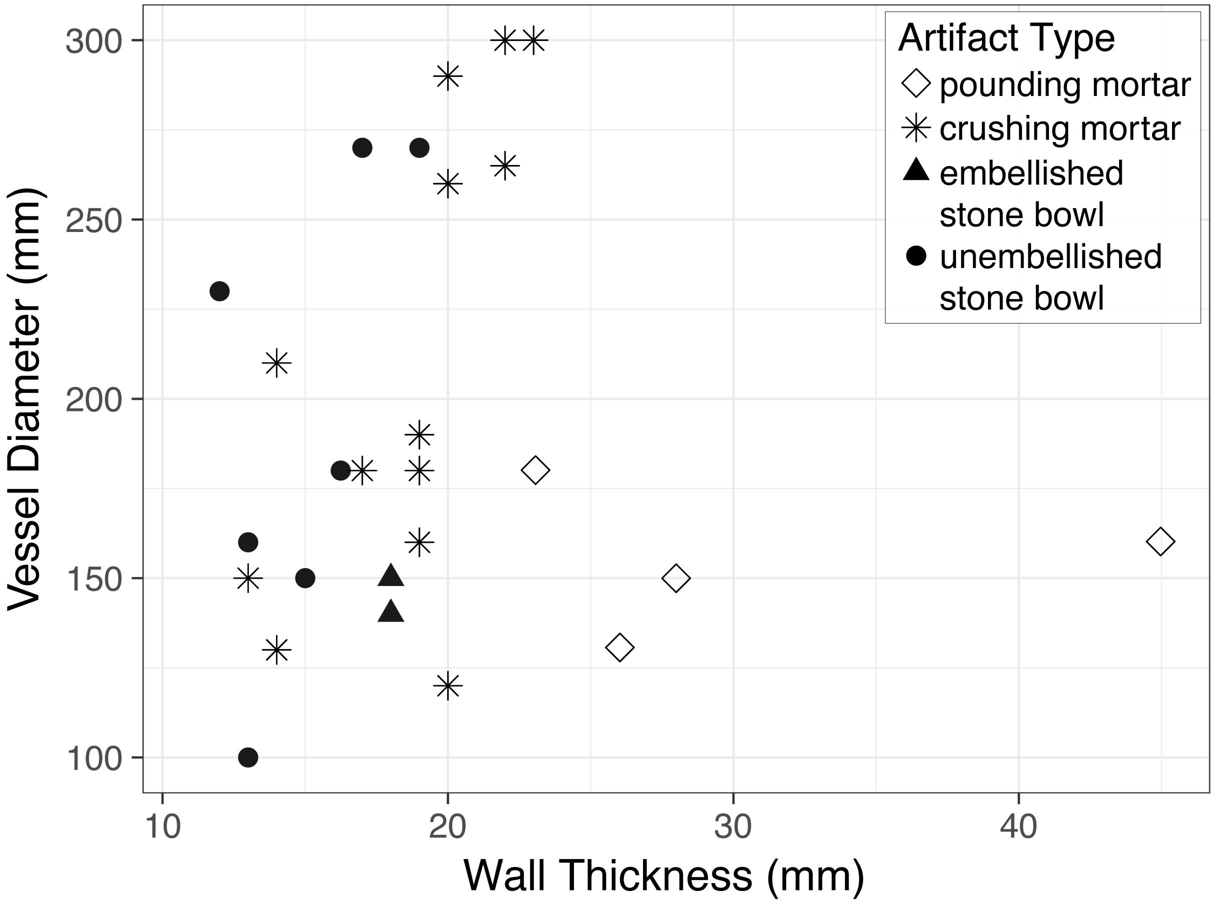


Figure 2.15. Scatterplot comparing the diameter and wall thickness of mortars and stone bowls.

Table 2.7. Stone Bowl Metric Attributes and Vessel Counts per Phase.

Stone Bowl Type / Subtype	**N=**	**Mean Diameter**	**Mean Wall Thick**	**Mean Basal Thick**	**Locona Count**	**Ocos Count**	**Cherla Count**
Embellished type	3	14.5	1.8	2.2	-	1	1
Unembellished type	15	20.8	1.6	1.9	1	3	4
Flared Rim subtype	6	18.1	1.7	2.1	1	1	1
Hemispherical subtype	1	22.0	1.9	2.2	-	-	-
Tecomate subtype	2	-	1.5	-	-	2	-
Beveled Rim Bowl subtype	1	30.0	-	-	-	-	1
Embellished type w/ zoomorph	1	15.0	1.8	2.4	-	1	-
Embellished type w/ clapboard	1	14.0	1.8	2.0	-	-	1
Embellished type w/ tripartite stand	1	-	-	-	-	-	-
Total	*18*	*19.5*	*1.6*	*1.9*	*1*	*4*	*5*

Note: Diameter measured with a sheet with projections.

Stone bowls were classified into two types, embellished and unembellished (Figure 2.5). One embellished stone bowl from Mound 12 Ocós deposits has an effigy of a probable zoomorphic face protruding from the exterior wall (Figure 2.5, #304297), and the second, from Mound 1 Cherla deposits, has a deeply incised line running around the exterior of the vessel, which gives the vessel a clapboard appearance (Figure 2.5, #304928). The third and last example of an embellished stone bowl, recovered from undifferentiated Intial/Early Formative deposits, had a "leg" protruding from the juncture between the wall and base of the vessel, likely part of a tripartite stand (#304917). The fragment was reused as an abrader along the break. Ceja Tenorio 1985:(109-111) uncovered three similar objects but these were also fragmentary.

Half of the stone bowls were further classified to subtypes based on morphology. Most stone bowls had a circular shape in planview, a flat exterior base, a flat to slightly convex interior base, and relatively straight to slightly flaring walls that made an obtuse angle at the point where the base meets the vessel walls. These *flared rim* stone bowls are morphologically similar to several "pounding" mortars in the assemblage, but have far thinner walls and bases (see description above), and compare favorably to "flaring rim b(MacNeish et al. 1967:116–117), "hemispherical bowls or mortars" previously described from owls" from the Tehuacan Valley Paso de la Amada (Ceja Tenorio 1985:110-111), "round bowls" from La Victoria (Coe 1961:101) and vessels from Altamira (Green and Lowe 1967:28, 130) (Figure 2.5 #304309). Locona, Ocós, and Cherla deposits each contained a single example of a flared-rim stone bowl.

A single *hemispherical* subtype stone bowl from undifferentiated Initial/Early Formative deposits had a circular shape in plan-view, gently sloping slightly excurvate walls on the exterior, and a slightly convex exterior base, and slightly concave interior base. The morphology of this specimen is similar to many of the "crushing style" mortars, and roughly similar to the “hemispherical bowls” from the Tehuacan Project (MacNeish et al. 1967:116–117). Two small rim fragments of stone vessels from Mound 12 and Mound 32 Ocós deposits are classified as *tecomate* subtype vessels. Both are made from unidentified high-quality, fine-grained materials (likely basalt) and were very well made. These artifacts and another rim fragment from a stone bowl dating to the Cherla phase were initially thought to be ceramic bowl rim sherds, but upon further inspection are clearly ground stone vessels. The entire interior of one tecomate-shaped rim fragment was coated in a uniform thin layer of red pigment. MacNeish et al. (1967:117) also report tecomate-shaped stone vessels with very thin walls from the Tehuacan Valley. The sherd-like specimen from Mound 1 is well-made from gray andesite and is in the form of a common Locona-phase ceramic vessel type, the *beveled rim bowl* (#305196). It is possible that this specimen is a Locona-phase carry up in the Mound 1 Cherla deposit.

Trends in Morphology and Design

Due in part to the small size of the sample, little can be said about differences between the types and subtypes of stone bowls in the assemblage. The average diameter of embellished stone bowls is smaller, and mean wall thickness and base thickness is greater compared to unembellished types (see Figure 2.15 and Table 2.7), but this only includes measurements from two embellished artifacts (Figure 2.5, #304928, #304297). Vessel diameters range from 10 to 30 cm among eight measurable specimens (specific measured rim diameters in centimeters are: 10, 15 [Ocós], 15.8 [Locona], 18, 22, 23 [Cherla], 27, and 30 [Cherla deposit, the possible Locona carryup]). A high proportion (50%) of the stone bowls, including both embellished examples are made from lightweight, soft, and less durable materials such as white andesite, limestone, and volcanic tuff. From a functional perspective, this might be because these materials are easy to shape, and the durability of a stone bowl probably was not as important as the durability of passive ground stone. Many examples from the Tehuacan Valley were also made from lightweight and less durable materials (MacNeish et al. 1967: 116–117).

Trends in Ground Stone Manufacture and Use During the Initial to Early Formative Transition

The Paso de la Amada assemblage provides an opportunity to explore change in ground stone manufacture and use during the Initial and Early Formative periods. While ground stone tools were undoubtedly used to process a wide variety of domesticated, cultivated, and collected plants during the second millennium BC in the Soconusco, prior studies of Initial Formative and Early Formative food processing have been hampered by small sample sizes. Researchers have interpreted the low densities of such ground stone tools as evidence for a lack of reliance on maize, the relative unimportance of stone-ground plant foods more broadly, or have drawn similar inferences from more detailed analyses of small assemblages (Clark 1994:234; Lowe 1967:50, 1975; Rosenswig 2006, 2010). It is clear that mobile farmer-foragers cultivated maize for thousands of years in the Soconusco prior to the formation of sedentary villages (Kennett et al. 2010; Voorhies 2004), but whether or not the onset of the Initial Formative involved any significant change in foodways now seems uncertain. Given the deep history of this particular question in the Soconusco (Lowe 1967:50, 1975), it will therefore receive ample attention in the remaining portion of the chapter.

We divide the topic of the role of maize in the subsistence economy of Soconusco villages during the second millennium BC into three basic questions. First, was there an *early tipping point* in maize orientation at around 1900 BC? Second, was there a trajectory of *amplification* in the use of maize (or, instead, stability) *during* the second millennium? Third, how strongly do changes around 1000 BC indicate a *late tipping point* in the emergence of maize as a staple crop? The remainder of this section concentrates on the second of those questions; the full set of questions is considered in Chapter 26.

Active Ground Stone Use and Manufacture Through Time

Researchers considering whether or not maize was processed for daily meals during the Initial, Early, and Middle Formative periods have compared and contrasted the relative proportion of active ground stone tools presumed to process maize compared to tools used to process other plants foods (Arnold 2009; Blake and Neff 2011; Clark 1994; Clark et al. 2007; Rosenswig 2006, 2010). At Cuauhtémoc, Rosenswig (2006: Figure 3) found a sharp increase in the ratio of manos and metates to mortars and pestles in the Conchas phase (5:1). In Clark's (1994: Table 9) Mazatán data, that ratio is quite noisy, ranging to twice the Conchas-phase Cuauhtémoc value in Ocós before declining.

Manos dominate active ground stone tool classes in the Paso de la Amada assemblage compared to pestles throughout the sequence (Figure 2.16a). A sharp increase in the relative frequency of manos is registered between Ocós and Cherla (Figure 2.16b). In the Cherla phase sample, the ratio of manos to metates is over 7:1.

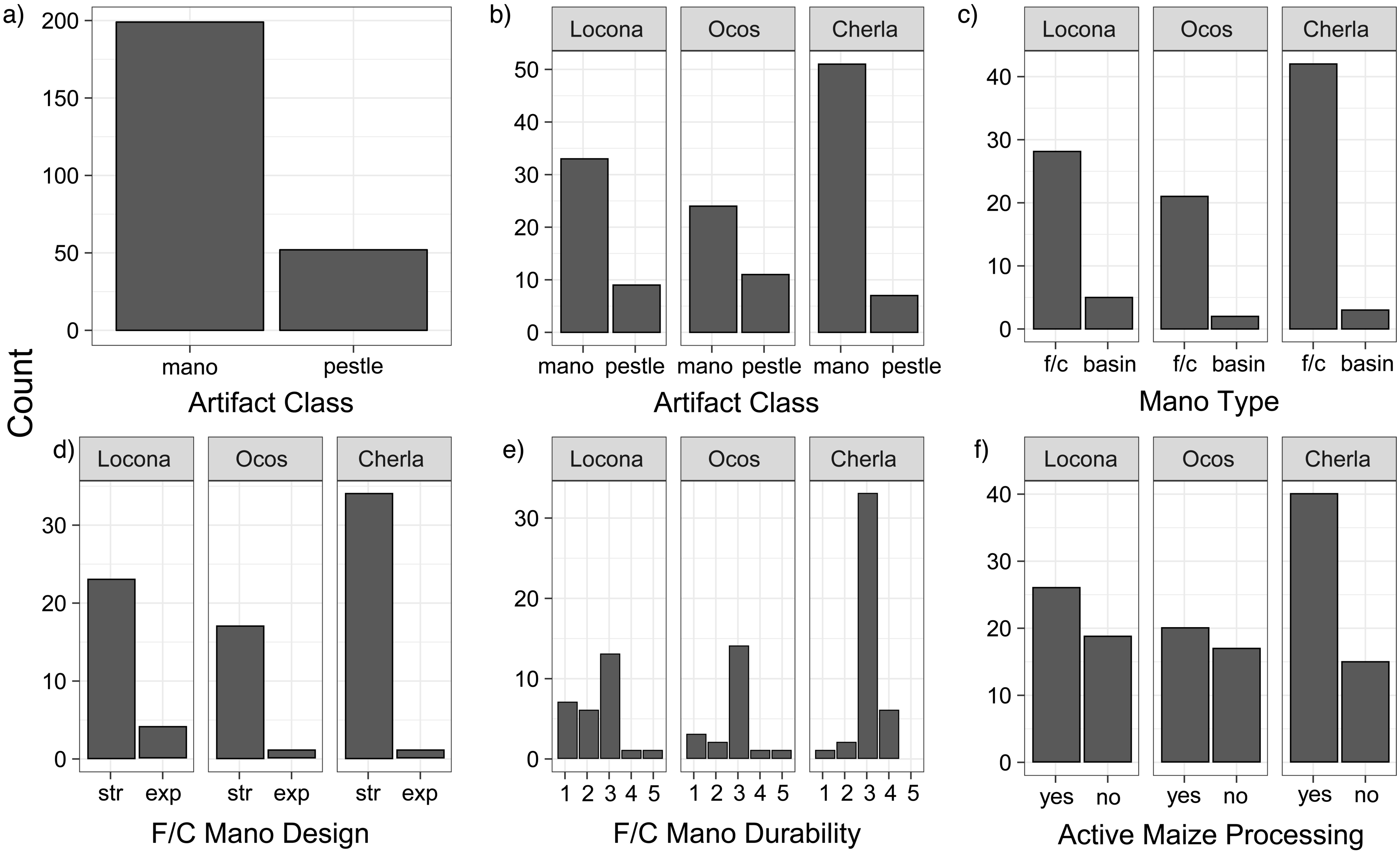


Figure 2.16. Active ground stone tool use and manufacture through time at Paso de la Amada: **(a)** counts of manos and pestles in the broader Initial Formative and Early Formative assemblage; **(b)** mano and pestle counts from Locona, Ocós, and Cherla contexts; **(c)** counts of flat/concave and basin manos; **(d)** counts of strategically designed and expedient flat/concave manos; **(e)** durability of flat/concave manos; **(f)** active ground stone tools likely designed to process maize compared to active tools likely designed or used to process other foods.

Table 2.8. Counts and Proportions of Active Grinding Tools per-Temporal Phase.

Phase	**Flat/ Concave Manos (not small, count)**	**Small Flat/ Concave Manos (count)**	**Basin Manos (count)**	**Untyped Manos (count)**	**Pestles (count)**	**Hand-stones (count)**	**Percent Active Maize Tools** [b]	**Percent Designed Flat/Concave Manos**	**Maize Processing Durability Index**[a]
Locona	26	2	5	-	9	2	59.1%	85.2%	2.42
Ocós	20	1	2	1	11	6	50.0%	94.4%	2.85
Cherla	40	2	3	6	7	3	72.7%	97.1%	3.02
Undifferentiated 1700-1300 BC	75	1	7	9	25	10	63.6%	97.2%	2.88
Total	*161*	*6*	*17*	*16*	*52*	*21*	*62.6%*	*94.7%*	*2.84*

[a] Mean durability index, which ranks all raw materials on a scale of 1 to 5 from least to most durable.

[b] Maize processing tools include flat/concave manos other than small subtypes; non-maize food processing tools include small flat/concave manos, basin manos, handstones, and pestles.

More importantly, the frequency of flat/concave manos – likely used to process maize – increases through time at Paso de la Amada in relation to the frequency of basin manos (Figure 2.16c). Further, the percentage of flat/concave manos that were strategically designed rose in the Cherla phase (Figure 2.16d). Community members also began favoring more durable materials for flat/concave manos. The Locona assemblage contains a greater relative frequency of less durable material (mainly soft white andesite). This is visible as a left-skewed distribution in Figure 2.16e. During the Ocós phase, less durable materials began to drop out of use, and during the succeeding Cherla phase moderate durability materials (mainly gray andesite) dominate the assemblage and less durable materials become rare (visible as a right skewed distribution in Figure 2.16e). It is, however, noteworthy that the rare examples of highest quality materials, in this case granite and vesicular basalt, mostly occur in Locona and Ocós contexts.

In the typology portion of this chapter I argued that not all manos were used to process maize. It is therefore important to compare not only manos to pestles or basin manos to flat/concave manos, but active grinding stones likely used to process maize (flat/concave manos other than small subtypes) to active ground stone likely used to process other foods (basin manos, pestles, and handstones, small flat/concave manos). That analysis is shown in Figure 2.16f. Maize processing tools are more ubiquitous compared to non-maize processing tools during Locona and Ocós, but there is a dramatic shift in the Cherla phase, with maize processing tools at that point dominating the assemblage. This analysis should be considered very cautious, since it includes pestles likely used exclusively for manufacturing activities, and other small active tools likely used to process spices, medicines, condiments, or pigments along with the non-maize food processing tools.

Raw data and the above patterns are brought together in Table 2.8. The pattern to note is that in each analysis the Cherla sample of active grinding stones emerges as more appropriate for intensive grinding of maize than the samples of previous phases. In some cases, the Cherla sample constitutes a jump with respect to the Locona-Ocós pattern (e.g., percent of flat/concave manos in the active tool assemblage), whereas other measures suggest a steadier trajectory of change across the three phases (e.g., the mean durability indices, flat/concave mano design). In the Late Formative period in Mesoamerica, maize-grinding equipment certainly became even more oriented to intensive grinding (e.g., Biskowski 1997, 2015). Yet given recent emphasis on 1000 BC as a tipping point in the emergence of maize as a staple, discovery of a clear trajectory towards intensified maize grinding at Paso de la Amada in the mid-second millennium BC is particularly important.

Passive Ground Stone Through Time

Analyses of passive ground stone use and manufacture through time show similar trends to those observed among the active grinding stones (Table 2.9). Metates are present in far greater quantities compared to mortars when the is viewed as a whole (Figure 2.17a). While the ratio of metates to mortars is slightly greater during the Cherla phase compared to the Locona phase, the Ocós phase assemblage has the greatest metate to mortar ratio (Figure 2.17b). I note, however, that this ratio includes two mortar types used primarily for pigment processing (see mortar section). The ratio of flat/concave to basin metates is high throughout the occupation, with the most prominent increase taking place during the Ocós to Cherla phase transition (Figure 2.17c).

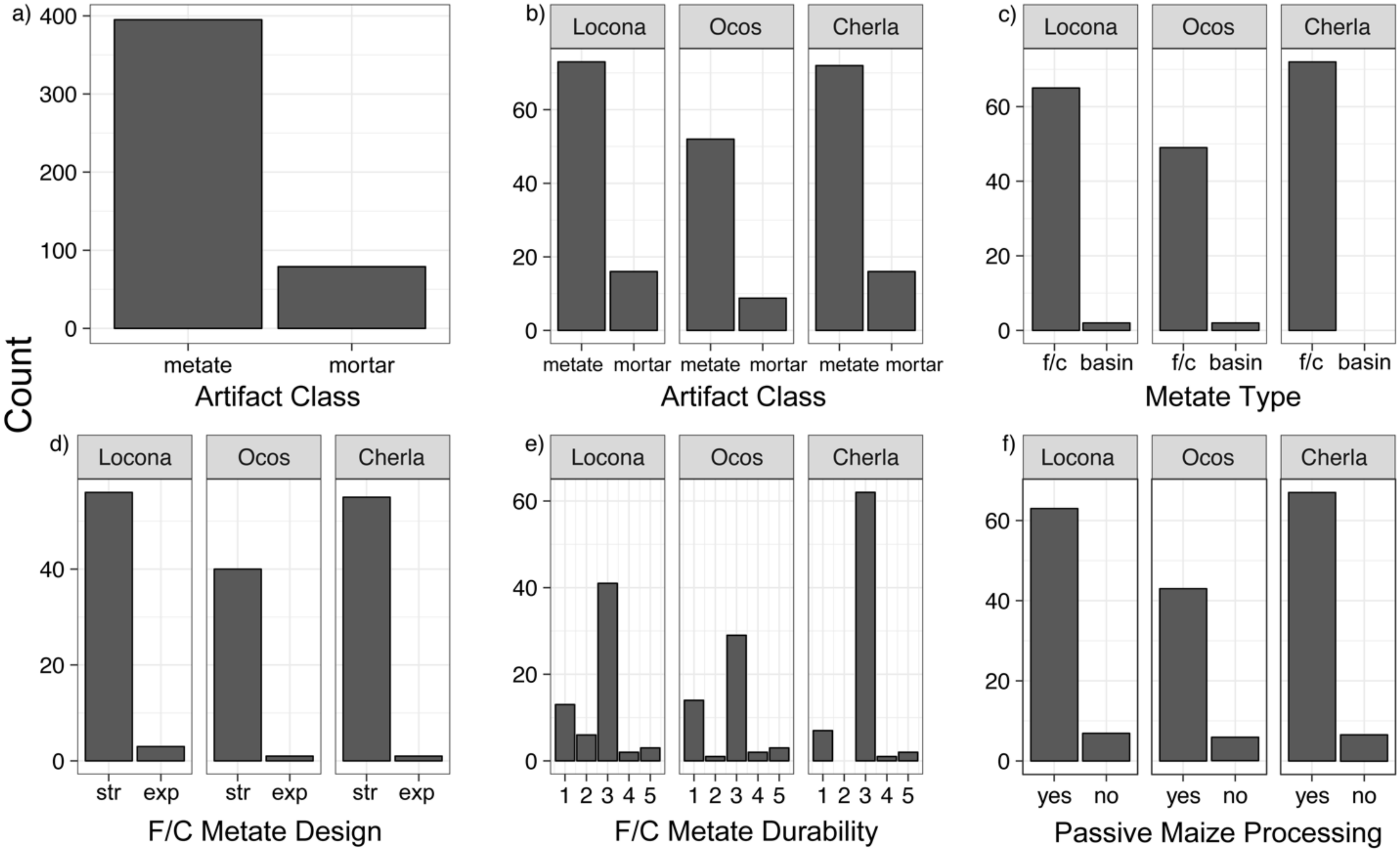


Figure 2.17. Passive ground stone tool use and manufacture through time at Paso de la Amada: **(a)** mano and mortar counts in the broader Initial Formative and Early Formative assemblage; **(b)** metate and mortar counts from Locona, Ocós, and Cherla contexts; **(c)** counts of flat/concave and basin metates; **(d)** counts of strategically designed and expedient flat/concave metates; **(e)** durability of flat/concave metates; **(f)** passive ground stone tools likely designed to process maize compared to passive tools likely designed or used to process other foods.

Table 2.9 Counts and Relative Proportions of Passive Ground Stone Tools per-Temporal Phase

Phase	**Flat/ Concave Metates (not small or rectangular)**	**Rectangular & Small Flat/ Concave Metates**	**Basin Metates**	**Untyped Metates**	**Mortars (not medium or large)**	**Medium & Large Mortars[a]**	**Percent Maize Process-ing[b]**	**Percent Designed Flat/ Concave Metates**	**Flat/ Concave Metate Durability Index[c]**
Locona	63	2	2	6	12	6	81.8%	95.0%	2.68
Ocós	42	7	2	1	2	4	85.7%	97.5%	2.60
Cherla	67	5	0	1	11	6	90.5%	98.4%	2.88
Undifferentiated 1700-1300 BC	172	3	4	18	29	23	79.3%	97.2%	2.73
Total	*344*	*17*	*8*	*26*	*54*	*39*	*82.5%*	*97.9%*	*2.72*

[a] Includes undifferentiated stone bowls/mortars.

[b] Maize processing tools include flat/concave metates other than rectangular subtypes and small varieties; non-maize food processing tools include basin metates, undifferentiated metates, medium and large mortars, and undifferentiated medium and large stone bowls/mortars.

[c] Mean durability index, which ranks all raw materials on a scale of 1 to 5 from least to most durable.

Similar to the pattern documented for flat/concave manos, flat/concave metates were strategically designed more often during the Cherla phase compared to both Locona and Ocós (Figure 2.17d). Although the pattern is not as dramatic in comparison to flat/concave manos, the use of less-durable materials for manufacturing flat/concave metates decreased during the Ocós to Cherla transition (Figure 2.17e). This less dramatic shift is likely due to the size of raw material necessary to manufacture a metate compared to mano, and the scarcity of large enough high-quality raw material near Paso de la Amada. Finally, similar to the trends noted for active ground stone, the ratio of passive tools likely used to process maize to tools that were likely *not* used to process maize increases through time, with the greatest ratio during Cherla and the lowest ratio during Locona (Figure 2.17f, Table 2.9). The pattern of using higher quality raw materials for active and passive maize processing equipment is also illustrated by comparing the stone density of maize processing tools to non-maize processing tools (Figure 2.18). Passive maize processing ground stone is denser compared to non-maize processing tools from Locona through Cherla, while the Locona to Ocós transition marked a decrease in the relative density of non-maize processing tools. The density of passive maize processing tools, however, remains relatively stable at values well-above those of non-maize processing, likely due to a lack of access of higher quality raw materials (e. g. vesicular basalt and granite).

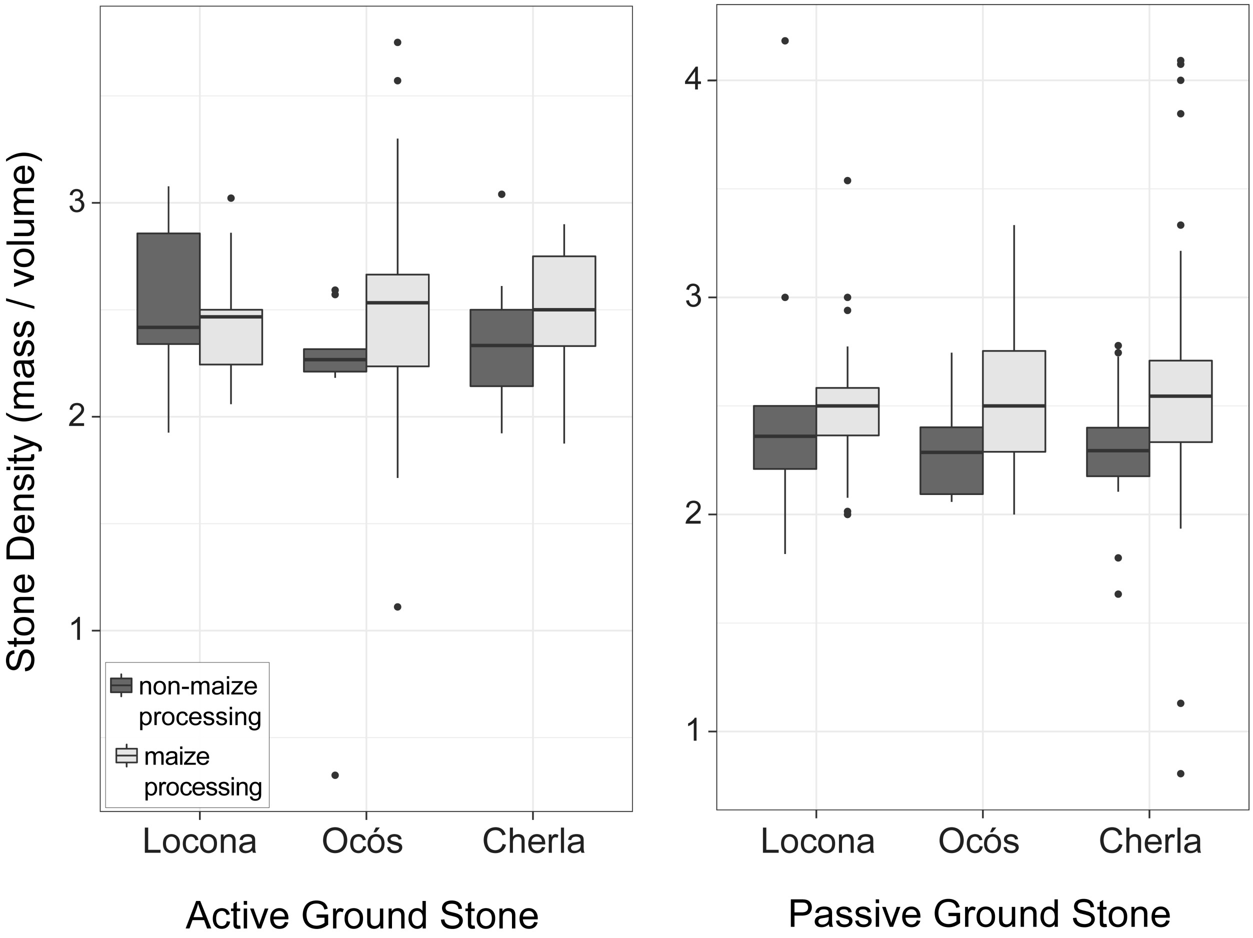


Figure 2.18. Stone densities of active and passive ground stone tools likely designed primarily to process maize compared to tools designed or used primarily to process other foods or materials.

Ground Stone Reuse, Recycling, and Discard

Researchers have argued that multi-use tools are a hallmark of Late Archaic, Initial Formative, and Early Formative groups who retained a high degree of residential mobility and were less invested in agricultural pursuits (Arnold 2009:404; Clark et al. 2007:29; McCormack 2002:170–182; Rosenswig 2010). While ground stone tools at Paso de la Amada were frequently reused and redesigned for a range of activities that differed from their designed primary function (Figure 2.19), the assemblage does not exhibit clear diachronic trends in the reuse of artifacts through time (Figure 2.20a, b, Table 2.10). Instead, food processing and non-food processing tool classes display distinctive yet stable patterns of reuse and discard that span the Initial through Early Formative transition. For example, in the full assemblage, manos (11.1%), oval flat/concave metates (9.8%) and mortars (8.9%) were used *sequentially* for processing or manufacturing that differed from their designed function in similar frequencies (Figure 2.20c, d). Such sequential reuse of food processing equipment is well-documented for intensive agriculturalists in the ethnographic and archaeological records (Clark 1988:94, 103; Hayden 1987:188; see also Searcy 2011:76). In contrast, pestles were used for *concomitant* secondary manufacturing activities (while use as a pestle continued, see Figure 2.19, #304206, #304894, #304887) in far greater relative proportions compared to all other expedient or designed active and passive tool classes. This pattern remained stable throughout the occupation (Figure 2.20c, d).

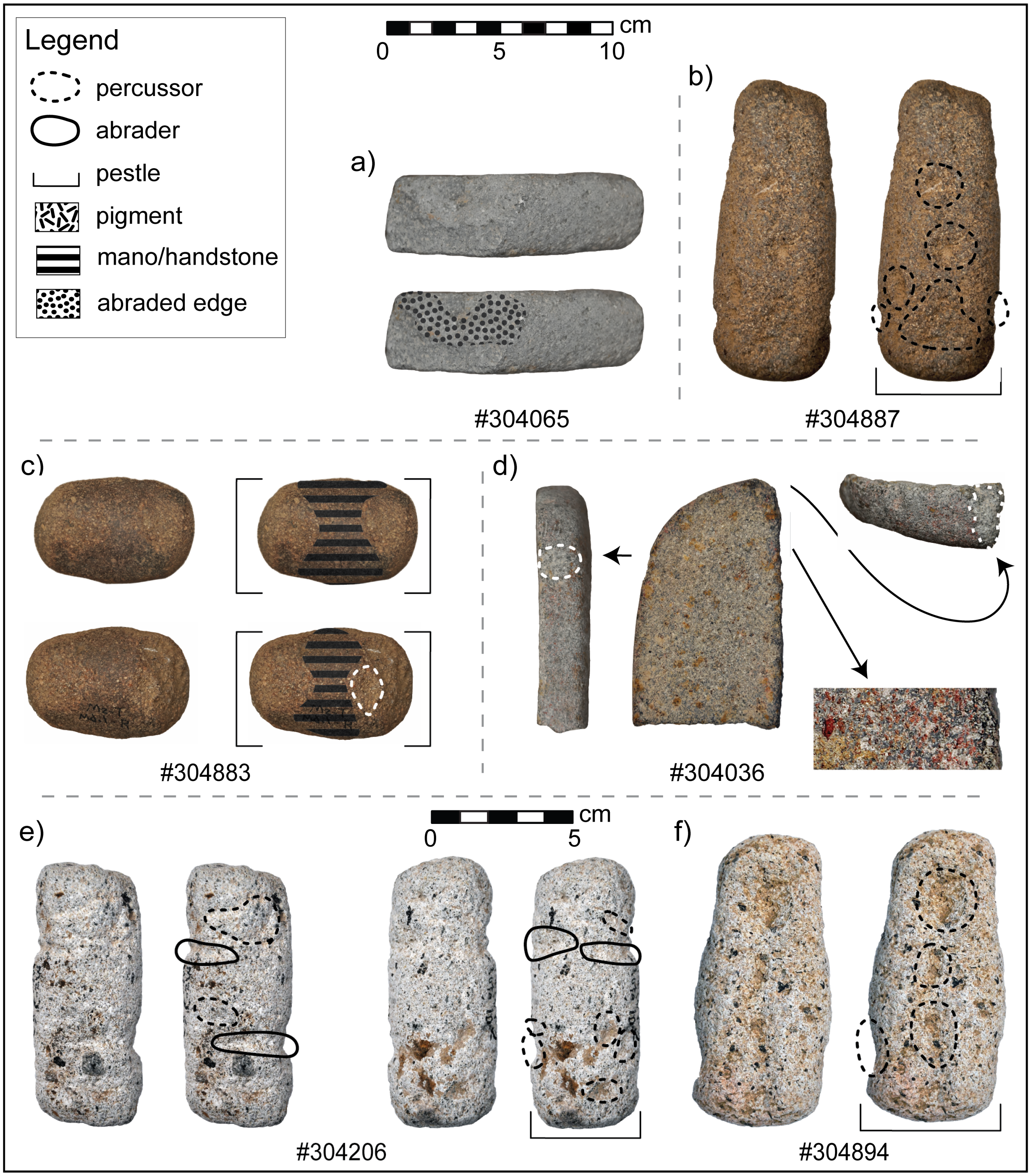


Figure 2.19. Select examples of sequential and concomitant secondary tool use at Paso de la Amada. A photograph of each artifact with and without reuse coded is displayed. Note that subfigures e and f are shown at a larger scale in comparison to all other subfigures: **(a)** Cross section view of a rectangular flat/concave metate edge fragment. The artifact was redesigned into a lapstone after breaking, by squaring off the broken edge, and was then used for manufacturing activities and pigment processing. **(b)** Dorsal surface of a pestle with abundant percussion scars along length of the shaft from concomitant use as a bipolar hammerstone.

(c) Dorsal and ventral surfaces of a small flat/concave mano. The artifact was used with a reciprocal stroke on its dorsal and ventral surfaces, sequentially reused as a pestle in a stone mortar on its proximal and distal ends, and, finally, sequentially reused as a percussor. **(d)** Rectangular metate sequentially reused as a percussion tool along a broken edge and used as a lapstone for pigment processing after breaking. The inset shows pigment extending over and into the broken edge of the artifact. **(e)** Dorsal and ventral surfaces of a straight-shafted, lightweight pestle made from white andesite. The artifact was used concomitantly as a pestle, a bipolar hammerstone, and an abrader. The latter two uses are likely both associated with bipolar obsidian reduction. **(f)** Dorsal surface of a lightweight, straight-shafted pestle, used concomitantly as a pestle in a stone mortar on its proximal end and as a bipolar hammerstone across the length of its shaft.

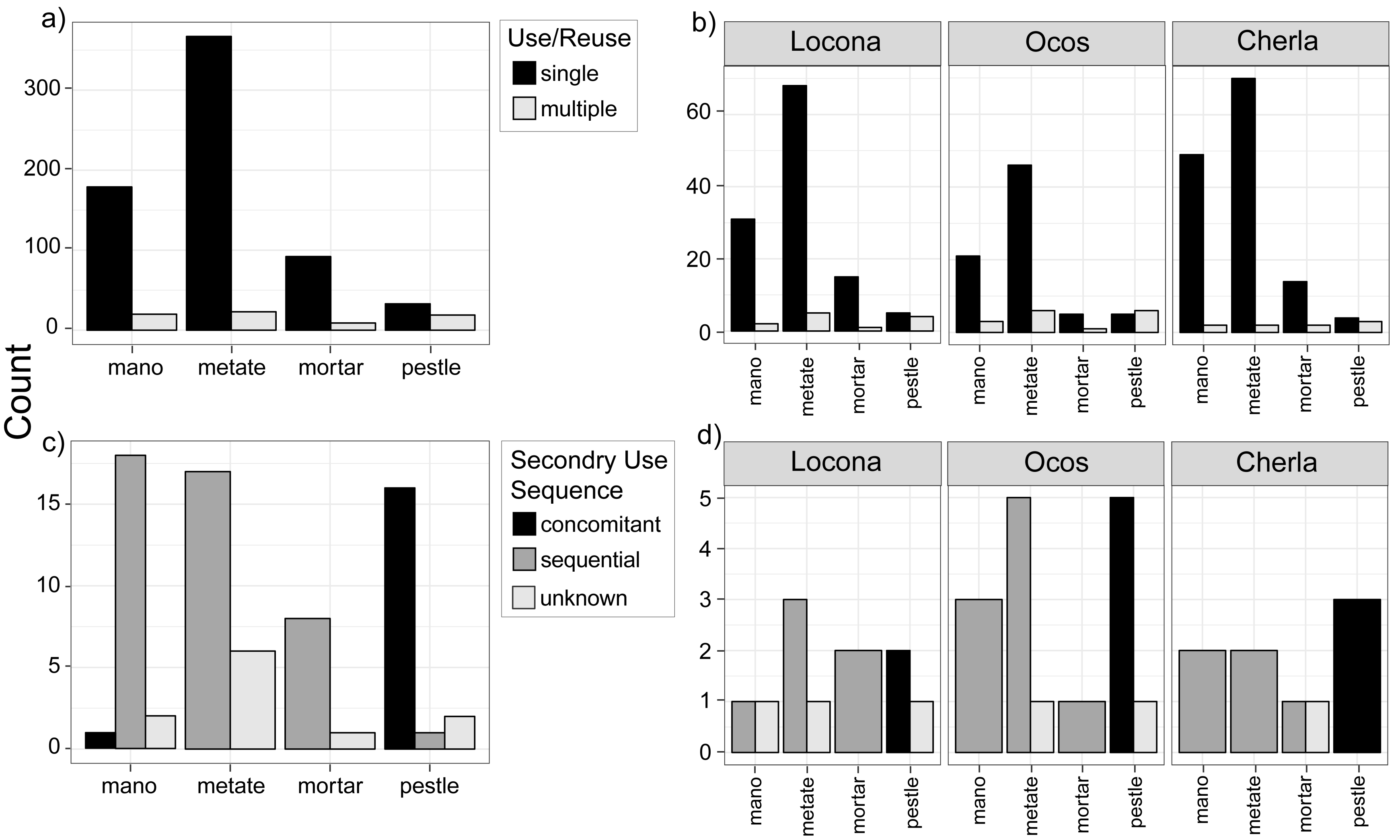


Figure 2.20. Tool use and reuse patterns among the four most common artifact classes: manos, metates, mortars, and pestles: (a) counts of single and multiple-use tools in the greater 1700–1300 BC assemblage; (b) trends in artifact reuse through time; (c) sequence of secondary tool use in the greater 1700–1300 BC assemblage; (d) sequence of secondary tool use through time.

Table 2.10. Trends in Ground Stone Reuse at Paso de la Amada Through Time.

Phase	**Secondary Use All Ground Stone**	**Secondary Use Manos**	**Secondary Use Metates**	**Secondary Use Mortars**	**Secondary Use Pestles**
Locona	7.5%	6.1%	6.9%	6.3%	44.4%
Ocos	16.1%	12.5%	11.5%	16.7%	54.5%
Cherla	6.1%	3.9%	2.9%	12.5%	42.9%
1700-1300 BC	10.8%	10.0%	6.3%	8.9%	40%

Note: Table 2.10 includes tools with evidence of two or more uses.

Table 2.11 Reuse of Food Processing and Non-food Processing Tools at Paso de la Amada.

	Food Processing				**Non-Food Processing / Manufacture**		
Date Range	**Basin Mano**	**Flat/ Concave Mano**	**Oval Plan Flat/ Concave Metates**	**Medium & Large Mortars**	**Pestles**	**Rectangular Flat/ Concave Metate**	**Hand-stone**
1700-1300 BC	5.9% (s)	10.1% (s)	9.8% (s)	3.8% (s)	40% (c)	31.3% (s)	38% (c)

Note: Letters in parentheses indicate the dominant reuse sequence associated with each tool: (s) = sequential reuse; (c) = concomitant reuse.

Differential Reuse of Processing and Manufacturing Tools

In addition, the discard and recycling behavior associated with these tool classes also exhibited strongly patterned differences that remained consistent through time (Table 2.12). All but a single specimen of the most common food processing equipment at Paso de la Amada (medium to large flat/concave manos, flat/concave metates, and medium to large mortars), were recovered in fragmentary condition (Figure 2.21a). In contrast, more complete pestles (20 of 53) were recovered than complete tools from all other artifact classes combined (15 of 874), and this pattern remains consistent through Locona, Ocós, and Cherla. I acknowledge that this is in part due to smaller size of pestles (see left side of Figure 2.21a), but one would expect that basin manos and handstones, with their circular shape and more durable raw materials, would be found complete in higher frequencies compared to pestles. Moreover, the recycling behavior associated with pestles also stands in contrast to all other active tools in the assemblage (Figure 2.21b). For example, in the full assemblage over half of all manos (53.5%), nearly half of all medium to large manos (45.9%) and nearly one-third of basin manos and handstones (30.8%) were recycled as hot rocks for stone boiling, but less than ten percent of pestles were found in fire-cracked condition. This pattern remains fairly stable during the occupation (Table 2.12). This suggests different cultural practices associated with the recycling and disposal of food processing and non-food processing/manufacturing tools. Perhaps these pestles, frequently used for bipolar reduction, were not considered appropriate for food preparation even in recycled form.

In summary, the stable yet distinctive trends noted for the design, use, reuse, recycling, and discard of food processing and manufacturing tools at Paso de la Amada demonstrate strongly patterned cultural behaviors associated with all phases of the life-history of ground stone artifacts. This extends not only to food processing equipment, such as manos and metates, but also tools designed and used for multiple concomitant processing and manufacturing tasks. Such strongly patterned behavior suggests a degree of intentionality in the manufacture, use, and reuse of designed multi-use pestles at Paso de la Amada that does not bear a close resemblance to the expedient multi-use grinding and percussion tools common on Late Archaic sites in the Soconusco (Voorhies 2004).

Table 2.12. Proportions of Ground Stone Tools Recovered in Fire-Cracked Condition.

Phase	**All Ground Stone**	**Manos**	**Pestles**	**Metates**	**Mortars**	**Medium-Large Flat/ Concave Mano**	**Flat/ Concave Metate**
Locona	37.3%	45.5%	0%	45.2%	6.3%	26.7%	44.6%
Ocos	28.8%	50.0%	0%	19.2%	16.7%	42.9%	20.4%
Cherla	38.6%	60.8%	14.3%	31.9%	31.3%	53.3%	68.1%
All 1700-1300 BC	36.3%	53.5%	9.6%	33.9%	24%	45.9%	33.5%

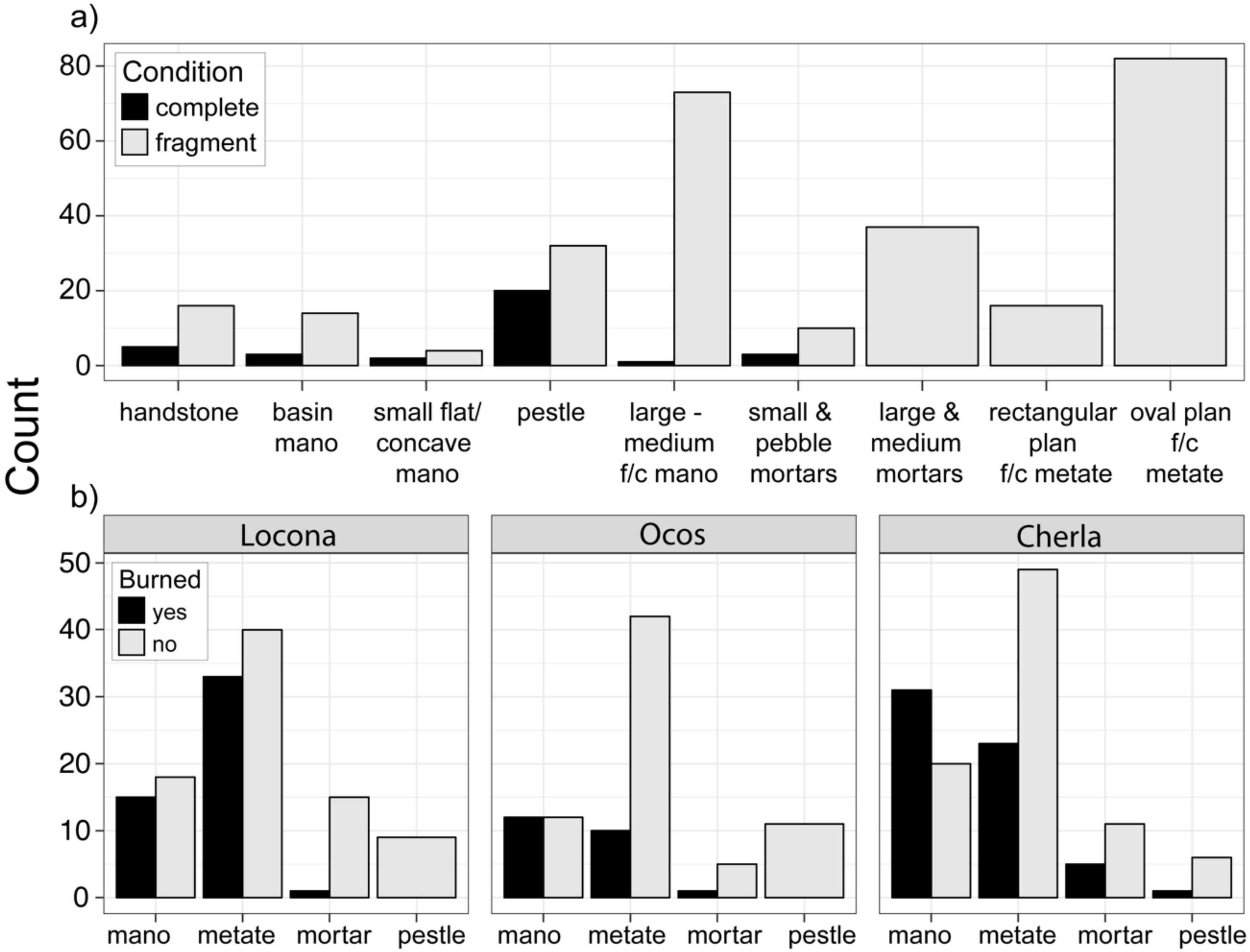


Figure 2.21. Ground stone artifact condition at Paso de la Amada: **(a)** Condition of passive and active tools in the broader Initial Formative and Early Formative assemblage. **(b)** Counts of manos, metates, mortars, and pestles recovered as fire-cracked rock or recovered with no evidence of thermal alteration.

Beyond Paso de La Amada: Comparing Late Archaic through Middle Formative Ground Stone Assemblages

One research question posed in the introduction to this chapter was what the Paso de la Amada assemblage tells us about the foodways during the second millennium BC. Comparing the ground stone tools from Late Archaic sites and a well-published Middle Formative site in Central Chiapas (La Libertad) to ground stone assemblage from Paso de la Amada exhibits both continuity and change in food processing activities. For example, handstones and basin manos comprise 100% of the active ground stone assemblages at coastal and inland sites in the Soconusco during the Late Archaic (Voorhies 2004:381–384)[1] (Table 2.13). While these tools continue to be used between 1700 and 1300 BC, flat/concave manos (reciprocal stroke) outnumber other active food processing tools (Figure 2.22a). The ratio of basin manos and handstones to flat/concave manos decreases steadily during the Cherla phase, and the Middle Formative (Figure 2.22b). Thus, the assemblage at Paso de la Amada shows some continuity with the Late Archaic traditions, in the form of larger relative proportions of handstones and rotary manos, but displays a punctuated shift, with routine food processing focused on reciprocal grinding with designed manos and metates–as 94% of all metates at Paso de la Amada were used exclusively with a reciprocal stroke. (Table 2.14).

The well-documented ground stone assemblage from La Libertad shows an even narrower focus on reciprocal grinding with designed manos and metates (Figure 2.22c, d). All

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[1] Voorhies (2004) classifies to the dominant active ground stone tools from Inland and Coastal Late Archaic sites in the Soconusco as “handstones”. In the current typology, these artifacts would likely be classified as handstones (*sensu* Adams 2014:102) or expedient or strategically designed basin manos used for concomitant or sequential secondary activities.

but two manos (n=44) and all metates (n=40) at La Libertad were used with a reciprocal grinding motion, and an even larger portion of the assemblage is dominated by medium-large manos (Tables 9.13, 9.14). The mean length and width of reciprocal manos at La Libertad, is also greater than those at Paso de la Amada (Table 2.15, Figure 2.23), and the same is true of the mean thickness of oval-plan and rectangular-plan metates (Table 2.16). Moreover, the designed maize grinding manos at La Libertad display greater morphological consistency, with reduced standard deviations in length (Table 2.15). Yet, the fairly low standard deviations in metate and mano thicknesses, and the widths of medium to large flat/concave manos in the Paso de la Amada assemblage suggests that these were intentionally designed differences, and these track with a broader focus on tool portability during the Initial Formative and Early Formative periods.

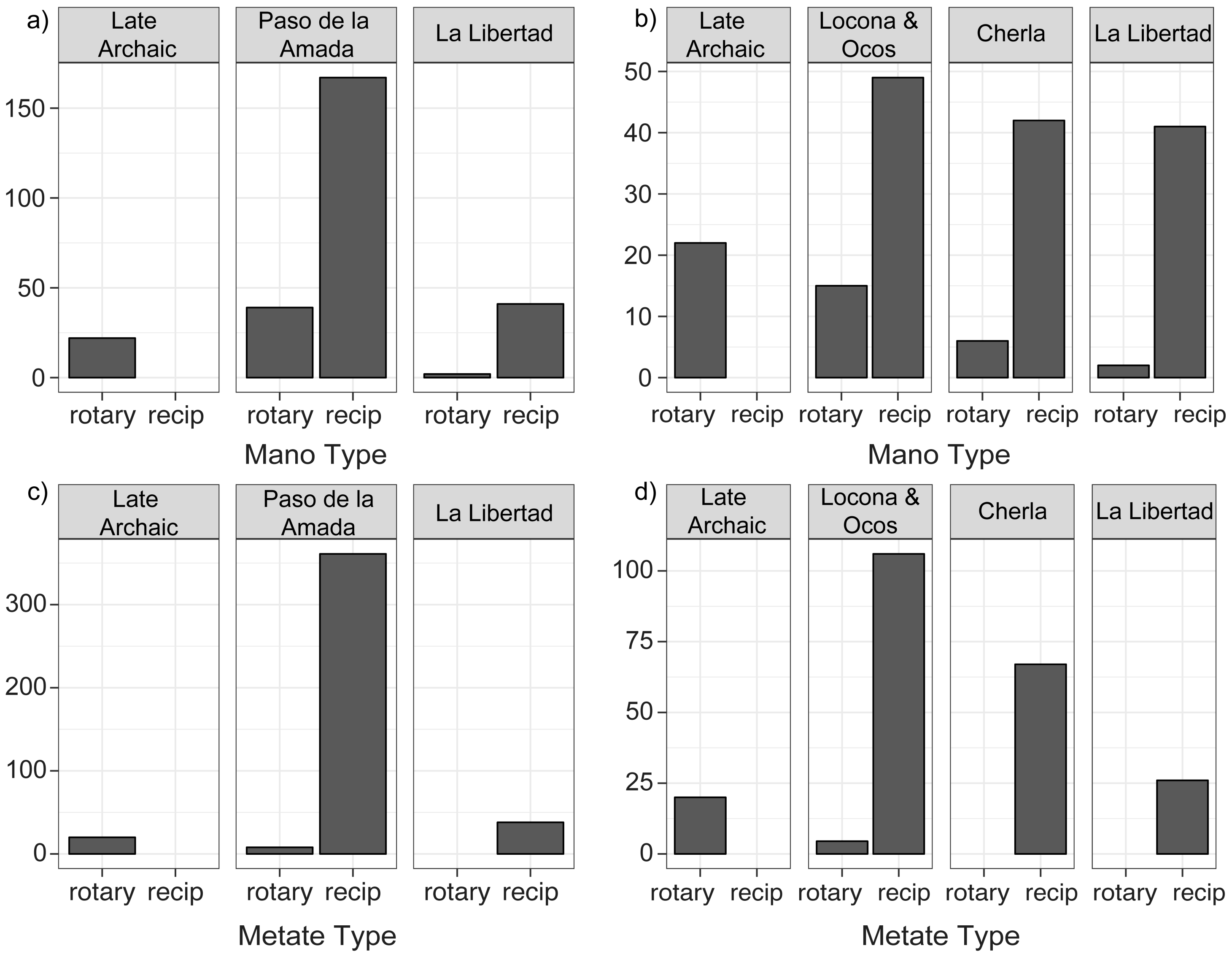

Figure 2.22. Proportions of rotary and reciprocal grinding tools from Late Archaic sites in the Soconusco (Voorhies 1976, 2004), Paso de la Amada, and La Libertad (Clark 1988): **(a)** counts of reciprocal and rotary manos. **(b)** counts of reciprocal and rotary manos at a finer temporal scale. **(c)** counts of rotary and reciprocal metates. **(d)** counts of rotary and reciprocal metates at a finer temporal scale.

Table 2.13. Rotary and Reciprocal Mano Type Counts from the Soconusco and Southern Chiapas.

Period / Site	**Mano Type / Subtype**						
	Rotary/ Handstone (count)	*Small Reciprocal (count)*	*Medium-Large Reciprocal Manos (count)*	*Untyped Reciprocal Manos (count)*	*Percent Rotary/ Handstone*	*Percent All Reciprocal*	*Percent Medium-Large Reciprocal*
All Late Archaic	22	0	0	0	100%	0%	0%
Paso de la Amada	38	5	74	87	19%	81%	75%
La Libertad	2	1	31	12	4%	96%	94%

Note: Late Archaic data are from Voorhies (1976, 2004), La Libertad data are from Clark (1988).

Table 2.14 Rotary and Reciprocal Metate Type Counts from the Soconusco and Southern Chiapas.

Period	**Metate Type / Subtype**					
	Rotary/ Netherstone (count)	*Strategic Reciprocal (count)*	*Expedient Reciprocal (count)*	*Footed Metates (count)*	*Percent Rotary/ Netherstone*	*Percent Reciprocal*
All Late Archaic	20	0	0	0	100%	0%
Paso de la Amada	11	289	6	0	4%	94%
La Libertad	0	29	11	1	0%	100%

Note: Late Archaic data derived from Voorhies (1976, 2004), La Libertad data derived from Clark (1998).

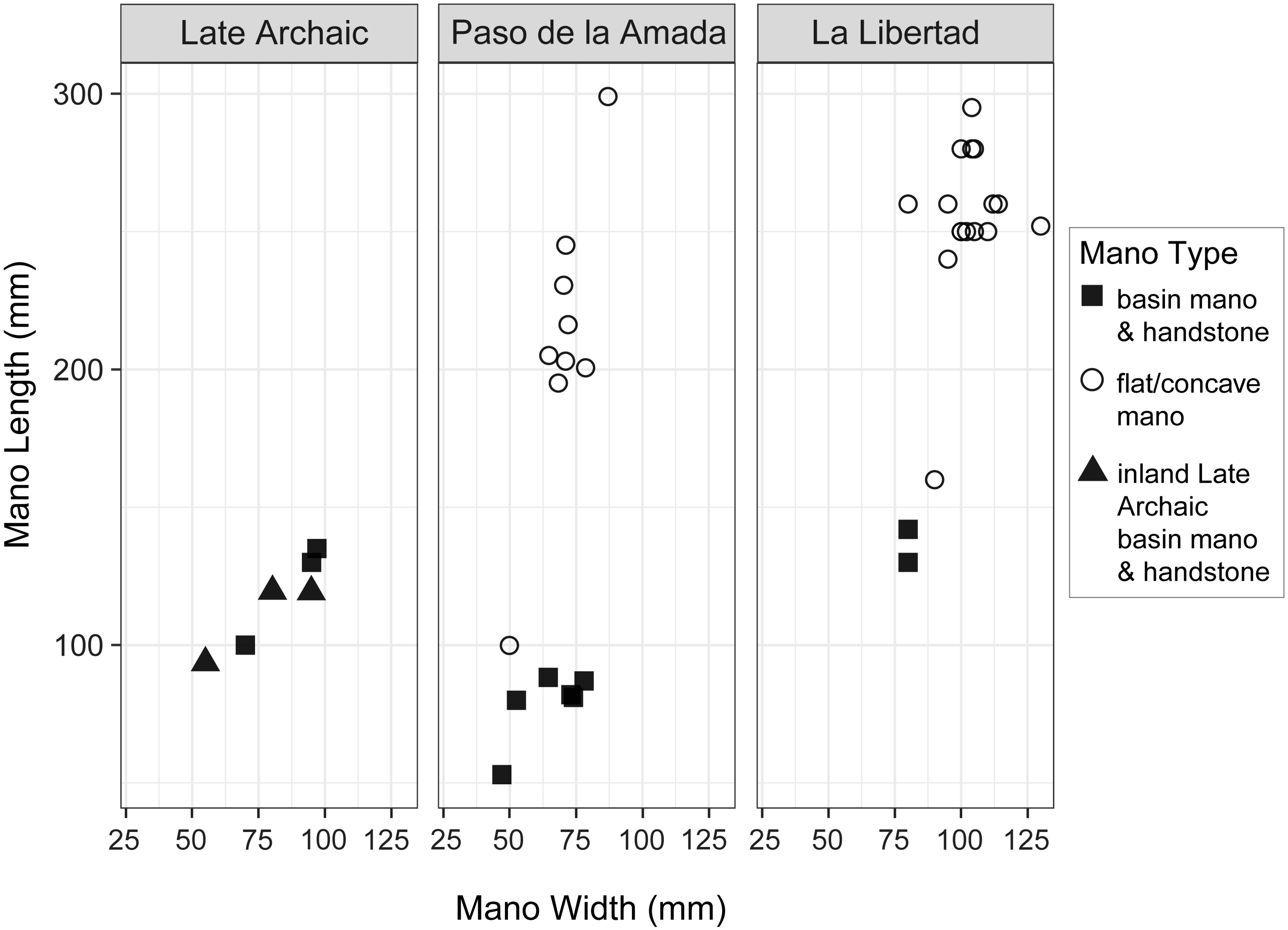

Figure 2.23. Metric attributes of manos and handstones from Late Archaic sites in the Soconusco, Paso de la Amada, and La Libertad. Note that the single flat/concave mano outlier at La Libertad and Paso de la Amada are the rare "small" subtypes described in the current chapter. Late Archaic data are from Voorhies (1976, 2004); La Libertad data are from Clark (1988).

However, the assemblages from La Libertad and Paso de la Amada have far more in common than the Late Archaic and Initial or Early Formative assemblages of interest. Even seemingly non-functional design attributes of manos at Paso de la Amada and La Libertad bear a resemblance to one another. For example, the ends of most manos at La Libertad were well-shaped or polished during manufacture even though few were used on bordered reciprocal metates (Clark 1988:116–127). This description, verbatim, also applies to the dominant mano style at Paso de la Amada, although here no manos showed evidence of use in a bordered reciprocal metate (Figure 2.6). These data suggest that the Late Archaic to Initial Formative transition represented a qualitative change in food processing for daily meals, while the Early Formative to Middle Formative transition is better characterized as an intensification of the maize processing tradition.

One last important yet subtle point of contrast between the designed maize processing tools at La Libertad and Paso de la Amada is worth noting. Clark (1988:129) argues that the maize processing manos at La Libertad were made by craft specialists. The morphological consistency displayed in Figure 2.23 and Table 2.15 lend support to this. I doubt that this was the case at Paso de la Amada and find it likely that the greater standard deviations in the lengths of maize processing manos at Paso de la Amada are related to the manufacture of such tools at the household level.

Table 2.15. Projected Lengths and Widths of Medium to Large Flat/Concave Manos.

Site	**Proj. Len. N=**	**Mean Len. (cm)**	**SD Len. (cm)**	**Proj. Wid. N=**	**Mean Wid. (cm)**	**SD Wid. (cm)**	**Thic-kness N=**	**Mean Thic-kness (cm)**	**SD Thic-kness (cm)**	**Mean Area (cm^2)**	**SD Area (cm^2)**
Paso	8	22.4	3.5	19	7.3	0.8	32	5.6	1.5	165.7	41.4
La Libertad	15	26.1	1.6	24	10.4	1.1	24	6.7	1.5	270.9	31.8

Note: La Libertad data derived from Clark (1988).

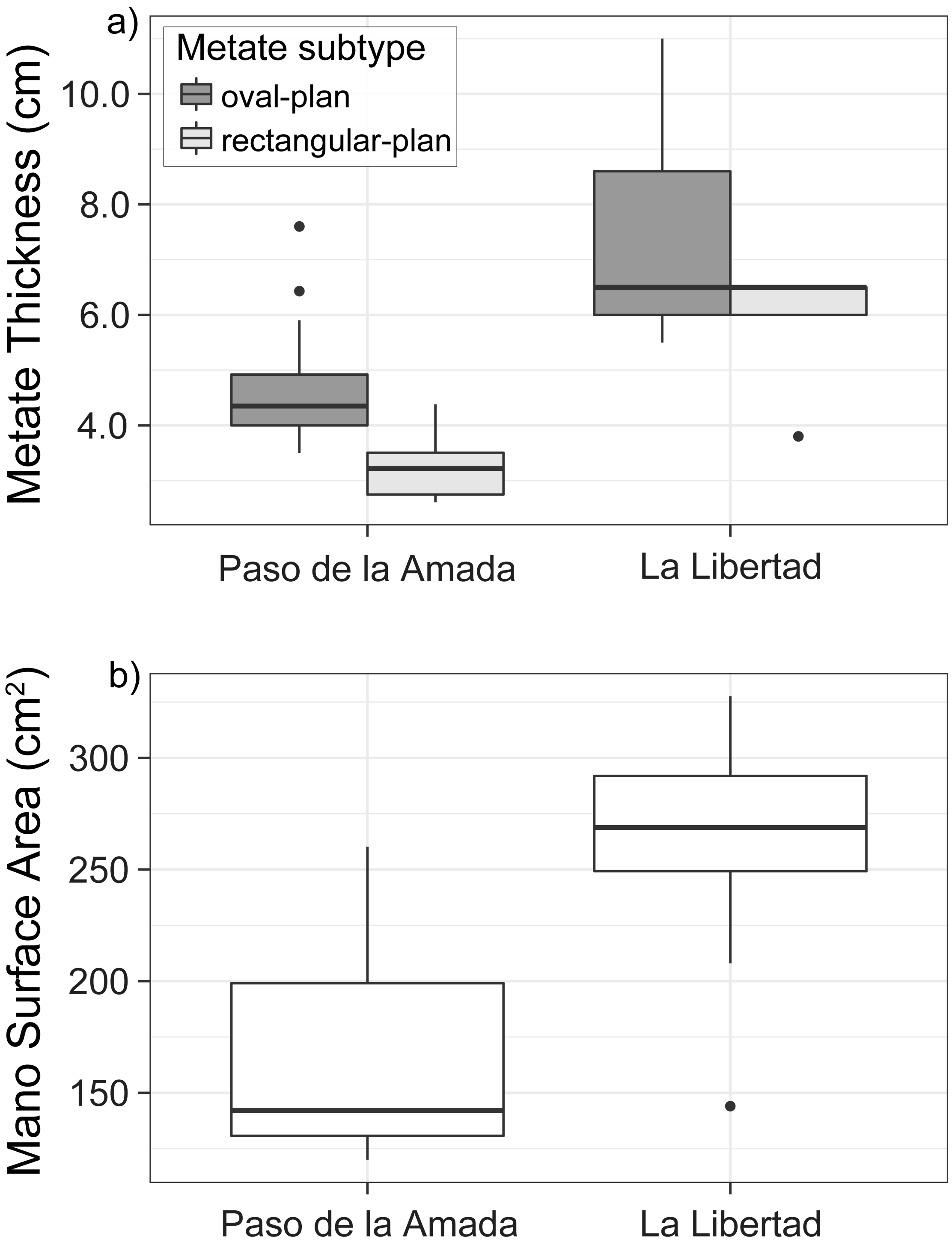

Figure 2.24. Metric attributes of designed, reciprocal-stroke, active and passive ground stone tools from Paso de la Amada and La Libertad: **(a)** Thickness of oval-plan and rectangular-plan flat/concave metates. **(b)** Surface area (length * width) of medium to large flat/concave manos. La Libertad data are from Clark (1988).

Table 2.16. Mean Thicknesses of Flat/Concave Metate Subtypes Recovered from Paso de la Amada and La Libertad.

Site	**Oval Plan Metate Thickness N=**	**Mean Oval Plan Metate Thickness**	**SD Oval Plan Metate Thickness**	**Rectangular Plan Metate Thickness N=**	**Mean Rectangular Plan Metate Thickness**	**SD Rectangular Plan Metate Thickness**
Paso de la Amada	41	4.6 cm	0.9 cm	10	3.2 cm	0.6 cm
La Libertad	11	7.5 cm	2.0 cm	5	5.9 cm	1.2 cm

Note: La Libertad data are from Clark (1988).

Discussion

In-depth analysis of 927 ground stone tools from Paso de la Amada supports the basic premise that maize was processed for daily meals with increasing frequency between the Late Archaic and the Middle Formative, but makes clear that technological style associated with such culinary traditions were in place by 1700 BC and intensified through time. Although the current research cannot provide insight into plant food processing traditions during the Barra phase (1900–1700 BC), previous assessments suggest a greater affinity with Late Archaic traditions (Clark 1994:234–236; Clark et al. 2007:29; Lowe 1967). If this is indeed the case, Locona plant food processing represents a dramatic shift, with early villagers converging on a shared set of routine practices that currently have no known antecedent at coastal or inland Late Archaic sites in the Soconusco. This is not surprising considering the pace, scale, and scope of social change that occurred between 2200-1700 BC, and Paso de la Amada's status as the largest known community center during the Locona phase. Instead, the focus on reciprocal-stroke grinding using designed manos and metates shares a greater affinity with maize-centric food processing practices at community centers during the Middle Formative, albeit with tools that were not as efficient as those used later in time.

Focus on processing maize for daily meals intensified in the Cherla phase. That may have been a hinge point, when maize processing equipment became relatively standardized with respect to the selection of higher quality raw materials and formally shaped tools. The toolkit associated with pigment processing also changed at this time (see previous discussion), and such shifts and are likely related to broader social changes that at Paso de la Amada following the onset of the Early Formative. Nevertheless, it is clear that the technological style associated with designed, reciprocal-stroke ground stone tools used to intensively process maize in Mesoamerica for thousands of years preceding Spanish arrival has its roots in the Initial Formative.

Towards a Cuisine of the Initial Formative

The current study also suggests that even while the shift towards more frequent maize processing for daily meals was underway, community members continued using mortars, pestles and rotary stroke manos. While strategically designed mortars and pestles are well-represented at Paso de la Amada (albeit in far smaller relative proportions compared to maize processing tools) and other Initial/Early Formative sites, few have been found at coastal or inland Late Archaic sites in the Soconusco. Formal mortars and pestles were therefore used in greater quantities at Paso de la Amada compared to the current Late Archaic sample, even as formal maize processing tools began dominating ground stone equipment. Thus, the designed pestles and mortars widely noted from Initial and Early Formative contexts may represent a *break* with local Late Archaic culinary traditions, or at the very least, a break with Late Archaic stone-grinding traditions in the Soconusco. This compares favorably to Clark's (1994:242) proposal that the mortars and pestles used during the Late Archaic are more far robust in comparison to the lightweight, thin mortars and pestles manufactured during the Initial and Early Formative.

In general, these findings bear a resemblance to those from large projects in Central Mexico that span the Late Archaic to Formative divide. For example, the Tehuacan Valley project uncovered a far greater relative frequency of strategically designed flat/concave metates and medium to large flat/concave manos, *and* strategically designed pestles from Early Formative contexts compared to Late Archaic contexts. Furthermore, Initial and Early Formative deposits also contained new pestle (bell-shaped) and mortar (shallow-lipped) types, both of which are represented in the Paso de la Amada assemblage. I therefore contend that setting up a dichotomy between intensive maize processing and the use of mortars and pestles during the Initial and Early Formative may in fact mask evolving culinary traditions even if these artifact classes largely fell into disuse by the Middle Formative. Given the persistence of medium and large-sized crushing mortars in the Initial and Early Formative assemblage, even when use of formal reciprocal stroke manos and metates intensifies, it seems clear that all of these tools were part of a single culinary tradition that uncoincidentally emerged during a period of dramatic social and political change.

Conclusion

Given the myriad of social changes that undoubtedly accompanied the shift to village life (Bandy and Fox 2010; Kohler and Varien 2012), and the importance of daily meals in the construction and maintenance of a collective identity (Hastorf 2010, 2016; Twiss 2007, 2012; Pollock 2015), a shared cuisine was likely crucial for the growth and success of Paso de la Amada. I argue that the appearance of designed and morphologically consistent food processing equipment with no currently known local precedent is evidence for the emergence of a shared cuisine capable of integrating community members into the grind of early village life. From the social learning associated with the initial manufacture of ground stone tools with a strong technological style, to the routine food processing associated with daily meals and communal events, individuals and households at Paso de la Amada reproduced and negotiated the social fabric of Initial Formative and Early Formative society through emerging and evolving foodways. Previous studies have considered the relationship between food, identity, and social change at Paso de la Amada primarily through a focus on prestige foods and competitive feasting (Blake and Clark 1999; Blake et al. 1991; Blake et al. 2004; Clark 2004; Lesure and Blake 2002; Smalley and Blake 2003). However, archaeological studies of food and feasting in more egalitarian early village dwelling societies illustrate an emphasis on the collective, with feasting foods often comprised of scaled-up versions of daily meals (Dietler and Hayden 2001; Mills 1999, 2004; Potter 2000; Wills and Crown 2004). Given that leadership in such societies is contingent on group consensus (e.g. Carballo 2012; Carballo et al. 2014; DeMarrais and Earle 2017; Halperin 2017; Mills 2000), and the labor associated with financing such meals extends well-beyond a single household (Gumerman 1997; Pollock 2012) the emergence of shared food processing traditions and morphologically consistent tools also provided an opportunity for incipient elites to draw on the labor of community members for communal events. If we are interested in understanding the relationship between food and social change at Initial Formative villages in the Soconusco a focus on quotidian household practices would help untangle the relationship between daily meals and feasts (see Pollock 2015). I find it likely that there was a reciprocal relationship between the development of a shared Initial Formative cuisine and its promotion by elites that could benefit from the labor of community members using a standardized set of tools and recipes (cf. Joyce and Henderson 2007). This may in part explain the increasing manufacture and use of designed, reciprocal, passive and active ground stone tools during the Initial Formative to Early Formative transition. These tools share many functional and stylistic characteristics with maize processing tools found at proto-urban centers in southern Mesoamerica during the Middle Formative and Late Formative periods (see previous discussion), and I argue that the tools at Paso de la Amada and these later sites are part of a shared technological style (*sensu* Dietler and Herbisch 1998) associated with strongly patterned social and cultural behaviors.

In summary, Paso de la Amada residents manufactured and used a distinctive suite of food processing, non-food processing, and manufacturing ground stone tools with no currently known precedent in the Soconusco from 1700 BC onwards. This suggests a distinctive cuisine either accompanied the shift to settled village life, or developed soon thereafter alongside dramatic social changes during Locona phase. Initial Formative and Early Formative ground stone tool manufacturing traditions and food processing practices at Paso de la Amada share a greater affinity with Middle Formative practices than those during the Late Archaic. This pattern intensifies through time with a narrower focus on reciprocal stroke maize grinding tools of a technological style that remains in place through the Early Formative and Middle Formative periods. At the same time, aspects of Initial and Early Formative ground stone tool manufacture and use are unique in comparison to both Late Archaic and Middle Formative strategies. Unique elements include; 1), the manufacture and use of lightweight pestles and a mortars; 2), designed multi-use pestles used for concomitant processing and manufacturing activities; 3), formal, yet more portable reciprocal stroke metates compared to similar passive reciprocal tools dating to the Middle Formative period; 4), less-wide and less-thick reciprocal stroke manos of a technological style that continues to be used primarily for maize processing during the Middle Formative and Late Formative periods; 5), strongly patterned behavior associated with the manufacture, use, reuse, recycling, and discard of these food processing and non-food processing tools. The latter point deserves greater attention in the future, as our understanding of changing culinary traditions in the Soconusco would benefit from starch-grain and phytolith studies that would allow for the direct identification of the types of foods that were prepared with these unique tools, which undoubtedly extended well-beyond *Zea mays*.

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CHAPTER 3: Diversity-Disturbance Relationships in the Late Archaic Southwest: Implications for Farmer-Forager Foodways

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Abstract:

The late second and early first millennium BC village of La Capas has produced the earliest irrefutable evidence for the intensification of maize agriculture in the Southwest/Northwest. By the second millennium BC early agricultural communities in the Tucson Basin of southern Arizona built sophisticated canal system to increase crop yields. Analyses of macrobotanical data, agricultural soils, and construction and maintenance histories canals during the San Pedro phase at the Las Capas site provides evidence of continuity and changing plant cultivation and collection practices in response to environmental disturbances during the San Pedro phase (1220-730 BC) of the Early Agricultural/Late Archaic Period (2100 BC-AD 50). Although preceramic foodways in the region are widely considered to have remained stable for roughly 2,500 years following the introduction of maize during the third millennium BC, analyses of macrobotanical data reveal that moderate intensity flood events during the Middle San Pedro phase (930-800 BC) preceded the greatest richness and diversity of harvested plants, while reliance on maize was reduced. In contrast, in periods with little environmental disturbance maize was more dominant, with less diversity in other cultivated and foraged plants. Novel cultivation, processing, and foraging practices were initiated in response to disturbance, but persisted after floodplain conditions stabilized. In this paper we suggest that the reciprocal relationship between disturbance and botanical diversity is integral for understanding the long-term resilience of Late Archaic foodways, and that this relationship is best modeled using ecological theories termed the Intermediate Disturbance Hypothesis and the Intermediate Productivity Hypothesis.

El análisis de más de 1300 muestras de flotación provenientes de la excavación de miles de depósitos culturales de la fase "San Pedro" (1220-730 a.C.) en el sitio arqueológico de Las Capas, ubicado en el sur de Arizona, aporta evidencias de continuidad y cambio en el cultivo de recursos vegetales y en las prácticas de recolección como respuesta a perturbaciones ambientales ocurridas durante el periodo "Arcaico Tardío" (2100 a.C. - 50 d.C.). Aunque generalmente se considera que las dietas del periodo pre-cerámico de la región se mantuvieron estables por casi 2500 años después de la introducción de maíz antes de 2100 a.C., los análisis de vestigios macrobotánicos demuestran que eventos de inundación de intensidad mediana ocurridos durante la fase " San Pedro Medio" precedieron el incremento máximo en cuanto a la riqueza y diversidad de plantas recolectadas, mientras que la dependencia en el maíz disminuyó. Por el contrario, en los periodos con menos perturbaciones ambientes, el maíz fue el cultivo dominante, y se redujo la diversidad de plantas recolectadas y cosechadas. Nuevas prácticas de cultivo, procesamiento, y recolección fueron iniciadas en respuesta a estas perturbaciones, las cuales permanecieron después de la estabilización de las condiciones ambientales de la llanura aluvial. Argumentamos que la relación recíproca entre las perturbaciones y la diversidad botánica es esencial para entender la resiliencia a largo plazo de los sistemas de subsistencia del Arcáico Tardío, y que las teorías ecológicas conocidas como “Hipótesis de la Perturbación

Intermedia" e "Hipotesis de la Productividad Intermedia" son los mejores modelos para estudiar dicha relación.

Introduction

Over the last fifty years, a specific set of theoretical perspectives developed in the biological sciences has dominated archaeological research on mobile or nonagricultural subsistence strategies. This research draws primarily on human behavioral ecology (HBE), and more recently on niche construction theory (NCT) to investigate human-environmental relationships following the adoption or development of domesticated plants and animals. While practitioners debate the utility of these perspectives (Codding and Bird 2015; Gremillion et al. 2014; Smith 2015; Zeanah 2017; Zeder 2012, 2015a), or attempt to engage with both frameworks (Mohlenhoff et al. 2015; Steiner and Kuhn 2016; however see Zeder 2014, 2015b), recent complementary research highlights how anthropogenic and natural environmental disturbance factors can influence the long-term trajectory of farming and foraging practices (Bliege Bird 2015; Bird et al. 2016; Codding et al. 2014; Lightfoot et al. 2013). Furthermore, both perspectives also identify risk as a significant factor influencing the decision making of farmers and foragers (Kelly 2013:68-69; Winterhalder and Kennet 2006; Zeder 2012:251).

This paper identifies the relationship between disturbance, risk, and Archaic period foodways through the analysis of macrobotanical remains collected from archaeological features at the Las Capas site, located in the Tucson Basin of southeastern Arizona (Figure 3.1). Macrobotanical data are interpreted in concert with data derived from geoarchaeological and geochemical studies of agricultural systems and soils. When viewed in tandem, these data afford a rich understanding of late second millennium BC food production systems–diachronic trends in the diversity and density of farmed, foraged and cultivated plant foods had implications for long-term stability and change in food production, collection, and consumption practices by community members at Las Capas. Theoretical frameworks developed by ecologists to identify the parameters of diversity-disturbance relationships (DDRs) provide clear and testable expectations for the archaeobotanical assemblages. Results indicate that moderate intensity disturbance events limited the productivity of food production systems and promoted greater short-term ecological and dietary diversity, expectations that are best interpreted using the ecological frameworks of the "Intermediate Disturbance Hypothesis" (IDH) and the "Intermediate Productivity Hypothesis" (IPH). Such moderate-intensity disturbance events can serve as partial barriers to the adoption of more productive yet unsustainable food production practices, and provide community members with the ecological knowledge necessary to overcome future disturbances (Marston 2015). Due to the constrained chronology of the most intensive occupation at Las Capas, and its high-resolution identification via radiocarbon dating, it is possible to empirically track the dynamic relationships among people, plants, and environmental disturbance in early villages through time, and consider the implications of these interactions for the resilience of food production systems.

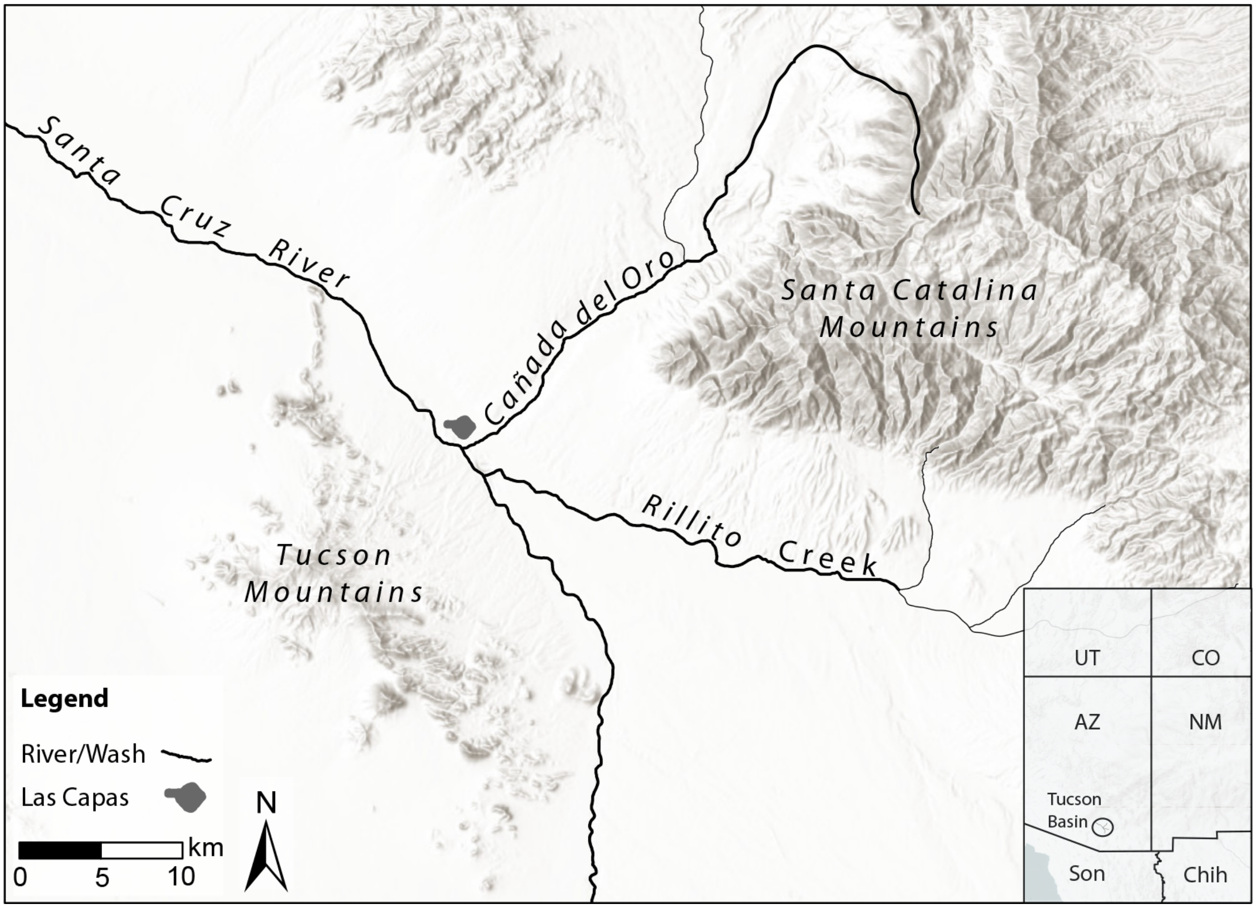


Figure 3.1. Location of Las Capas in the Tucson Basin.

A Global Context for Late Archaic Foodways

In a pattern similar to early food producing societies worldwide (Smith 2001:25; Zeder 2012:248-249), some researchers in the US Southwest and northwestern Mexico have noted a roughly 2500-year period of low-level food production with domesticates dating from the arrival of domesticated maize (*Zea mays* L.) prior to 2100 BC, [1] until the manifestation of large sedentary villages between roughly AD 400-750. Following Smith (2001), low-level food producing societies inhabit the extensive area between foraging and intensive agriculture, and may or may not use domesticated plants. Archaeologists working in southern Arizona and northwestern Mexico have referred to the 2100 BC–AD 50 interval as the "Early Agricultural Period" in lieu of the "Late Archaic", however Smith's (2001) framework requires a "fuzzy" threshold of 30-50% reliance on domesticated plants to be an “agricultural” society. Referring to all groups that adopted maize during this interval as “early agricultural” can gloss over those groups that were not agricultural but invested in “low-level” food production either with or without the aid of domesticates (Smith 2001:27), and mask our ability to study interactions between farming and foraging communities. Regardless, during this period some farmer-foragers built irrigation systems to increase crop yields, yet consistently relied on a wide variety of wild plants.

Several lines of evidence indicate that the structure of Late Archaic foodways cannot be completely attributed to simple causal factors such as population pressure, the limited productivity of early cultivars, and the lack of functional ceramics. For example, heavy reliance on a wide range of small-seeded annual plants began during the Middle Archaic (3500-2100 BC; Roth and DeMaio 2015; Roth and Freeman 2008), and increased dramatically with the adoption of maize during the Late Archaic (Supplemental 3.1), but continued even following the widespread use of ceramics and more productive maize varieties in southern Arizona between AD 50-500 (Diehl 2003:285; Huckell 1998:128-129). In addition, recent demographic reconstructions demonstrate that sustained population growth did not occur in the Sonoran Desert until roughly AD 500-1000 (Kohler and Reese 2014:10102), and individuals from Late Archaic contexts do not exhibit food-related stress pathologies (Watson 2011; Watson and Byrd 2015). Furthermore, during the San Pedro phase (1220-730 BC), farmer-foragers did not have a negative impact on agricultural soils or local fauna even in the most densely occupied areas (Homburg 2015:224; Macphail 2015:153; Waters et al. 2015:301) providing additional evidence for low population densities. There is, however, evidence for widespread conflict (Watson 2011; Watson and Byrd 2015), which may indicate competition over resources without pressure

(Watson and Phelps 2016).

Diversity, Resilience, and Ecological Theory

Diversity, here defined as the abundance of individuals distributed across a number of different observed categories (Maurer and McGill 2011), is often invoked in archaeological research that examines large-scale social and environmental change (Hegmon et al. 2016; Nelson et al. 2011). Despite increasing attention to the role of diversity in these processes, archaeologists have not overtly investigated how the intensity or frequency of disturbance events, impacted the resilience of socio-environmental systems–these are critical components of creating and maintaining diversity. In contrast, ecologists have frameworks that identify the parameters and outcomes of diversity-disturbance relationships in diverse ecological contexts (Connell 1978; Huston 1979, 2014; Sheil and Burslem 2013). These frameworks supply explicit expectations as to how individual responses to discrete disturbance events influence the trajectories, in aggregate, of diversity within groups (for reviews see: Hughes et al. 2007; Huston 2014; Kershaw and Mallik 2013; Miller et al. 2011). In this paper, *resilience* is defined as the ability of a system to absorb disturbance and maintain similar function and structure (Walker et al. 2006), and *disturbance* is defined as any discrete anthropogenic or non-anthropogenic environmental, climatological, or geological event that changes resource availability and/or alters the structure of a biological or anthropogenic system or community (Picket and White 1985).

Two of the most influential, and at the same time contested, DDRs used in ecology are the Intermediate Disturbance Hypothesis (IDH), and the Intermediate Productivity Hypothesis (IPH). Both frameworks seek to problematize relationships amongst (1) disturbance frequency, (2) disturbance intensity, and (3) productivity. The IDH predicts that frequent and/or intense disturbance will suppress diversity in low productivity environments (Figure 3.2a), while infrequent and/or less-intense disturbance will promote the dominance of a narrow range of species in high productivity environments (Figure 3.2b). Moderate intensity disturbance and/or disturbance that occurs in moderate frequencies in intermediate productivity environments are predicted to promote maximum diversity, resulting in what is known as the unimodal or “single-humped model” (Figure 3.2c; Catford et al. 2012; Miller et al. 2011:5643). In turn, the IPH predicts unimodal diversity patterns in response to intermediate disturbance only when productivity is also intermediate (Huston 2014:2383). When productivity is low, less intense disturbance is expected to promote diversity (Figure 3.2d), and when productivity is high, greater intensity disturbance is expected to produce peak diversity (Figure 3.2e).

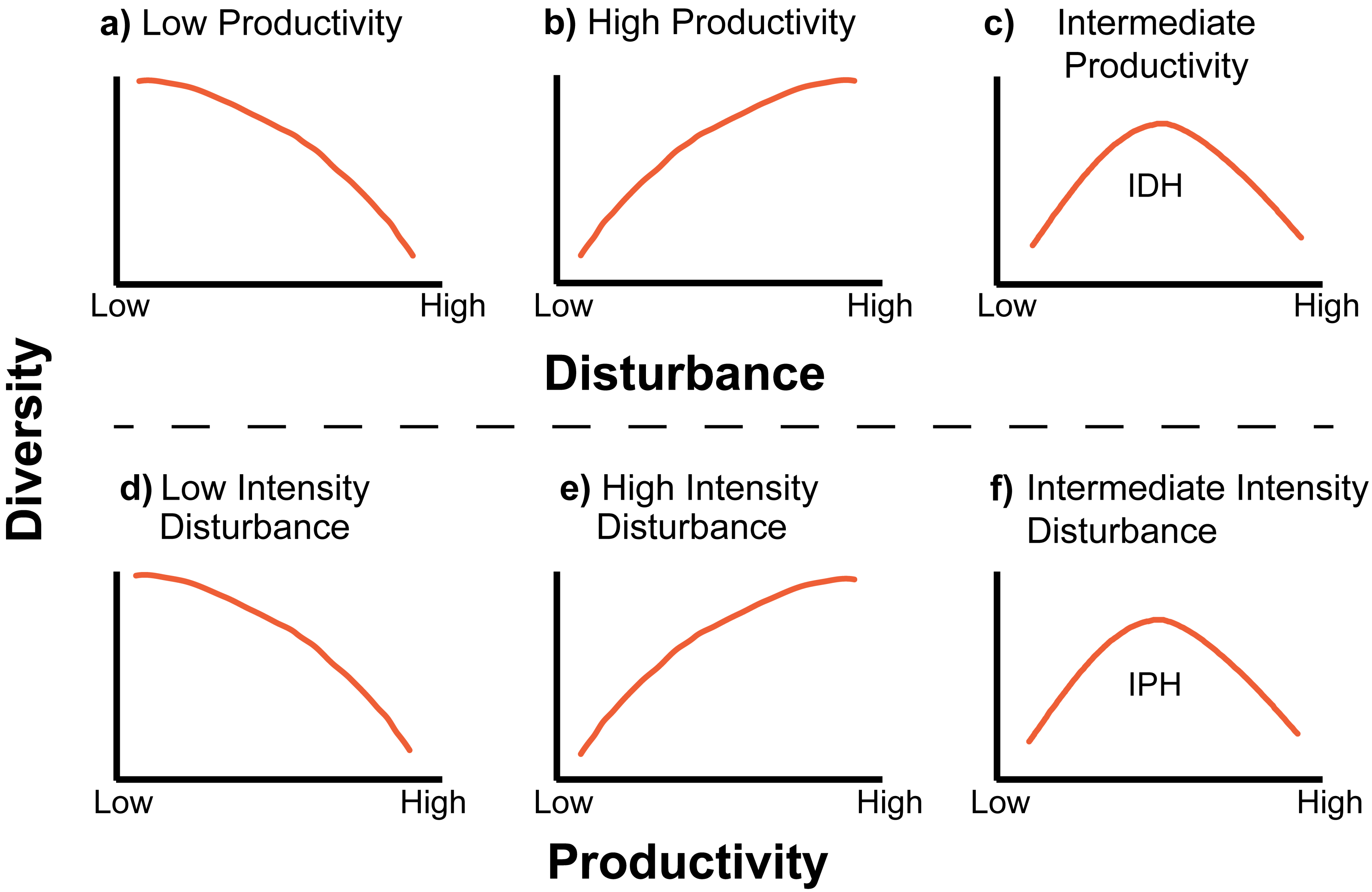


Figure 3.2. Predicted relationships between diversity and disturbance under different productivity and disturbance regimes. The unimodal or "single humped" model known as the "Intermediate Disturbance Hypothesis" occurs when both productivity and disturbance are intermediate. Figure adapted from Huston (2014, Figure 1D).

Ecologists (Miller and Chesson 2009) and archaeologists (Hegmon et al. 2008; Hegmon et al. 2016) view such diversity as a critical factor influencing the resilience of biological and socio-ecological systems, and so the identification of disturbance events via a DDR framework is critical to archaeological studies of human-environmental relationships. However, in addition to non-anthropogenic environmental variables, anthropologists must also consider the dynamic relationship between disturbance, productivity, and diversity within the context of landscapes that are constructed, managed, and manipulated by people for generations. Building on this, some anthropologists have recognized the potential for the IDH to address human-environmental interactions (Baleè 2006:83; Bliege Bird 2015:243-245; Codding et al. 2014; Smith and Wishnie 2000). For example, researchers have recently argued that intermediate levels of anthropogenic disturbance caused by Martu hunters in Australia (Bliege Bird et al. 2013) and Miskitu farmer-foragers in Honduras (Dunn et al. 2012) increase the diversity and patchiness of ecological communities, and contribute to the reliability and sustainability of subsistence strategies. Although ecologists debate the use of the IDH and the IPH as explanatory frameworks (Fox 2013; Huston 2014; Sheil and Burmslem 2013), recent research has identified the IDH as the most accurate predictor of diversity-disturbance relationships in a wide range of plant communities (Kershaw and Mallik 2013; Mackey and Currie 2001). Huston (2014) found that while certain critiques of the manner in which ecologists have employed the IDH and IPH are valid, particularly application with unclear reliance on verbal rather than mathematical models for prediction building, there is still enough empirical validation of the IDH and IPH through field and experimental studies to warrant their use (Huston 2014:2383).

Recall the productivity of a biological community is critical to understanding DDRs. Ecologists argue that the specific mechanisms driving IDH/IPH-like diversity in ecological contexts are plant mortality and latent soil productivity. This is because productivity is directly tied to population growth rates (Huston 2014:2384), and in an agroecosystemic context, growth rates are linked to soil fertility and moisture. Huston (2014:2383) has further specified plant mortality to be “mortality causing events”–in this paper such events are referenced as *disturbance* more broadly, since disturbance events affect plant mortality either through external environmental perturbation, or through changes in plant harvesting and collection activities within an agroecosystemic context. Building on this framework, we propose a model that identifies the mechanisms expected to drive diversity in plant communities and in Late Archaic foodways that considers the relationship between productivity and disturbance within the context of the Las Capas agroecosystem. Before exploring DDRs in the context of late second millennium BC food production systems we need to understand the

The Las Capas Site in a Regional Context

Although maize arrived in the Southwest before 2100 BC, archaeologists debate whether maize was incorporated into the existing hunter-gatherer economy with a minimal impact (Minnis 1992; Wills 1995), a moderate impact (Diehl and Waters 2006), or quickly became a dietary staple (Coltrain et al. 2007; Hard et al. 2008). Despite the disagreement, paleoethnobotanists concur that second and early first millennium BC maize varieties were not as productive as those grown later in the prehispanic era (Adams 1994; Diehl 2005a; Huckell 2006). Recent research suggests that maize was quickly and intensively adopted by some groups, but only casually adopted by others (McBrinn 2010:303-306; Roth 2015, 2016). The Las Capas site has produced the most thoroughly documented evidence of agricultural intensification focused on maize during the late second and early first millennia BC in the Southwest. Las

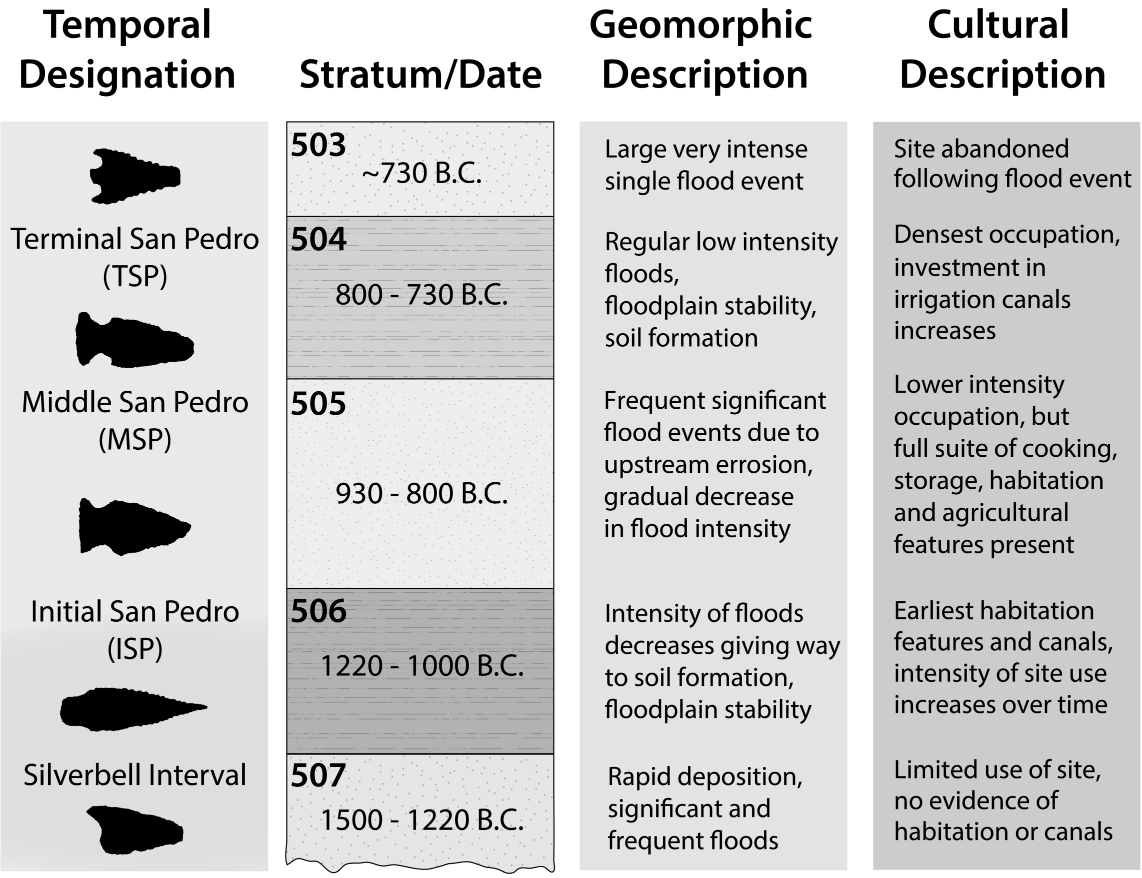
Capas covers roughly 0.8 km^2 and was inhabited between 1500-400 BC, but was intensively and potentially continuously inhabited between 1220-730 BC by a group of roughly 80-250 relatively mobile farmers (Mabry 2008:57-58; Mabry et al. 2008:241-245; Vint 2015:27; Whittlesey et al. 2010:80). Archaeologists have excavated over five thousand cultural features at the site ranging from domestic structures to extramural cooking and storage features. Excavated, mapped, and analyzed ancient agricultural field systems include canals, field cells, and even individual planting pits (Figure 3.3). Analyses of paleoethnobotanical remains from more than thirteen hundred cultural features (Diehl 2005b, 2010, 2015a, 2015b; Sinensky 2013), totaling nearly 6,900 L of archaeological sediment, provide a high-resolution record of human-environmental interactions during the Late Archaic Period, and thus an ideal case study to assess the efficacy of the IDH and IPH in an archaeological context.

Climate, Chronology and the Environmental Context

Las Capas is one of many Late Archaic sites located in the floodplain of the Santa Cruz River in the Tucson Basin. Abundant riparian and floodplain resources were available locally at an elevation of about 750 masl, while bajada (750-1400 masl) and mountain (1400-2800 masl) plants were available within 20 km of the site. A variety of geologic and hydrologic factors contributed to Las Capas being one of only several locations with reliable perennial surface water in the Tucson Basin (Nials et al. 2011:737). Access to moisture is the primary limiting factor for agriculture in the sweltering Sonoran Desert, and the earliest evidence for habitation at Las Capas dates to a stable interval of extended aridity between 1220-930 BC. Community members built canals to increase crop yields, but agroecosystems were still susceptible to destructive floods due to the sites proximity to the Santa Cruz River.

Figure 3.3. Terminal San Pedro Phase (800-730 BC) fields from the 2008-2009 excavations at the Las Capas site. Berms separating individual fields and berms serving as borders along field lateral canals are highlighted in white. Photo courtesy of James Vint, Desert Archaeology, Inc.

The rapid pace of overbank flood deposits and intensive/continuous site occupation has facilitated the development of a detailed chronology of the San Pedro phase occupation (Figure 3.4). The stratum designations developed by Nials (2008, 2015a), as well as the chronology developed by Vint (2015), are used throughout the discussion below, with the most recent strata given the lowest numeric designation (e.g., Stratum 504).[1] Following this chronology, Stratum 506 consists of a stable floodplain deposit that dates between 1220-1000 BC, the Initial San Pedro (ISP) phase. Floodplain conditions during the deposition of Stratum 505 (930-800 BC), the Middle San Pedro (MSP) phase, were characterized by alternating periods of rapid deposition and erosion due to multiple intense flood events triggered by heavy upstream erosion (Nials 2008:50, 2015a:58, 2015b:468). These events likely scoured the latter portions of Stratum 506 and removed the 1000-930 BC stratigraphic interval (Vint 2015:25). Although Stratum 505 was previously considered "culturally sterile" (Mabry 2008:55), recent excavations identified a variety of cultural features indicating that the site was continuously occupied through this period of instability. Stratum 504 (800-730 BC), the Terminal San Pedro (TSP) phase, is characterized by regular low impact overbank flood events (Nials 2008:50), and the time which it represents coincided with a period of reliable precipitation. Each stratum contains a similar range of archaeological features including irrigation canals, domestic structures, and large bell-shaped storage pits. The termination of the San Pedro phase occupation coincides with the deposition of Stratum 503 in roughly 730 BC, a large flood event that inundated the floodplain with an enormous quantity of coarse alluvial material that ultimately led to the site's abandonment.



Temporal Designation	Stratum/Date	Geomorphic Description	Cultural Description
	503 ~730 B.C.	Large very intense single flood event	Site abandoned following flood event
Terminal San Pedro (TSP)	**504** 800 - 730 B.C.	Regular low intensity floods, floodplain stability, soil formation	Densest occupation, investment in irrigation canals increases
Middle San Pedro (MSP)	**505** 930 - 800 B.C.	Frequent significant flood events due to upstream errosion, gradual decrease in flood intensity	Lower intensity occupation, but full suite of cooking, storage, habitation and agricultural features present
Initial San Pedro (ISP)	**506** 1220 - 1000 B.C.	Intensity of floods decreases giving way to soil formation, floodplain stability	Earliest habitation features and canals, intensity of site use increases over time
Silverbell Interval	**507** 1500 - 1220 B.C.	Rapid deposition, significant and frequent floods	Limited use of site, no evidence of habitation or canals

Figure 3.4. Descriptions of San Pedro phase strata and chronology.

Methods and Expected Trends

The effect of the numerous intermittent non-anthropogenic flood events at Las Capas can be modeled by DDRs, which provide a series of expectations for plant diversity. However, accurately gauging the response of local plant communities to different degrees of disturbance requires an assessment of productivity, and the intensity of disturbance events. Since Las Capas community members constructed, modified, and maintained a stable anthropogenic landscape for roughly 500 years, and the agroecosystem revolved around maize production, expectations for productivity are developed from geoarchaeological analyses of agricultural soils and agricultural features (Homburg 2015; Nials 2008, 2015a, 2015b), and are then tested against archaeobotanical data. The intensity of flood events is measured using diachronic studies of floodplain geomorphology, and by assessing the degree to which disturbances impacted agricultural features.

_Productivity and Disturbance at Las Capas

The well-preserved Las Capas canals and fields provide an extensive record of preceramic agricultural systems and soils. Homburg (2015) analyzed nearly three hundred soil samples from these agricultural fields to gauge soil productivity, and concluded that conditions were sufficient for maize farming throughout the 1220-730 BC inhabitation. However, in arid and semiarid environments, such as southern Arizona, access to moisture also influences productivity. Local precipitation patterns reconstructed from regional tree ring records and on-site geomorphology indicate that precipitation was predictable during the ISP and TSP (Nials 2015a:29, 2015b:44, 61), which produced low-intensity overbank flood events, and provided crucial water for irrigation at regular intervals. However, precipitation was more intense and erratic during the MSP, which impacted the reliability of irrigation water (Nials 2008:50, 2015b:58).

Analyses of irrigation features and agricultural soils demonstrate that more intensive cultivation took place when rainfall was reliable. For example, elevated levels of soil salinity only occur in 1220-1000 BC and 800-730 BC fields, which may indicate more intensive irrigation during these periods (Homburg 2015:217). Soil bulk density, a measure of soil compaction attributable to the intensity and frequency of the application of irrigation water to individual fields, is lowest during the 930-800 BC interval and greatest during the earlier 1220-1000 BC period (Figure 3.5a). The concentration of nitrogen in the soils of agricultural fields, however, increases sharply following the transition to the MSP (930-800 BC, see Figure 3.5b). This illustrates that soils were potentially more productive during the intervening MSP, however greater nitrogen content in agricultural soils is also expected when fields are left fallow, or are less intensively cultivated.

One reason that fields may have been less intensively cultivated during the MSP (930-800 BC) is due to several closely spaced and relatively heavy flood events. In contrast to all other floods that occurred during the 1220-730 BC inhabitation, the MSP floods caused changes to local topography and hydrology (Nials 2015b:58), and limited the community's ability to ensure that the built environment provided the primary agricultural plant–maize–with a competitive advantage. For instance, geoarchaeological investigation of the construction, use, and upkeep of canals show that several generations of MSP (930-800 BC) canals were inundated with flood deposits and quickly abandoned, and in one case, a canal was abandoned before it was used (Nials 2015b:50, 60). These 930-800 BC canals were small, and do not show evidence of long-term use or maintenance. However, despite these frequent MSP flood events, communities continued living at Las Capas and investing in irrigation infrastructure, which probably attests to a degree of success in this water management strategy. In contrast, canals were abundant, intensively used, and thoroughly maintained during the earlier ISP (1220-1000 BC, see Nials 2015b:55), and were larger, more abundant, more intensively used and maintained during the subsequent TSP (800-730 BC, see Nials 2015b:63-64).

Therefore, the available evidence demonstrates that the highest levels of latent productivity occurred during the earlier TSP (1220-1000 BC) and most recent periods (TSP 800-730 BC), while erratic precipitation during the intervening MSP most likely supported intermediate productivity. Since the MSP floods were more frequent and more intense than the predictable overbank floods that occurred during the ISP and TSP, but far less intense than the single massive flood at the end of the TSP, the MSP floods are considered intermediate disturbance events. Differences in how community members responded to floods also supports the aforementioned characterization of disturbance events. Community members responded to low intensity floods during the ISP and TSP by maintaining canals, responded to the intermediate flood events by abandoning inundated features and constructing new canals, and responded to the single flood event at the end of the TSP by ceasing to occupy Las Capas after nearly twenty generations.

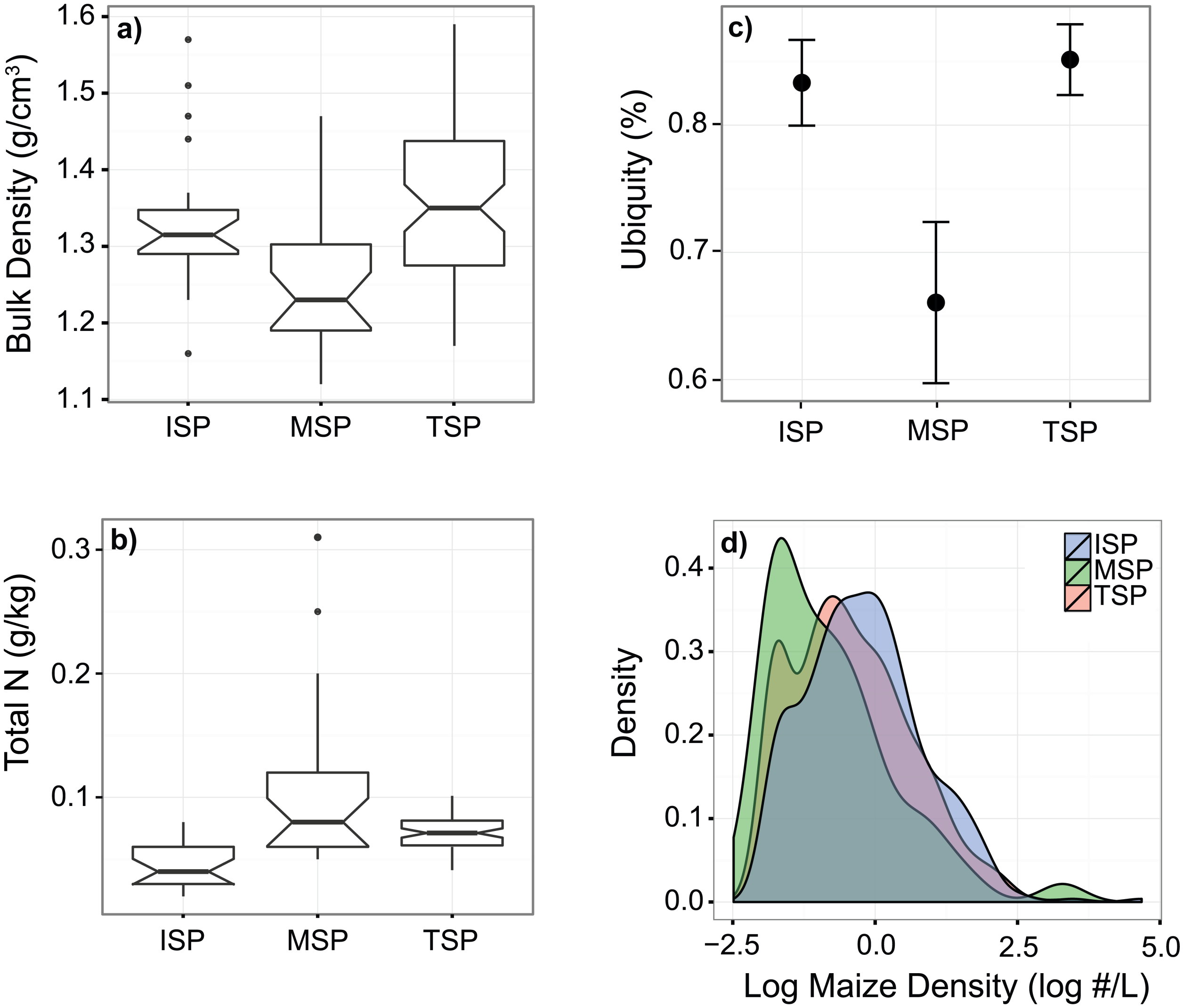


Figure 3.5. Analyses of 1220-730 BC agricultural soils and the primary crop grown by early farmers–maize. **(a)** Mean bulk density of agricultural soils, which is directly related to the intensity and frequency at which irrigation water was applied to fields. **(b)** Total available nitrogen content of agricultural soils through time. **(c)** Mean maize ubiquity with 95% confidence intervals derived from an exact binomial distribution. **(d)** Log transformed maize density.

Expectations for Diversity and Productivity

Drawing on the Intermediate Disturbance and Intermediate Productivity Hypotheses, plant communities during the intervening period of moderate disturbance (930-800 BC, MSP) are expected to diversify in response to intermediate disturbance (Figure 3.6). While one of the ultimate causes of fluctuations in plant diversity detectable in the archaeobotanical record will be due to the intermediate disturbance of the flood events, the proximate mechanisms that increased plant diversity in each time periods are more difficult to ascertain. The influence of the intermediate intensity floods on local plant communities, moreover, was itself shaped by nearly ten generations of farmers that manipulated floodplain conditions. Within this managed agroecosystem the MSP floods would have depressed maize yields through field destruction, as the geoarchaeological evidence above shows, but they also would have increased the diversity of small-seeded ruderal plants that thrive in in fallow fields. As maize yields declined, Las Capas community members may have diversified their food production and foraging practices as risk management strategies (Marston 2011; VanDerwarker et al. 2013). Therefore, any diversity detectable in the archaeobotanical record could indicate either an absolute increase of different resources available to the community, with a congruent change in diet, and/or a change in more diverse harvesting and foraging practices independent of plant type abundance. Neither mechanism is mutually exclusive, although neither possibility can be excluded at the moment.

First, we identify broad patterns in the archaeobotanical data that document the influence of variable environmental conditions on maize productivity and ecological diversity within the agroecosystem. Then, we assess how community members, in aggregate, responded to changes through a focus on particular taxa and groups of plant taxa. We evaluate plant taxa diversity using richness and diversity indices developed in ecology and biology (Magurran 2004).

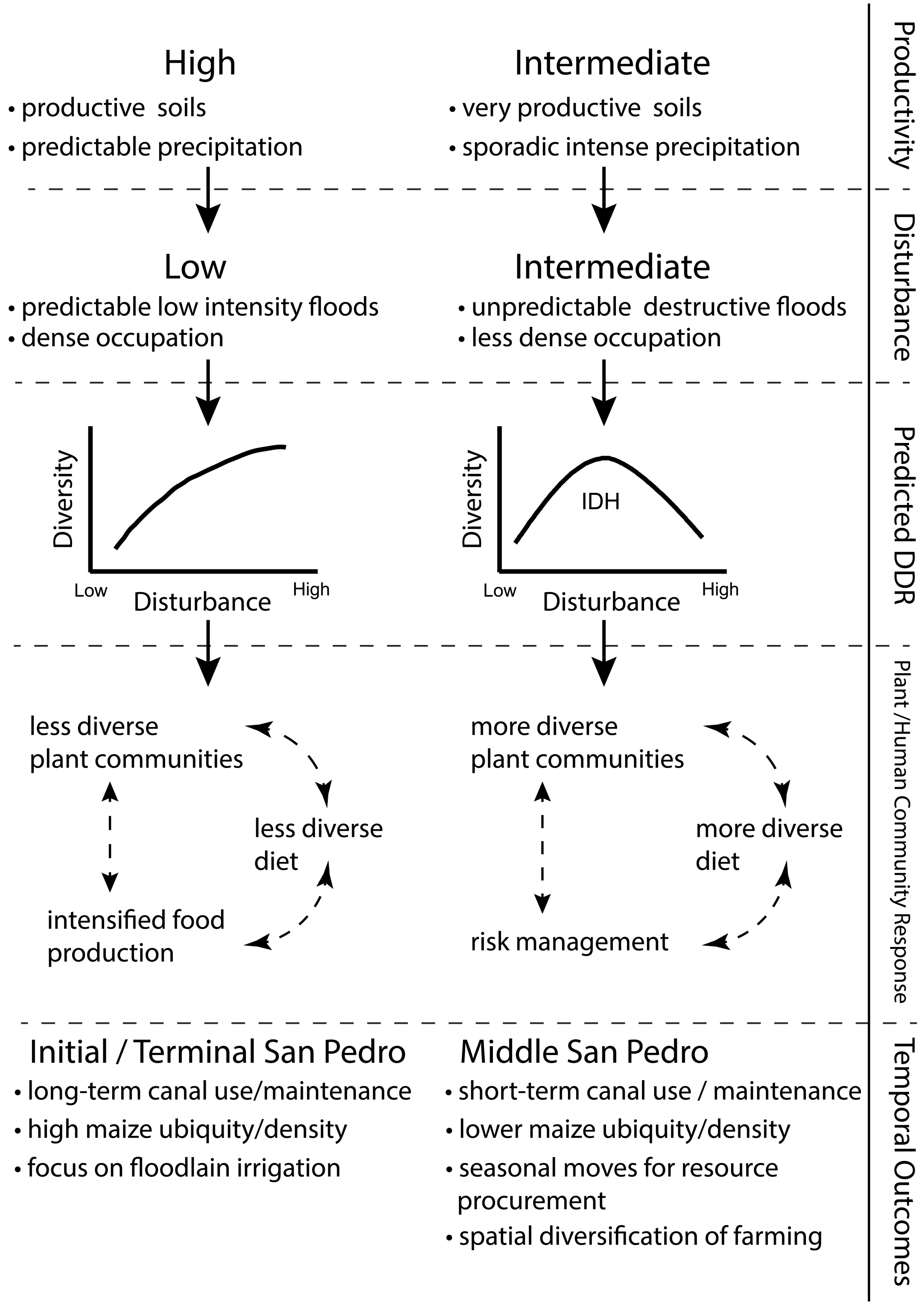


Figure 3.6. Hypothesized relationships between productivity, disturbance, plant biodiversity, dietary diversity, and risk management at Las Capas. The Diversity-Disturbance Relationship (DDR) known as the Intermediate Disturbance Hypothesis (IDH) is expected during the Middle San Pedro since productivity and disturbance intensity were both argued to be intermediate.

Field Collection and Analysis Methods

The data used to address these model expectations were derived from samples of archaeological sediment processed via flotation, and were collected from cultural features by Desert Archaeology in 1998 and 2008-2009. Archaeological plant remains were collected from a variety of intramural and extramural contexts. Information on processing and identification procedures can be found in Diehl (2005b, 2015a) and Sinensky (2013). Sediment samples were processed in a Flote-Tech machine. Light fractions were sorted using nested 2.0 mm, 1.0 mm and 0.5 mm geologic screens. Data used in these analyses are available in Supplemental .2, and Supplemental Table 3.3, and the "R" code used to create the figures is available in Supplemental Text 1. Strategies used to integrate and operationalize the data are described in Supplemental Text 2. In total, 2,391 L from 474 samples yielding 15,492 specimens were analyzed from ISP contexts, 1,138 L from 217 samples yielding 16,233 specimens were analyzed from MSP contexts, and 3,345 L from 633 samples yielding 39,099 specimens were analyzed from TSP contexts (Table 3.1).

Table 3.1. Flotation Sample Information, *Zea mays* Quantitative Measures, and Mean Diversity.

Interval	***N***	**Number of Identified Specimens (NISP)**	**Mean Volume (Liters)**	**Mean Maize Ubiquity**	**Mean Maize Density[a]**	**Kernel: Cupule Index[b]**	**Mean Inverse Simpson Diversity**
ISP total	474	15,492	5.04	83.3%	1.103	1:45	2.323
ISP intramural	37	787	4.70	91.9%	.814	-	-
ISP extramural	437	14,705	5.07	82.6%	1.127	-	-
MSP total	217	16,233	5.24	65.6%	.469	1:6	2.800
MSP intramural	4	174	5.50	75.0%	.625	-	-
MSP extramural	213	16,059	5.24	65.4%	.466	-	-
TSP total	633	39,099	5.28	85.2%	.989	1:174	1.640
TSP intramural	56	2,866	5.08	80.4%	.855	-	-
TSP extramural	577	36,586	5.31	85.6%	1.002	-	-
Total	1324	70,824	5.19	81.3%	0.945	-	-

Note: ISP = Initial San Pedro (1220-1000 BC), MSP = Middle San Pedro (930-800 BC), TSP = Terminal San Pedro (800-730 BC).

[a] Specimen count divided by sample volume–maize density calculation does not include seven extreme outliers with maize counts greater than 80.

[b] Kernel to cupule index only includes samples with available “specimen part” data. This includes 87 samples from the ISP, 45 samples from the MSP, and 355 samples from the TSP.

Intermediate Disturbance, Food Production, and Shifting and Routine Practices

Analyses of the macrobotanical data show that the productivity of the Las Capas agroecosystem was high during the earlier ISP and latter TSP, but intermediate during the MSP. Maize ubiquities (proportional presence across samples) are high during the ISP and are well above the values of all other plant resources (Figure 3.5c; Supplemental Table 3.4). However, maize ubiquities decline, and are lower than preferentially cultivated and collected ruderal plants during the following MSP. During the TSP, maize ubiquities return to high levels and are again more ubiquitous than all other plant resources. Maize density (number of specimens per analyzed liter of sediment) values suggest a similar pattern, with a high density during the ISP and TSP, and lower values during the MSP (Figure 3.5d). In summary, paleoclimate proxies, studies of agricultural soils, the construction and upkeep histories of canals, and macrobotanical data demonstrate that the intermediate flood events had a notable impact on food production, but community members continued farming in the floodplain.

Diversity in Response to Disturbance

Two diversity measures were calculated from the macrobotanical data to test the empirical predictions of the IDH, namely the increased diversity of botanical resources after moderate disturbance. As stated previously, there are numerous indices with which both diversity and richness might be calculated. Richness , which measures the number of different species or taxonomic categories present within a sampled population (Magurran 2004:76), is one of the most common indices, and is highly correlated with the number of identified specimens (*NISP*) in archaeobotanical (Lepofsky and Lertzman 2005), archaeological (Kintigh 1984), and ecological assemblages (Magurran 2004:74-84). Therefore, statistical methods are necessary to control for differences between the number of identified botanical specimens in ISP (15,492), MSP (16,233) and TSP (39,099) contexts (see Table 3.1). For sample-based assemblages, like those in archaeobotanical research, statistical methods must adjust for not only the number of samples (*N*), but also for sample volumes (see Table 3.1 for sample counts and volume information).

Mitigating Sample Size Effects

We mitigate the effects of sample size through *sample-based rarefaction*, a re-sampling *X* times with replacement of a pool of *N* samples, at random, with the average number of distinct taxonomic categories (*S*) plotted against the number of samples (*N*) or individuals (*NISP*). Sample-based rarefaction reduces the heterogeneity introduced by the varying numbers identified specimens in samples of different volumes through resampling. However, despite being sample-based, all analyses focused on *species richness* must ultimately compare the number of species against the number of *individuals* (NISP; Gotelli and Collwell 2001:382). In contrast, if the object of analysis is *species density*, then a comparison of the number of samples to the average expected richness should be used (Colwell et al. 2004). The sample-based rarefaction employed in this paper weights the expected richness per sample by "sampling effort," which here is an adjustment for different flotation volume sizes. Therefore the species richness presented below is more properly a species density per sample (per stratum) adjusted for equivalent quantities of sampled sediment. The analysis of species richness was conducted in program R (R core team 2013), primarily using the vegan package (Oksanen et al. 2016).

We also identified changes in the diversity of Las Capas plant foods using the Simpson's

Index (Magurran 2004:115). The index computes the sum of the squared proportional abundance of individuals (p_i^2) across a set of taxa, and in the current paper is expressed as the inverse ($1/D$) to place it on a scale such that larger numbers imply a greater amount of diversity, that is, less dominance by any set group of taxa (eq. 3.1, also see Maurer and McGill 2011:56). A sample-based rarefaction using the Inverse Simpson's Index was calculated using the freely available software EstimateS (Colwell 2013), again to control for differences in sample size (and NISP) between strata (Supplemental Table 3.3).

$$D_{Simpson} = \frac{1}{\sum p_i^2} \qquad \text{(eq. 1)}$$

$$E = \frac{D_{Simpson}}{S} \qquad \text{(eq. 2)}$$

The results of the modified sample-based rarefaction indicate that Las Capas inhabitants relied on a restricted number of taxa during the ISP, on a wider variety of resources following moderate disturbance during the MSP, and then returned to a more restricted strategy during the TSP (Figure 3.7a). However, the rarefaction curves for the ISP and MSP do not reach an asymptote (plateau) and as a result have not reached a species saturation point–further sampling could yield different curves (Gotelli and Colwell 2001:388). The Inverse Simpson's Index also illustrates that assemblage diversity is highest during the MSP, and reaches its lowest level in the TSP (Figure 3.7b). Overall, these diversity measures present clear evidence of considerable directional change in plant use following the intermediate flood events. The fact that these changes track other archaeobotanical and geoarchaeological measures of maize productivity suggest a broader food procurement and production strategy in response to the greater risk and uncertainty associated with floodplain farming during the MSP. The decision to cultivate or collect certain native plants, however, and the particular ways that community members interacted with these resources reflects local decision making in response to such changes. While increasing diversity in the archaeobotanical assemblage in part reflects the aforementioned greater plant diversity in floodplain plant communities predicted by the IDH, it is not strictly necessary that dietary change is congruent with plant community diversity (Figure 3.6). The specific responses of Las Capas community members to increased plant diversity would have been mediated through decision making in routine cultivation and collection practices, which are identifiable in the macrobotanical assemblage.

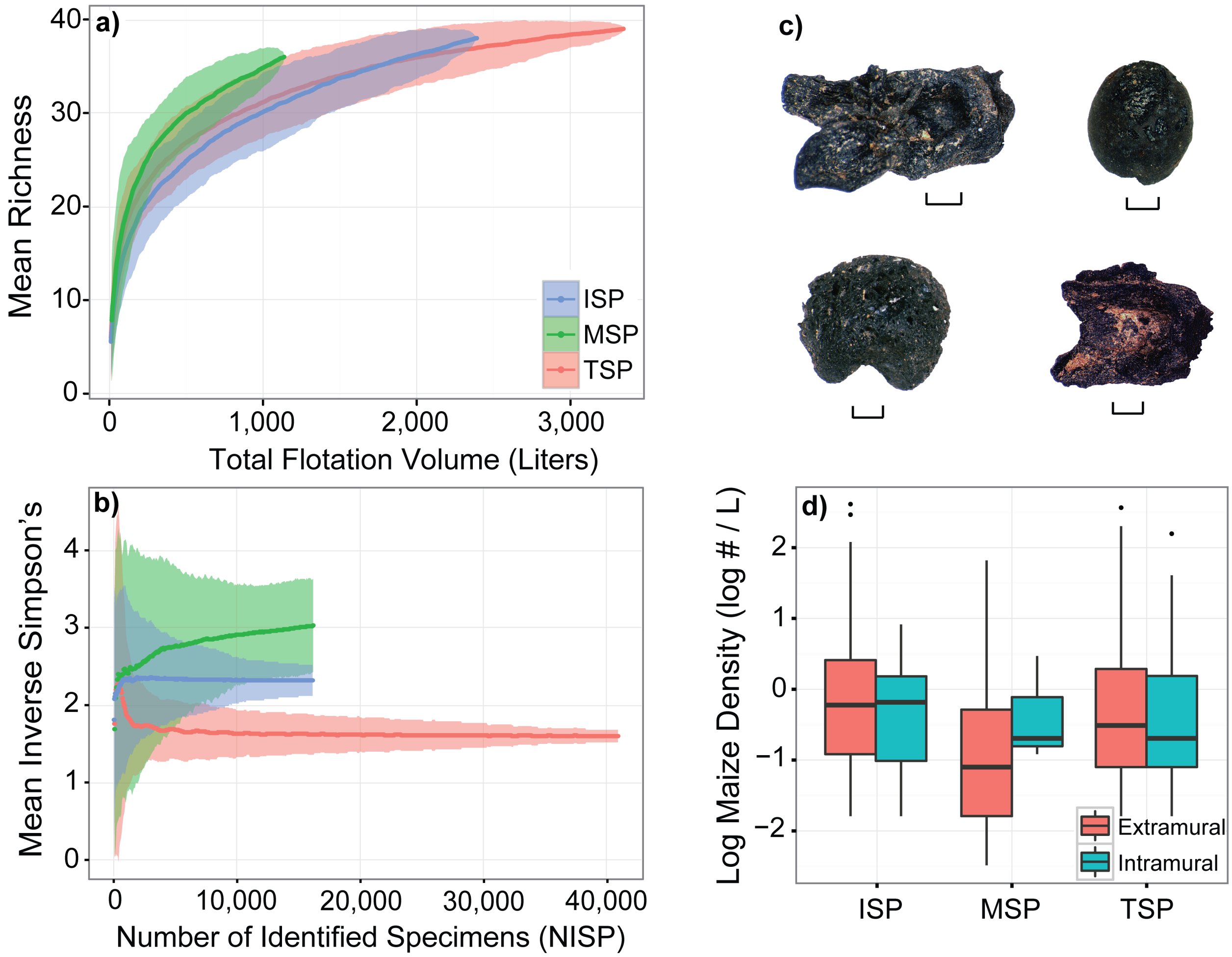


Figure 3.7. Diversity measures, and intramural/extramural maize densities. **(a)** A species accumulation curve based on a "random" rarefaction method (Gotelli and Colwell 2001) comparing mean richness to the amount of sampling effort, which here is represented as the total quantity of sampled sediment volume per stratum. Shaded areas represent 95% confidence intervals. **(b)** Sample based rarefaction using mean Inverse Simpson's Diversity Index values. Shaded areas represent two standard deviations from the mean–these approximate confidence intervals. **(c)** Carbonized maize cob and kernels parts recovered from Middle San Pedro phase (930–800 BC) contexts at Las Capas. All scales represent one millimeter. **(d)** Log transformed maize densities by stratum from intramural and extramural feature contexts dating to the Initial (ISP, 1220-1000 BC), the Middle (MSP, 930-800 BC), and Terminal San Pedro (TSP, 800-730).

Changing Routine Cultivation Practices

Although plant remains uncovered from a single feature usually represent the aggregation of a number of discrete events, fluctuating resource ubiquity and density are indicative of changing daily plant procurement and processing (van der Veen 2007). We can see such changes in the relative proportions of taxa present in flotation samples collected from intramural and extramural contexts through time at Las Capas. Maize density is roughly equivalent on average across strata in intramural floor contexts, although the MSP sample is small (Table 3.1; Figure 3.7d). This suggests that maize at Las Capas was processed, stored, or used for fuel in a similar fashion within domestic structures over time. Conversely, maize density and ubiquity is considerably lower in extramural contexts during the MSP, and this change suggests shifting in maize processing practices.

This change is also seen in the ratio of maize kernels to cupules over time. Paleoethnobotanists working in diverse environmental and cultural contexts have proposed that lower kernel-to-cupule ratios are evidence of processing activities such as dehusking and shelling, while higher kernel-to-cupule ratios are more likely indicative of consumption (Scarry and Steponaitis 1997; Turkon 2004:236; VanDerwarker 2006:102-106). In arid regions worldwide, crop byproducts, including maize cobs, are typically burned for fuel (Miksicek 1987:227; Rocek 1995:230; van der Veen 1999), while kernels more likely represent consumption events. MSP contexts contain much greater kernel-to-cupule ratios compared to ISP and TSP deposits (Table 3.1). This may indicate that productive fields were located a greater distance from the Las Capas site during the MSP, and that crops were processed at a distance from the site to reduce transport costs, or that maize was processed and consumed in ways that aided the preservation of kernels with increasing frequency during the MSP. Concomitant shifts in kernel-to-cupule ratios declining investment in irrigation infrastructure may suggest spatial diversification as a risk management strategy (Goland 1993; Marston 2011; Stone and Downum 1999). Floodplain irrigation was likely one of several farming strategies practiced by mobile farmers at Las Capas, and when the risk posed by sporadic rainfall and the intermediate flood events was recognized, inhabitants may have redirected their labor to farming the mouths of alluvial fans and ephemeral streams (Bryan 1929; Mabry 2005; Nabhan 1979). While the increasing importance of non-irrigation farming likely encouraged community members to diversify food production strategy, discrete changes to how people collected, processed, and stored foraged foods during the MSP also had implications for the resilience of Late Archaic foodways.

Shifting Foraging Strategies

In addition to a potential spatial diversification of farming practices, archaeobotanical data also provide evidence for changing foraging practices at Las Capas. Quantitative measures suggest that community members responded to the changing structure of floodplain plant ecology by harvesting larger quantities of certain types of ruderals taxa–plants that are encouraged by farming activities and human impacts more broadly. While the ubiquity of the most economically significant ruderal taxa such as *Chenopodium* spp. and *Amaranthus* spp. (Cheno-ams) remains high throughout the 1220-730 BC interval, the ubiquity and density of dispersed ruderal plants, and the density of wild grass seeds both increase dramatically during the MSP (Figure 3.8; Supplemental Table 3.4). This suggests that dispersed ruderal plants were more intensively culled to limit competition with maize during the ISP and TSP, and were perhaps consumed as greens (Castetter and Bell 1942; Crosswhite 1980), but were permitted to grow to maturity during the MSP.

Trends in the macrobotanical data also reveal a changing procurement practices associated with culturally economically significant foraged plants that were only available in significant quantities by venturing from the floodplain village into the uplands–the fruit of columnar cacti. While cactus seeds are ubiquitous during the ISP, they are less ubiquitous following the intermediate flood events, and remain low following the MSP to TSP transition. Furthermore, the primary locus of on-site cactus processing and/or consumption shifted from extramural contexts during the ISP to intramural contexts during the TSP (Figure 3.8, Supplemental Table 3.4). Historically, Tohono O'odham people–farmers Indigenous to the Sonoran Desert– relocated to upland bajada camps to collect and process saguaro cactus (*Carnegiea gigantea*) fruit immediately before moving to summer farming villages (Castetter and Bell 1942:223-224; Crosswhite 1980). Lower cactus ubiquities, particularly in extramural contexts, may signal similar logistical moves to processing camps, while higher intramural ubiquities perhaps suggest that cactus fruits were increasingly stored or consumed within domestic spaces. Researchers have documented similar shifts in residential and logistical mobility as reliable risk management strategies worldwide (Marston 2011:193; O'Shea 1989:62).

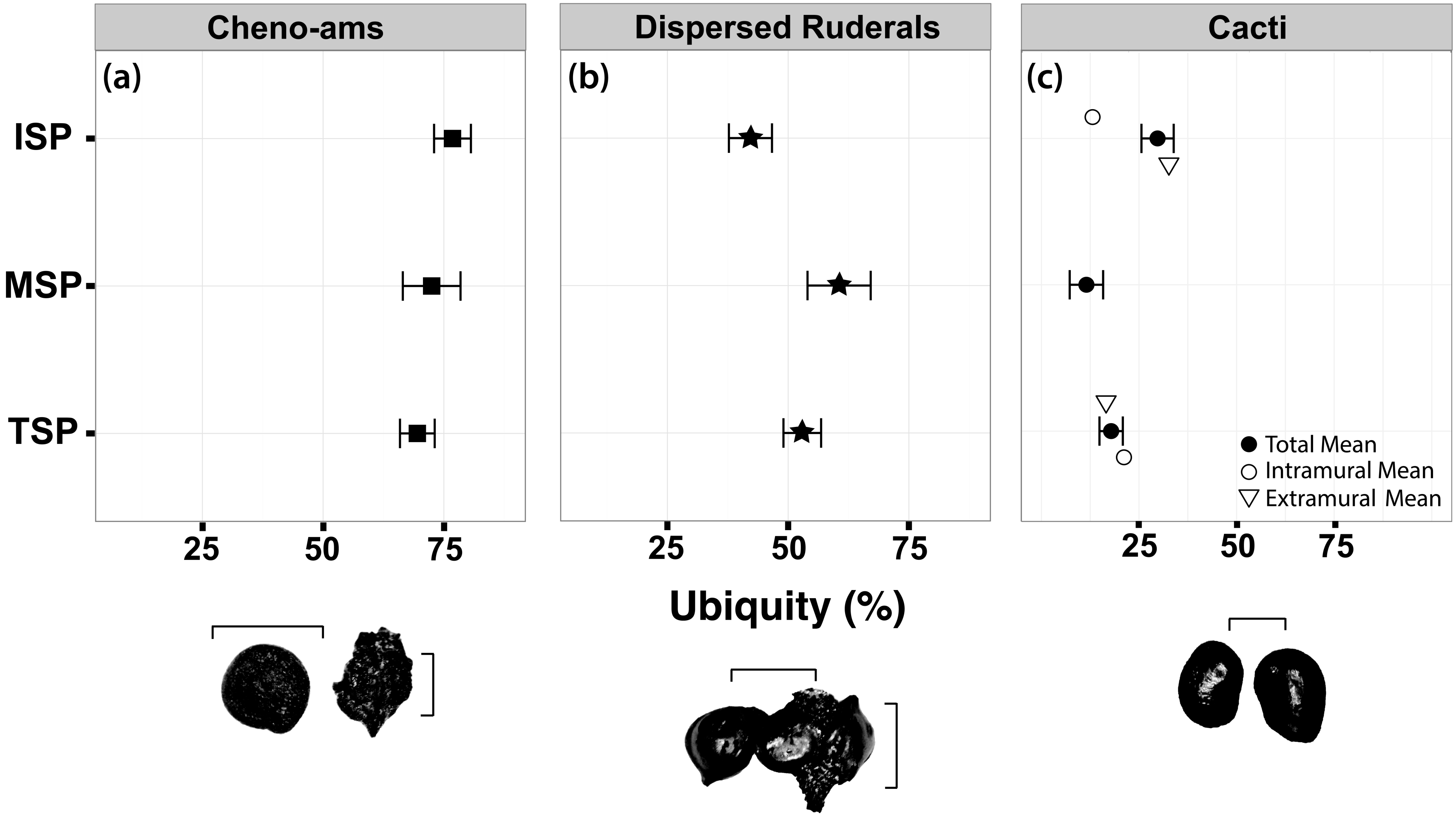


Figure 3.8. Mean plant group ubiquities with confidence intervals derived from an exact binomial distribution from Initial San Pedro (ISP, 1220-1000 BC), Middle San Pedro (MSP, 930-800 BC), and Terminal San Pedro (TSP, 800-730 BC) cultural features. Specimen photos from left to right; carbonized *Chenopodium* sp. seed and *Chenopodium* sp. bract, carbonized *Polygonum* sp. (knotweed) seeds, carbonized *Carnegiea gigantea* (saguaro cactus) seeds. All scales equal one millimeter.

Discussion

A focus on the recursive relationship among diversity, productivity, and disturbance using well-established ecological theories provides a more robust perspective on the changing makeup of plant communities within the Las Capas agroecosystem through time. Drawing on paleoclimatic proxies for precipitation, the geochemistry of agricultural soils, the construction and maintenance histories of canal systems, floodplain dynamics, and a robust archaeobotanical record, this paper assessed the productivity and disturbance regimes of 1220-730 BC coupled human-environmental systems at Las Capas. High productivity and low levels of disturbance during the earliest period of inhabitation (1220-1000 BC) supported less diverse plant communities within the intensively managed agroecosystem. Unpredictable precipitation, intermediate disturbance, and changing land management practices by community members did not provide maize with the same competitive advantage during the MSP (930-800 BC), and the modified landscape supported a more diverse plant community dominated by small-seeded, ruderal plants. In response to declining maize productivity and the changing makeup of the agroecosystem, community members may have pursued spatially diversified farming practices, and began harvesting greater quantities of dispersed crop weed and wild grass seeds. These dispersed crop weeds, however are expected to grow in maize fields even during periods when maize agriculture was more productive. Increasing ubiquities and densities of the seeds of these ruderal taxa suggest that the ways in which early farmers interacted with these plants changed–instead of culling these plants from fields when they are you and consuming the plants as quelites community members allowed these plants reach maturity and harvested seeds.

Routine processing and consumption practices associated with important non-floodplain foods also changed–community members may have processed/consumed larger quantities of cactus fruits in upland procurement areas. While changes in daily practices related to the production, procurement, and processing of domesticated, cultivated, and wild plants were most dramatic during the period of intermediate productivity and moderate disturbance (the 930-800 BC), several changes initiated during that time influenced routine practices even after productivity returned to pre-disturbance levels and diversity contracted. Two of the most prominent examples of this pattern are the continued harvesting of dispersed ruderals and wild grass seeds at quantities well above pre-disturbance levels, and changing cactus procurement, processing, and storage practices also continuing into the TSP (Figure 3.8).

Implications for Modeling Past Socio-Environmental Relationships

While utilizing an IDH and IPH-based perspective highlights the dynamic relationship between disturbance events such as the intermediate flood events, and plant diversity, exploring the situated responses of societies to changing biodiversity requires pairing DDRs with a compatible theoretical framework. Although this paper draws on resilience theory, DDRs such as the IDH and IPH hold promise for use alongside a range of theoretical approaches currently favored by archaeologists to explore human-environmental relationships. For instance, without a focus on the dynamic relationship between productivity, diversity, and disturbance, dietary expansion during the MSP could have been attributed exclusively to a decline of the post-encounter return rate of preferred resources, most notably maize. However, the legacy of nearly ten generations of floodplain manipulation during the ISP and the initiation of the intermediate flood events increased the abundance of ruderal plants with a competitive advantage in the less intensively managed Las Capas agroecosystem. This would have shifted the post encounter return rate of small-seeded ruderal plants that were previously culled from maize fields. In this example, the benefits of ecological inheritance (*sensu* Odling Smee and Laland 2011) associated with generations of investment in floodplain farming could have persisted *in spite* of declining crop yields. This may in part explain why some community members remained at Las Capas during the MSP. The empirical foundations of this study provide a platform for future work that can utilize different perspectives, such as HBE and NCT, and more precisely determine the proximate decision making mechanisms that led to changes in plant diversity and foodways.

Moreover, long before resilience theory concepts were incorporated into the ecologically oriented social sciences, anthropologists noted that many small-scale farming societies living in marginal environments practiced broad yet sustainable food production strategies focused on minimizing risk rather than maximizing food production (Netting 1974:44, 1990:39-40). Building on this foundational research, recent approaches highlight how environmental and/or anthropogenic disturbances shape and stabilize biological communities by encouraging biodiversity (Bleige Bird et al. 2013; Bleige Bird 2015; Dunn et al. 2012). This in turn increases the reliability and long-term resilience of socio-environmental systems by minimizing the inter-annual variability, and is particularly beneficial when communities maintain a broad diet (Bleige Bird 2015). Regardless of whether community members at Las Capas recognized the consequences, greater floodplain biodiversity and subtle changes to routine cultivation and foraging practices encouraged by a legacy of landscape modification and episodic intermediate disturbance increased the resilience of food production systems. For example, since community members incorporated a broader range of small-seeded ruderal plants into their diet not only when maize productivity was reduced, but also when maize yields were high, they reduced long-term risk, as these plants are expected to be present in the agroecosystem regardless of external factors that impact maize yields. Even when risk-averse practices initiated in response to intermediate disturbance did not persist, they still may have had implications for the resilience of food production strategies. For instance spatially diversified farming practices do not appear to have persisted into the TSP (Table 3.1), these practices likely contributed to higher nutrient levels noted in TSP agricultural soils. Since the IDH and IPH provide explicit expectations for the biodiversity of ecological communities under known productivity and disturbance regimes, they can also serve as powerful tools to identify whether coupled human-environmental systems encouraged long-term diversity and minimized variability.

Conclusion

Models predicting relationships among diversity, disturbance and productivity can provide additional rigor to archaeological studies of plant and animals diversity in the ancient past. In this case, two particular DDRs–the Intermediate Disturbance Hypothesis and the Intermediate Productivity Hypothesis provided an opportunity to shift the focus from the stability of Late Archaic subsistence strategies to discrete changes to plant biodiversity in the Las Capas agroecosystem, and shifting foodways in response to fluctuating risk. Taken as a whole, these DDRs provided greater context for observed changes to dietary diversity that may not have changed the underlying structure of Late Archaic foodways, but nonetheless played a significant role in shaping short-term and long-term resilience. Risk-averse strategies adopted in response to episodic disturbance events may have contributed to the resilience of Late Archaic foodways, and may in part explain the persistence of societies engaged in low-level food production with domesticates and broad diet breadth for nearly 2,500 years in the Sonoran Desert of the southwestern United States and northwestern Mexico.

Data Availability Statement. Data and code used in these analyses are available for download as supplements to this article.

Supplemental Materials. For supplementary material accompanying this paper, visit https://doi.org/10.1017/aaq.2017.74

Supplemental Table 3.1. Ethnographic and Archaeological Evidence of Select Low Return Plant Resources from Late Archaic contexts in Southern Arizona and Northwestern Mexico.

Supplemental Table 3.2. Las Capas Flotation Data.

Supplemental Table 3.3. Las Capas "Estimate S" Output.

Supplemental Table 3.4. Mean Ubiquity Descriptive Statistics and Select Density Measures.

Supplemental Text 3.1. R markdown document with code used for Figures 3.5, 3.7, and 3.8.

Supplemental Text 3.2. Notes on data of supplemental Table 3.2.

Supplemental Text 3.3. References cited in supplemental materials.

Supplemental Table 3.1. Archaeological Evidence of Select Low Caloric Return Plants from Late Archaic/Early Agricultural Contexts in Southern Arizona and Northwestern Mexico, and Ethnographic Uses.

Taxon and Ethnographic Uses	**Caloric Return Rate**	**Archaeological Evidence**
Cyperaceae[h, o, z] cyperus family	202[ad, ae, w, x] (*Carex* sp.) 470[ad, ae, w, x] (*Scirpus* sp.)	Las Capas[k,m,n,ac], Wetlands[r], Los Ojitos[r], Los Pozos[j,k], Donaldson[r], Valley Farms[u], Stone Pipe[t], Cerro Juanaqueno[q]
Lepidium sp.[e, h, z] peppergrass	537[ad, ae, x]	Las Capas [k,m,n,ac], Los Pozos[j, k]
Poaceae[b, c, d, g, i, z] grass family	143-473[ad, ae, x]	Las Capas[k,m,n,ac], Los Pozos[j,k], Clearwater[l], Milagro[s], Valley Farms[u], Donaldson[r], Wetlands, Santa Cruz Bend[t], Stone Pipe[t], La Playa[p], Cerro Juanaqueno[q], Los Ojoitos[r], Coffee Camp[v]
Muhlenbergia sp. muhly grass	162-294[ah]	Las Capas[k,m,n,ac], Los Pozos[j,k], Santa Cruz Bend[t], Stone Pipe[t], Cerro Juanaqueno[q]
Hordeum sp. wild/foxtail barley	138-273 [ad, ae, x]	Las Capas[k,m,n,ac], Los Pozos[j,k]
Sporobolus sp.[b, e, h, i, z] dropseed	162-294[ad, ae, x]	Las Capas[k,m,n,ac], Stone Pipe[t], Santa Cruz Bend[t], Clearwater[l], Donaldson[r], Milagro[s], Valley Farms[U]
Achnatherum hymenoides ricegrass[a, h, i, z]	301-364[w, x, ad, ae]	Las Capas[k,m,n,ac]
Portulaca sp.[d, f, o, z] purslane	200[ag] (560[aj])[ab] (*P.* oleracea)	Las Capas[k,m,n,ac], Los Pozos[j,k], Clearwater[l] Milagro[s], Valley Farms[u], Donaldson[r], La Playa[p]
Polygonaceae[b, c, d, h] knotweed family	360[aa] (380[aj]) [af]	Las Capas[k,m,n,ac], Los Pozos[j,k], Donaldson[r], Valley Farms[u], La Playa[p], Los Ojitos[r]
Trianthema portulacastrum[g] horse purslane	300[aa, ag] (761[aj])[y]	Las Capas[k,m,n,ac], Los Pozos[j,k], Milagro[s], Donaldson[r], Valley Farms[u], Coffee Camp[v], Santa Cruz Bend[t], Stone Pipe[t], Cerro Juanaqueno[q]
Chenopodium sp. goosefoot	400-500[ah]	Las Capas[k,m,n,ac], Los Pozos[j,k], Milagro[s], Donaldson[r], Valley Farms[u], Coffee Camp[v], Santa Cruz Bend[t], Stone Pipe[t], Cerro Juanaqueno[q]

Note: Post encounter/post processing rates are listed for seeds, unless noted otherwise.

[a] Bailey (1940). [b] Castetter (1935).[c] Castetter and Bell (1942).[d] Castetter and Opler (1936). [e]Castetter and Underhill (1935). [f]Crosswhite (1980). [g]Crosswhite (1981). [h]Curtin (1949). [i]Doebley (1984). [j]Diehl (2001). [k]Diehl (2005b). [l]Diehl (2006). [m]Diehl (2010). [n]Diehl (2015). [o]Ebeling (1986). [p]Guadalupe Sanchez de Carpenter (1998). [q]Hanselka (2000). [r]Huckell (1995a). [s]Huckell (1995b). [t]Huckell(1998). [u]Huckell (2008). [v]Hutira (1993). [w]Jones (1981) [x]Jones and Madsen (1991) [y]Kahn et al. (2013). [z]Rea (1997). [aa]Schaefer (2011). [ab]Sheela et al. (2004). [ac]Sinensky (2013). [ad]Simms (1984 [ae]Simms (1987). [af]Trichopoulou et al. (2000). [ag]Hudspeth (2000). [ah]Gremillion (2004).

[aj] Pre-encounter, pre-processing return rate for vegetative portion.

Supplemental Table 3.4. Tabular Presentation of Ubiquity Descriptive Statistics, Upper and Lower 95% Confidence Interval Boundaries, and Select Density Measures.

Table 3.4a. Mean Maize Ubiquity Descriptive Statistics.

Date Range	*N*	Mean Ubiquity	SD Ubiquity	SE Ubiquity	Ubiquity Lower CI	Ubiquity Upper CI
800-730 BC	633	0.8515	0.3559	0.0141	0.8237	0.8793
930-800 BC	217	0.6544	0.4767	0.0324	0.5906	0.7182
1220-1000 BC	474	0.8333	0.3731	0.0171	0.7997	0.8670

Table 3.4b. Cheno-am Seed Ubiquity Descriptive Statistics and Mean Density Values.

Date Range	*N*	Mean Ubiq	SD Ubiq	SE Ubiq	Ubiquity Lower CI	Ubiquity Upper CI	Density	Trimmed Density[a]
800-730 BC	633	0.6888	0.4633	0.0184	0.6526	0.7249	9.5313	6.8510
930-800 BC	217	0.7143	0.4528	0.0307	0.6537	0.7749	8.4425	5.5044
1220-1000 BC	474	0.7658	0.4239	0.0194	0.7276	0.8041	4.0753	4.0753

Note: Density refers to the number of identified seeds per-liter of analyzed sediment. [a] Density values with samples containing greater than 100 Cheno-ams per-liter trimmed (800-730 BC n=9; 930-800 BC n=4).

Table 3.4c. Dispersed Ruderal Plant Group Ubiquity Descriptive Statistics and Densities.

Stratum	*N*	Mean Ubiq	SD Ubiq	SE Ubiq	Ubiquity Lower CI	Ubiquity Upper CI	Density	Trimmed Density[a]
800-730 BC	633	0.5276	0.4996	0.0199	0.4886	0.5666	1.1724	0.8655
930-800 BC	217	0.6004	0.4903	0.0333	0.5381	0.6693	1.9214	0.9001
1220-1000 BC	474	0.4156	0.4933	0.0227	0.3711	0.4601	0.5960	0.3474

Density refers to the number of identified seeds per analyzed liter of sediment. [a] Mean density values with samples containing greater than 20 dispersed ruderal seeds per-liter trimmed (800-730 BC n=5, 930-800 BC n=7, 1220-1000 BC n=3).

Table 3.4d. Cactus Seed Ubiquity Descriptive Statistics.

Date Range (BC)	*N*	Mean Ubiq	SD Ubiq	SE Ubiq	Ubiquity Lower CI	Ubiquity Upper CI	Intramural Ubiquity	Extramural Ubiquity
800-730	633	0.1785	0.3832	0.0152	0.1486	0.2084	0.2690	0.1738
930-800	217	0.1152	0.3200	0.0217	0.0739	0.1580	-	-
1220-1000	474	0.2975	0.4576	0.0210	0.2562	0.3388	0.1081	0.3135

Table 3.4e. Mean Wild Grass Seed Ubiquity Descriptive Statistics and Mean Density Values.

Stratum	*N*	Mean Ubiq	SD Ubiq	SE Ubiq	Ubiquity Lower CI	Ubiquity Upper CI	Density	Trimmed Density[a]
504	633	0.2196	0.4143	0.0165	0.1873	0.2519	0.2385	0.2076
505	217	0.2120	0.4097	0.0278	0.1572	0.2688	1.9957	0.3747
506	474	0.0949	0.2934	0.0135	0.0685	0.1214	0.0745	0.0745

Note: Density refers to the number of identified seeds per analyzed liter of analyzed sediment.
[a] Mean wild grass density with samples containing more than 20 wild grass specimens trimmed (800-730 BC n=1, 930-800 BC n=2).

Supplemental Text 3.1. R markdown Document with Code used for Figures 3.5, 3.7, and 3.8.

Note that the data files used to generate the figures presented below, and an .rmd version of this Markdown file are available as digital supplements to this dissertation, and as digital supplements provided with with Sinensky and Farahani 2018.

Analysis of Las Capas Paleoethnobotanical Data

R. J. Sinensky and A. Farahani

October 30, 2017

```
knitr::opts_chunk$set(echo = TRUE)

# These packages are necessary for all subsequent analysis
# and can be installed via the install.packages() function
library(plyr)
library(dplyr)
```

```
##
## Attaching package: 'dplyr'
```

```
## The following objects are masked from 'package:plyr':
##
##     arrange, count, desc, failwith, id, mutate, rename, summarise,
##     summarize
```

```
## The following objects are masked from 'package:stats':
##
##     filter, lag
```

```
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
```

```
library(ggplot2)
library(lazyeval)
library(vegan)
```

```
## Loading required package: permute
```

```
## Loading required package: lattice
```

```
## This is vegan 2.4-5
```

```
library(reshape2)
```

Introduction

The following R Markdown file contains the code necessary to generate Figures 5c, 5d, 7a, 7b, and 7d in Sinensky and Farahani 2018.

Loading the Data

Please note that the CSV files should be in the same folder as this .RMD file. In addition, CSV file names may have been changed by the publisher. If so, change them back to “Sinensky_and_Farahani_Supplement_2.csv” and “Sinensky_and_Farahani_Supplement_3.csv”.

```r
las_capas_data <- read.csv("Sinensky_and_Farahani_Supplement_2.csv")
estimate_s_output <- read.csv("Sinensky_and_Farahani_Supplement_3.csv")

# These FN's are numerical outliers -- these fifteen samples alone add 18,000 additional specimens
# in just two strata -- it should be noted that their inclusion or exclusion dramatically
# affects the quantitative outcomes of several tests presented here
outlier.fns <- c(349, 1673, 4748, 5017, 7872, 7882, 13080, 102838, 102838, 103129, 104578, 104648, 104737, 104781, 105249)
las_capas_data$outlier <- ifelse(las_capas_data$FN %in% outlier.fns,1,0)

# This is generally used in the following analyses
strat_list <- list("504" = "TSP", "505" = "MSP", "506" = "ISP")
```

Figure 5c

```
#This is a custom function to easily create data frames to procure moment trends
#from a given data frame and grouping variable.

ci<-function(df, grp.var, variable){
  if(missing(variable)){
    df1<- df %>%
      summarise_(n=interp(~n()),
                 median=interp(~median(v,na.rm=TRUE),v=as.name(grp.var)),
                 mean=interp(~mean(q,na.rm=TRUE),q=as.name(grp.var)),
                 sd=interp(~sd(q,na.rm=TRUE),q=as.name(grp.var)),
                 se=interp(~(sd/sqrt(n))),
                 lowerCI=interp(~(mean+(qt(.025,n-1)*se))),
                 upperCI=interp(~(mean-(qt(.025,n-1)*se)))
      )
    df1<-as.data.frame(df1)
    return(df1)
  }

  df2<- df %>% group_by_(grp.var) %>%
    summarise_(n=interp(~n()),
               median=interp(~median(v,na.rm=TRUE),v=as.name(variable)),
               mean=interp(~mean(q,na.rm=TRUE),q=as.name(variable)),
               sd=interp(~sd(q,na.rm=TRUE),q=as.name(variable)),
               se=interp(~(sd/sqrt(n))),
               lowerCI=interp(~(mean+(qt(.025,n-1)*se))),
               upperCI=interp(~(mean-(qt(.025,n-1)*se)))
    )
  df2<-as.data.frame(df2)
  return(df2)

}

ci(las_capas_data %>% mutate(Zea_mays = ifelse(Zea_mays>0,1,0)),"Stratum", "Zea_mays") %
>%
  mutate(Stratum = recode(Stratum,!!!strat_list)) %>%
  ggplot(aes(Stratum,mean)) +
    geom_point(size=2) +
    geom_errorbar(aes(ymin=lowerCI,ymax=upperCI), width=.2) +
    theme_bw(base_size = 20)+
    ggtitle("Maize Ubiquity")+
    xlab("") +
    ylab("%")
```

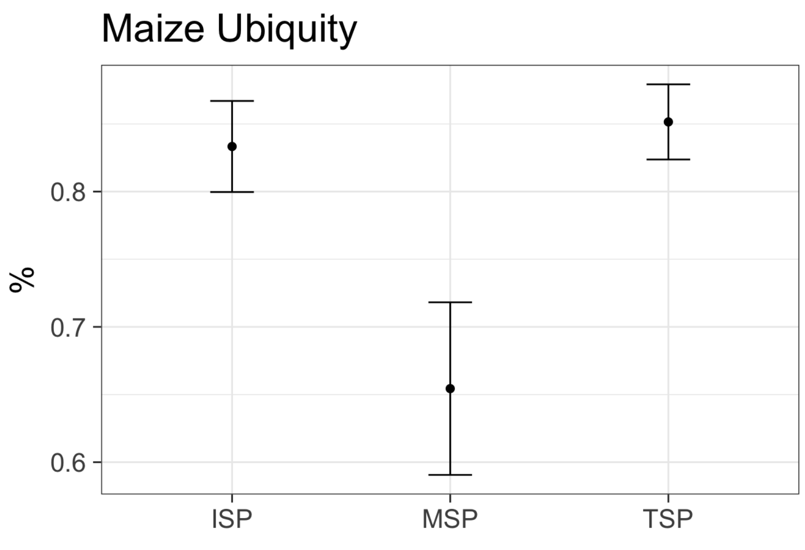


Figure 5d

Maize density here uses `log()` which computes natural logarithms, and therefore removes samples that have no data. Therefore this plot only compares samples where $n_{Zea} > 1$. Mean density values presented in Table 1, however, include samples with no maize.

```
las_capas_data %>% mutate(ZeaDens = log(Zea_mays/Volume), Stratum = as.factor(Stratum))
%>%
    ggplot(aes(ZeaDens)) +
    geom_density(aes(fill = Stratum), alpha = .5) +
    theme_bw(base_size = 20)
```

```
## Warning: Removed 248 rows containing non-finite values (stat_density).
```

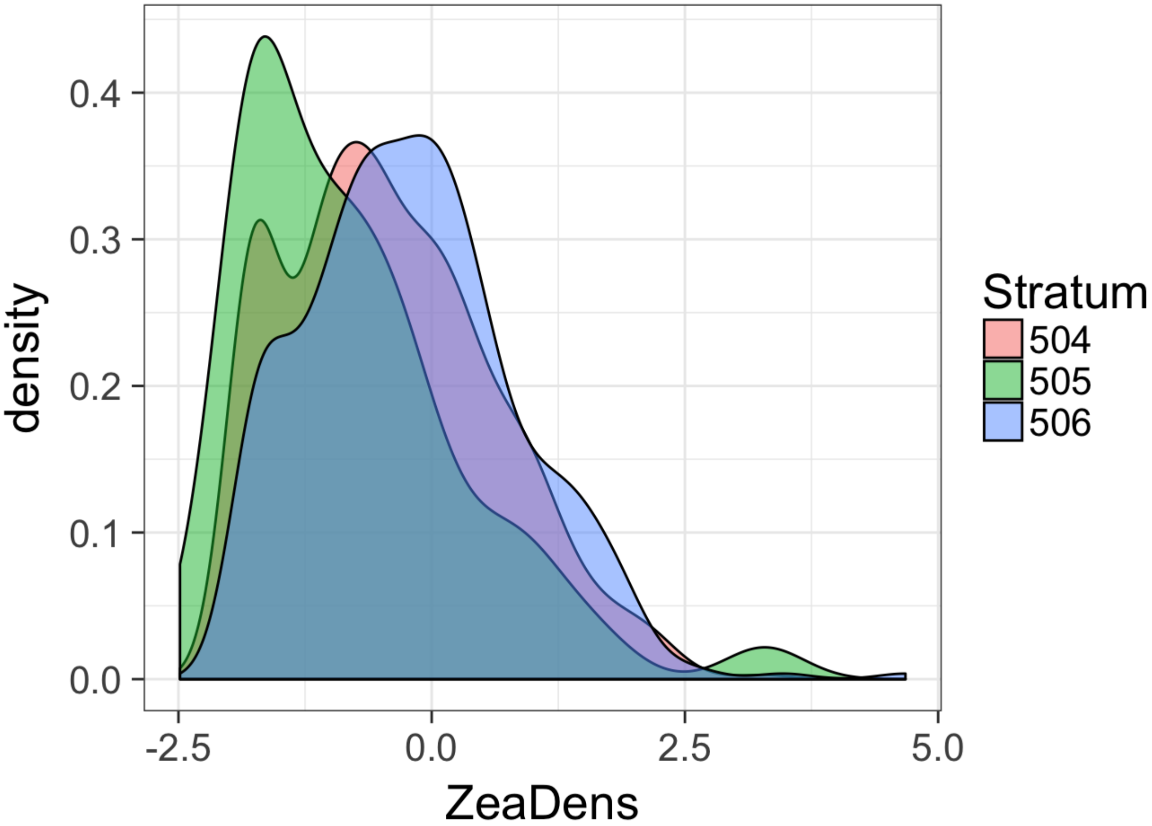


Figure 7a

This method uses the “random” permutation function in vegan, for more on this see the help file for the function `specaccum()`, which cites Gotelli and Colwell 2001. Note that the “random” argument of `specaccum()` does samples *without* replacement.

```
# set the stratum designations
strat_titles <- c(504,506,505)

#create colors for our different strata
redtrans <- rgb(255, 0, 0, 127, maxColorValue=255)
chartrans <- rgb(102, 205, 0, 200, maxColorValue=255)
lightbluetrans <- rgb(173, 216, 230, 200, maxColorValue=255)

# this loops through the data and creates a different species accumulation curve through random permutations of the data

for (i in 1:length(strat_titles)){
    x <- las_capas_data %>%
        # filter (outlier == 0) %>%
        select(Stratum, Achnatherum:Zea_mays,Volume) %>%
        filter(Stratum == strat_titles[i]) %>%
        select(-Stratum)

    if(i == 1){
         plot(specaccum(x, method = "random",w=x$Volume),xvar="effort",ci.type="poly", col="darkred", lwd=2, ci.lty=0, ci.col=redtrans, xlab = "Total Flotation Volume (L)", ylab = "Mean Richness")
    }
    else if(i == 2){
       plot(specaccum(x, method = "random",w=x$Volume),xvar="effort",ci.type="poly",col="blue", lwd=2, ci.lty=0, ci.col=lightbluetrans, add=TRUE)
    }
    else{
        plot(specaccum(x, method = "random",w=x$Volume),xvar="effort",ci.type="poly", col="darkgreen", lwd=2, ci.lty=0, ci.col=chartrans, add=TRUE)
    }

}
```

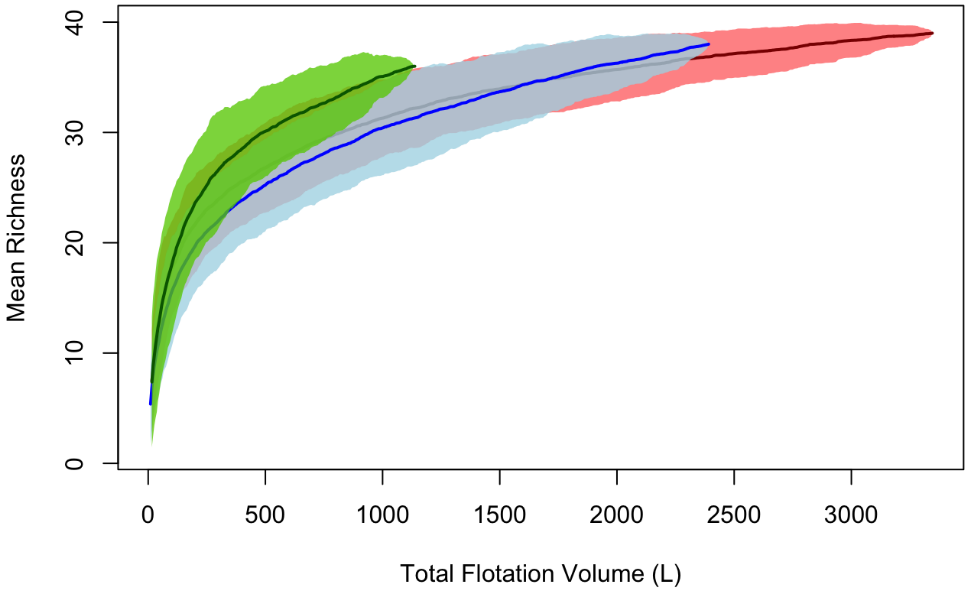


Figure 7b

Although the underlying species-accumulation curve was based on sampling without replacement, the option was chosen in the freely available Estimate S to sample with replacement due to its favorable qualities with respect to estimations of variance. The settings included 100 permutations and no extrapolation of rarefaction curves.

```
estimate_s_output %>%
  mutate(Stratum = as.factor(Stratum)) %>%
  ggplot(aes(Individuals..computed.,Simpson.Inv.Mean)) +
    geom_ribbon(aes(ymin = Simpson.Inv.Mean - 2*(Simpson.Inv.SD..runs.), ymax = Simpson.
Inv.Mean + (2*Simpson.Inv.SD..runs.), fill = Stratum),colour="black",alpha=.5) +
    geom_point(aes(colour = Stratum)) +
    theme_bw(base_size = 20) +
    theme(panel.grid = element_blank()) +
    xlab("Number of Identified Specimens (NISP)") +
    ylab ("Mean Inverse Simpson's")
```

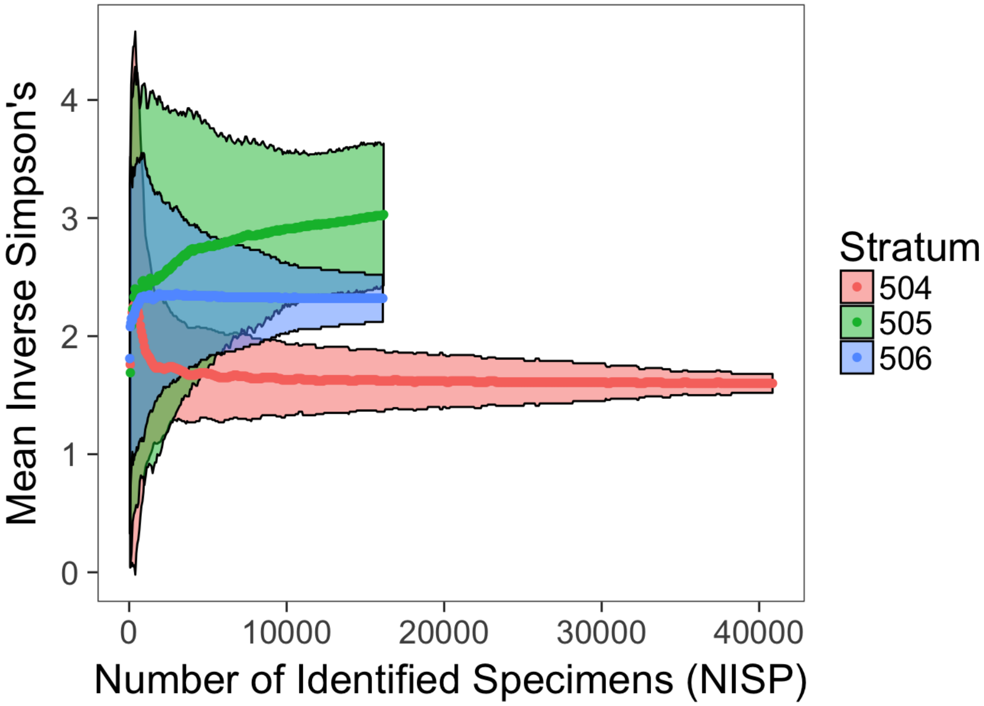


Figure 7c

Two possibilities of the data are presented here, one which is published, and the other which is not. By commenting the `filter()` function the graph includes seven samples with extremely high Zea counts relative to other samples, and the standard published graph includes all of the data.

`log()` was chosen over `log1p()`, although the two offer similar results. The use of `log()` excludes samples that have no maize, which is equivalent to 248 samples.

```
las_capas_data %>%
  filter(Zea_mays<80) %>%
  mutate(logZeadens = log(Zea_mays/Volume), Stratum=as.factor(Stratum)) %>%
  mutate(Stratum = factor(Stratum,levels = rev(levels(Stratum)))) %>%
  ggplot(aes (Stratum, logZeadens, fill = Intramural)) +
    geom_boxplot() + theme_bw (base_size =20) +
    ggtitle ("Maize Density") +
    xlab ("Stratum") +
    ylab("Log Maize Density (log #/L)")
```

```
## Warning: Removed 248 rows containing non-finite values (stat_boxplot).
```

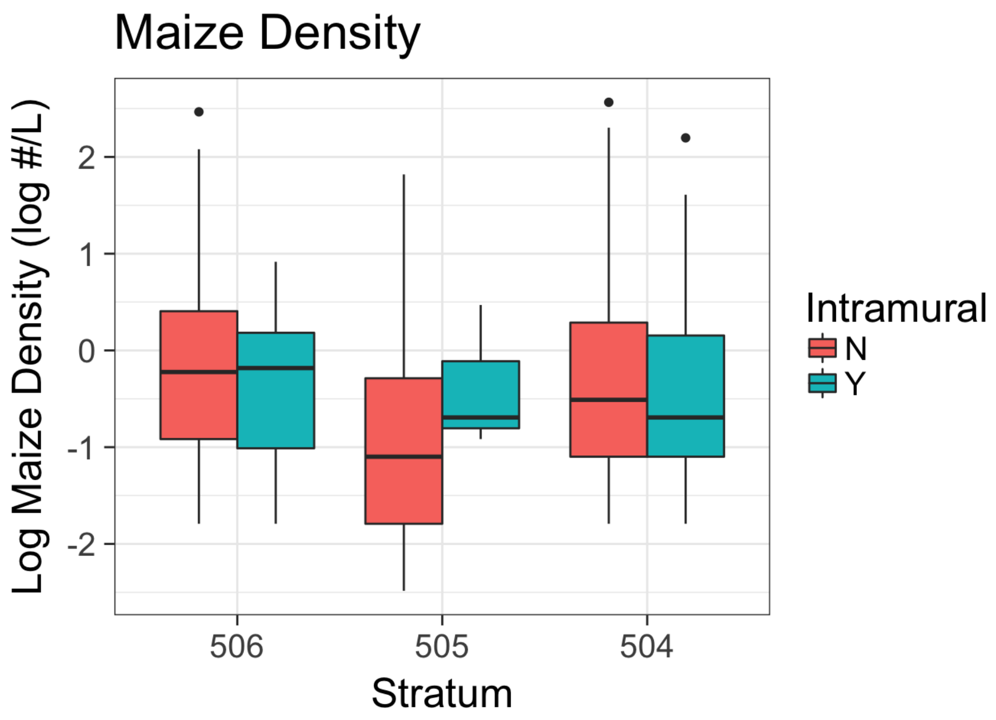


Figure 8

```
las_capas_data %>%
mutate(Cacti = Carnegiea + Cereus + Dasylirion + Echinocereus.Mammillaria + Ferocactus +
Opuntia,
       Ch_Am = Chenoam,
       DCW = Astragalus + Boerhaavia + Cleome.Polanisia + Cucurbitaceae + Cyperaceae +
  Eschscholtzia + Euphorbiaceae + Kallstroemia + Lamiaceae + Lepidium + Mollugo +
  Oxalis + Papaveraceae + Polygonaceae + Portulaca + Sphaeralcea + Suaeda + Trianthema,
  Stratum = as.factor(Stratum)) %>%
  select(Stratum,Cacti,Ch_Am,DCW) %>%
  group_by(Stratum) %>%
  mutate_all(funs(decostand(.,method="pa"))) %>% melt() %>%
  group_by(Stratum,variable) %>%
  summarize(n=n(), median = median(value,na.rm=TRUE),
               mean = mean(value,na.rm=TRUE),
               sd = sd(value,na.rm=TRUE),
               se = (sd/sqrt(n)),
               lowerCI = (mean+(qt(.025,n-1)*se)),
               upperCI = (mean-(qt(.025,n-1)*se))) %>%
  mutate(variable = recode(variable,"Ch_Am" = "Cheno Ams", "DCW" = "Dispersed Ruderal
s")) %>%
  ggplot (aes(Stratum , mean)) +
    geom_point (size=2, aes(shape = variable)) +
    geom_errorbar (aes (ymin = lowerCI , ymax = upperCI) , width = .2) +
    ylim (0,1) + coord_flip() +
    theme_bw (base_size = 20) +
    facet_wrap (~variable) +
    ggtitle("Plant Group Ubiquity")+
    xlab("")+
    ylab("%")+
    theme(legend.position = "none")
```

```
## Using Stratum as id variables
```

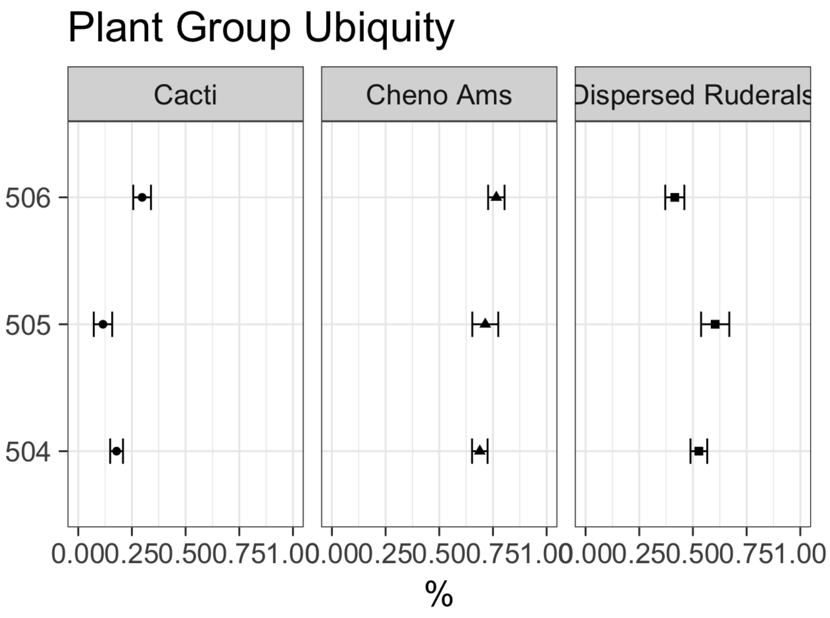


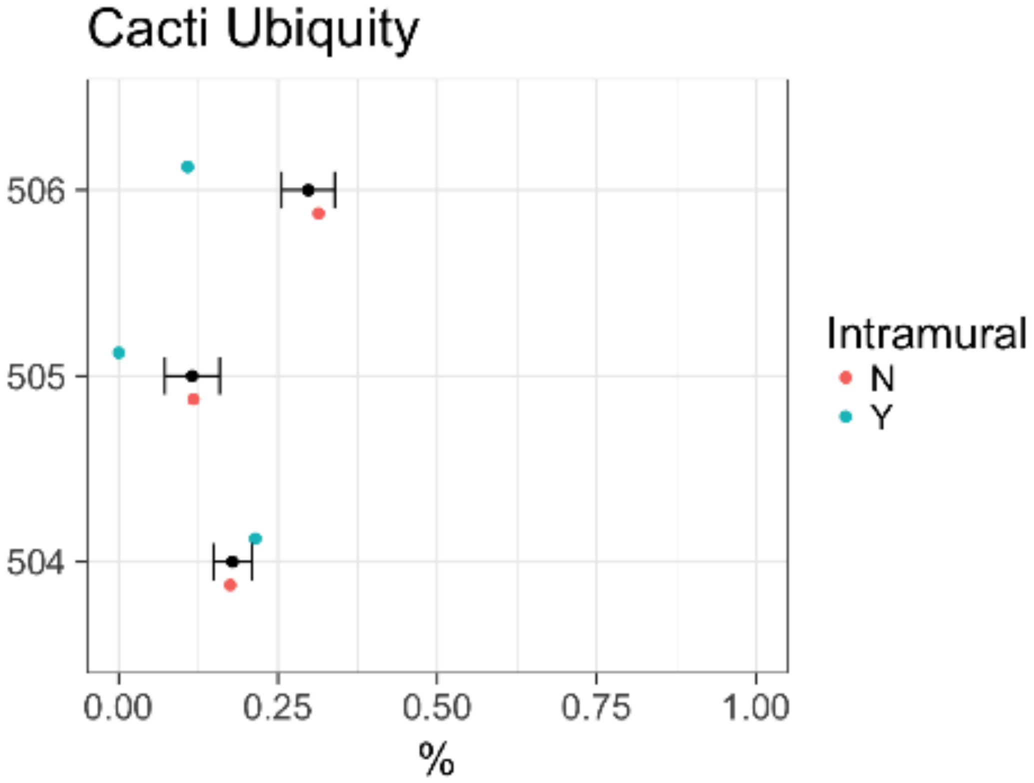
Figure 8 - Cacti

```
intramural_cactus <- las_capas_data %>%
  mutate(Cacti = Carnegiea + Cereus + Dasylirion + Echinocereus.Mammillaria + Ferocactus
+ Opuntia,
  Stratum = as.factor(Stratum)) %>%
  select(Stratum,Intramural,Cacti) %>%
  group_by(Stratum,Intramural) %>%
  mutate_all(funs(decostand(.,method="pa"))) %>% melt() %>%
  group_by(Stratum,Intramural) %>%
  summarize(n=n(), median = median(value,na.rm=TRUE),
               mean = mean(value,na.rm=TRUE),
               sd = sd(value,na.rm=TRUE),
               se = (sd/sqrt(n)),
               lowerCI = (mean+(qt(.025,n-1)*se)),
               upperCI = (mean-(qt(.025,n-1)*se)))
```

```
## Using Stratum, Intramural as id variables
```

```
las_capas_data %>%
  mutate(Cacti = Carnegiea + Cereus + Dasylirion + Echinocereus.Mammillaria + Ferocactus
+ Opuntia,
  Stratum = as.factor(Stratum)) %>%
  select(Stratum,Cacti) %>%
  group_by(Stratum) %>%
  mutate_all(funs(decostand(.,method="pa"))) %>% melt() %>%
  group_by(Stratum) %>%
  summarize(n=n(), median = median(value,na.rm=TRUE),
               mean = mean(value,na.rm=TRUE),
               sd = sd(value,na.rm=TRUE),
               se = (sd/sqrt(n)),
               lowerCI = (mean+(qt(.025,n-1)*se)),
               upperCI = (mean-(qt(.025,n-1)*se))) %>%
  ggplot (aes(Stratum , mean)) +
    geom_point(size=2) +
    geom_point(data=intramural_cactus,aes(y=mean, colour=Intramural), size = 2, position
= position_dodge(width = .5))+
    geom_errorbar(aes (ymin = lowerCI , ymax = upperCI) , width = .2) +
    ylim (0,1) +
    coord_flip() +
    theme_bw (base_size = 20) +
    ggtitle("Cacti Ubiquity")+
    xlab("")+
    ylab("%")
```

```
## Using Stratum as id variables
```


Cacti Ubiquity
506
505
504
0.00
0.25
0.50
0.75
1.00
%
Intramural
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CHAPTER 4: Volcanic Climate Forcing, Extreme Cold and the Neolithic Transition in the Northern US Southwest

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Abstract

The impacts on global climate of the AD 536 and 541 volcanic eruptions are well attested in palaeoclimatic datasets and in Eurasian historical records. Their effects on pre-Hispanic farmers in the arid uplands of western North America, however, remain poorly understood. The authors investigate whether extreme cold caused by these eruptions influenced the scale, scope and timing of the Neolithic Transition in the northern US Southwest. Archaeological tree-ring, radiocarbon dates and settlement survey data suggest that extreme cooling generated the physical and social space that enabled early farmers to transition from diverse, kin-focused socio-economic strategies to increasingly complex and widely shared forms of social organisation that served as foundational elements of burgeoning Ancestral Pueblo societies.

Keywords: American Southwest, Northern Southwest, Colorado Plateau, Formative, Basketmaker, Early Pueblo, Ancestral Pueblo, climate change, social change, volcanic climate forcing, dendrochronology, radiocarbon, Neolithic Transition, early agriculture

Introduction

For Pueblo peoples, farming is not merely an economic pursuit that produces food. Maize agriculture permeates all aspects of Pueblo identity, connecting widely dispersed peoples that speak mutually unintelligible languages with remarkably consistent values and traditions. The rapid spread of sedentary agricultural communities across the Colorado Plateau of western North America during the late sixth and early seventh centuries AD completed an economic and social transformation fundamental to this shared Pueblo history. Our understanding of the critical final steps of this transformation, however, remains poor due to a lack of focused research on the sixth and preceding centuries AD.

Although domesticated maize (*Zea mays* L.) arrived in the northern US Southwest from Mesoamerica thousands of years earlier, the tempo and uniformity of the adoption of agriculture was uneven for the next 2500 years (Roth 2016; Vierra & Carvalho 2019). Yet, following AD 580, there was rapid and widespread adoption of a package of domesticates, technologies and socio-political institutions capable of integrating large groups of unrelated households (Young & Herr 2012). These attributes ultimately served as the foundation for a swift sequence of developments that have parallels in the earliest Formative periods in Mesoamerica and Neolithic transitions in Eurasia, including the rapid formation and demise of large villages, increasing social inequality and, in the northern US Southwest in particular, the rise of the Chaco regional system (Wilshusen *et al*. 2012; Plog 2018).

How do we explain this rapid late sixth-century transition from a landscape of cultural and socioeconomic heterogeneity to one in which there was widespread adoption of the Neolithic package and sedentary agriculture? Drawing on high-quality archaeological tree-ring, radiocarbon and palaeoclimatic data, we propose that an extreme cold interval brought on by volcanic eruptions in AD 536 and 541 disrupted a period of accumulating social and technological advancements, influencing the timing, scale and scope of this rapid Neolithic Transition.

To explore this process, we place this history and the agricultural practices of early farmers into context and demonstrate the significance of both temperature and precipitation for successful maize agriculture on the arid yet temperate, high-elevation Colorado Plateau. We also show that there was a hiatus in construction, economic activity and material culture traditions that coincided with the mid-sixth-century extreme cold interval, and that this break was of sufficient length and magnitude to create an opening for the regional transformation that followed. A convergence of 'bottom-up' and 'top-down' factors allowed a shared set of social, economic, material and landscape practices to be adopted rapidly across the northern Southwest—not unlike other Neolithic Transitions in secondary locales of domestication worldwide (Robb 2013).

The Neolithic Transition and Early Agriculture

Over the last century, archaeologists working in the northern US Southwest have hypothesised a continuous, gradual transition from mobile hunting and gathering to sedentary farming, followed by a slow increase in population size, and finally, the rise of progressively larger villages (e.g. Roberts 1935). This slow, steady evolutionary model for Formative economies, however, has been critiqued. Using tree-ring and radiocarbon datasets, Berry (1982) identified population boom-and-bust cycles similar to those later noted in European Neolithic societies (Shennan *et al*. 2013), and argued for intermittent demographic changes influenced by episodic, plateau-wide droughts (also see Bocinsky *et al*. 2016; Schwindt *et al*. 2016).

Regardless of the tempo of change, researchers agree that the start of the Basketmaker II period (400 BC–AD 400) represents a transitional stage in the development of Formative economies, as people in some areas began to rely on maize as a dietary staple (Geib 2011; Coltrain & Janetski 2019). Other groups, however, remained primarily foragers. Hence, the regional socio-economic variability persisted throughout this period (Vierra & Carvalho 2019). Perhaps more importantly, both farmers and foragers continued to live in dispersed hamlets and retained a high degree of residential mobility. Increasing sedentism, aggregation and a shift from communal to household production occurred during the subsequent Basketmaker III period (AD 550–750). By this time, accelerated population growth had constrained the availability of arable land. Instead of dispersed farmers spreading into new territories, communities grew and socio-political organisation became more complex amongst increasingly dense concentrations of unrelated households (Wilshusen *et al*. 2012; Young & Herr 2012). What remains to be understood are the events immediately preceding the completion of this Neolithic Transition; this question forms the focus of our research.

The Early Brown Ware Horizon

We identify three distinct periods associated with this shift to sedentary agriculture: a well-defined preceramic farming interval, called Basketmaker II; a less well-understood, somewhat later but overlapping interval, termed the Early Brown Ware Horizon (EBWH); and finally, Basketmaker III, with its wholesale adoption of the Neolithic package. Throughout the EBWH, farmers adopted components of the Neolithic package in a piecemeal fashion, yet retained a mosaic of subsistence strategies and cultural practices associated with high mobility (see Table S1 in the online supplementary material).

Our research and a synthesis of earlier work suggests the pace at which early farmers adopted specific components of the Neolithic package was contingent upon diverse local histories and traditions (Table S1). Securely dated AD 200–400 EBWH sites in the Puerco Valley and Navajo Mountain areas, for example, have produced early ceramic assemblages, but contemporaneous groups dwelling on Cedar Mesa to the north-east did not adopt ceramic technology (Figure 4.1). Moreover, unlike their ceramic producing neighbours to the south-east, farmers occupying Cedar Mesa and nearby Grand Gulch raised domesticated turkeys—a practice that became common across the entire region only after AD 550 (Lipe *et al*. 2016). Even within early ceramic-producing areas, the adoption of ceramics and other new technologies was far from uniform (Geib 2011: 280–84). Nevertheless, a general trajectory distinguishing EBWH sites from earlier and later settlements is apparent.

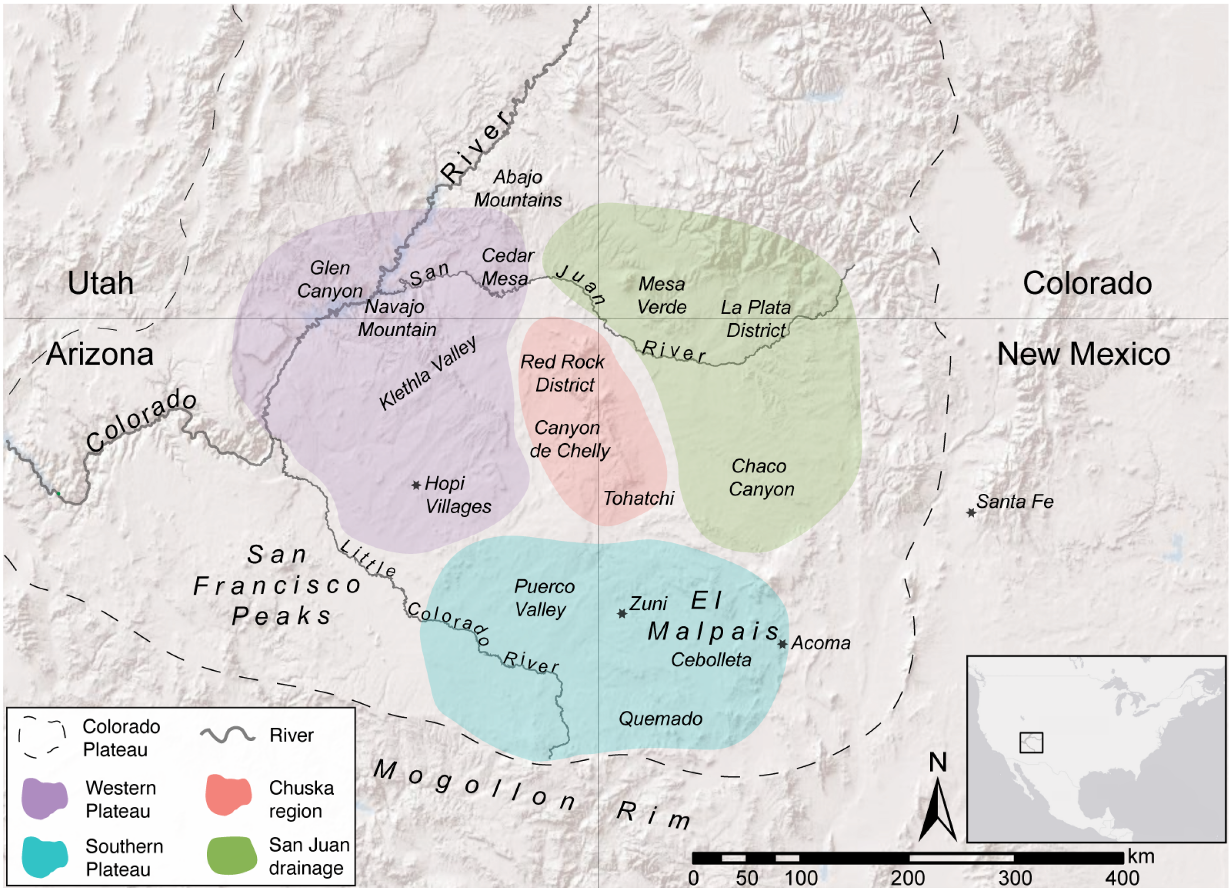

Figure 4.1. The northern US Southwest highlighting the regions discussed herein.

Similar to many open-air Basketmaker II settlements, EBWH sites are characterised by unstructured layouts, shallow pit-houses, subterranean storage facilities and a lack of discrete refuse middens (Figure 4.2a). Unlike Basketmaker II settlements, EBWH sites often contain communal architecture, ceramics fired under poorly controlled conditions and other components of the Neolithic package (Figure 4.2b). Conversely, Basketmaker III sites usually have organised site layouts, discrete refuse middens, abundant, above-ground storage structures fronted by deep residential pit-houses, larger and more formal communal architecture, and contain ceramics produced using consistent paste recipes and controlled firing conditions (Figure 4.2c–d).

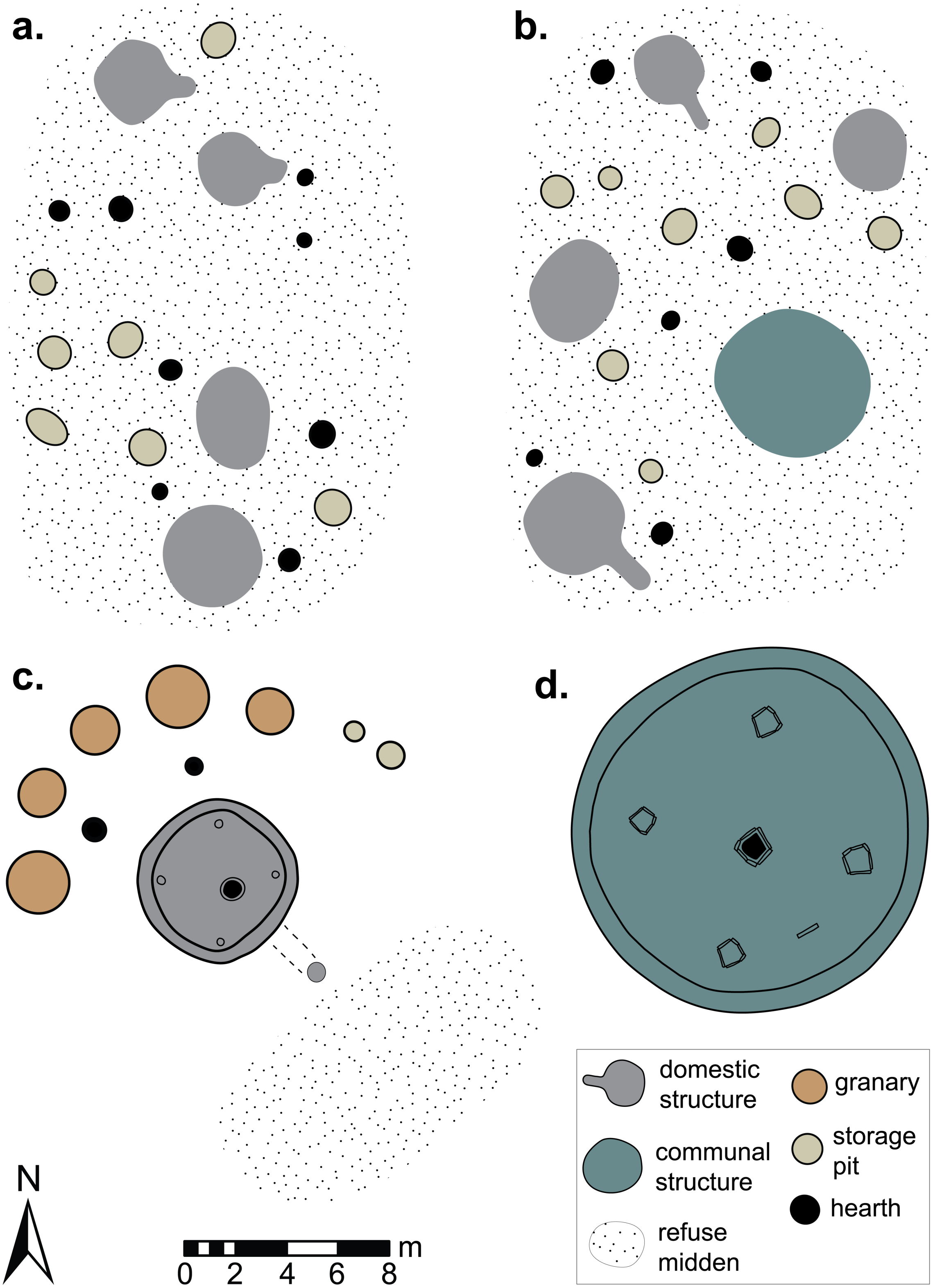

Figure 4.2. Neolithic transition site layouts: a) Basketmaker II (400 BC–AD 400); b) Early Brown Ware Horizon (AD 250–550); c) Basketmaker III (AD 550–750); d) Basketmaker III communal architecture.

Climate and Agriculture

The temperate, yet arid high-elevation Colorado Plateau presents risks for agriculture due to the moisture and temperature requirements of maize. Mean precipitation is greater and temperatures are cooler in the higher elevations of the northern US Southwest than in the lower elevation basin and range province to the south, and perennial water sources suitable for irrigation are rare. Most ancient farmers on the Colorado Plateau relied on direct rainfall, the moisture retaining capacity of soils and the diversion of runoff to supplement direct precipitation (Dominguez & Kolm 2005). Only upland areas above 2300m asl seldom occupied by farmers regularly receive insufficient accumulated heat during the summer growing season to produce a successful maize crop. Consequently, most recent studies of the relationship between regional demography and climate in the arid plateau Southwest have portrayed fluctuating precipitation as the key variable affecting farmers (e.g. Bocinsky & Kohler 2014). Since precipitation increases along an elevation gradient in the northern Southwest, and moisture is the primary limiting factor for agriculture region-wide, high elevation areas served as refugia during frequent droughts (Bocinsky & Kohler 2014; Vierra & Carvalho 2019).

Crops, however, can fail even if they receive sufficient moisture and accumulated heat, if, for example, a field does not maintain an adequate number of consecutive frost-free days, or a single hard freeze terminates plant growth (Adams 2015). Petersen (1987) argued that the demographic trajectories of well-watered, higher elevation areas were closely tied to fluctuating growing season lengths (also see Thomson *et al.* 2019). Here, we posit that rare, extreme and prolonged cooling events would have adversely affected farmers across the Colorado Plateau due to shortened growing seasons, decreased accumulated heat and more frequent hard frosts. These periods would have required a unique response by farming communities, since high-elevation locations that served as refugia during more-frequent droughts were even more susceptible to crop failure caused by infrequent, extreme cooling events, such as those triggered by volcanic eruptions.

Volcanic Climate Forcing, Paleoclimate and Demography

A growing number of high-quality tree-ring chronologies and well-dated ice-cores demonstrates that the most severe temperature anomalies during the Late Holocene were initiated by volcanic eruptions (Sigl *et al*. 2015; Anchukaitis *et al*. 2017). Two of the most consistently identified climate forcing events occurred in AD 536 and 541. These nearly coterminous, massive eruptions caused the coldest decade across the northern hemisphere in the past 2500 years (Sigl *et al*. 2015). Research by Dull *et al*. (2019) suggests that the Ilopango volcano in El Salvador was responsible for the latter event, while cryptotephra compositional data suggest that the former may have included eruptions in Alaska, British Columbia and California within a single year (Sigl *et al.* 2015). While the impacts of these events are well attested in Eurasian historical sources (Stothers 1984; Arjava 2005), and have recently been cited as responsible for social upheaval across that region (Büntgen *et al*. 2016; see, however, Helama *et al.* 2017), few studies have explored effects on contemporaneous, smaller-scale North American societies, even though these events are prominent in the paleoclimate records of the region.

Volcanic Events and Extreme Cold in the Regional Paleoclimate Record

Climate forcing from the eruptions of AD 536 and 541 is visible in tree-ring chronologies across western North America (Salzer & Hughes 2007; Salzer *et al*. 2014). Of importance to the current study, these effects are visible as frost-terminated growth rings in the temperaturesensitive San Francisco Peaks bristlecone pine chronology from northern Arizona (Table S2). We rely on the San Francisco Peaks chronology for temperature reconstruction (Salzer 2000) and the El Malpais chronology from western New Mexico for precipitation reconstruction (Grissino-Mayer 1995), as these represent the highest-quality temperature- and precipitation-sensitive chronologies covering the period of interest (Van West & Grissino-Mayer 2005; Stahle & Dean 2011: 321). They are also located close to the southern plateau—an area that hosted a dense, contemporaneous EBWH population (Figure 5.1). Van West & Grissino-Mayer (2005) converted the standardised mean annual temperature and precipitation departures from these respective chronologies to z-scores, which represent standard deviations from the 2100-year mean. A value of 0 is equivalent to the mean, while a value of +1 or −1 represents one-standard deviation above or below the mean. We also present growing degree-day reconstructions, an agronomy term shorthand for the total amount of accumulated heat units necessary for a plant to reach maturity. Our growing degree-day reconstruction uses methods developed by Bocinsky *et al*. (2016), which draw on numerous regional tree-ring chronologies (for accessible web-based modelling tools, see https://www.openskope.org).

The AD 536 and 541 eruptions are associated with one of the most significant cold periods on record in the San Francisco Peaks chronology. Salzer (2000) designates AD 534–553 as the sixth coldest interval, while Van West & Grissino-Mayer (2005) describe a seven-year cold and dry interval spanning AD 538–545 as the single coldest. Regardless, for 16 consecutive years (AD 538–553) temperature indices were over one standard deviation below the 2100-year mean—a pattern that does not occur at any other point in the San Francisco Peaks chronology (Figure 5.3). Moreover, nine of the 20 years with the lowest accumulated heat units on record since AD 1 occurred between AD 536–553. Temperatures finally rebounded in AD 555, but this was immediately followed by a 14-year drought between AD 556 and 569. Some 30 years later—only a single generation removed from these extreme events—the Colorado Plateau experienced four decades of the most productive and stable conditions for agriculture on record (AD 584–625). Both the extreme cold that followed the eruptions and the subsequent stable, warm and wet interval must have had important consequences for farming groups. The question is whether the effects of these events are visible in the archaeological tree-ring and radiocarbon records.

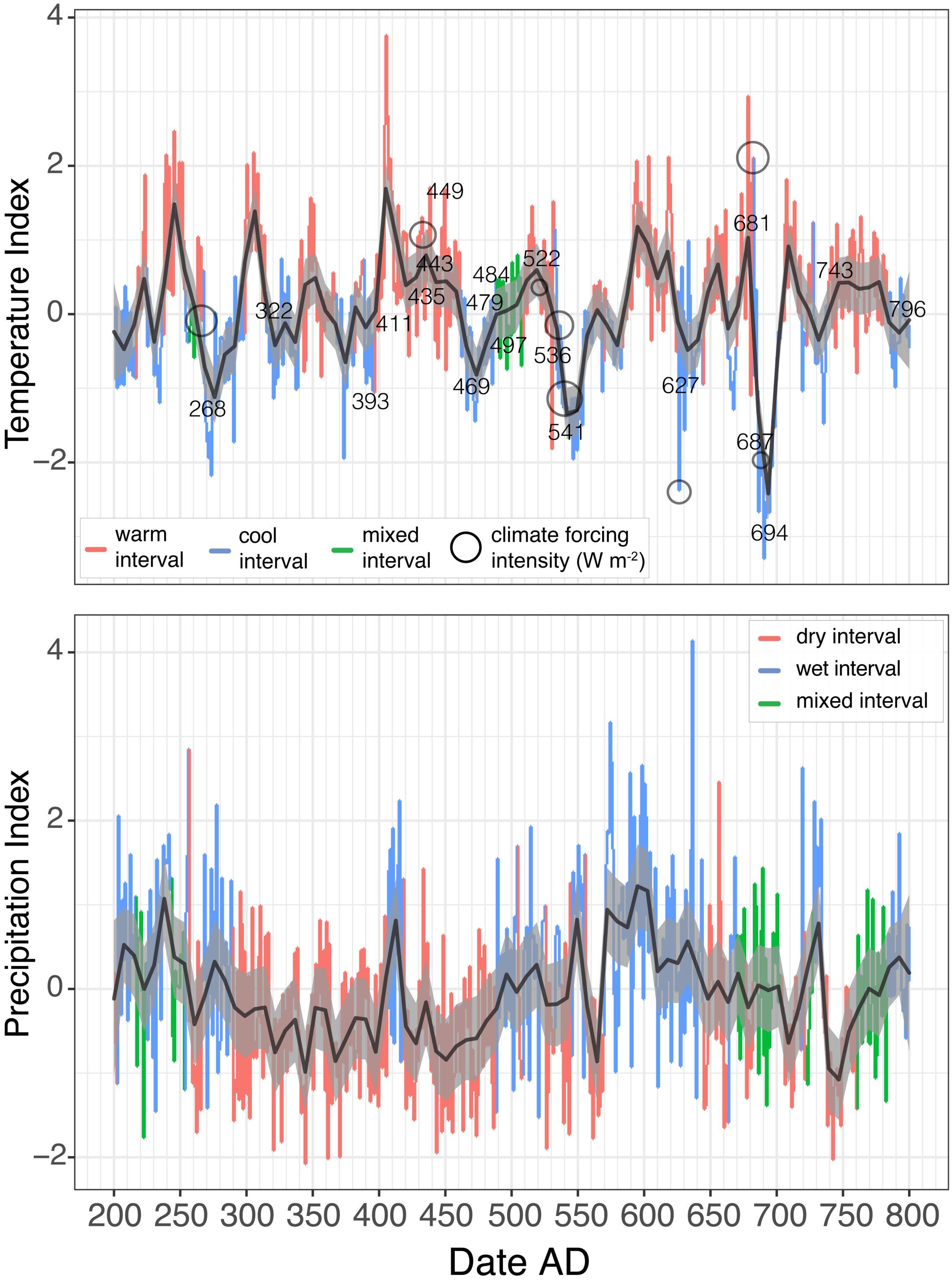

Figure 4.3. Temperature and precipitation reconstructions fitted with LOESS smoothed regression lines and 95% confidence intervals (span=0.05). Numbered years indicate frost terminated growth rings and black circles represent the timing and intensity of volcanic forcing (see Table S2). Note that y-axes for both panels are z-scores.

Archaeological chronologies

Baillie (1994: 214) appears to be the first to argue that the fallout of sixth-century climate forcing was visible in the archaeological dendrochronology record of the US Southwest. Here, we explore whether this remains the case, with an expanded dataset that includes 4886 outer-ring dates from the Colorado Plateau that fall between AD 200 and 800 (Figure 4.4). Of these, 1274 are cutting dates (indicative of the year a tree died), and 429 are near-cutting dates, to within one or two years of the true final cutting date (Speer 2010: 163). We expect the count and density of cutting and near-cutting dates to correlate with shifting demography and agricultural productivity (Bocinsky *et al*. 2016).

The earliest spike in construction activity evident from the archaeological tree-ring dates (AD 460–488) occurred in a limited number of high-elevation areas and locations with access to perennial water on the Colorado Plateau, at the end of a prolonged drought (AD 419–488). During a favourable interval that followed (AD 489–525), migrants from drought refugia introduced core components of the Neolithic package to vast expanses of the Colorado Plateau (Windes 2018; Vierra & Carvalho 2019: 212; Figure S1). Although precipitation varied during this early spike in construction, temperatures remained consistent from AD 468 to 521 (Salzer 2000: 76), enabling demographic expansion into new regions. The overall density of dates begins a precipitous decline during a short, warm, dry period (AD 526–532), and reaches its lowest point during the initial, intensely cold and dry portion of the anomaly (AD 538–545), for which no cutting dates have been recovered (Table S3). Date density remains low during the cold and wet portion of the anomaly (AD 546–553), throughout a period of drought (AD 556–569), and during a wet, cool period (AD 570–583), before the number of cutting dates increases over tenfold during the stable wet, warm interval (AD 584–629).

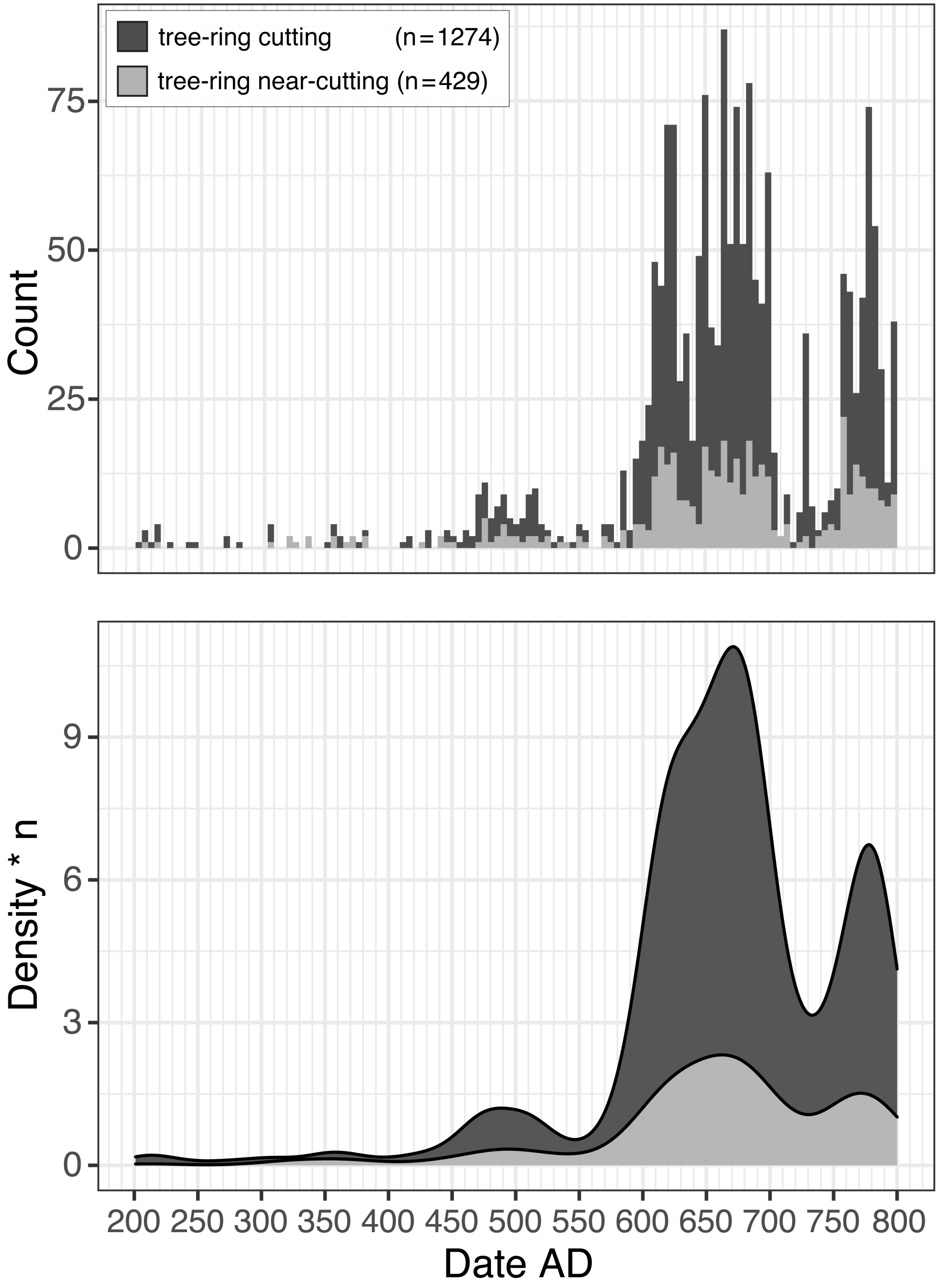

Figure 4.4. Tree-ring cutting and near-cutting dates from the Colorado Plateau, AD 200–800. Histogram bins represent five-year intervals.

Combined, the archaeological tree-ring data offer considerable evidence for the influence of the anomaly, as it coincides with the most pronounced decline in construction and the lowest density of cutting dates. Radiocarbon data also must be examined to provide coverage in lower elevation areas that less frequently produce wood suitable for tree-ring dating, and during earlier periods when it was less common for Ancestral Pueblo peoples to build with substantial timbers conducive to tree-ring dating.

We compiled a database of 682 radiocarbon dates from the northern US Southwest with calibrated, unmodelled medians (calibrated using IntCal20 (Reimer *et al*. 2020)) falling between AD 200 and 800—a range well before and after the climate event of interest. To visualise varying radiocarbon measurement density, yet minimise bias introduced by the calibration curve, we present a kernel density estimation model that incorporates 648 measurements from 230 archaeological sites, with measurement errors of ±100 radiocarbon years or fewer, and a second model that only includes a subset of 334 dates derived from higher-quality materials (Figure 5 & Figures S2–3). We believe that such models are appropriate, as they offer independent lines of evidence for comparison with the trends noted in the higher-resolution tree-ring data.

Our models display comparable patterns to the tree-ring dates. These comprise increasing radiocarbon measurement density during the late fifth and early sixth centuries, followed by a sharp decrease associated with the climate anomaly, and a sustained increase during the late sixth and early seventh centuries. Similar to the tree-ring dates, the minimum radiocarbon density corresponds with the peak effects of volcanic climate forcing, whereas the initial decline begins prior to peak effects. Although the end of a plateau in the radiocarbon curve (*c.* AD 440–540) potentially influences the apparent timing of the declining radiocarbon density, close agreement between the modelled radiocarbon data and tree-ring cutting dates strongly suggests that this plateau is not solely responsible (Figure 4.6). Given these results, we now explore the timing and tempo of the phase transition that ultimately led to the widespread adoption the Neolithic package and the transformation of Ancestral Pueblo societies.

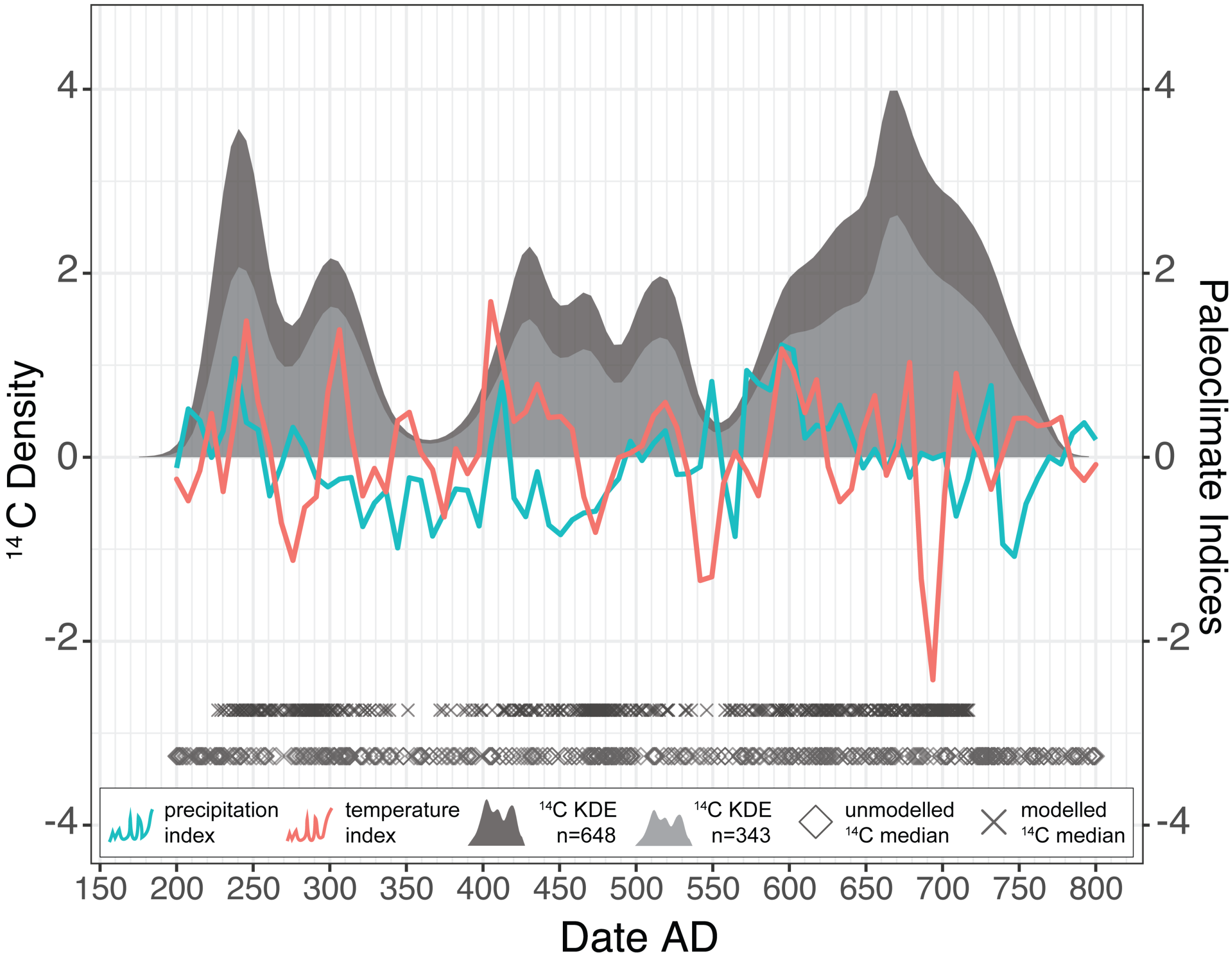

Figure 4.5. KDE_Model derived radiocarbon probability densities (Bronk Ramsey 2017) displayed with the temperature and precipitation indices presented in Figure 5.3 (see Figures S2–S3 for additional model details).

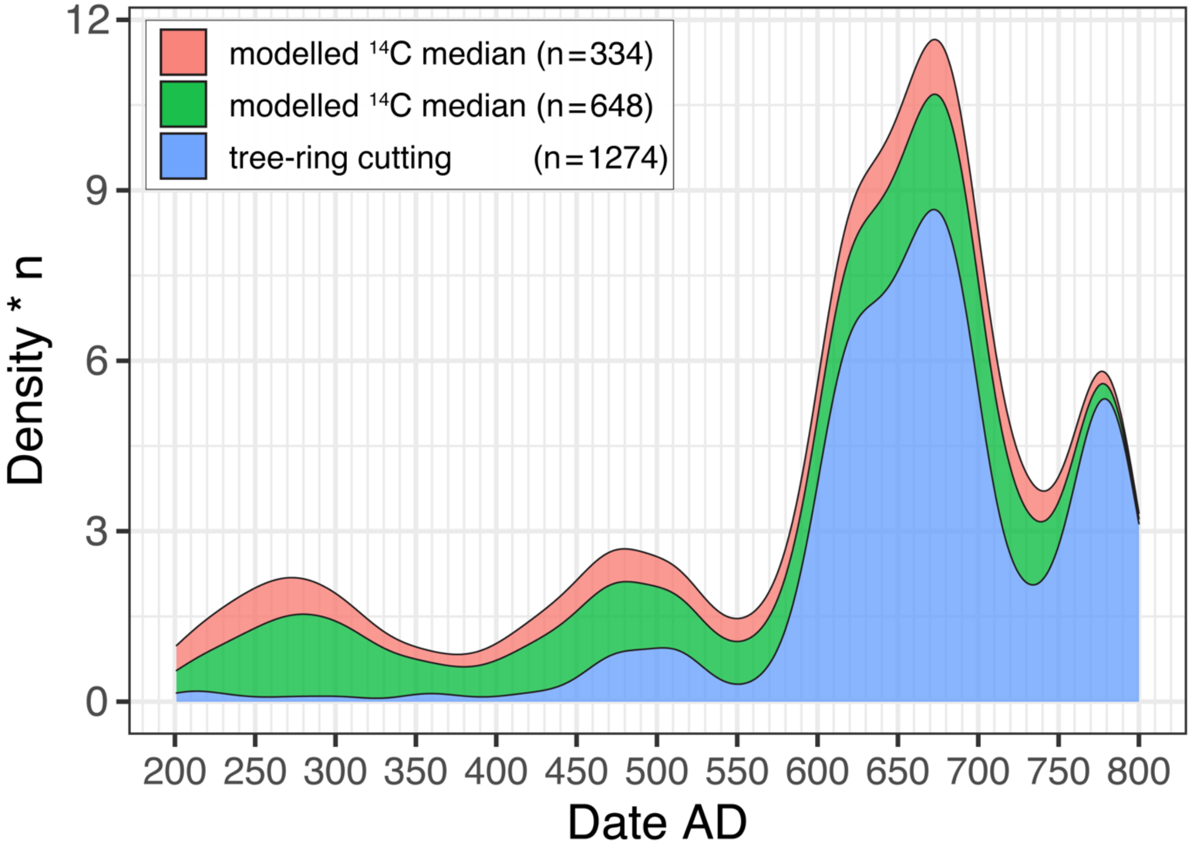

Figure 4.6. Densities of tree-ring cutting and radiocarbon dates using modelled ^{14}C medians as point estimates.

Disentangling the chronology of the sixth century

As groups adopted the Neolithic package in a piecemeal fashion, it is important to consider the potential temporal overlap between the EBWH and the Basketmaker II and III periods. Archaeologists have previously argued that the EBWH overlaps with the earlier Basketmaker II (Geib 2011) and later Basketmaker III periods (e.g. Wilson & Blinman 1994; Reed *et al*. 2000). An overlapping phase Bayesian model (Bronk Ramsey 2009: 348) reveals differences between phase transitions, with up to 65 years of overlap between the end of Basketmaker II and the onset of the EBWH, yet a gap spanning 33–87 years between the end of the EBWH and start of Basketmaker III (Figure 4.7 & Figure S4). Moreover, the model strongly suggests that the end of the EBWH coincided with the climate anomaly (AD 522–545 [68.3%]; AD 506–555 [95.4%]), while the socio-economic and demographic changes associated with the Basketmaker III period are not evident until the climate improved. This interpretation is corroborated by the tree-ring data discussed previously.

We find the gap between the EBWH and Basketmaker III to be particularly significant, as it matches patterns that we have noted on the southern plateau, in which long-lived ceramic traditions and architectural styles used throughout the EBWH were abruptly disused and do not appear subsequently alongside material culture or architecture typical of the Basketmaker III period. This break is also evident in the dendrochronological record of numerous regions of the Colorado Plateau with well-documented Basketmaker II and Basketmaker III occupations (Reed 2000; Wilshusen *et al*. 2012; Young & Herr 2012; see also Figure S5). This suggests that the disruption caused by extreme cooling could not be alleviated with farmers' existing risk-mitigation strategies.

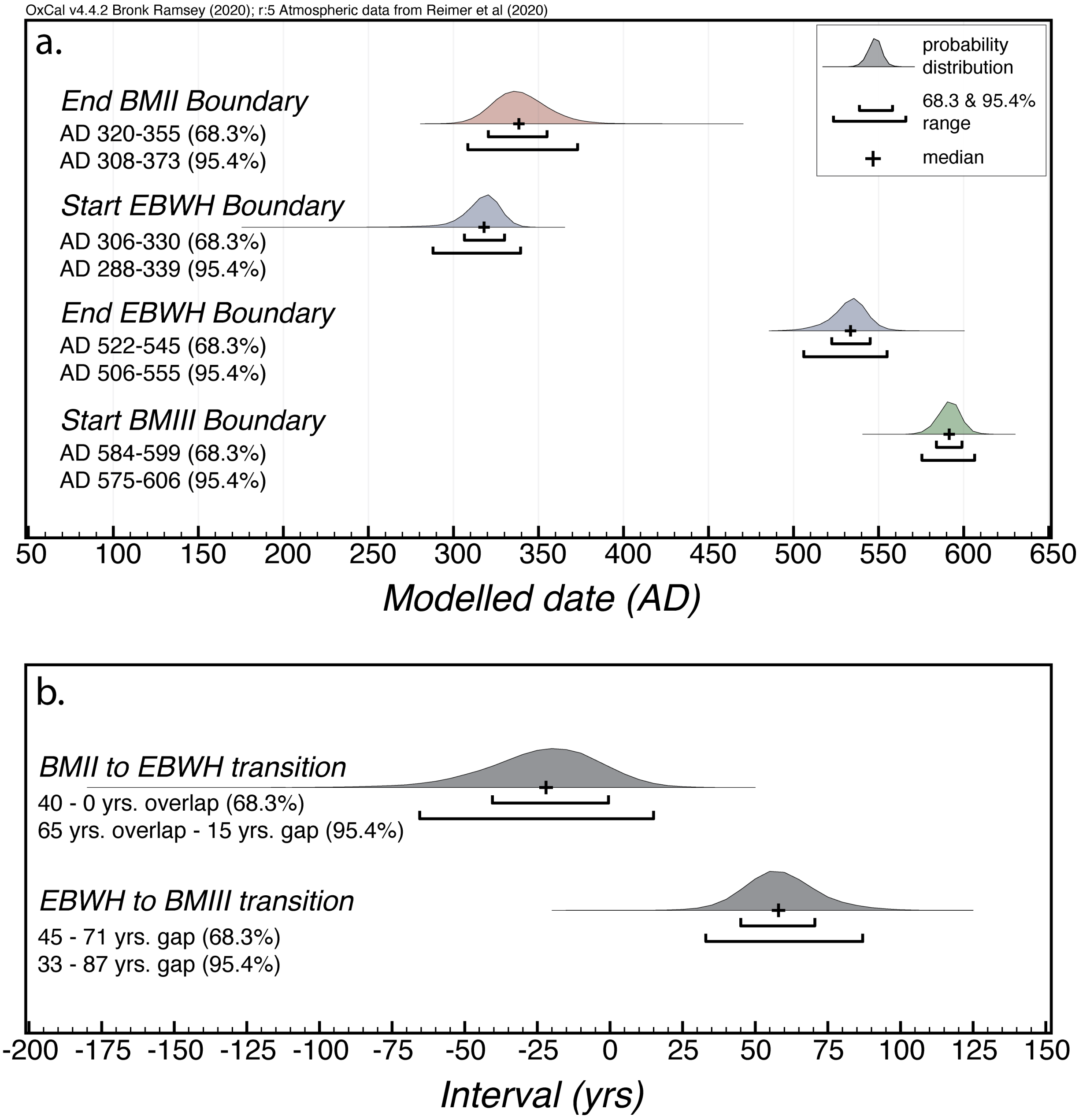

Figure 4.7. An overlapping phase Bayesian model that includes 402 radiocarbon measurements derived from annual plants, textiles, and bone (for further discussion, see Figure S4): a) start and end boundaries for select phases; b) Probability distributions for the span of phase transitions (dates calibrated and modelled using OxCal v.4.4.2 and the IntCal20 atmospheric curve [Bronk Ramsey 2020; Reimer et al. 2020]).

Mobility and Risk

In small-scale farming societies, strong social ties between groups living in different environmental zones help to minimise risk (Rautman 1993; Borck *et al*. 2015). During periods of acute environmental disturbance or social strife these ties also facilitate population movements that can last for several months, or even decades (Waddell 1975). Ephemeral residential architecture, unstructured site layouts and a lack of dedicated storage facilities during the EBWH suggest that residential moves were frequent and anticipated, and therefore probably occurred within well-developed social networks. Insufficient growing-season moisture is the most common variable affecting interannual crop yields on the Colorado Plateau. Consequently, social networks connected groups living in low-elevation areas with high-elevation drought refugia. Such locations were particularly important to farmers during the EBWH, due to long and persistent droughts between AD 290 and 488 (Figure 5.3). Archaeological evidence from sites of this era suggests that farmers moved between high and low-elevation locations as necessary; such movements formed a flexible, yet stable settlement system (Burton 2007; Rogge *et al.* 2016; cf. Vierra & Carvalho 2019: 212). In contrast, the extreme cooling brought on by the sixth century eruptions—and particularly the initial cold and dry interval of the anomaly (AD 538–545)—could not be addressed by drought resilient strategies, since high-elevation refugia were even more susceptible to crop failure caused by extreme cooling. Indeed, growing degree-day reconstructions show that high-elevation areas across the Colorado Plateau and regions immediately to the south fell below critical thresholds for successful maize agriculture, affecting regions well beyond the social networks of EBWH farmers (Figure 4.8 & Figure S6).

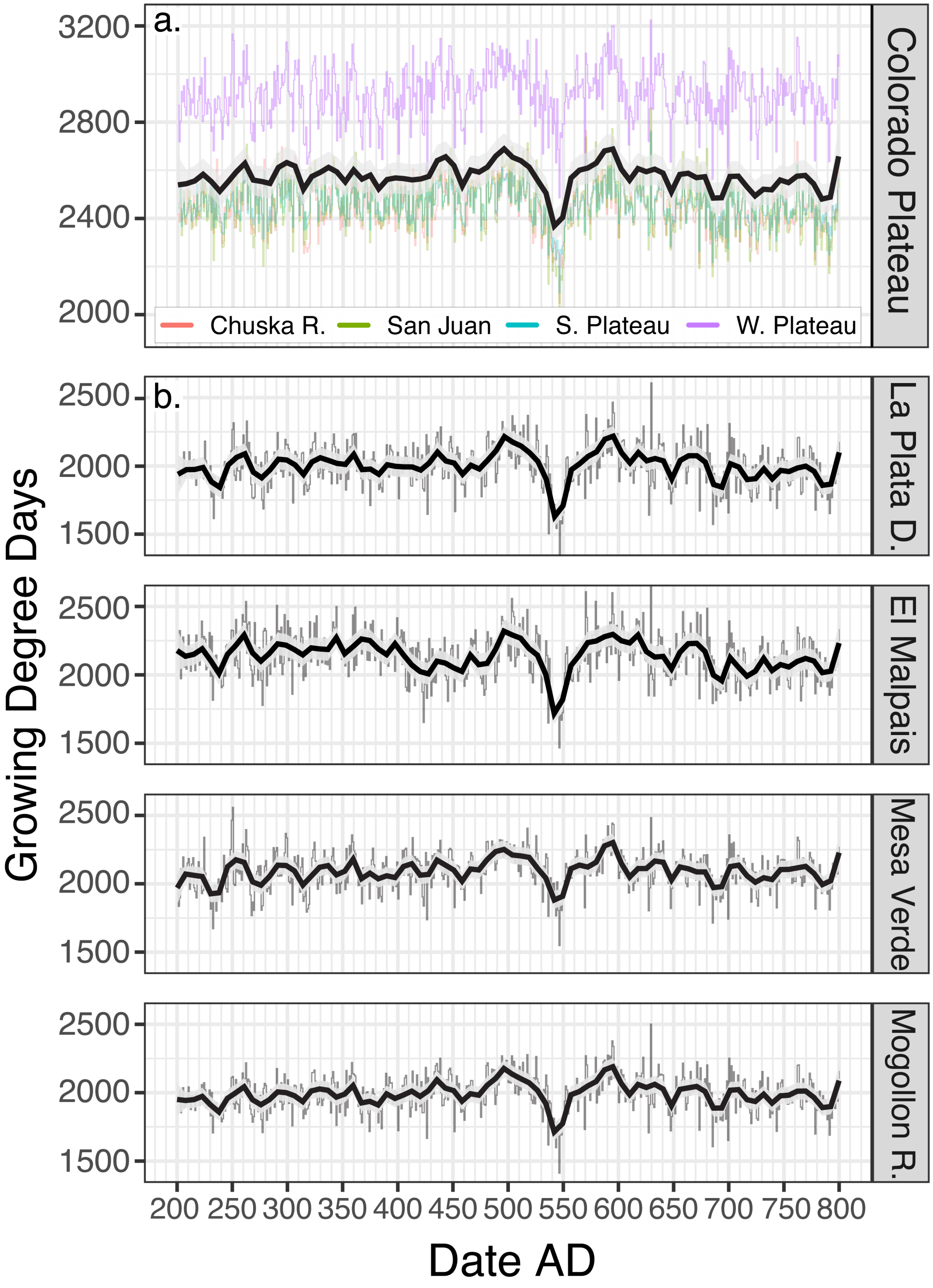

Figure 4.8. AD 200–800 May–September growing degree-day reconstructions fitted with LOESS smoothed regression lines (span=0.05): a) annual reconstructions for regions of the Colorado Plateau. Note that the western plateau encompasses arid and lower elevation areas unsuitable for rain-fed agriculture, and including these areas inflates the plateau-wide reconstruction (displayed in black); b) annual reconstructions for select high-elevation drought refugia.

Given the close correspondence between the climate anomaly and the hiatus evident in the radiocarbon and dendrochronological data (Figure 4.9), we conclude that the suddenness, severity and length of mid sixth-century extreme cooling triggered large-scale population movements beyond the limits of established social networks, along with significant population decline among groups that remained on the Colorado Plateau. Diverse populations across this region were uniformly affected. Prior to the anomaly, farmers on the southern plateau had rapidly adopted ceramic technology and built larger settlements with greater population densities compared to regions to the north (Table S4); during and after the anomaly, abrupt changes in pottery traditions, architecture and settlement patterns occurred. More sparsely populated areas that did not exhibit similar sharp changes in material culture were still affected, as occupational gaps and unexpected disruptions to previously stable settlement patterns occurred (Geib 2011; Hovezak & Sesler 2006).

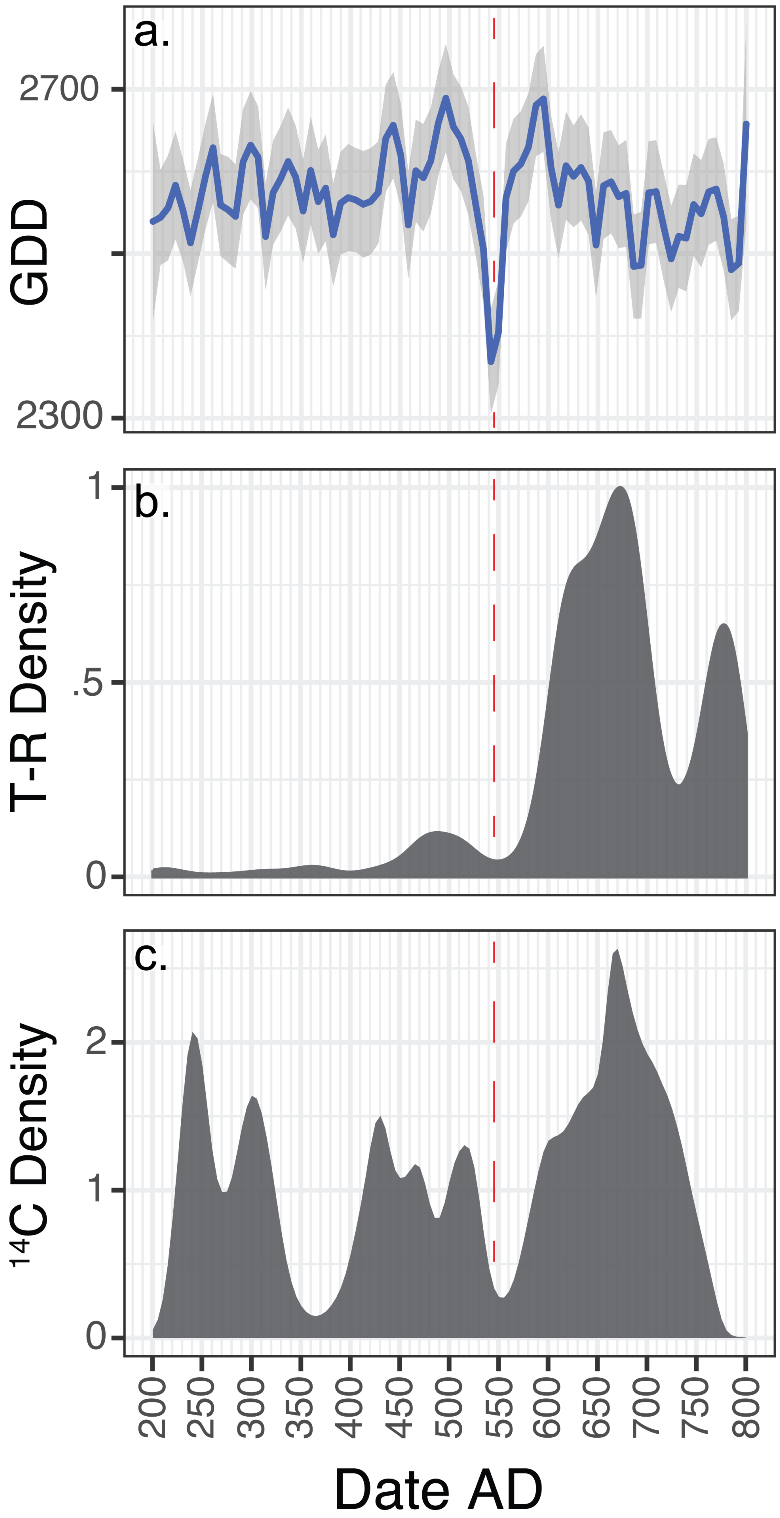

Figure 4.9. Temporal correspondence between sixth-century extreme cooling and chronometric data. The dashed red line represents the end of the extreme cold and dry interval (AD 545): **(a)** Growing degree-day reconstruction. **(b)** Cutting and near-cutting tree-ring date density. **(c)** modelled radiocarbon density.

Disturbance, Reorganisation and Social Change

Archaeologists have long recognised that demographic and social change transformed Ancestral Pueblo societies during the late sixth and early seventh centuries AD, but we contend that these changes are best understood when juxtaposed with the consequences of extreme cold at the beginning of this interval. The climate anomaly upended diverse, longstanding settlement systems on the Colorado Plateau by pushing population movements beyond the boundaries of established social networks. This generated a cultural milieu ripe for the renegotiation of distinct and long-held local traditions. Swift resettlement by increasingly sedentary and rapidly growing populations allowed for the spread of shared socio-economic traditions, fuelled by exceptionally favourable conditions for farming. We suggest that the rapid population displacement, spurred by extreme cooling and the swift resettlement and colonisation of the Colorado Plateau during the subsequent warm and wet interval, constituted critical ingredients in a long process of cultural construction that facilitated the development of more complex and widely shared forms of socio-economic organisation (Robins & Hays-Gilpin 2000). We view these changes not as mechanistic reactions to climate change, but as sophisticated societal responses critical to the long-term emergence of Ancestral Pueblo traditions.

In smaller-scale societies worldwide, significant disruptions to socio-economic systems can lead to the rapid reorganisation of social structures within a surprisingly short timeframe (Aldenderfer 1993; Kohler & Bocinsky 2017). Such events, whether triggered by social or environmental factors, provide opportunities for the influence of new ideologies and powerful individuals to spread rapidly through a group. As the climate anomaly forced migrants into regions beyond existing social networks—and such migrants often occupy the lowest status in small-scale societies (Watson 1970; McGuire & Saitta 1996)—the large-scale population movements prompted by the AD 536 and 541 eruptions enabled the development of complex social structures that cross-cut group boundaries and amplified social inequality; these are all characteristics that mark the Neolithic Transition in the northern US Southwest. Indeed, some archaeologists now locate the foundations of social inequality at Chaco Canyon in changes that began during this interval (Plog 2018).

Although physical manifestations of these changes were not as overt as those that accompanied the founding of later, eighth-century villages on the Colorado Plateau, one important example of local leaders capitalising on the declining importance of drought refugia appears to have occurred in Chaco Canyon. Here, remodelling of the earliest well-dated great kiva on the Colorado Plateau took place during the climatic anomaly (AD 550–557 cutting dates; see Windes 2018). Soon thereafter, these large, subterranean ceremonial structures became the dominant form of communal architecture across the northern Southwest (Diederichs 2020; Gilpin & Benallie 2000), and Chaco experienced its initial rise as a demographic centre (Windes 2018). While maize agriculture in Chaco Canyon was probably impossible during the initial dry and cold portion of the anomaly (AD 538–545), farmers likely fared better than those in higher elevation areas during the wet and cold interval that followed (AD 546–553). Future research should consider the potential relationship between population movements sparked by extreme cooling and other contemporaneous social changes that unfolded across the US Southwest more broadly, including the Early to Late Pithouse period transition in the Mogollon region, the emergence of the first large Hohokam villages and the initial construction of labour-intensive terrace-top canal systems in the Sonoran Desert (Wallace & Lindeman 2012: 38–41; Roth *et al.* 2018).

Conclusion

The Neolithic Transition in the northern US Southwest has long been associated with the Basketmaker II and III periods of the Pecos chronology, yet exactly when, how, or why this transition arose has been the subject of considerable debate. Based on a suite of environmental and chronological evidence, we propose that extreme cold brought on by catastrophic volcanic eruptions in AD 536 and 541 triggered a generation-long crisis across an area of more than 160 000km^2. This region-wide disruption tore apart the social fabric of the various kin-based groups, who, over the course of a millennium, had adapted to a wide range of different locales and who were marked as much by their differences as by what they shared. The region-wide depopulation and the favourable agricultural conditions that followed enabled a total reorganisation of Ancestral Pueblo societies that incorporated a full Neolithic package of domesticates, technologies and increasingly complex forms of supra-household organisation. This shared lifeway enabled farmers to spread quickly across much of the area, and offered the foundational elements of early villages, the rise of regional systems and the origins of social inequality over the next two centuries.

Acknowledgements

We thank the two anonymous reviewers and the many individuals at Petrified Forest National Park, the Hopi Cultural Preservation Office, the Museum of Northern Arizona, the Arizona State Museum, the Western Archaeological and Conservation Center, the Field Museum and the Crow Canyon Archaeological Center for their help with this research.

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Supplementary material

To view supplementary material for this article visit: https://doi.org/10.15184/aqy.2021.19.

All data and code used to generate the figures are provided in the Colorado Plateau Dataverse.

To view replication data and code associated with analyses in R, please visit https://doi.org/10.25346/S6/N3RVLC.

To view radiocarbon data, OxCal model output and code, please visit https://doi.org/10.25346/S6/LFS4H9.

Supplement 4.2. Rendered R Markdown File that Reproduces Figures 4.3 – 4.6, and 4.8 – 4.9.

Analysis of data associated with: Sixth century volcanic climate forcing, extreme cold, and the Neolithic transition in the northern US Southwest, by R. J. Sinensky, G. Schachner, R. H. Wilshusen and B. M. Damiata, submitted to the journal ‘Antiquity’.

September, 2020

```
knitr::opts_chunk$set(echo = TRUE)

# These packages are necessary for all subsequent analyses
# and can be installed via the install.packages() function
library (tidyverse)
```

```
## ── Attaching packages ────────────────────────────────── tidyverse 1.3.0 ──
```

```
## ✓ ggplot2 3.3.2     ✓ purrr   0.3.4
## ✓ tibble  3.0.3     ✓ dplyr   1.0.2
## ✓ tidyr   1.1.2     ✓ stringr 1.4.0
## ✓ readr   1.3.1     ✓ forcats 0.5.0
```

```
## ── Conflicts ──────────────────────────────────── tidyverse_conflicts() ──
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library (gridExtra)
```

```
##
## Attaching package: 'gridExtra'
```

```
## The following object is masked from 'package:dplyr':
##
##     combine
```

```
library (grid)
library (lubridate)
```

```
##
## Attaching package: 'lubridate'
```

```
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
library (cowplot)
```

```
##
## Attaching package: 'cowplot'
```

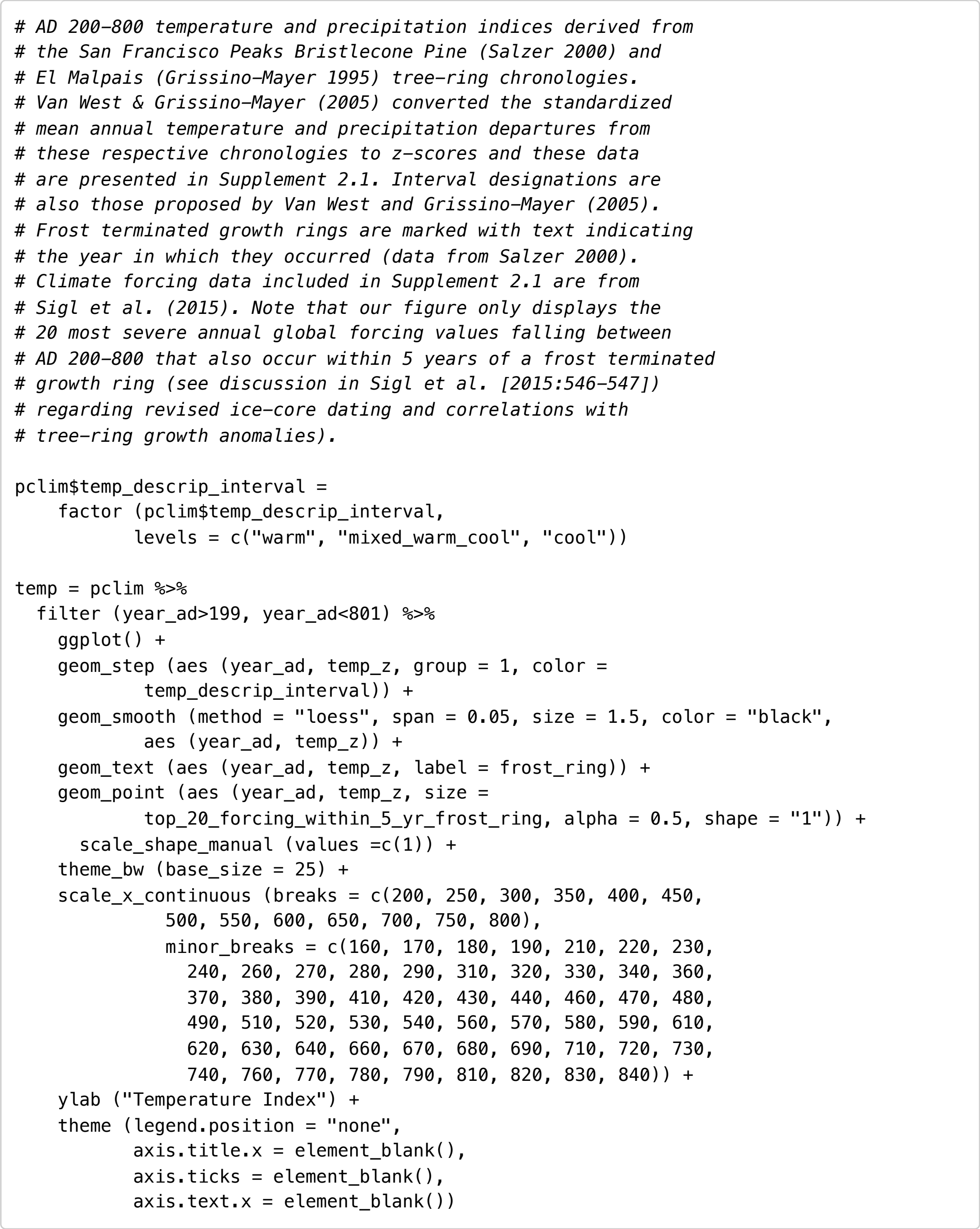
```
## The following object is masked from 'package:lubridate':
##
##     stamp
```

```
library (egg)
library (gtable)
```

The following R Markdown file contains the code necessary to generate Figures 3, 4, 5, 7, 8 and 9 presented in Sinensky et al., and Figures 1, 5 and 6 presented in Supplement 1. Please note that the CSV files must be in the same folder as this .RMD file.

```
pclim = read.csv ("Supplement_2.1.csv")
tr_chron = read.csv ("Supplement_2.2.csv")
rc_kde = read.csv ("Supplement_2.3.csv")
n648 = read.csv ("Supplement_2.4.csv")
gdd = read.csv ("Supplement_2.5.csv")
pt_est = read.csv ("Supplement_2.6.csv")
```

Figure 3



```r
# AD 200-800 temperature and precipitation indices derived from
# the San Francisco Peaks Bristlecone Pine (Salzer 2000) and
# El Malpais (Grissino-Mayer 1995) tree-ring chronologies.
# Van West & Grissino-Mayer (2005) converted the standardized
# mean annual temperature and precipitation departures from
# these respective chronologies to z-scores and these data
# are presented in Supplement 2.1. Interval designations are
# also those proposed by Van West and Grissino-Mayer (2005).
# Frost terminated growth rings are marked with text indicating
# the year in which they occurred (data from Salzer 2000).
# Climate forcing data included in Supplement 2.1 are from
# Sigl et al. (2015). Note that our figure only displays the
# 20 most severe annual global forcing values falling between
# AD 200-800 that also occur within 5 years of a frost terminated
# growth ring (see discussion in Sigl et al. [2015:546-547])
# regarding revised ice-core dating and correlations with
# tree-ring growth anomalies).

pclim$temp_descrip_interval =
    factor (pclim$temp_descrip_interval,
           levels = c("warm", "mixed_warm_cool", "cool"))

temp = pclim %>%
  filter (year_ad>199, year_ad<801) %>%
    ggplot() +
    geom_step (aes (year_ad, temp_z, group = 1, color =
            temp_descrip_interval)) +
    geom_smooth (method = "loess", span = 0.05, size = 1.5, color = "black",
            aes (year_ad, temp_z)) +
    geom_text (aes (year_ad, temp_z, label = frost_ring)) +
    geom_point (aes (year_ad, temp_z, size =
            top_20_forcing_within_5_yr_frost_ring, alpha = 0.5, shape = "1")) +
      scale_shape_manual (values =c(1)) +
    theme_bw (base_size = 25) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450,
              500, 550, 600, 650, 700, 750, 800),
              minor_breaks = c(160, 170, 180, 190, 210, 220, 230,
                240, 260, 270, 280, 290, 310, 320, 330, 340, 360,
                370, 380, 390, 410, 420, 430, 440, 460, 470, 480,
                490, 510, 520, 530, 540, 560, 570, 580, 590, 610,
                620, 630, 640, 660, 670, 680, 690, 710, 720, 730,
                740, 760, 770, 780, 790, 810, 820, 830, 840)) +
    ylab ("Temperature Index") +
    theme (legend.position = "none",
           axis.title.x = element_blank(),
           axis.ticks = element_blank(),
           axis.text.x = element_blank())
```

```
precip = pclim %>%
  filter (year_ad>199, year_ad<801) %>%
    ggplot() +
    geom_step (aes (year_ad, precip_z, group = 1, color =
                    precip_descrip_interval)) +
    geom_smooth (method = "loess", span = 0.05, size = 1.5,
                 color = "black",
                 aes (year_ad, precip_z)) +
    theme_bw (base_size = 25) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450,
                    500, 550, 600, 650, 700, 750, 800),
                    minor_breaks = c(160, 170, 180, 190, 210,
                      220, 230, 240, 260, 270, 280, 290, 310, 320,
                      330, 340, 360, 370, 380, 390, 410, 420, 430,
                      440, 460, 470, 480, 490, 510, 520, 530, 540,
                      560, 570, 580, 590, 610, 620, 630, 640, 660,
                      670, 680, 690, 710, 720, 730, 740, 760, 770,
                      780, 790, 810, 820, 830, 840)) +
    xlab ("Date AD") +
    ylab ("Precipitation Index") +
    theme (legend.position = "none")
```

```
grid.arrange (temp, precip)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 581 rows containing missing values (geom_text).
```

```
## Warning: Removed 593 rows containing missing values (geom_point).
```

```
## `geom_smooth()` using formula 'y ~ x'
```

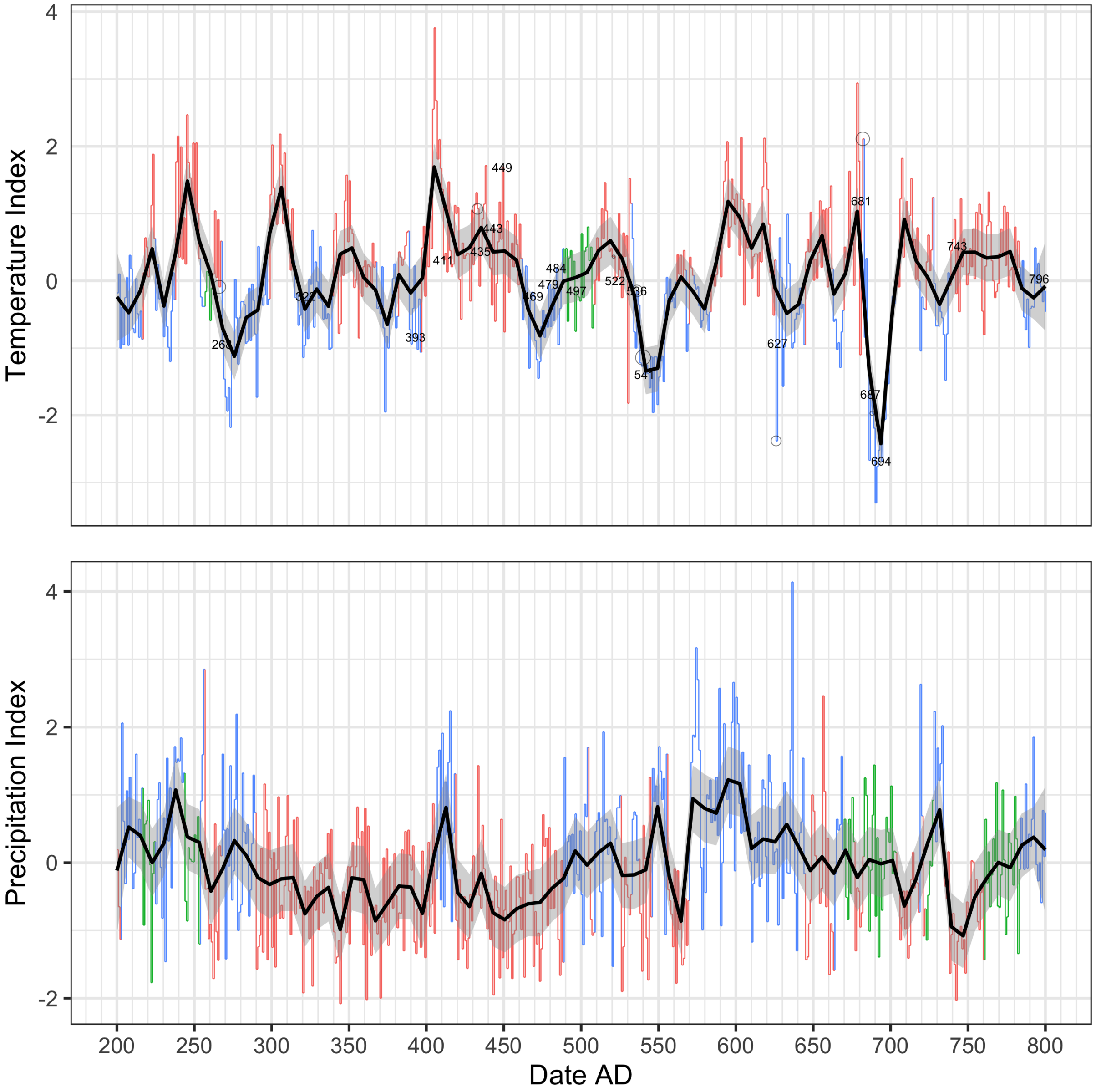

Temperature Index
Precipitation Index
Date AD
4
2
0
-2
200
250
300
350
400
450
500
550
600
650
700
750
800
268
322
393
411
435
443
449
469
479
484
497
522
536
541
627
681
687
694
743
796

Figure 4

```
# Histogram of tree-ring cutting and near-cutting dates.
# Note that only tree-ring dates from the Colorado Plateau are
# included. Most of the data included in Supplement 2.2 are from
# Kohler & Bocinsky (2016) and the references cited therein.
# We also include additional tree-ring dates from EBWH and
# Basketmaker III sites located on the southern plateau
# (Aikens 1998), the western plateau (Ambler and Olson 1977;
# Sebastian 1985; Smiley and Ahlstrom 1998; Swarthout et al. 1986)
# and the San Juan drainage (Windes 2018).

tr_hist = tr_chron %>%
  filter (Region == "San Juan Drainage" |
            Region == "Southern Plateau" |
            Region == "Western Plateau" |
            Region == "Chuskas",
            conf_level == "cutting" |
            conf_level == "near_cutting") %>%
    ggplot (aes (x = Outer_Date_AD, stat (count),
                 fill = conf_level)) +
    geom_histogram (binwidth = 5, position = "stack") +
    scale_fill_grey (start = 0.3, end = 0.7) +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400,
                                   450, 500, 550, 600, 650, 700,
                                   750, 800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                   220, 230, 240, 260, 270, 280, 290,
                                   310, 320, 330, 340, 360, 370, 380,
                                   390, 410, 420, 430, 440, 460, 470,
                                   480, 490, 510, 520, 530, 540, 560,
                                   570, 580, 590, 610, 620, 630, 640,
                                   660, 670, 680, 690, 710, 720, 730,
                                   740, 760, 770, 780, 790, 810, 820,
                                   830, 840)) +
    ylab ("Count") +
    theme (legend.position = "none",
           axis.title.x = element_blank(),
           axis.ticks = element_blank(),
           axis.text.x = element_blank())
```

```
# Tree-ring cutting and near cutting date densities. Note that the
# y-axis represents density * n, which provides a more intuitive
# scale for direct comparison with the date counts displayed in the
# histogram.

tr_den = tr_chron %>%
  filter (Region == "San Juan Drainage" |
            Region == "Southern Plateau" |
            Region == "Western Plateau" |
            Region == "Chuskas",
            conf_level == "cutting" |
            conf_level == "near_cutting") %>%
    ggplot (aes (x = Outer_Date_AD, stat (count),
                 fill = conf_level)) +
    geom_density (position = "stack", aes (alpha = 0.8)) +
    scale_fill_grey (start = 0.3, end = 0.7) +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400,
                                   450, 500, 550, 600, 650, 700,
                                   750, 800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                    220, 230, 240, 260, 270, 280,
                                    290, 310, 320, 330, 340, 360,
                                    370, 380, 390, 410, 420, 430,
                                    440, 460, 470, 480, 490, 510,
                                    520, 530, 540, 560, 570, 580,
                                    590, 610, 620, 630, 640, 660,
                                    670, 680, 690, 710, 720, 730,
                                    740, 760, 770, 780, 790, 810,
                                    820, 830, 840)) +
    xlab ("Date AD") +
    ylab ("Density * n") +
    theme (legend.position = "none")
```

```
grid.newpage()
  grid.draw (rbind (ggplotGrob (tr_hist),
                ggplotGrob (tr_den), size = "last"))
```

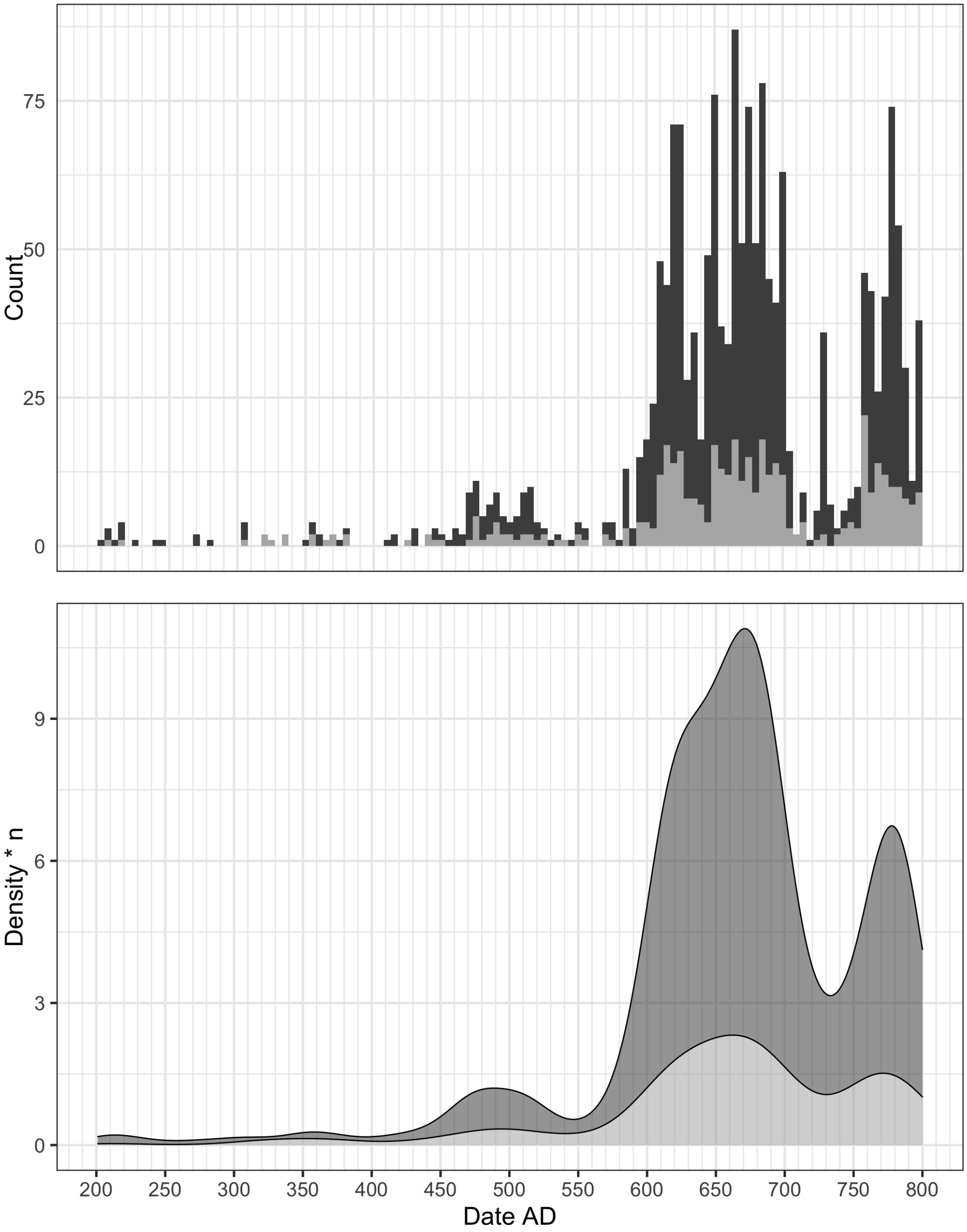

Count
0
25
50
75
Density * n
0
3
6
9
200
250
300
350
400
450
500
550
600
650
700
750
800
Date AD

Figure 5

```
# KDE_Model derived radiocarbon probability densities and
# paleoclimate indices. Figure 5 displays probability
# densities associated with two models. The first model includes 648
# radiocarbon measurements with calibrated, unmodelled medians
# (calibrated using IntCal20) dating between AD 200-800 with
# measurement errors of 100 rcbp or less, and the second model
# includes a subset of  334 measurements derived from higher quality
# materials, including domesticated annual plants, non-domesticated
# annual plants commonly used for food, human bone collagen and
# coprolites, and perishable objects manufactured from short-lived
# plants and animals). Modelled and unmodelled median dates displayed
# below the probability distributions are associated with larger model
# that includes 648 measurements. Note that the radiocarbon data were
# modelled using the OxCal v4.4.2 software and the data and code for
# these models are presented in Supplement 3.2 & 3.3.

rc_kde %>%
    filter (model == "n648_post" |
                model == "n334_post", yr>149, yr<851) %>%
    ggplot() +
    geom_area (aes (yr, prob, alpha=0.5, fill = model)) +
    scale_fill_grey (start = 0.2, end = 0.5) +
    geom_smooth (data = pclim, method = "loess",
                 alpha = 0.25, span = 0.05, level = NA, size = 2,
                 aes (year_ad, precip_z, color = "red")) +
    geom_smooth (data = pclim, method = "loess", alpha = 0.25,
                 span = 0.05, level = NA, size = 2,
                 aes (year_ad, temp_z, color = "blue2")) +
    geom_point (data = n648,
                aes (mod_median, -2.75, shape = "4",
                     alpha = 0.5, size = 4)) +
    geom_point (data = n648,
                aes (cal_median, -3.25, shape = "5",
                     alpha = 0.5, size = 4)) +
    scale_shape_manual (values =c(4, 5)) +
    theme_bw (base_size = 25) +
    scale_x_continuous (breaks = c(150, 200, 250, 300, 350, 400,
                                   450, 500, 550, 600, 650, 700,
                                   750, 800),
                        minor_breaks = c(110, 120, 130, 140, 160,
                                         170, 180, 190, 210, 220,
                                         230, 240, 260, 270, 280,
                                         290, 310, 320, 330, 340,
                                         360, 370, 380, 390, 410,
                                         420, 430, 440, 460, 470,
                                         480, 490, 510, 520, 530,
                                         540, 560, 570, 580, 590,
                                         610, 620, 630, 640, 660,
                                         670, 680, 690, 710, 720,
                                         730, 740, 760, 770, 780,
                                         790, 810, 820, 830, 840),
                        limits = c(175, 800)) +
```

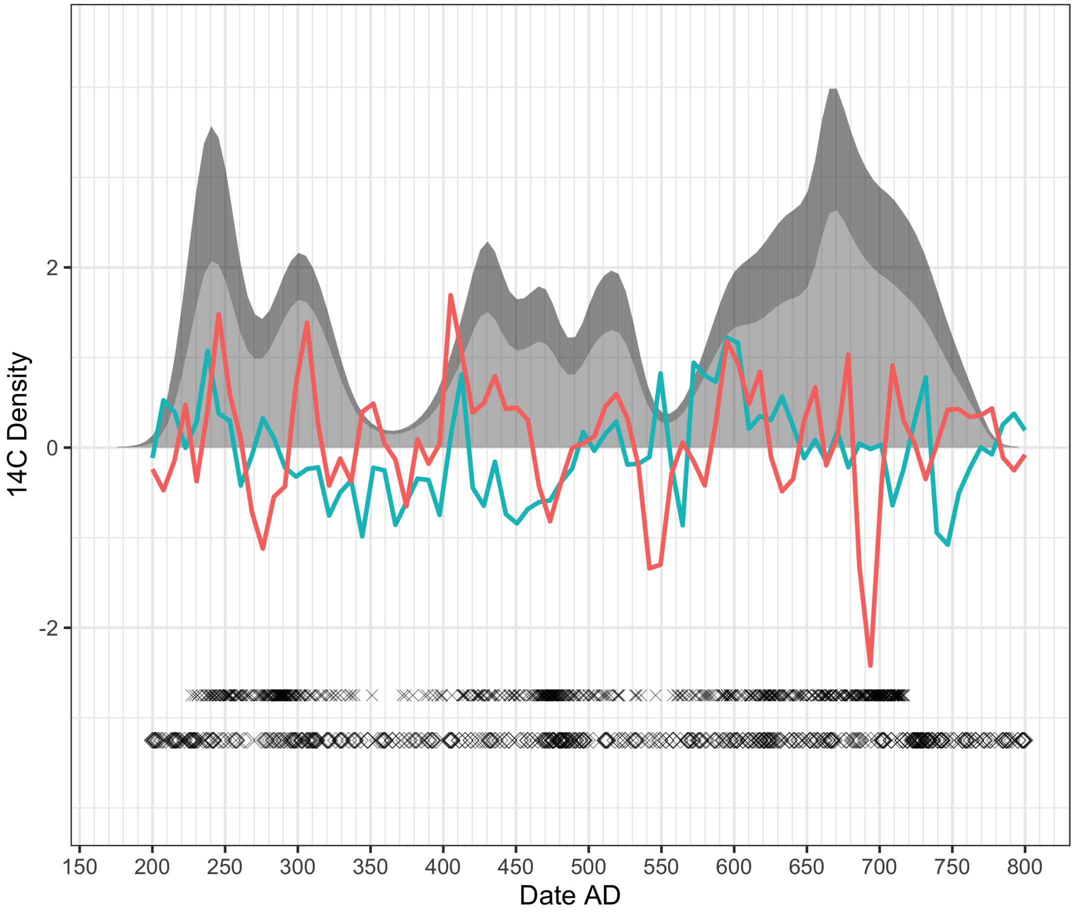
```
    scale_y_continuous (breaks = c(-2, 0, 2),
                        limits = c(-4.0, 4.5)) +
    xlab ("Date AD") +
    ylab ("14C Density") +
    theme (legend.position = "none")
```

```
## `geom_smooth()` using formula 'y ~ x'
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 32 rows containing missing values (position_stack).
```

```
## Warning in max(ids, na.rm = TRUE): no non-missing arguments to max; returning -
## Inf

## Warning in max(ids, na.rm = TRUE): no non-missing arguments to max; returning -
## Inf
```



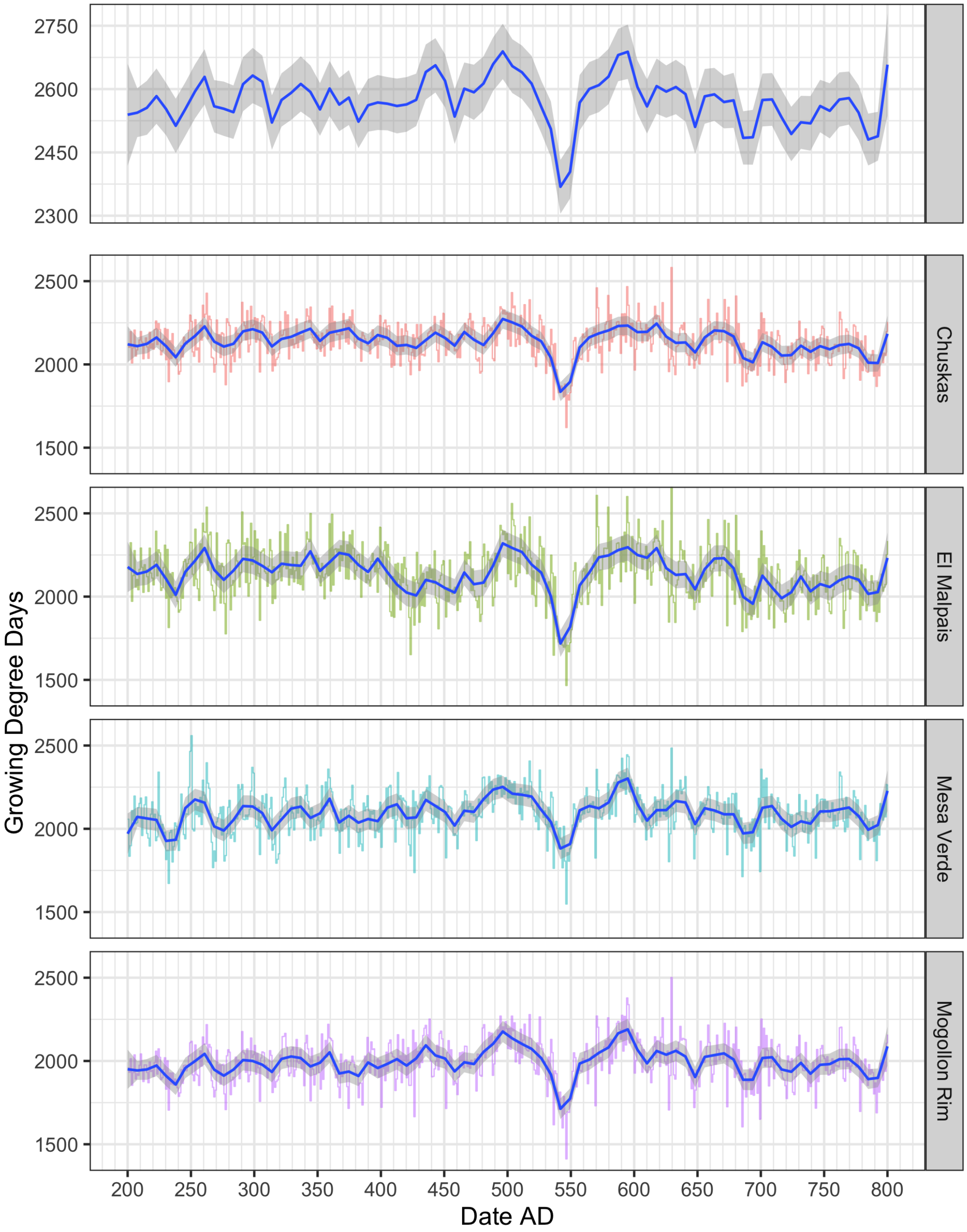
```
# AD 200–800 growing degree day reconstructions for the
# Colorado Plateau derived using the methods discussed by
# Bocinsky & Kohler (2014) and Bocinsky et al. (2016).
# We used the PaleoCAR application available on the SCOPE website
# (https://www.openskope.org/) to generate the growing degree day
# reconstructions for the four regions of the Colorado Plateau
# displayed in Figure 1, and various sub–regions that likely
# served as high elevation refugia during droughts (also displayed
# in Figure 1). Note that the PaleoCAR package generates models
# for polygon shaped areas using four coordinates, and therefore
# the region boundaries displayed in Figure 1 are similar but not
# identical to those used in the PaleoCAR reconstruction.
cp_gdd = gdd %>%
  filter (region == "Western Plateau" |
            region == "Southern Plateau" |
            region == "San Juan" |
            region == "Chuskas") %>%
ggplot(aes (year, agdd)) +
    geom_smooth (method = "loess", span = 0.05) +
        facet_grid(rows = "prov") +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450,
                                   500, 550, 600, 650, 700, 750,
                                   800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                         220, 230, 240, 260, 270,
                                         280, 290, 310, 320, 330,
                                         340, 360, 370, 380, 390,
                                         410, 420, 430, 440, 460,
                                         470, 480, 490, 510, 520,
                                         530, 540, 560, 570, 580,
                                         590, 610, 620, 630, 640,
                                         660, 670, 680, 690, 710,
                                         720, 730, 740, 760, 770,
                                         780, 790, 810, 820, 830,
                                         840)) +
    scale_y_continuous (breaks =  c(2300, 2450, 2600, 2750)) +
    theme (axis.title.x = element_blank()) +
    ylab ("") +
    theme (legend.position = "none",
           axis.title.x = element_blank(),
           axis.ticks = element_blank(),
           axis.text.x = element_blank())
```

```
# High-elevation drought refugia gdd reconstructions. Note that the
# data presented for the Chuska Mountains here (prov == "Chuskas")
# is only representative of a high elevation portion of the mountain
# range, while the data included in the Colorado Plateau reconstruction
# (region == "Chuskas") better represents the area labeled the
# Chuska region in Figure 1.

prov_gdd = gdd %>%
  filter (prov == "Chuskas" |
            prov =="Mesa Verde" |
            prov =="Mogollon Rim" |
            prov =="El Malpais") %>%
    ggplot (aes (year, agdd)) +
    geom_step (alpha = 0.5,
               aes (color = prov)) +
    geom_smooth (method = "loess", span = 0.05) +
    facet_grid (rows = "prov") +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450,
                                   500, 550, 600, 650, 700, 750,
                                   800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                         220, 230, 240, 260, 270,
                                         280, 290, 310, 320, 330,
                                         340, 360, 370, 380, 390,
                                         410, 420, 430, 440, 460,
                                         470, 480, 490, 510, 520,
                                         530, 540, 560, 570, 580,
                                         590, 610, 620, 630, 640,
                                         660, 670, 680, 690, 710,
                                         720, 730, 740, 760, 770,
                                         780, 790, 810, 820, 830,
                                         840)) +
    scale_y_continuous (breaks =  c(1500, 2000, 2500)) +
    coord_cartesian (xlim =c(200, 800), ylim = c(1400, 2600)) +
    xlab ("Date AD") +
    ylab ("Growing Degree Days") +
    theme (legend.position = "none")
```

```
grid.newpage()
  grid.draw (rbind (ggplotGrob (cp_gdd),
                 ggplotGrob(prov_gdd), size = "last"))
```

```
## `geom_smooth()` using formula 'y ~ x'
## `geom_smooth()` using formula 'y ~ x'
```



2750
2600
2450
2300
2500
2000
1500
Chuskas
2500
2000
1500
El Malpais
2500
2000
1500
Mesa Verde
2500
2000
1500
Mogollon Rim
Growing Degree Days
200
250
300
350
400
450
500
550
600
650
700
750
800
Date AD

Figure 9

```
# AD 200-800 growing degree day reconstructions, tree-ring cutting
# and near cutting date densities and KDE_Model derived radiocarbon # densities for the
Colorado Plateau.

# Colorado Plateau growing degree day reconstruction.
cp_gdd2 = gdd %>%
  filter (region == "Western Plateau" |
            region == "Southern Plateau" |
            region == "San Juan" |
            region == "Chuskas") %>%
    ggplot (aes (year, agdd)) +
    geom_smooth (method = "loess", span = 0.05) +
    theme_bw (base_size = 20) +
scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450, 500,
                               550, 600, 650, 700, 750, 800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                         220, 230, 240, 260, 270,
                                         280, 290, 310, 320, 330,
                                         340, 360, 370, 380, 390,
                                         410, 420, 430, 440, 460,
                                         470, 480, 490, 510, 520,
                                         530, 540, 560, 570, 580,
                                         590, 610, 620, 630, 640,
                                         660, 670, 680, 690, 710,
                                         720, 730, 740, 760, 770,
                                         780, 790, 810, 820, 830,
                                         840)) +
    scale_y_continuous (breaks =  c(2300, 2450, 2600, 2750)) +
    theme (axis.title.x = element_blank()) +
    ylab ("") +
    theme (legend.position = "none",
           axis.title.x = element_blank(),
           axis.ticks = element_blank(),
           axis.text.x = element_blank())
```

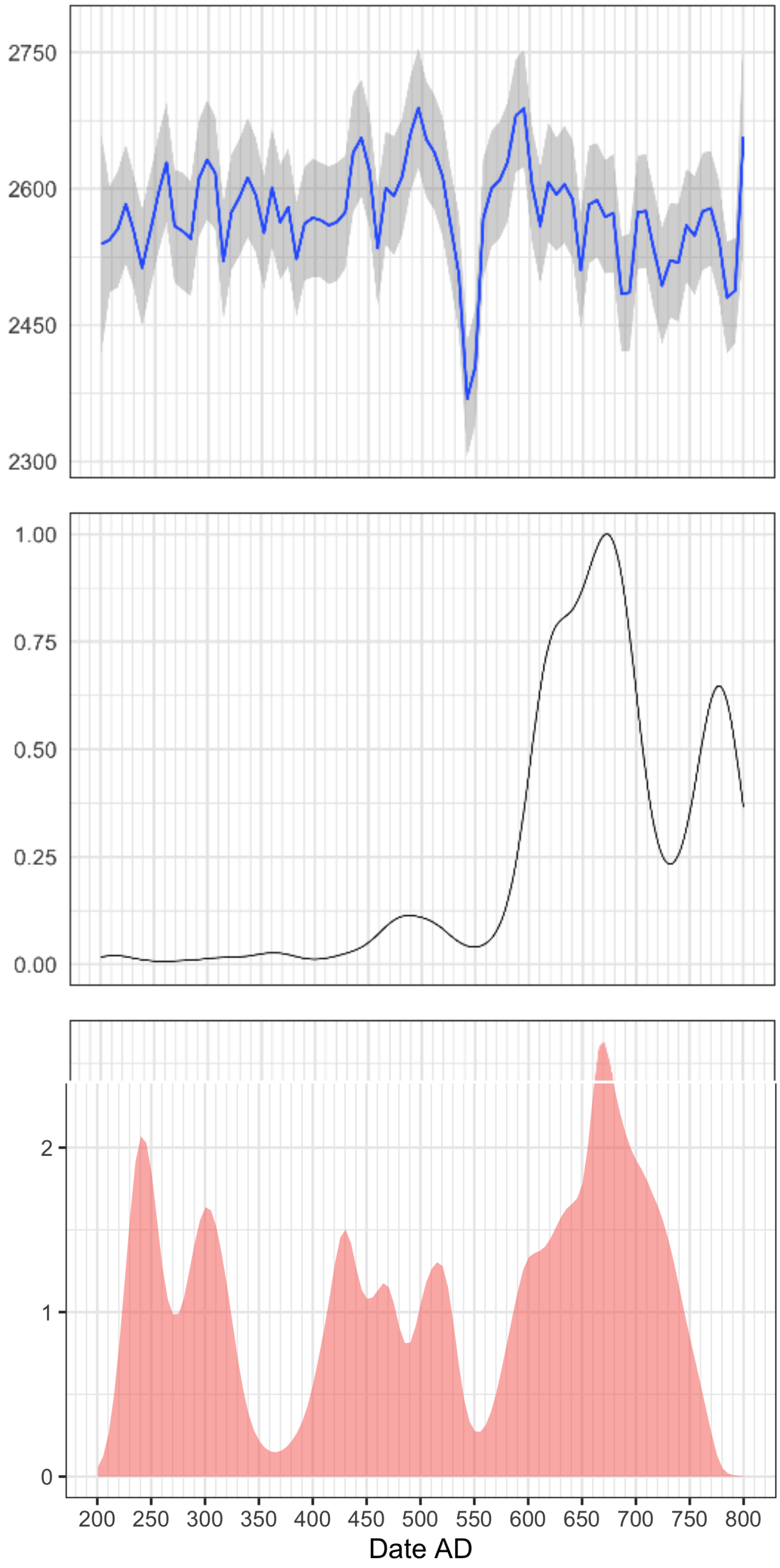
```
# Tree-ring cutting and near-cutting date cutting density.
# Note that we present a "scaled" version of density here
# (y-axis scaled from 0 to 1) in order to ensure that the y-axes
# of all three portions of Figure 9 are equally spaced, but the
# underlying data and distribution are identical to the versions
# presented in Figures 4 and 6 (density * n).

tr_den2 = tr_chron %>%
  filter (Region == "Southern Plateau" |
            Region == "Chuskas" |
            Region == "San Juan Drainage" |
            Region == "Western Plateau",
          Outer_Date_AD>199, Outer_Date_AD<801,
          conf_level == "cutting" |
            conf_level == "near_cutting") %>%
    ggplot (aes (x = Outer_Date_AD, stat(scaled))) +
    geom_density () +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(200, 250, 300, 350, 400, 450,
                                   500, 550, 600, 650, 700, 750,
                                   800),
                        minor_breaks = c(160, 170, 180, 190, 210,
                                         220, 230, 240, 260, 270,
                                         280, 290, 310, 320, 330,
                                         340, 360, 370, 380, 390,
                                         410, 420, 430, 440, 460,
                                         470, 480, 490, 510, 520,
                                         530, 540, 560, 570, 580,
                                         590, 610, 620, 630, 640,
                                         660, 670, 680, 690, 710,
                                         720, 730, 740, 760, 770,
                                         780, 790, 810, 820, 830,
                                         840)) +
    theme (axis.title.x = element_blank()) +
    ylab ("") +
    theme (legend.position = "none",
           axis.title.x = element_blank(),
           axis.ticks = element_blank(),
           axis.text.x = element_blank())
```

```
# Modelled radiocarbon density.
rc_den = rc_kde %>% filter (model == "n648_post",
                            yr>199, yr<801) %>%
    ggplot() +
    geom_area (aes (yr, prob, alpha=0.5, fill = model)) +
    theme_bw (base_size = 20) +
    scale_x_continuous (breaks = c(150, 200, 250, 300, 350, 400,
                                   450, 500, 550, 600, 650, 700,
                                   750, 800, 850),
                        minor_breaks = c(60, 70, 80, 90, 100,
                                          110, 120, 130, 140, 160,
                                          170, 180, 190, 210, 220,
                                          230, 240, 260, 270, 280,
                                          290, 310, 320, 330, 340,
                                          360, 370, 380, 390, 410,
                                          420, 430, 440, 460, 470,
                                          480, 490, 510, 520, 530,
                                          540, 560, 570, 580, 590,
                                          610, 620, 630, 640, 660,
                                          670, 680, 690, 710, 720,
                                          730, 740, 760, 770, 780,
                                          790, 810, 820, 830, 840,
                                          860, 870, 880, 890)) +
    xlab ("Date AD") +
    ylab ("") +
    theme (legend.position = "none")
```

```
grid.newpage()
  grid.draw (rbind (ggplotGrob (cp_gdd2), ggplotGrob (tr_den2),
                  ggplotGrob (rc_den), size = "last"))
```

```
## `geom_smooth()` using formula 'y ~ x'
```


2750
2600
2450
2300
1.00
0.75
0.50
0.25
0.00
2
1
0
200
250
300
350
400
450
500
550
600
650
700
750
800
Date AD

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CHAPTER 5: Early Pueblo Period Population Aggregation and Dispersal in the Petrified Forest Region, East-Central Arizona

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Abstract

The Western Puerco region of east-central Arizona figured prominently in foundational studies of the Early Pueblo period (AD 650-950) yet remains on the periphery of recent research. This article presents new survey and chronometric data from three communities located in a densely occupied portion of the Western Puerco, the Petrified Forest. These data suggest that the Petrified Forest hosted the earliest known aggregated settlement in the region, circa AD 700-800, before residents transitioned to a dispersed settlement pattern that remained in place through the Chaco era. Neighboring portions of the Western Puerco, however, only hosted settlements of a similar size from AD 840 forward. Chaco great houses were founded in these communities during the tenth and eleventh centuries. Unlike better known examples of aggregation in the northern San Juan region that unfolded within only a few generations, similar developments in the Petrified Forest were likely the culmination of hundreds of years of local population growth, increasing sedentism, and use of prominent natural features on the landscape. The lack of fit

between the causal factors proposed for village formation in the northern San Juan and eighth century aggregation in the Petrified Forest suggests alternative models are needed to explain the formation of early population aggregates in the Western Puerco and across much of the western portion of the northern Southwest more broadly.

La región oeste de Puerco, en el centro-este de Arizona, figura de manera prominente en los estudios fundacionales del periodo Pueblo Temprano (650-950 d.C.) pero permanece en la periferia de las investigaciones actuales. Este artículo presenta nuevos resultados de recorridos de superficie y datos cronométricos de tres comunidades localizadas en una porción densamente poblada del oeste de Puerco: el Bosque Petrificado. Dichos datos sugieren que el Bosque Petrificado albergó el asentamiento agregado más temprano de la región, ca. 700-800 d.C., el cual pasó en poco tiempo a un patrón de asentamiento disperso que se mantuvo como tal durante todo el periodo Chaco. Sin embargo, las zonas aledañas al oeste de Puerco albergaron únicamente asentamientos de tamaño similar a partir de 840 d. C. Las "great houses" de Chaco fueron fundadas en estas comunidades durante los siglos diez y once de nuestra era. A diferencia de ejemplos de agregación mejor conocidos, como aquellos observados en el norte de San Juan que ocurrieron en tan solo unas cuantas generaciones, los desarrollos similares vistos en el Bosque Petrificado probablemente fueron la culminación de cientos de años de crecimiento de la población local. Para poder situar el Bosque Petrificado en el contexto regional de una mejor manera, comparamos y contrastamos la arquitectura, la cultura material y los patrones de asentamiento de dicho sitio con aquellos presentes en sitios seminales del oeste de Puerco; asimismo, discutimos las implicaciones que el fenómeno de agregación temprana tuvo en la demografía regional y en las historias de los asentamientos a largo plazo.

Introduction

Our understanding of the dramatic and often abrupt changes that accompanied the formation and demise of the earliest Ancestral Pueblo villages in the northern Southwest has been shaped in large part by work in the northern San Juan region (Brew 1946; Kohler and Varien 2012; Martin 1939; Morris 1939; Roberts 1930; Wilshusen and Ortman 1999; Wilshusen and Potter 2010). Yet it remains unclear whether the northern San Juan is a useful analogue for other regions with dense contemporary occupations due in part to differences in long-term regional demographic trends prior to, during, and following the Early Pueblo period (AD 650-950) (Peeples et al. 2012; Schachner et al. 2012; Young and Gilpin 2012). Here, we present the results of recent fieldwork and collections research in the Western Puerco region of east-central Arizona, an area that was the focus of foundational research on the Early Pueblo period (Roberts 1931, 1939, 1940; Gladwin 1945; Wendorf 1953), but has remained on the periphery of recent work. Our research has focused on a densely occupied portion of the Western Puerco that remains poorly understood, the Petrified Forest. The Petrified Forest hosted the earliest known aggregated settlement in the region, circa AD 700-800, prior to residents transitioning to a dispersed settlement pattern shortly thereafter. In contrast, neighboring areas to the east and south did not witness the rise of large aggregated settlements until the ninth century. These communities eventually became the locations of Chaco era great houses, unlike the earlier Petrified Forest aggregates. The development of early aggregated communities based on long-term, in-situ population growth and strong attachment to prominent landscape features in the Petrified Forest, and the Western Puerco more broadly, provides an alternative to models of early village development proposed for the northern San Juan region.

Models for Early Village Development

Nearly four generations of southwestern archaeologists have offered detailed descriptions of the household and community-scale social, economic, and ritual changes that occurred during the Early Pueblo period, yet few have offered explicit models to explain the initial formation of early villages. Here, we use the term village to describe settlements occupied year-round by a group "…large enough that the households would not consider themselves closely related to all the other households" (Kohler and Varien 2010:37-38, see also Wilshusen 1991:204). Recent well-developed models focused on the northern San Juan suggest a number of interconnected push and pull factors that ultimately led to early villages including, migration, population pressure, competition over resources, and the perceived threat of violence (Kohler and Varien 2012; Wilshusen and Potter 2010). Kohler (2012:256) posits population pressure on resources and the resulting competition between households as the ultimate causal mechanism.

Facilities capable of integrating people into large non-kin groups have also been a central focus of research on the Early Pueblo period. A strong relationship between great kivas and early villages is apparent in the northern San Juan (Wilshusen et al. 2012a:23-25), while others have noted a link between great kivas and decreasing residential/seasonal mobility regardless of early village development (Gilpin and Benallie 2000; Young and Gilpin 2012). The formation of an eighth century village in the Petrified Forest with no associated great kiva, and the long-term stability of ninth century community centers in the Western Puerco, offer important points of contrast to similar developments in the northern San Juan, and suggest multiple trajectories for early village development in the northern Southwest.

Environment and Previous Research

As defined here, the Western Puerco is bounded on the west, northwest and south by Leroux Wash, the Puerco River, the Zuni River and the Little Colorado River, bounded on the east by Hardscrabble Wash, and bordered on the north by Chinde Mesa, Padres Mesa, and the Defiance Plateau. Cultural variation has remained a dominant research theme in the region for over 80 years (Gladwin 1945; Mera 1934; Mills 2007; Peeples et al. 2012; Schachner et al. 2012; Throgmorton 2018; Wendorf 1953), and we find it useful to further subdivide this roughly 5000 km^2 area into distinct subregions based on environmental differences and subtle yet persistent cultural distinctions (Figure 5.1, Table 5.1). Dividing the Western Puerco into Petrified Forest, Hardscrabble, and Middle Puerco subregions allows much of this variability to be understood as clinal variation within an area with shared cultural traditions.

Intensive research focused on the Early Pueblo period in the Western Puerco commenced with excavations at Kiatuthlanna, Whitewater Village, White Mound Village, and Twin Butte, and with survey and ceramic seriation at Petrified Forest and in the Hardscrabble area (Beeson 1966; Gladwin 1945; Mera 1934; Reed 1947; Roberts 1931, 1939, 1940; Wendorf 1953). Numerous Early Pueblo sites were excavated along the I-40 corridor during the early contract era, but technical reports remain unpublished (Gumerman and Olsen 1968; Gumerman et al. 1982; Ripey 1969; Sciscenti 1962; Wasley 1960). While excavation reports were completed from the next wave of contract work, they often lack feature maps and ceramic counts (Stebbins et al. 1986; Swarthout and Dulaney 1982). The pace of survey and excavation in the region increased dramatically during the late 1980s-1990s during the development of the Chambers-Sanders Trust Lands (Hays-Gilpin and van Hartesveldt 1998:37-39). Table 5.2 contains a list of survey and excavation projects with sizable Early Pueblo components that are included in the current synthesis.

Several environmental and historical factors have influenced our understanding of the Early Pueblo period. Unlike the northern San Juan, no single large project in an area rich with Early Pueblo archaeology has occurred and data must be gleaned from numerous small projects. While development in the Middle Puerco and Petrified Forest subregions has facilitated survey and excavation, the Hardscrabble area has received little attention beyond Beeson's reconnaissance survey (1966) and Roberts' work (1931). Environmental differences between these areas also influence the efficacy of chronometric methods. Unlike the Middle Puerco and the Hardscrabble areas, the Petrified Forest has not produced datable dendrochronological specimens. In the past it was difficult to compare conventional radiocarbon dates on wood charcoal in a meaningful way to tree-ring dates, but advances in AMS technology, improved sample selection, and Bayesian modeling may help bridge this gap. Nevertheless, we have pieced together a better understanding of Early Pueblo chronology through a combination of survey, reanalysis of curated collections, accessing rare reports and excavation notes, and consulting knowledgeable researchers.

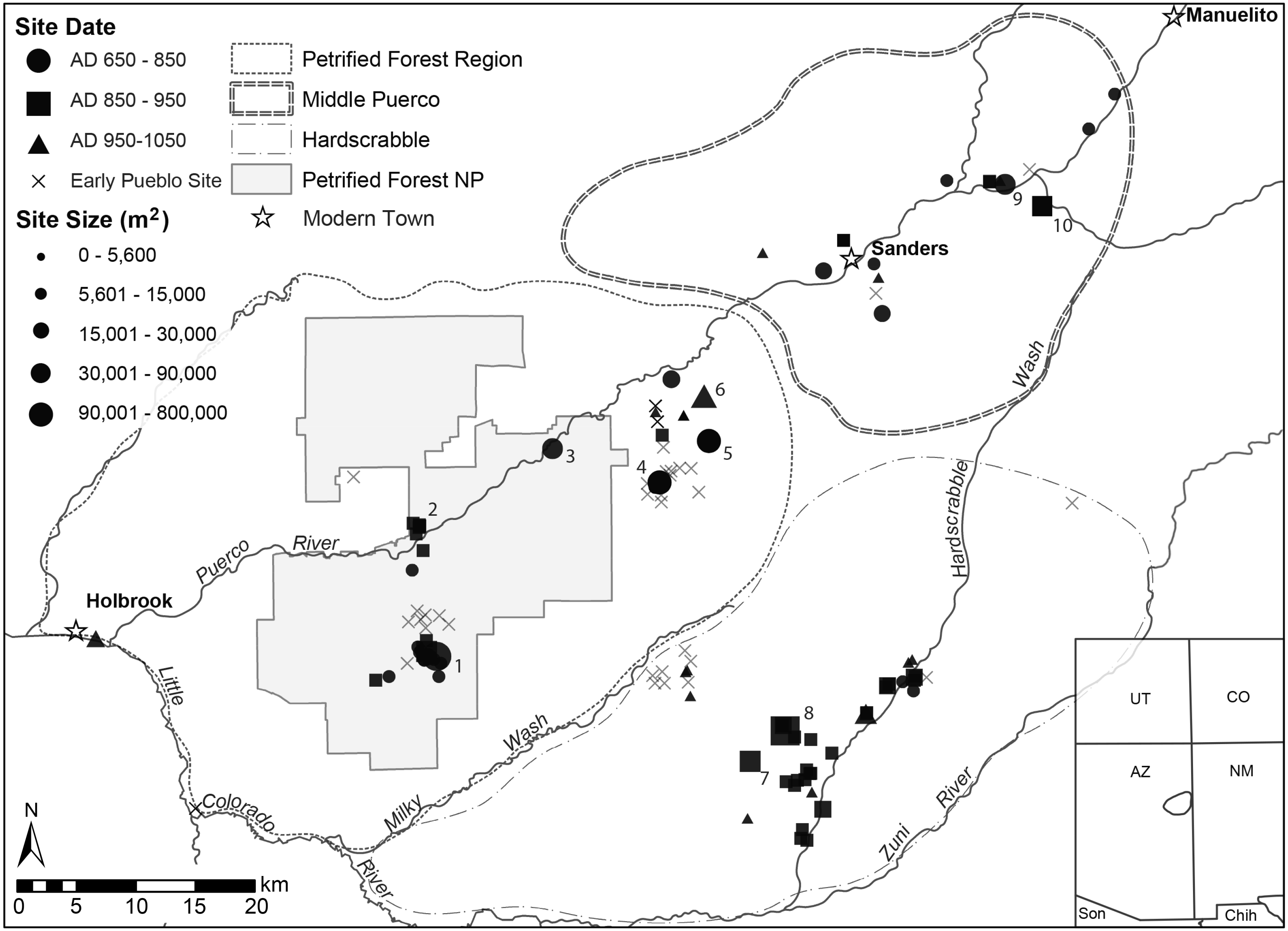

Figure 5.1. Early Pueblo period sites of the Western Puerco. Descriptions of the numbered sites are provided in Table 5.1.

Table 5.1. Significant Early Pueblo Period Sites in the Western Puerco.

#	Site Name/ Number	Primary/ Maximum Occupation Span (AD)	Chrono-logical Data	Size (Ha)	Surface Room Count	Roomblock Count	Pithouse Count
1	Twin Butte[a, b]	700-800, 650-950	^{14}C maize, ceramics	78	200-400	40-60	50-120
1	Twin Butte Community[a-i]	700-800, 650-950	ceramics, architecture	417	65-100	20-35	45-90
2	Dead Wash[a,g-i] South Comm.	850-950, 850-1125	ceramics, architecture	12	6	1	10-25
3	Weathertop Late[a]	750-900, 700-950	ceramics, architecture	3.2	50-110	5-12	5-25
4	Cottonwood Seep/South[j-l]	575-700, 400-700	^{14}C wood, ceramics	60	N/A	N/A	300+
5	AZ-P-60-31/ NA 20801[m]	650-700, 600-700	^{14}C wood, ceramics	90	N/A	N/A	100+
6	Navajo Springs Great Kiva[n]	900-1050, 850-1200	ceramics	19	-	5-14	5-20
7	NA 14654[o-p]	850-950, 850-1050	ceramics, architecture	1.5	20	2	10
8	Kiatuthlanna [q-s]	850-950, 750-1100	ceramics, architecture	65	-	-	100+
9	White Mound[t-u]	775-825, 745-1050	tree-ring, ceramics	3	80	8	24
10	Whitewater[t, v]	840-1050, 810-1050	tree-ring	7	35+	5+	24+

Note: Pithouse counts from Twin Butte and the surrounding community are derived from pithouses and likely pithouses visible on the modern ground surface and the expectation that each roomblock or non-contiguous arc of storage structures is associated with at least a single pithouse. The upper end of the estimate projects an average of *two* pithouses per roomblock/non-contiguous arc. Our pithouse counts do *not* consider superimposed structures, which Wendorf encountered during excavations. Excavations at other sizable Early Pueblo era sites in the Western Puerco such as White Mound (three pithouses per roomblock) and NA 14654 (3-4 pithouses per roomblock) suggest that two pithouses per roomblock might be a conservative estimate.

[a]Current project; [b]Schachner and Bernardini 2014; [c]Unpublished NPS survey PEFO1998B; [d]Burton 1993; [e]Burton et al. 2007; [f]Corey 2008; [g]Hammack 1979; [h]Jones 1987; [i]Mera 1934; [j]Hays 1993; [k]Marek et al. 1993; [l]Site size estimate connects the area between NA 14674, 14675, 14767 and 14771; [m]Latady 1991; Leach-Palm 1994; [n]Harden 1992; [o]MNA Site Files; [p]Stebins et al. 1986; [q]Beeson 1966; [r]Roberts 1931; [s]Estimate based on Beeson's descriptions and considering AZ Q:3:1(ASM) and AZ Q:3:73(ASM) as a single site; [t]Bannister et al. 1966; [u]Gladwin 1945; Throgmorton (personal communication, 2018) noted 5 additional PI units at the site distinct from the three excavated by Gladwin; the listed number of surface rooms and pithouses assumes each additional unit contains similar counts of pithouses and surface rooms to those excavated by Gladwin; [v]Roberts 1939; site size estimate assuming area between Group 1 and Group 2 contains contemporary features.

Table 5.2. Western Puerco Projects with Sizable Early Pueblo Components.

Project	Location	References
Kiatuthlanna	Hardscrabble	Roberts 1931
Whitewater	Middle Puerco	Roberts 1939, 1940
White Mound	Middle Puerco	Gladwin 1945
NPS Survey and Test Excavations[a]	Petrified Forest	Burton 1993; Burton et al. 2007; Corey 2008; Hammack 1979; Jones 1983, 1987; Mera 1934; Reed 1947; Wells 1988; Crystal Forest Inventory Survey (PEFO1998-B, unpublished)
Twin Butte	Petrified Forest	Schachner and Bernardini 2014; Wendorf 1953[b]
I-40 Salvage	Middle Puerco	Ferg 1978; Gumerman and Olson 1968[b], Gumerman et al. 1982[b]; Sciscenti 1962; Wasley 1960[c]
Dissertation/ Thesis	Hardscrabble, Middle Puerco, Petrified Forest	Beeson 1966; Throgmorton 2012
Coronado Project	Petrified Forest, Hardscrabble	Ahlstrom et al. 1993; Greenwald et al. 1993; Marek et al. 1993; Stebbins et al. 1986[b]
Chambers-Sanders Trust Lands	Middle Puerco, Petrified Forest	Billman and Ruppe 1996; Dosh 1993; Fowler 1989; Harden 1992; Latady 1991; Lawson 1991; Leach-Palm 1994; Sant and Marek 1994
Other Contract Projects	Middle Puerco, Petrified Forest, Hardscrabble	Anduze and Greenwald 1994; Breternitz 1957; Ripey 1969[b]; Van West 1994

[a] Includes data from survey on file with Petrified Forest National Park.

[b] Includes data from excavation and analysis notes on file with the Museum of Northern Arizona.

[c] Includes data from excavation and analysis notes on file with the Arizona State Museum.

The Early Pueblo Period in the Petrified Forest, Ephemeral or Intensive?

Since Mera and Cosgrove's 1933 survey at then Petrified Forest National Monument, researchers have debated whether the area hosted a dense concentration or a lack of sites dating between AD 700-950 (Burton 1993; Hammack 1979; Jones 1983, 1987; Mera 1934; Reed 1947; Stewart 1980; Theuer and Reed 2011; Wendorf 1953). These disparate interpretations can be attributed to chronological issues related to the rarity of, and poor chronometric data for, early diagnostic ceramic types (Hays-Gilpin and van Hartesveldt 1998:45, 193), and the poor surface visibility of Early Pueblo period architecture. Our current study clarifies the scale, scope, and timing of the Early Pueblo period occupation of the Petrified Forest and considers it within a regional context.

First, we provide an overview of three Early Pueblo period site clusters in the Petrified Forest area, here called communities based on spatial and temporal proximity (Gilpin 2003; Varien 1999). Our overview presents new data, including radiocarbon dates, from Twin Butte, the largest known Early Pueblo period community in the subregion, and then additional documentation for two other communities, Dead Wash South and Weathertop, previously recorded via NPS surveys. We then present a new ceramic seriation for the Early Pueblo period sites in the region, placing these communities in a more secure temporal and regional context. Finally, we discuss the implications of our research for the study of demography, population movement, and settlement histories in the Western Puerco, and then proceed to a broader consideration of early village development in the northern Southwest.

Twin Butte

Twin Butte was first recorded by Hough (1903:318) as Metate Ruin, and then mapped and excavated as part of Wendorf's (1953) dissertation research. Further documentation by Schachner and Bernardini (2014) and the current project shows that the site contains at least 70 discrete concentrations of artifacts and rubble spread over a 780,000 m^2 area (Supplement 1). Fifty of the artifact scatters have architectural rubble or in-situ stone alignments indicative of arcs or linear arrangements of surface structures, and each of these is likely associated with one or more pithouses. The densest concentration of features at Twin Butte is located on the south facing slope of a large conical butte (Figure 5.2). This area contains a minimum of ten heavily eroded arcs of contiguous and non-contiguous slab-lined surface structures and 20 linear sandstone alignments arranged parallel to the slope of the butte interpreted by Wendorf (1953:32-34) as windbreaks for crops. Given the size of the site, the density of rubble, and evidence for superimposed features revealed by Wendorf's excavations, a total of 50 pithouses across the entire site area is likely a conservative estimate and the total number of residential structures could easily be twice as high.

An Intensive and Temporally Restricted Occupation

Wendorf's excavations repeatedly encountered evidence of an intensive yet temporally restricted occupation. A long trench excavated into two-meter deep cultural deposits revealed a complex sequence of construction events (Wendorf 1953:80-84, 116-121), yet two screened stratigraphic test units suggested little change in ceramic assemblages through time (Supplement 2). Excavations in twelve structures associated with six discrete architectural units also documented a complex occupational sequence of superimposed, remodeled, and trash-filled features, yet all contexts produced similar material culture (Wendorf 1953). Our surface recording of ceramics at four unexcavated loci outside of the site core documented assemblages similar to those recovered from Wendorf's excavated features (Supplement 2).

Archaeological survey and limited test excavations within the broader Twin Butte community also support an intensive yet temporally restricted occupation. Survey by NPS (Burton 1993; Burton et al. 2007; Corey 2008; Hammack 1979; Jones 1987) has documented an additional 40 Early Pueblo habitation sites with similar ceramic assemblages within a 2-kilometer radius of Twin Butte (Supplement 1). Excavations at AZ Q:1:42 (ASM), located two kilometers northwest of Twin Butte, provide further evidence for contemporary occupation across the broader community (Jones 1983).

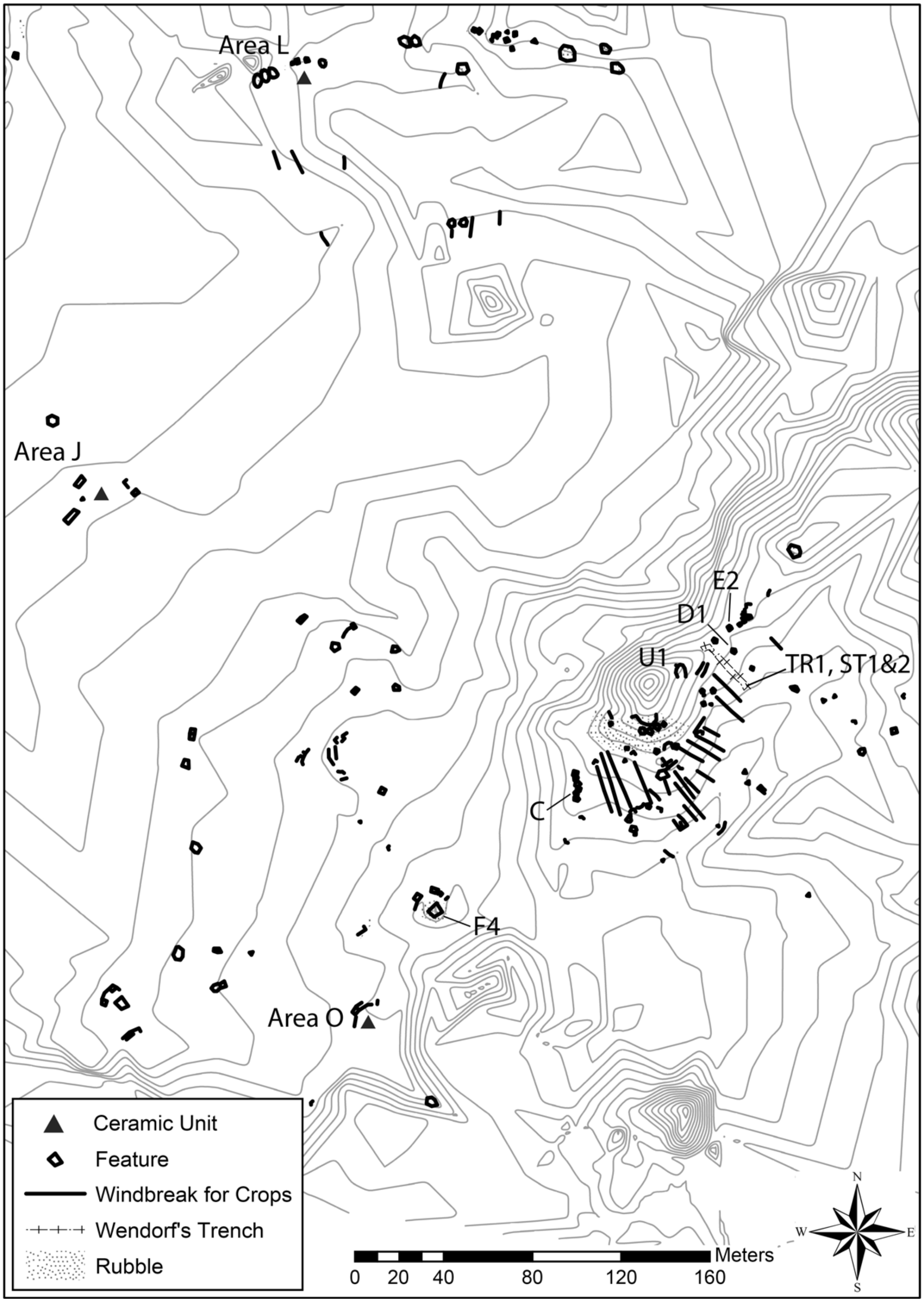

Figure 5.2. Map of the Twin Butte site core and adjacent loci. Features, loci. Excavation units with high-quality radiocarbon dates or ceramic recording units are labeled. Additional maps Twin Butte loci and the community more broadly are available in Supplement 1.

Twin Butte Radiocarbon Dates

Wendorf's excavations did not recover samples suitable for tree-ring dating and occurred prior to the development of radiocarbon dating, thus he had to rely on ceramic cross-dating for chronological control. We submitted twelve carbonized maize cob fragments and other short-lived plant parts from his excavations for AMS radiocarbon dating.[2] During the summers of 2013 and 2015, carbonized *Zea mays* and *Phaseolus vulgaris* (common bean) specimens were collected from features E2 and U1 in the Twin Butte core and also submitted for dating, bringing our total sample to fourteen.

The results indicate that Twin Butte was occupied between AD 650-900, but the most intensive occupation likely occurred between AD 700-800. A uniform phase Bayesian model on that includes ten tightly clustered dates (Bronk Ramsey 2009: 342-345) suggests a median start date of AD 710 and a median end date of 795 (AD 680-830, 68.3%, AD 655-885, 95.4%). All ten dates have modelled 68.3% ranges falling between AD 710-800 and median dates falling between AD 745-780 (Figure 5.3, Table 5.3). Five samples associated with four distinct architectural units produced dates with modeled 68.3% probability distributions between AD 710-780 (685-820, 95.4%), and this likely accurately represents the age of the most intensive period of occupation. Dates derived from a textile collected from the site's surface (Wendorf 1953:150-153) and a reed suggest continued use of the site during the tenth century (Table 4). This later use of the site appears to have been ephemeral, as no painted ceramic types post-dating AD 850 were reported from Wendorf's extensive excavations, our ceramic recording units, or excavations at AZ Q:1:42 (ASM).

Two specimens, a maize cob fragment from Feature D1 (Beta-330990, 795-540 BC, 95.4%) and a reed fragment from Feature C (Beta-330992, 1210-1000 BC, 95.4%), produced dates that were far earlier than expected (Table 4). Feature D1 is a 2.5-meter deep granary that likely disturbed preceramic cultural deposits when initially built. It is difficult to interpret the significance of the early date on the reed from Feature C, a prominent boulder and sandstone lined surface structure. We find it likely that the specimen is of cultural origin, but another reed collected from the same feature produced the most recent date from the site, contemporary only with the textile fragment collected from the surface. Due to these context concerns and a gap between the two early dates and the two more recent dates compared to the ten others that form a tight cluster, these four dates were not included in our Bayesian model.[3]

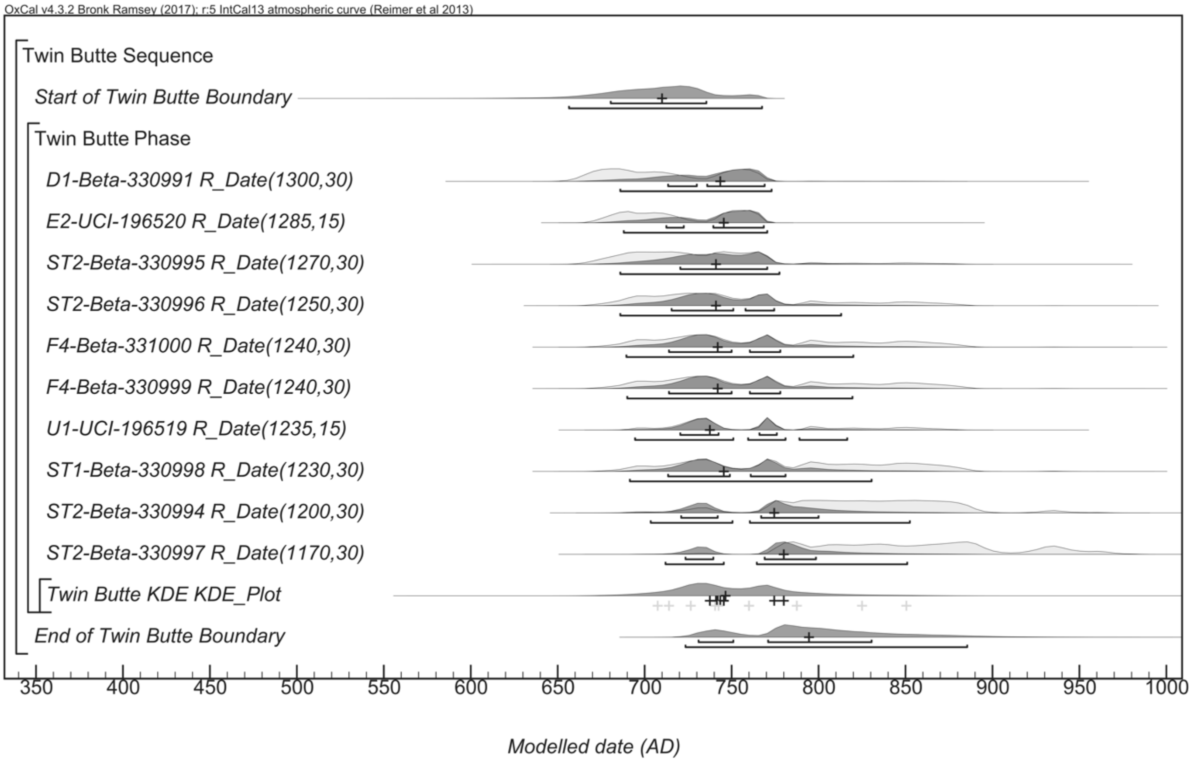

Figure 5.3. Bayesian model of the Early Pueblo occupation at Twin Butte that includes 10 radiocarbon dates derived domesticated annuals and short-lived plant parts (see Table 5.3 for tabular presentation of these data. Light gray outlines display unmodeled, calibrated probability (prior), and darker gray outlines display modeled posterior probabilities. Black brackets distributions display 68.3% and 95.4% extent probability. Additional details (*sensu* Bayliss 2015; Hamilton and Krus 2018) raw data, and the code used to create this Figure are available in Supplement of the 3 (visit https://doi.org/10.1080/00231940.2019.1577059 of https://escholarship.org/uc/item/3fc2w3nr).

Table 5.3. Modeled Radiocarbon Dates from Twin Butte.

Sample Number/Context	**Context Description**	**Material Type**	**68.3% (AD)**	**95.4% (AD)**	**Median (AD)**
Start of Primary Occupation	-	-	*680-740*	*655-770*	*710*
Beta-330991, Feature D1	slab/masonry granary	*Zea mays*	710-770	685-775	745
UCI-196520, Feature E2[a]	jacal pit-room	*Zea mays*	710-770	685-770	745
Beta-330995, Strat Test 2	Wendorf's screened test unit	*Zea mays*	720-770	685-780	740
Beta-330996, Strat Test 2	Wendorf's screened test unit	*Zea mays*	715-775	685-815	740
Beta-330999, Feature F4	pithouse	Grass stem[b]	710-780	685-820	740
Beta-331000, Feature F4	pithouse	Grass stem[b]	710-780	685-820	740
UCI-196519, Feature U1[a]	masonry- walled structure	*Phaseolous vulgaris*	720-780	690-820	735
Beta-330998, ST1/ST2	Wendorf's screened test unit	*Zea mays*	710-785	690-830	745
Beta-330994, Strat Test 2	Wendorf's screened test unit	*Zea mays*	720-800	700-855	775
Beta 330997, Strat Test 2	Wendorf's screened test unit	*Zea mays*	720-800	710-850	780
End of Primary Occupation	-	-	*730-830*	*720-885*	*795*

Agreement Indices: A_{model} = 107.1, $A_{overall}$ = 106.4.

Files with uncalibrated, calibrated, modeled dates, OxCal output and model code used in Oxcal v4.3.2 are available in Supplement 3.

[a] Feature number designated by the current project–all others designated by Wendorf.

[b] Wendorf called these specimens "cane fragments".

Table 5.4. Calibrated Radiocarbon Dates from Twin Butte not Included in the Bayesian Model.

Sample Number	Feature Number/ Type	Material Type	68.2%	95.4%	Median
Beta-33100	surface find	looped bag [a]	AD 895-980	AD 875-1015	AD 935
Beta-330993	Feature C jacal pit room	reed [b]	AD 895-980	AD 875-1015	AD 935
Beta-330992	Feature D1 deep granary	*Zea mays*	775-555 BC	795-540 BC	640 BC
Beta-331992	Feature C jacal pit room	reed [b]	1125-1020 BC	1210-1000 BC	1085 BC

Note: All dates calibrated using the IntCal13 atmospheric curve in OxCal v.4.3.2. Raw data and additional information is available in Supplement 3.

[a] See Wendorf (1953:150-153).

[b] Wendorf identified these specimens as reeds.

Dead Wash South

Dead Wash South is a cluster of dispersed hamlets located on a low ridge overlooking the confluence of the Puerco River and Dead Wash. This community was initially documented by Reed (1947) and Wendorf (1953:19-20) via Mera's 1934 survey collections and later by NPS (Jones 1987:16; Hammack 1979:44; Wells 1994:76), and has long been considered a key loci of Early Pueblo period occupation in the Petrified Forest. Most of these prior efforts considered individual sites as separate occupations, rather than portions of a single community, obscuring its total size. We re-mapped the community and recorded ceramics during 2016-2017.

Most sites in the Dead Wash South community are small, have low artifact densities, and usually lack visible surface architecture. In-situ architecture is only visible on the two largest sites within the community. AZ Q:1:81 (ASM) contains a heavily eroded likely jacal roomblock, and AZ Q:1:60 (ASM) has an alignment of slab-lined cists fronted by a possible pithouse and midden (Figure 5.4). AZ Q:1:81 (ASM) also contains a 22 x 19 meter shallow depression surrounded by a low berm in a prominent location. A dense midden is located just below this depression, and it is possible that this feature is a shallow great kiva or dance court, although we are not confident in this identification without subsurface testing. Ceramics within the community suggest an Early Pueblo period occupation that post-dates Twin Butte. Contemporary sites lacking surface architecture are rare in the Middle Puerco, but have been noted north of the Mogollon Rim, and in the Hardscrabble, and Zuni areas (Martin and Rinaldo 1960; Peeples et al. 2012: Roberts 1931). The full extent of the Early Pueblo Period community is obscured by more intensive landscape use during the late tenth and eleventh centuries AD.

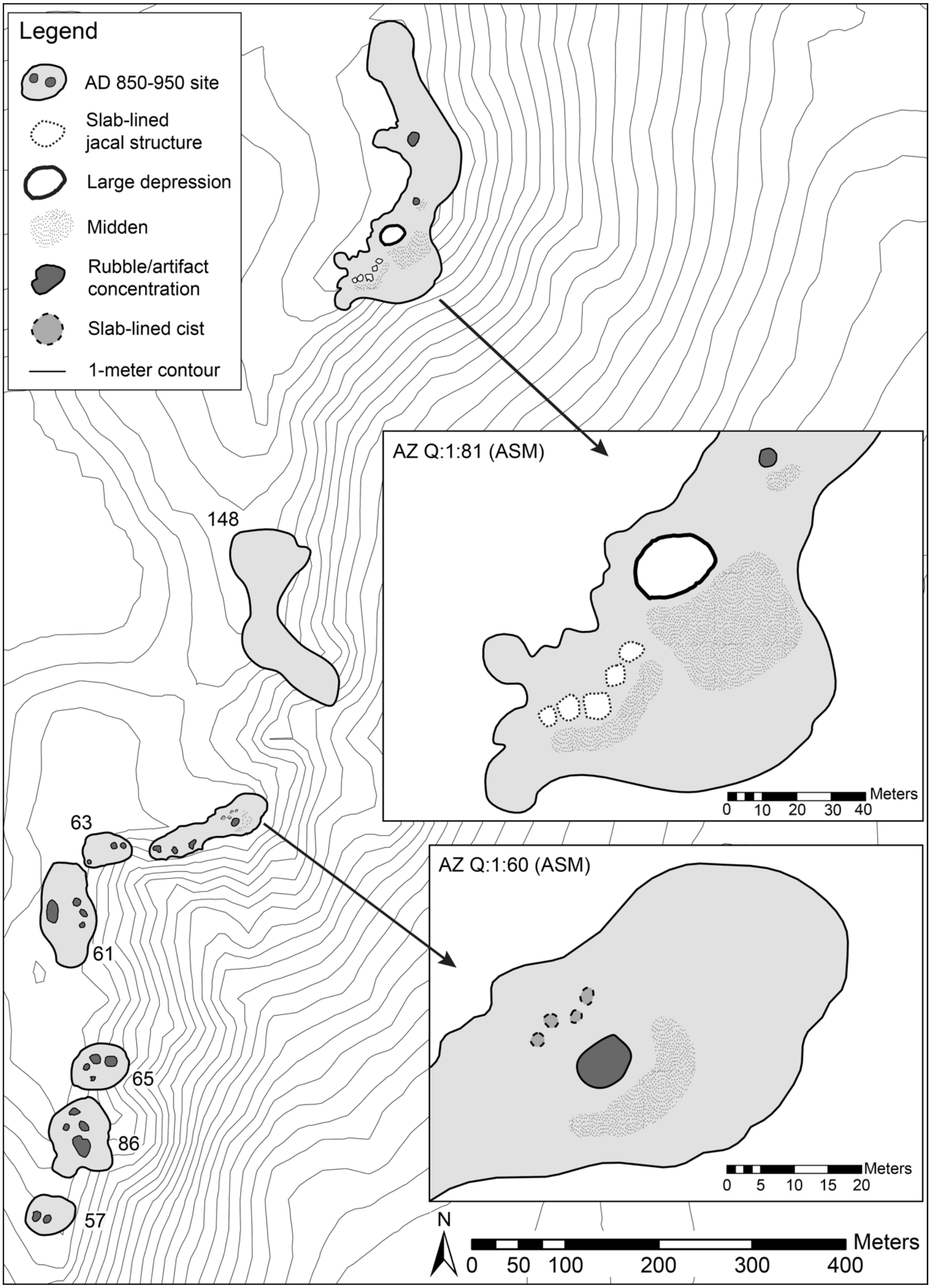

Figure 5.4. Map of the Dead Wash South community with insets of the two largest sites. Full site numbers are AZ Q:1:___ (ASM).

Weathertop

The final site targeted for additional recording, Weathertop (PEFO2013A-72), is located on an isolated mesa overlooking the Puerco River. The site contains more than 10 alignments of slab-lined jacal features, each likely associated with one or more pithouses, that are spread over the 32,000 m^2 extent of the mesa (Figure 5.5). Architecture on the site has been heavily impacted by looting, but consists primarily of contiguous arcing and linear roomblocks with slab foundations that are one or two rooms wide. Linear jacal roomblocks are more typically associated with sites dating to the ninth century in the Middle Puerco Puerco including Whitewater (Roberts 1939:22, 67), NA 8968/8969 (Gumerman et al. 1982; Throgmorton 2012:112-113), LA 4487 (Sciscenti 1962; Throgmorton 2012:100-104), and NA 14654 in the Hardscrabble area (Stebbins et al. 1986:389). The site that Weathertop bears the closest resemblance to, White Mound, is the only well-dated late eighth or early ninth century site with linear contiguous rooms in the Western Puerco known at this time, and it is also located on a mesa overlooking the Puerco River, albeit 30 miles to the east (Ahlstrom 1985:212; Gladwin 1945).

While the far western portion of Weathertop contains a typical Early Pueblo ceramic assemblage, ceramics in the eastern portion of the mesa and on a smaller mesa located nearby consist exclusively of fine-sand tempered brown ware sherds (Obelisk Utility/Woodruff Brown) with a smaller relative proportion of an early micaceous brown ware, Adamana Brown. Ceramics and architecture on Weathertop are suggestive of a punctuated occupation dating between approximately AD 200-550 and AD 750-900. Unlike Twin Butte and Dead Wash South, Weathertop does not appear to be associated with a larger community. Full coverage survey nearby is minimal, however, but informal survey by Sinensky of a 1 km radius around Weathertop in 2018 failed to identify any Early Pueblo sites other than petroglyphs.

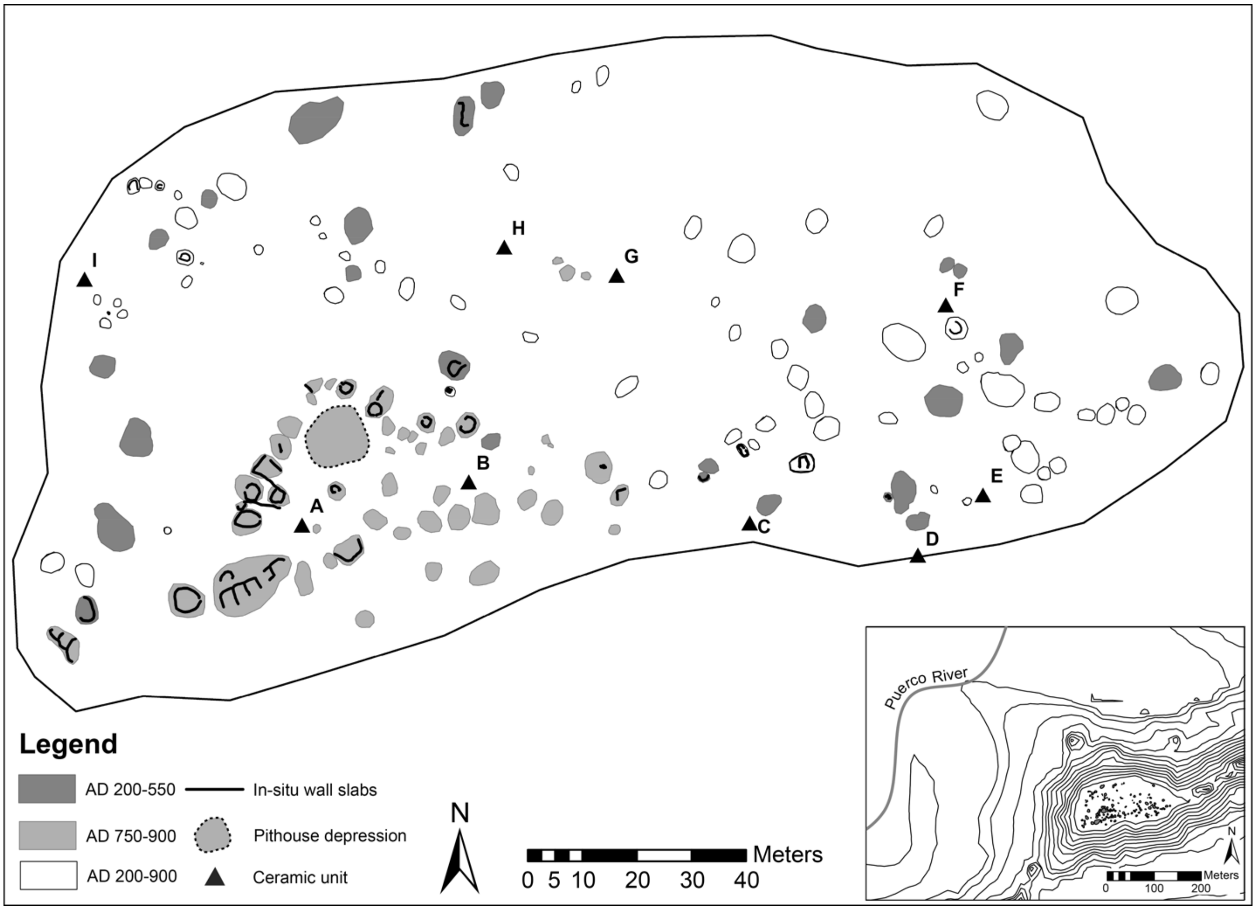

Figure 5.5. Map of PEFO2013A-72, Weathertop. Ceramic counts for numbered units are provided in Supplement 2.

Refining Early Pueblo Period Ceramic Dating in the Petrified Forest

A reassessment of Early Pueblo demographic trends in the Western Puerco relies primarily on ceramic dating. As noted above, dating Early Pueblo sites using ceramics has proven difficult in the Petrified Forest. This has led to numerous sites being assigned to a broad AD 550-950 interval (Mera 1934:7-9; Reed 1947; Stewart 1980:97; Theuer and Reed 2011:115). These assemblages are dominated by gray ceramics with coarse sand temper and a smoothed exterior (Lino Gray), and polished, brown ceramics with fine sand temper and that are often smudged (Woodruff Brown) (Hays-Gilpin and van Hartesveldt 1998:122, 139).[4] Here, we first consider the temporal placement of the Early Pueblo communities only within the Petrified Forest, and then more broadly among contemporary sites across the Western Puerco. Only sites with at least 15 identified sherds were included in our assessment, and only sherds from the best available contexts, for example a discrete temporal component, or the lowest level excavated in a structure were included.

We used two techniques to build our chronology, correspondence analysis (CA) and frequency seriation aided by Ford diagrams. Past applications of correspondence analysis for ceramic seriation in the Southwest have typically used painted types (e.g., Peeples and Schachner 2012). Since much of our period of interest predates the widespread use of painted ceramics, we included non-painted types. Our dataset also incorporates information from projects spanning 80 years, thus we only used broadly recognizable types in order to minimize inter-analyst biases.

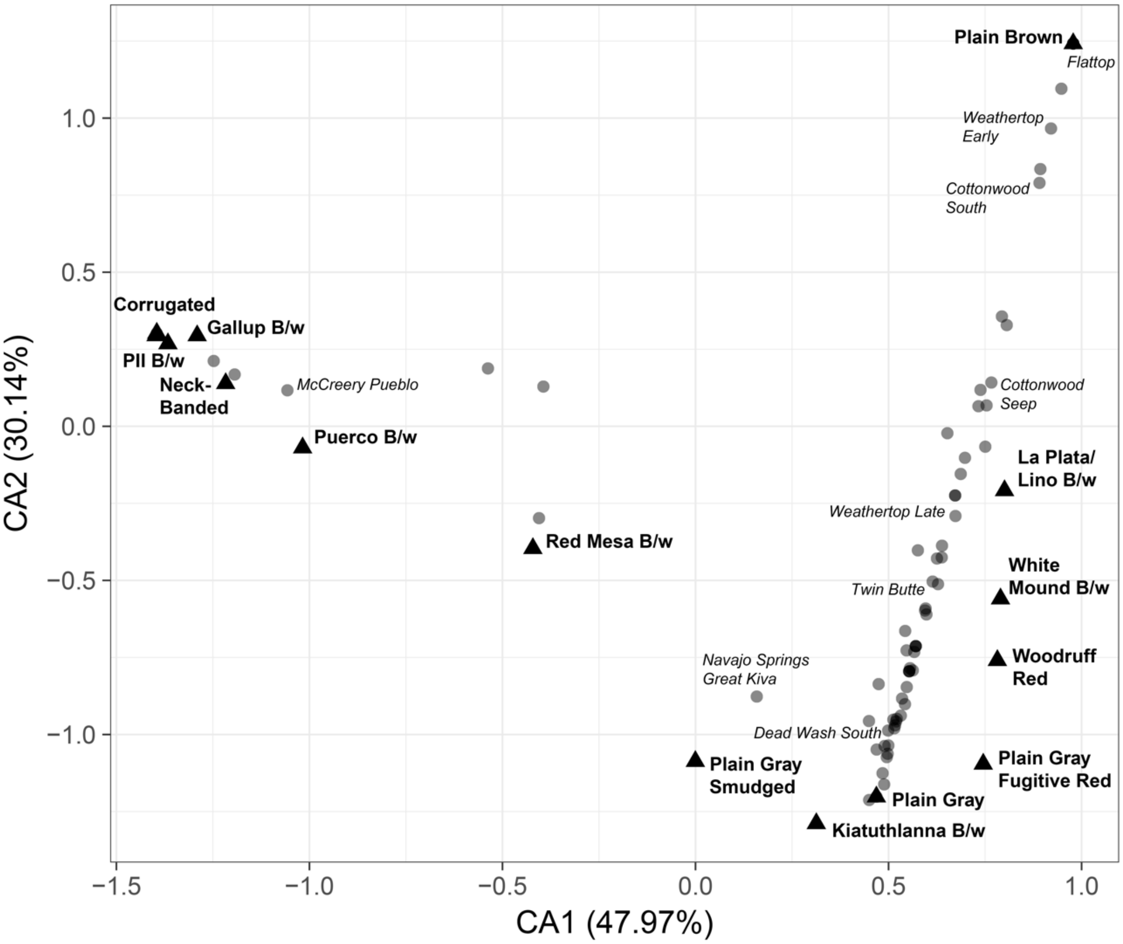

Figure 5.6. Correspondence analysis of 14 ceramic types from 82 Petrified Forest sites dating between AD 200-1125.

Our Petrified Forest focused CA includes counts of 14 ceramic types from 82 sites that date between AD 200-1125 (Figure 5.6). We include several sites that clearly predate and postdate the Early Pueblo period in order to anchor the axes of the biplot with ceramic data that exhibit little overlap. In Figure 5.6, the separation of assemblages along the y-axis tracks the relative proportions of plain brown and gray ceramics, while the x-axis tracks the proportion of plain gray and associated early painted and slipped types compared to corrugated and later painted types. The correspondence analysis illustrates that Twin Butte and Weathertop predate the Dead Wash South community, which in turn predates the Early Pueblo period great kiva at

Navajo Springs. The later was previously assigned a Pueblo I (AD 700-900) date based on surface ceramics (Hays-Gilpin and van Hartesveldt 1998). Thus including long lived utility types such as plain brown and gray provided an opportunity to visualize the temporal placement of a broader range of sites, many of which are nearly entirely lacking painted types, it also obscured subtler, yet temporally significant associations between less common types, and therefore did not allow us to divide sets of sites into temporally discrete groups.

Early Pueblo Period Chronology Across the Western Puerco

Next, we examined assemblages from 67 sites located across the Western Puerco, including a subset of the Petrified Forest sites, that were most likely occupied during the Early Pueblo period. This analysis incorporated seven ceramic types, including La Plata Black-on-white and Lino Black-on-white grouped as a single category, Woodruff Red (includes Forestdale Red, see Fowler 1991:134; Hays-Gilpin and van Hartesveldt 1998:152), White Mound Black-on-white, Kiatuthlanna Black-on-white, Red Mesa Black-on-white, and Neck-Banded (also known Kana'a Gray and fillet-neck) (see Hays-Gilpin and van Hartesveldt 1998 for a description of these types). Our refined correspondence analysis divided the sites into three chronological groups (Figure 5.7, Table 5). These groups follow widely accepted dates for regional ceramics with two caveats. First, our seriation shows a strong relationship between Woodruff Red (plain and smudged) and well-dated types typically found on sites between AD 650-850. Hays-Gilpin and van Hartesveldt (1998:152) do not posit a date range for Woodruff Red, and our seriation suggests that it is a likely indicator of occupation during the initial portion of the Early Pueblo period.[5] Second, our analysis suggests that neck-banded ceramics, despite often being thought of as a shorthand marker for a Pueblo I period (AD 700-900) occupation on the Colorado Plateau, are far more common on sites that post-date AD 950 in the Western Puerco (Fowler 1994:344, 352; Goetze 1994:92; Waterworth 1996:383, 659). The late appearance parallels patterns on Black Mesa, where Nichols (1987:11-12) found that neck-banded ceramics were rare at sites predating AD 900, increased in abundance after AD 940, and then peaked in usage between AD 1000-1020. Proportions of neck-banded then decreased rapidly between AD 1020-1070 as corrugated surface treatments were adopted (see also Ahlstrom 1998:197). Current information from the Western Puerco and much of northeastern Arizona suggests that unembellished gray ceramics continued to dominate assemblages until after AD 950.

Available chronometric information enables assignment of date ranges to our ceramic groups (Table 5). We find it particularly reassuring that ceramic assemblages from AD 700-850 tree-ring dated contexts in the Middle Puerco, including White Mound (AD 773-803), AZ K:12:8 (AD 730-768), AZ K:12:10 (AD 802-804), and NA 8948 (AD 758), fall into Group A, alongside our AD 700-800 radiocarbon dated contexts from Twin Butte. The discussion below considers the implications of this refined chronology for the Early Pueblo period occupation of Petrified Forest and regional demography across the Western Puerco.

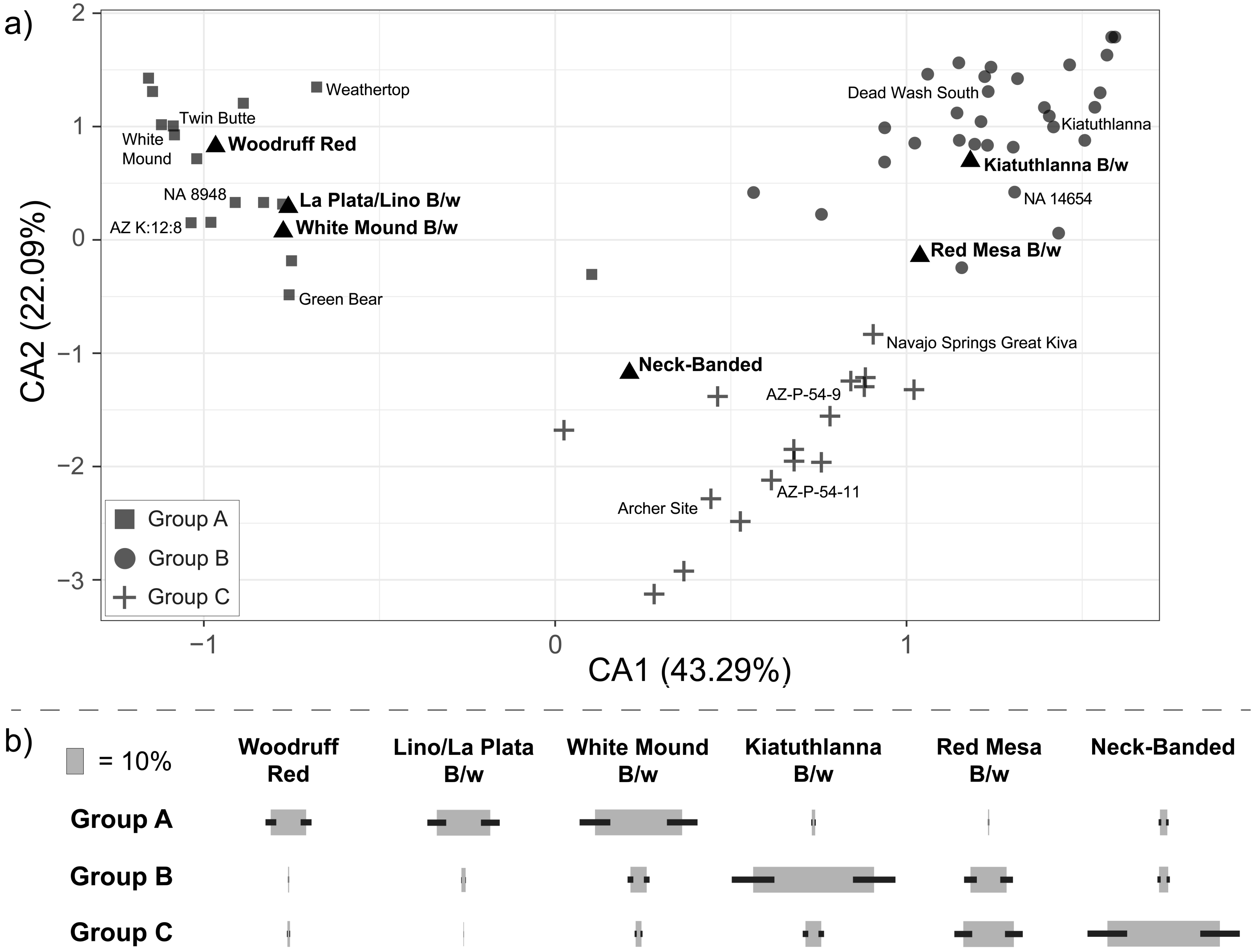

Figure 5.7. Ceramic seriation of Early Pueblo Period sites in the Western Puerco region. **(a)** Correspondence analysis of seven ceramic types from 67 sites. **(b)** Ford diagram showing the mean percentages of the types assigned to each ceramic group. Gray bars display mean counts of types and black bars represent 95% confidence intervals.

Table 5.5. Early Pueblo Period Ceramic Groups Derived from Correspondence Analysis.

Ceramic Group	Ceramic Types	Date Range	Number of Sites	Significant Sites
A	White Mound, Lino/La Plata, Woodruff Red	AD 650-850	18	Weathertop [a], Twin Butte [c], White Mound [d], Green Bear, AZ K:12:8 [e], AZ K:12:10 [f], NA 8948[g]
B	Kiatuthlanna, White Mound, Red Mesa	AD 850-950	32	Dead Wash South, Kiatuthlanna, NA 14654
C	Red Mesa, Neck-banded, Kiatuthlanna	AD 950-1050	17	Navajo Springs Great Kiva[b], Archer Site[b, h], AZ K:14:24[b] AZ-P-54-9[b], AZ-P-54-11[b]

[a] Late component;

[b] Early Component;

[c] AMS radiocarbon AD 700-800 (current study);

[d] Cutting and near cutting dates AD 765-803 (Bannister et al. 1966);

[e] Cutting and near cutting dates AD 730-765 (Bannister et al. 1966);

[f] Cutting and near cutting dates AD 802-804 (Bannister et al. 1966);

[g] Cutting date AD 758 (Gumerman et al. 1982; Throgmorton 2012:95);

[h] Conventional & AMS radiocarbon dates on wood charcoal and *Zea mays*, AD 950-1040 (Van West 1994:249).

Demography, Aggregation, and Settlement Histories of the Western Puerco

AD 650-850

Our reassessment of the Early Pueblo period in the Petrified Forest allows this poorly understood, yet intensively occupied, area to be integrated into a broader understanding of regional settlement patterns. Researchers have long agreed that the Petrified Forest hosted a higher population density compared to neighboring areas prior to the seventh century (Burton 1991; Greenwald et al. 1993; Reed 1947:208-210; Schachner et al. 2012:109; Wells 1994; Wendorf 1953:19-21; Young and Gilpin 2012:157), and our radiocarbon assay illustrates that the subregion continued to host the largest known community in the Western Puerco during the eighth century as well. This is particularly significant because the height of the Twin Butte occupation coincided with a hiatus in construction activity across the Middle Puerco (Throgmorton 2012:321, 2017:165). This pattern, however, shifted between AD 780-810 with evidence for intensifying construction at White Mound and several nearby hamlets, and took a dramatic turn from AD 840 forward with a flurry of construction activity at Whitewater and LA 4487 (Figure 5.8). We find it notable that the peak period of population growth in the Middle Puerco occurred at roughly the same time as, or shortly after, populations departed Twin Butte, a point we return to below.

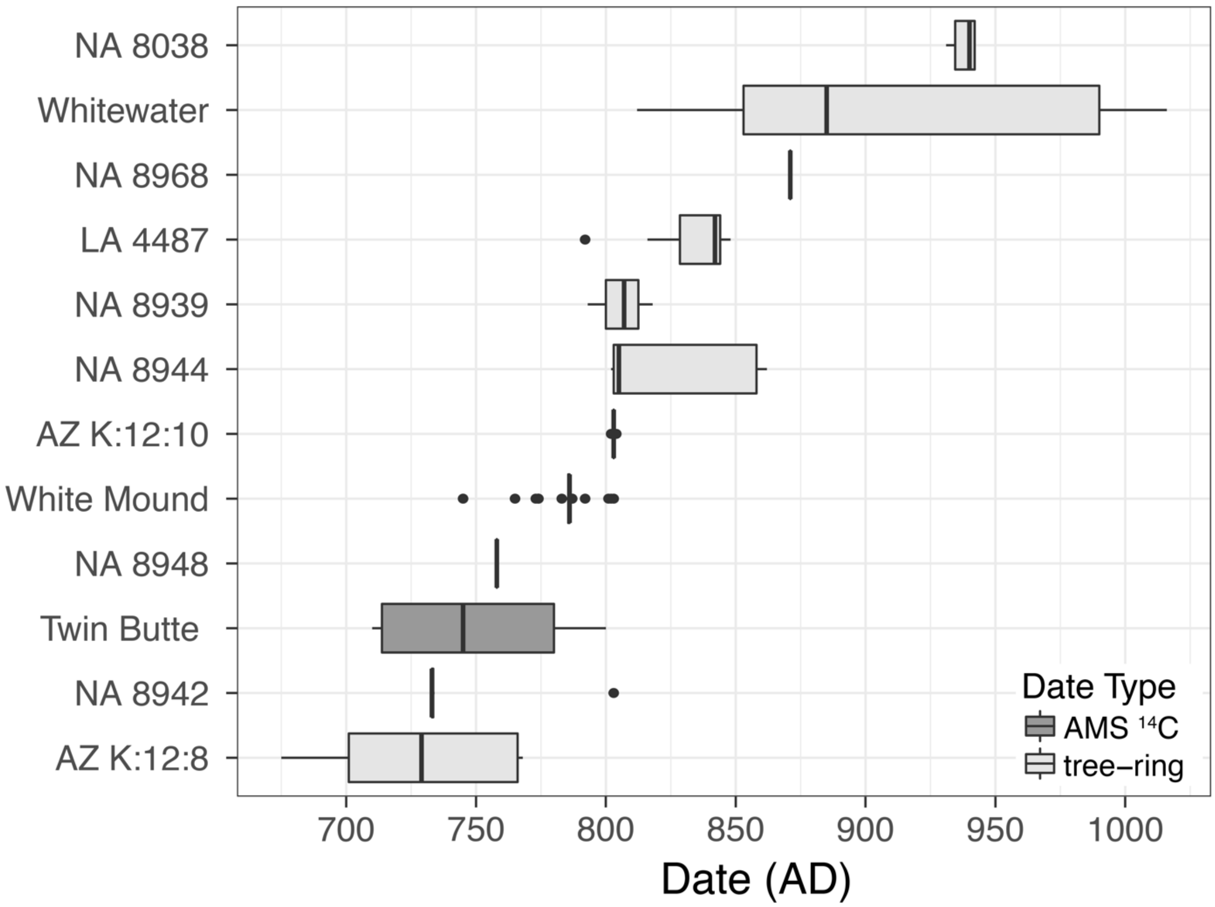

Figure 5.8. Cutting and near cutting tree-ring dates from Early Pueblo period sites in the Middle Puerco and radiocarbon dates from Twin Butte. Radiocarbon dates are displayed by plotting the earliest and most recent date of the 68.3% range of each modeled date. Tree-ring data are from Ahlstrom (1985), Bannister et al. (1966), and Gumerman et al. (1982).

Additional lines of evidence indicate that Twin Butte likely represents, at least in part, an in-situ social and economic transformation with local groups becoming increasingly sedentary rather than an influx of migrants. Looking only at ceramics data from excavated AD 600-700 sites in the Petrified Forest (Hays 1993; Latady 1991; Leach-Palm 1994), we see a preference for locally made plain brown and brown smudged ceramics that persists through the AD 700-800 occupation at Twin Butte (Supplement 2). In contrast, excavated AD 600-700 contexts in the Middle Puerco (Wasley 1960, Ripey 1969) contained few brown utility or smudged brown ceramics, and all excavated AD 700-800 sites (Ferg 1978:139; Gladwin 1945; Gumerman et al. 1982; Wasley 1960) contained far lower relative proportions of such ceramics compared to contemporary sites in the Petrified Forest. Some degree of cultural continuity between earlier sites in the Petrified Forest area and Twin Butte is also supported by similarities in architectural traditions (see Throgmorton 2012:315) and mortuary practices, particularly at AZ-P-60-31 and Twin Butte (Table 6). While similar mortuary practices appear to have been shared across much of the Petrified Forest and potentially the northern Mogollon Rim area between AD 600-800, such practices are not common at roughly contemporaneous sites across the Middle Puerco (see Spurr 2016).

We also suggest that rather than being an anomalous instance of population aggregation that occurred during the AD 700s in response to external events, that Twin Butte fits a long-term trend in the Petrified Forest of persistent places located at prominent points on the landscape. These places have evidence for consistent and recurrent use by far larger groups of people compared to contemporary sites in the subregion, including dense concentrations of domestic structures and storage features (Hough 1903: 318-319; Gilpin et al. 2000; Schachner and Bernardini 2014). Three prominent examples from the Petrified Forest, Flattop (~AD 200-550, 40+ pithouses), Woodruff Butte (~AD 500-600, 40+ pithouses), and Cottonwood Seep (~AD 600-700, 300+ pithouses), exhibit little evidence of temporal overlap with one another, with Cottonwood Seep largely falling into disuse by the time that Twin Butte was intensively occupied. Woodruff Butte and Twin Butte contain large, butte-top cleared areas potentially used for communal activities, suggesting use of a form of public space that contrasted with that used in contemporary great kiva communities in other regions. The early Petrified Forest community centers also exhibit evidence of decreasing seasonal and residential mobility through time, as the numerous small and shallow residential structures without hearths at Flattop were seasonally occupied during the summer months, the numerous small and shallow residential structures at Cottonwood Seep have hearths but still may have been seasonally occupied (Ahlstrom et al. 1993), and Twin Butte was likely occupied year-round for at least two generations.

Since community centers predating Twin Butte were primarily occupied during the summer, and community members were heavily invested in maize agriculture (Wendorf 1953:60, 72, 74; Ahlstrom et al. 1993), we find it likely that these sites were associated with labor pooling for farming activities at key points in the agricultural cycle. Such strategies are well-documented in ethnographic studies of indigenous mobile farmers in the broader Southwest (Graham 1994), and the importance of labor mobilization for small-scale farmers worldwide has long been noted (Stone et al. 1990). The central role of farming at community centers, however, appears to have continued even after seasonal and short-term mobility decreased, as attested by the numerous agricultural features in the heart of the site core at Twin Butte. Thus, while Twin Butte bears an undeniable resemblance to early Pueblo I era sites across the northern Southwest, it also appears to be the manifestation of a local tradition with deep roots in the Petrified Forest that incorporated the use of prominent natural points on the landscape, food storage, and farming activities.

Table 5.6. Mortuary Artifacts from Early Pueblo Sites in the Western Puerco and Northern Mogollon Rim.

Site	Region	Date (AD)	# of Burials	Mean Vessel Count	Pct. w/ Vessels	Max Vessel Count	Pct. w/ Smgd. Bowl	Pct. w/ Shell
Twin Butte[a]	Petrified Forest	700-800	8	3.63	87.5%	10	87.5%	87.5%
AZ-P-60-31[b]	Petrified Forest	650-700	9	2.75	77.8%	5	77.8%	44%
Bear Ruin[c]	Mogollon Rim	650-750	40	-	87.5%	17	most	5%
AZ Q:8:47[d]	Mogollon Rim	700-900	7	1.14	85.7%	2	42.9%	28.6%
CW Seep[e]	Petrified Forest	600-700	14	0.07	7.1%	2	0%	0%
All sites[f]	Middle Puerco	700-950	24	0.21	16.7%	2	0%	4.2%
White Mound[g]	Middle Puerco	750-850	33	-	few	-	few	few
NA 14654[h]	Hardscrabble	850-950	5	3.6	80.0%	14	20%	20%
Kiatut-hlanna[i]	Hardscrabble	850-950	-	-	most	-	most	occasional

[a]Wendorf 1953; [b]Latady 1991; Leach-Palm 1994; [c]Haury 1941; [d]Deats 2004; [e]Ahlstrom et al. 1993; [f]Data are from the following sites and sources: AZ K:15:14 (Anduze and Greenwald 1994), AZ-P-54-9 (Billman and Ruppe 1996), Green Bear (Ferg 1978), NA 8939, NA 8942, NA 8944, NA 8968, NA 8969, NA 8973 (Gumerman et al. 1982); [g]Gladwin 1945; [h]Stebbins et al. 1986; [i]Roberts 1931.

AD 850-950

After several hundred years of intensive, recurrent use of prominent high points in the Petrified Forest, the Dead Wash South community represents a sharp transition to a dispersed settlement pattern that remained dominant in the subregion for the next 400 years. The markers of residential stability apparent at Twin Butte, including large above ground storage facilities, deep trash middens, and front-oriented architecture contrast with the rarity of surface storage features, shallow sheet middens and dispersed haphazard site layouts at Dead Wash South. This transition to a more dispersed settlement pattern, however, is not apparent further east in the Western Puerco region, as exemplified by Kiatuthlanna (AD 850-950) an aggregated settlement that lacks a great kiva (Beeson 1966; Roberts 1931; Schachner et al. 2012:104-105, however see Peeples et al. 2012:177), and the Early Pueblo period component at Whitewater Village (AD 840-950), which contains an aggregated settlement and unroofed great kiva/dance plaza (Roberts 1939).

Even though it has been nearly 70 years since Wendorf completed his work in the Petrified Forest, our analysis suggests that he correctly identified a demographic shift to the southeast following the height of Twin Butte occupation (Wendorf 1953:20). Using the ceramic groups identified above, and placing sites into only a single temporal interval, only two sites in the Hardscrabble area date between AD 650-850, but 27 sites including Kiatuthlanna date between AD 850-950.[6] This compares favorably to previous research that identified an increase in the number of sites in the Hardscrabble area during the shift from the eighth century to the ninth century, while the Petrified Forest appears to be the only portion of the Western Puerco that experiences population decline (Schachner et al. 2012:119). The Middle Puerco also witnessed an AD 840-900 construction boom, much of this taking place at the first villages in the subregion (Figure 5.9). We find it likely that the population dispersal from the Petrified Forest subregion contributed in part to the noted demographic increase in the Middle Puerco and the Hardscrabble areas.

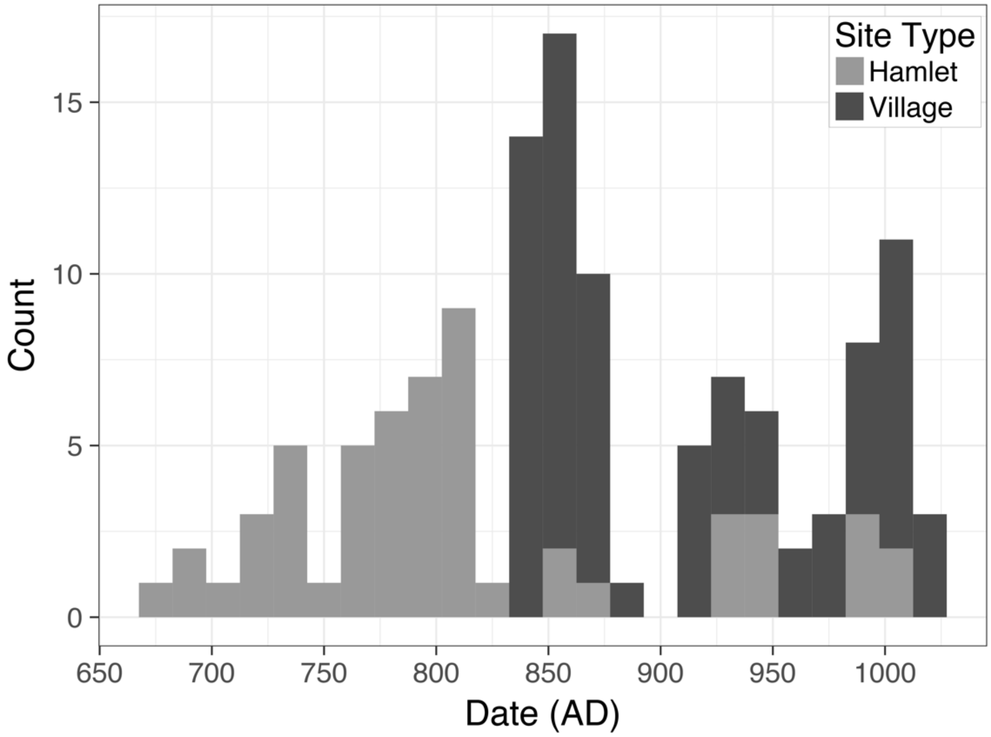

Figure 5.9. Cutting and near cutting tree-ring dates from Early Pueblo sites in the Middle Puerco. In order to minimize the bias of individual features with numerous dates from a particular year, only a single cutting date per calendar year per feature is visualized. All data are from Ahlstrom (1985) and Bannister et al. (1966).

While the frequency of residential moves increased in the Petrified Forest during the ninth century, contemporary community centers in the Middle Puerco and Hardscrabble areas display remarkable residential stability and eventually became the locations of great houses during the tenth and eleventh centuries (Peeples et al. 2012:177-178; Throgmorton 2012:326). These settlement patterns contrast rather dramatically with one another, but in each subregion the ninth century represents the point at which local groups established the settlement patterns that remained dominant until the late thirteenth century. To a certain degree, these later contrasting settlement patterns might have enabled one another, as marginalized residents of more populous areas were able to move in and out of the Petrified Forest in response to social and environmental perturbations, and local groups in the Petrified Forest could attract individuals living on the fringes of larger, more stable community centers to the east (Herr 2001; Schachner 2012).

Diverse Paths to Aggregation

Our reassessment of Early Pueblo period demography and settlement patterns across the Western Puerco suggest distinct trajectories for early village development in the Petrified Forest compared to the Middle Puerco and Hardscrabble areas. Moving now to a broader discussion of comparable developments across the northern Southwest, we explore how subregions of the Western Puerco compare to well-documented examples of early village formation in the northern San Juan (Table 7). We briefly juxtapose key elements of this process in each region, including the mechanisms that fostered collective identity and allowed for the integration of non-kin groups, evidence for competition over resources, and violence. In our discussion we distinguish between *first-wave* (AD 700-810) and *second-wave* (AD 810-950) early villages since they exhibit similarities across regional boundaries.

Table 5.7. Attributes of Early Village Development in the Northern San Juan and Western Puerco.

Region	Village Type	Interval as Regional Population Center	Population Growth	Integrative Mechanism	Population Pressure	Violence
WMV	first wave	AD 600-810	in-situ/ migration	local/non-local	moderate	unknown
EMV	first wave	AD 700-810	migration	non-local	moderate	high
PEFO	first wave	AD 200-810	in-situ	local	low	none
CMV	second wave	AD 810-880	migration	local/non-local	high	moderate
MP	second wave	AD 840-1275	in-situ/ migration	non-local	moderate	low
HS	second wave	AD 840- 1050	in-situ/ migration	unknown	moderate	unknown

WMV = Western Mesa Verde, EMV = Eastern Mesa Verde, PEFO = Petrified Forest, CMV = Central Mesa Verde, MP = Middle Puerco, HS = Hardscrabble.

Population Growth

We note similarities between the primary mechanisms driving population growth in the regions that hosted first wave and second wave villages. In the Petrified Forest and the western Mesa Verde region, first-wave villages developed in areas with the greatest population densities during the preceding centuries, and were therefore likely in part local developments (see Allison et al. 2012), while in the eastern Mesa Verde area, first-wave villages were founded by recent immigrants (Potter et al. 2012). However, all regions witnessed population dispersals in the early ninth century as former residents helped fuel unprecedented population growth at second-wave villages in neighboring regions (Wilshusen et al. 2012a). We find it likely that similar developments in the Middle Puerco and Hardscrabble areas during the early to mid-ninth century were fueled in part by immigrants from the Petrified Forest. In short, first-wave villages more often arise from in-situ growth, while second wave villages are more strongly linked to immigration. These contrasting long-term settlement histories are further apparent in the mechanisms that integrated non-households into village life at first and second wave villages.

Collective Action and Placemaking

In the eastern and western Mesa Verde regions, researchers have identified a close relationship between first-wave villages (circa AD 710-790) and great kivas (Allison et al. 2012; Potter et al. 2012), but the opposite is true at second-wave villages (AD 840-880) in the central Mesa Verde region (Wilshusen et al. 2012a). This pattern has been linked to early transcendent leaders harnessing the power of ritual performance that had a long local history during the founding of the earliest villages, and a transition to villages being the center of such performance and power irrespective of great kivas within only a few generations (Throgmorton 2017; Wilshusen et al. 2012b). In the Petrified Forest, however, a different pattern is apparent. No great kivas are present at Twin Butte or any of the earlier community centers that preceded it, but such structures are associated with the dispersed hamlets that typified settlement in the subregion during the later Chaco era. Smaller integrative structures present at community centers across the northern San Juan that lack great kivas (Allison et al. 2012; Potter and Chupika 2007; Wilshusen 1989) also have not been identified in the Western Puerco, although few structures from this era have been excavated.

Researchers have long seen communal ritual associated with great kivas as a key facet of the development of denser, larger residential communities in the northern Southwest. The long-lived tradition of community centers at butte-top locations in the Petrified Forest provided an alternative foundation for analogous developments. Such placemaking would arguably have depended on an even stronger connection to local landscape as no place-less, constructed communal features with obvious parallels to those used elsewhere in the northern Southwest were built. Instead, the collective social memory embodied by community centers associated with prominent landscape features provided the necessary foundation to maintain the shared identity of groups with deep roots in the region. Reference to culturally significant landscape features to promote social cohesion in-lieu of communal architecture has been noted in other edge regions of the Southwest (Miller 2018), and we find it likely that this was more typical than currently thought in locations and/or periods where communal architecture was not widespread. Although natural places have often been proposed as nodes of regional interaction and identity linked to ritual activities in the northern Southwest (e.g., Bernardini and Peeples 2015; Schachner 2011), less frequently have they been examined as places of local significance linked directly to habitation or seasonal aggregation for communal farming activities. Cooperative, seasonal farming activities could have served a similar function to communal rituals performed in a constructed space, gathering people together and forging collective identities. Agricultural themes permeate Pueblo ritual practice and cosmology, yet most archaeological examinations of communal ritual focus almost exclusively on social functions, perhaps missing key aspects of the development of ancient practices.

In contrast to both the first-wave Petrified Forest villages and second-wave northern San Juan villages, second-wave villages in the Middle Puerco are closely associated with great kivas during the period of peak population growth (AD 840-900). This pattern continues throughout the tenth and early eleventh centuries with the founding of early great houses on these sites. Here, aggregation and communal ritual appear more strongly linked to the long-term development of the Chaco regional system, and may have involved migrating groups from the northern San Juan (Throgmorton 2018:183).

Competition, Property Rights, and Violence

Archaeologists studying early village development in the northern San Juan have also argued that population pressure on resources and the resulting competition between households was the underlying mechanism that triggered aggregation (Kohler 2012:256). Moreover, Wilshusen and Potter (2010) suggest that early northern San Juan villages may have been an attempt to formalize property rights and lay claim to resources or productive land (also see Kohler 1992; Schachner 2010). It is important to note that first-wave villages in the northern San Juan did not develop in the more productive central Mesa Verde region, but rather to the east and west. In the Petrified Forest, there was likely no shortage of arable land given the low regional population densities, and it remains unclear why any particular location would have been more productive than others nearby. Instead, second-wave villages in the Western Puerco and northern San Juan are more closely associated with the most productive areas in their respective regions, and this suggests that alternative factors played a more prominent role in first wave village formation.

Wilshusen and Potter (2010) also suggest that the threat of violence may have played a critical role in first-wave and second-wave village formation in the northern San Juan. In the Petrified Forest, however, there are no known instances of violence or defensive features at Early Pueblo sites. The location of the Twin Butte site core further attests to a lack of concern over violence. Instead of occupying the area atop the western edge of Puerco Ridge located only 100 meters to the east, the core of the site is located just below the ridgetop and would have been an easy target from above. Defensively located Weathertop, which immediately post-dates the height of the Twin Butte occupation and is likely contemporary with similarly located White Mound, suggests Petrified Forest groups became more concerned with the threat of violence as aggregation increased in the Middle Puerco. The earliest evidence for violence in the Western Puerco occurred 30 years after the founding of second wave villages (Gumerman et al. 1982; Throgmorton 2012:298), and it therefore seems unlikely that violence played a causal role in the formation of first-wave or second-wave villages in the Western Puerco.

Alternative Models for Initial Village Formation

The lack of fit between these causal factors and the Petrified Forest archaeological record, and a clear distinction between the long-term, gradually developing settlement histories of the Petrified Forest and the boom-and-bust trajectory of northern San Juan between AD 200-800, suggests alternative models of initial village development are needed to explain the formation of early population aggregates in the Petrified Forest region, and much of the western portion of the northern Southwest more broadly. Twin Butte was the endpoint along a trajectory of community centers placed in culturally significant prominent locations in the Petrified Forest. Residents of these centers became increasingly sedentary and less residentially mobile through time. Similar steady, rather than boom-and-bust, trajectories are also evident in the Middle Puerco and Hardscrabble areas and are also comparable to developments noted across much of the Zuni area during this interval (Peeples et al. 2012), albeit with village development shifted later in time and more closely linked to the initial formation of the Chacoan regional system.

Conclusion

Our examination of aggregation, dispersal, and population dynamics during the Early Pueblo period occupation of the Western Puerco region offers an important point of contrast to patterns among better studied contemporary groups in the northern San Juan. This study suggests that the earliest villages in the Petrified Forest were the result of in-situ population growth and decreasing frequency of residential mobility that slowly unfolded between AD 200-700. During this era, community centers did not have great kivas and future research should consider whether communal rituals were distinct in the region, providing an alternative model for early village life that potentially had parallels in similarly “edge-situated” regions (cf. Miller 2018). The function served by great kivas in the Western Puerco during the ninth and tenth centuries varied considerably as these features are associated with fostering collective identity in socially diverse second-wave villages in the Middle Puerco, and later attracting families to land-rich-labor-poor areas in the Petrified Forest following a transition to an increasingly mobile dispersed settlement pattern (cf. Herr 2001).

The largest and longest-lived population centers in the Western Puerco were later founded during the ninth century in the Hardscrabble and Middle Puerco subregions, and their longevity contrasts with the often short-lived villages in more well-known regions to the north. The long-term, relatively stable settlement history of the Western Puerco may in part explain why the region continued to be occupied through the AD 900s and into the 1200s, while many early villages came to a rapid and abrupt end in the northern San Juan circa AD 900 as part of a longer, boom-and-bust demographic trend in the region. Wilshusen et al. (2012a:28) suggest that “…villages must establish deep rooted social stability and a clearly defined cultural identity if they are to avoid going bust.” In the Western Puerco, and particularly the Petrified Forest, deep local settlement histories based on farming and attachment to natural places likely contributed to the process of village formation unfolding in a steadier fashion. As noted previously by one of the current authors and others (Schachner et al. 2012; Young and Gilpin 2012), our improving understanding of the Early Pueblo period in the western and southern reaches of the Ancestral Pueblo region reveals marked contrasts with models of early village development proposed for the northern San Juan region. These contrasts suggest this era was far more dynamic than often portrayed, with much of the variability in social organization and material culture that characterizes later regional differentiation emerging early in Ancestral Pueblo history.

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Notes

[1] We thank Dennis Gilpin for sharing his personal field notes and helping us track down even the most difficult to find resources.

[2] Wendorf (1953:159) sent the majority of maize specimens from Twin Butte and Flattop to Paul Manglesdorf at Harvard for analysis, but no report was completed. We contacted Dr. Wendorf (in 2012) and numerous museums, but have not been able to locate these specimens. Please contact the authors if you have any information on their location.

[3] Agreement indices (*sensu* Bronk Ramsey 2009) suggest good fit for the ten dates used in the current model (see Supplement 3), but poor fit for Beta-330993 and Beta-331001 when they are included.

[4] Schachner and Bernardini (2014:42-48) submitted 60 sherds from the Twin Butte collections for instrumental neutron activation analysis at the University of Missouri Research Reactor. Woodruff Brown and Red were assigned to a single compositional group, while Lino Gray and White Mound Black-on-white samples were assigned to two additional compositional groups, both distinct from those used for Puerco Valley Brown Wares. Without further sampling of ceramics from this time period, identifying the production locales for these groups is difficult, but we think it is likely that the former and at least one of the latter were manufactured locally.

[5] Wendorf (1953:101) uncovered two Woodruff Red vessels on the floor of Structure F2, a surface room associated with Pithouse F4, which produced two radiocarbon dates of AD 710-780

(68.3%) or AD 685-820 (95.4%). Woodruff Red vessels were also present in two burials at Twin Butte, and a burial at AZ Q:8:47 (ASM), an AD 700-900 pithouse hamlet located 15 miles east of St. Johns, Arizona, that produced a single tree-ring cutting date of AD 721 (Deats 2004:411-422). Woodruff Red is present but relatively uncommon on AD 600-700 sites in the Petrified Forest (Hays 1993; Hays-Gilpin and van Hartesveldt 1998; Latady 1991), yet common at AD 700-900 sites. A production date of AD 550-950 for Woodruff Red is suggested and a peak production date of AD 700-900 seems likely. To our knowledge, Woodruff Red Smudged is not present in the Western Puerco until AD 700 and may be useful in differentiating between AD 550-700 and AD 700-900 sites.

[6] Our low population estimate for the Hardscrabble area between AD 650-850 contrasts with Schachner et al. (2012:118-119) because the previous assessment assigned individual sites to multiple temporal intervals while the current study constrained each site to a single temporal interval, unless multiple temporal components were identified and ceramics from each were recorded separately.

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